The Role of CFD in NPP Safety

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Experiments and CFD Code Applications to Nuclear Reactor Safety

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- Validation and user influence
- International co-operation
- Conclusion

CSNI Safety Issues and Topics (1/3)

- Shrinking nuclear infrastructure
  - Knowledge Management
  - Experimental Facility Loss
- Increased public expectation on safety in use of nuclear energy
  - Use of Risk-Informed Regulation
  - Transparent technical basis for safety assessment

CSNI Safety Issues and Topics (2/3)

- Industry initiatives to improve economics and safety performance
  - Management Strategies
  - Maintaining Safety Margins
  - Fuel and Fuel Cycle Safety
  - Maintaining Safety Culture

CSNI Safety Issues and Topics (3/3)

- Necessity to ensure safety over plant lifecycle
  - Ageing management
  - New risk perspective and safety requirements
  - Risk management across operating modes
- New reactors and new technology
  - Digital technology
  - New materials and fabrication technologies
  - New concepts of operation
  - New methods and tools

SESAR/SFEAR: TH Safety Issues with relevance for maintaining key research facilities (1/2)

Issue	Safety relevance of issue	State of knowledge on issue
Boron dilution	Medium	High
Passive safety system performance	High	Medium
Non-pipe breaks	Medium	Low
S. G. tube rupture	High	High
Stability and power oscillations	High	Medium
ECCS strainer clogging	High	Medium
Pressure tube reactor T/H	High	Medium

SESAR/SFEAR: TH Safety Issues with relevance for maintaining key research facilities (2/2)

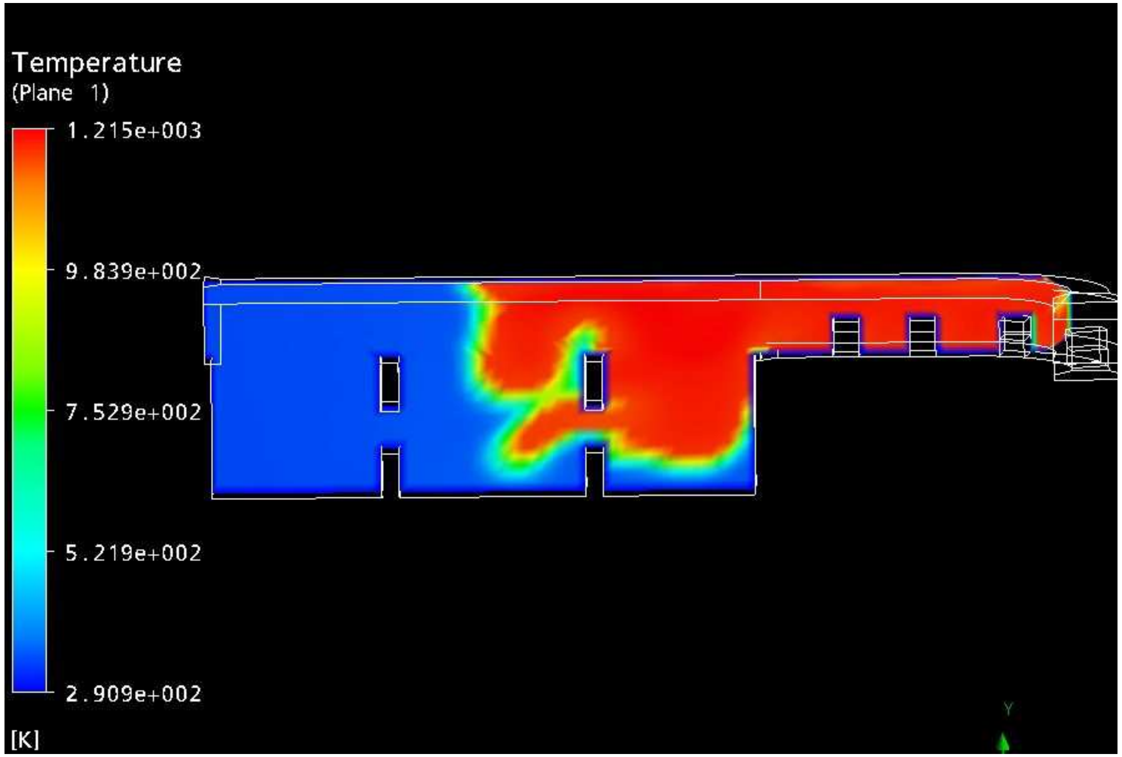
Issue	Safety relevance of issue	State of knowledge on issue
Two-phase natural circulation	High	Medium
Thermal stratification	Low	Medium
Thermal cycling	Low	Medium
Moderator T/H	Medium	High
3-D core flow distribution	Medium	Medium
Downcomer flow distribution	Low	Medium
Accidents initiated during shutdown	High	Medium

Enlarged Role of CFD for NRS

- CFD has a wider field of application in NRS than coolant system T/H, e. g.
  - Severe accident phenomena in the containment,
    - H_2 distribution and combustion
    - Aerosol and FP distribution
    - Fibre material in the sump
  - Fires in confined space or arrangements of rooms
  - Melt behaviour in vessel lower head
- Education & Training: Advanced simulation methods
- Link to non-nuclear industries

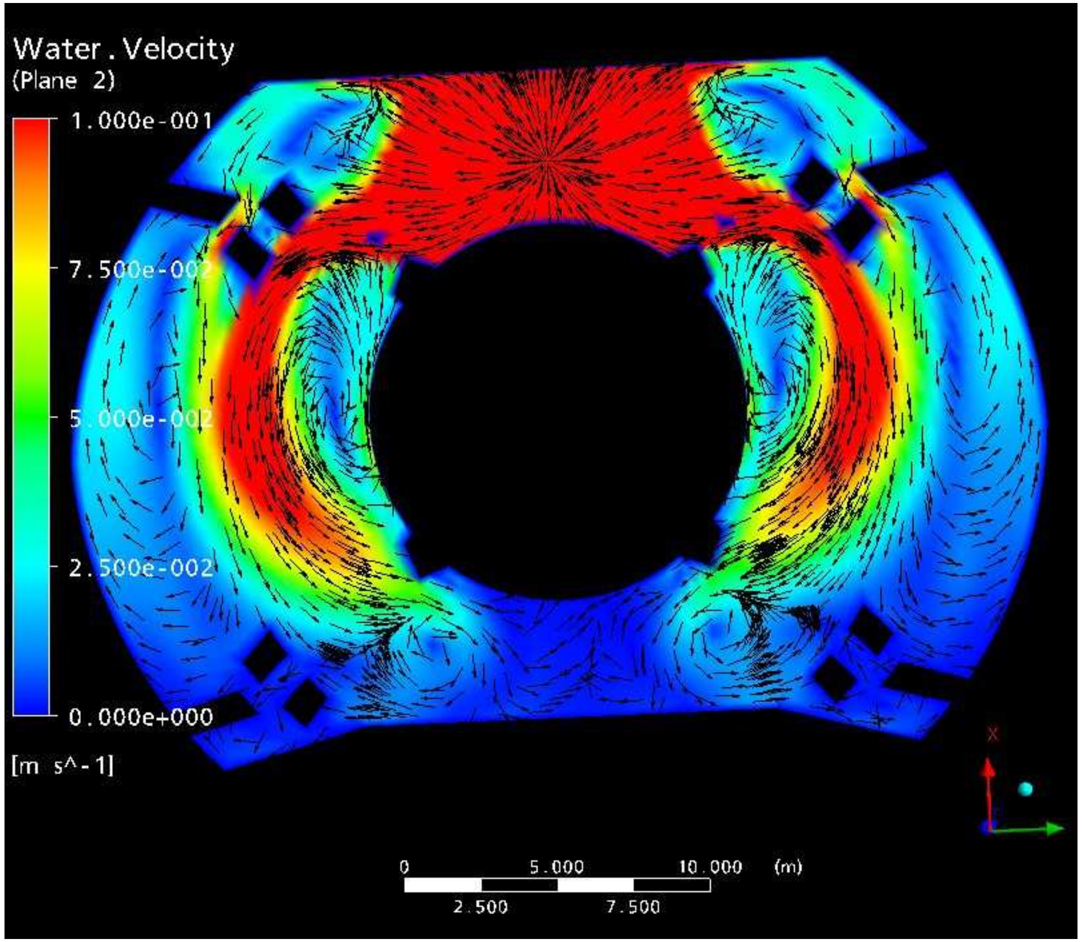
Simulation of H_2-Combustion with CFX

- Simulation of turbulent flame propagation with CFX
- Validation of combustion models
- Successful post-test calculations for experiments in Russian RUT facility and in German Battelle-Model-Containment

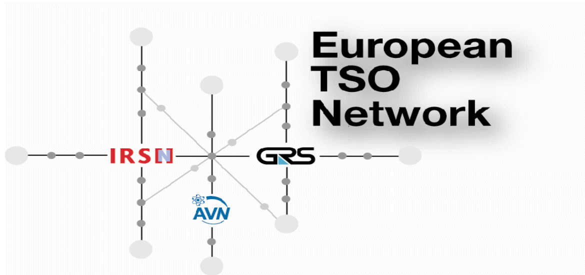


Clogging Issue: Particle Transport in the Sump

Experimental and modelling activities in progress for characterizing particles and their transport in sump water flows, including entrainment of air



Technical Safety Organisations (TSOs)

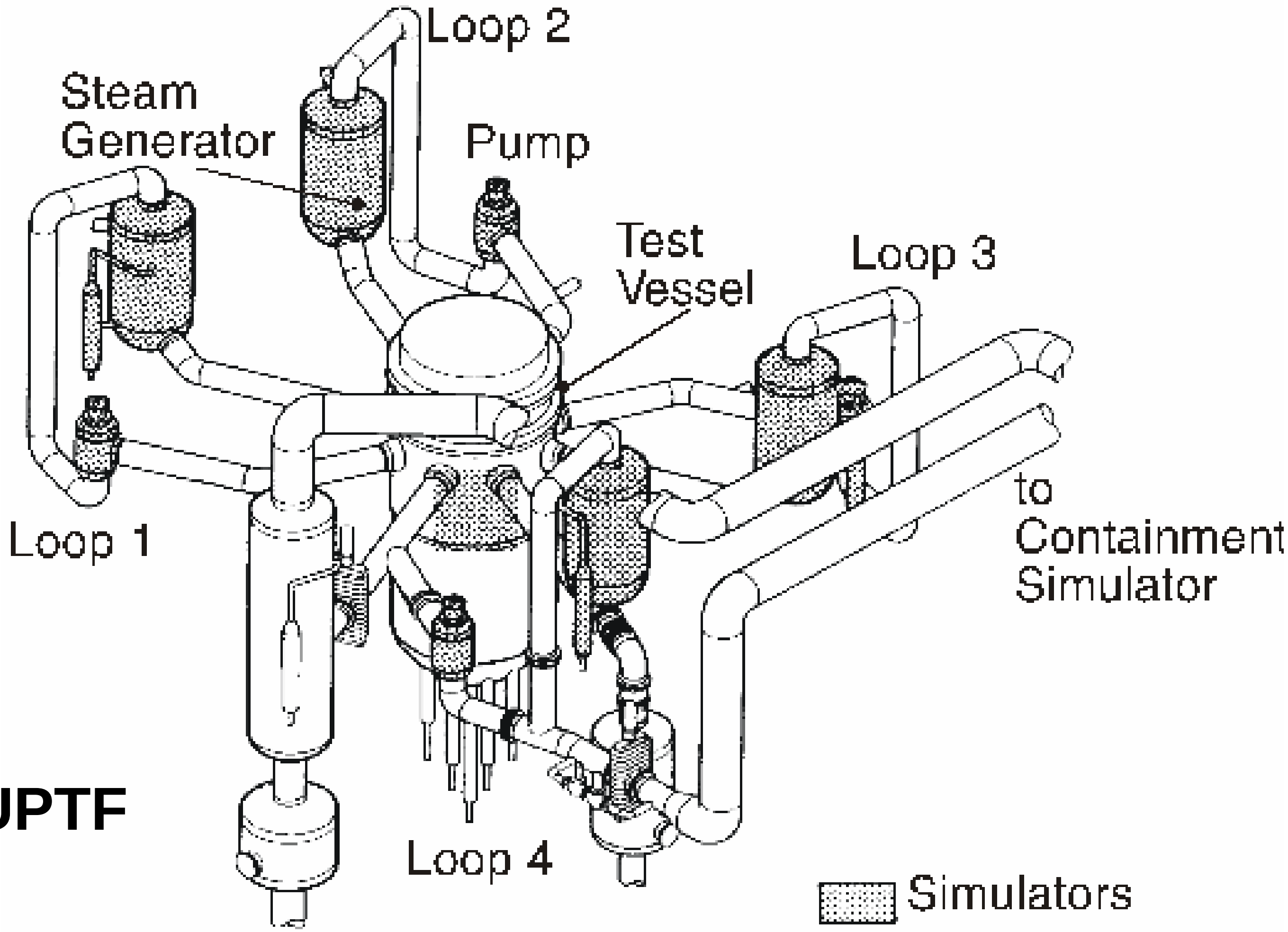


- TSOs are public organisations that
  - perform evaluations on nuclear safety and the radiation protection in a regulatory background
  - assure independence of technical judgements
- Technical Safety Organisations are committed to perform safety research. The TSO Concept explicitly states among the required characteristics that *“a TSO maintains an R&D programme allowing the development of new knowledge and techniques in support of its missions, and an independence of judgement from licensees”*.

Extensive Validation Necessary for Accepting CFX for Safety-Cases

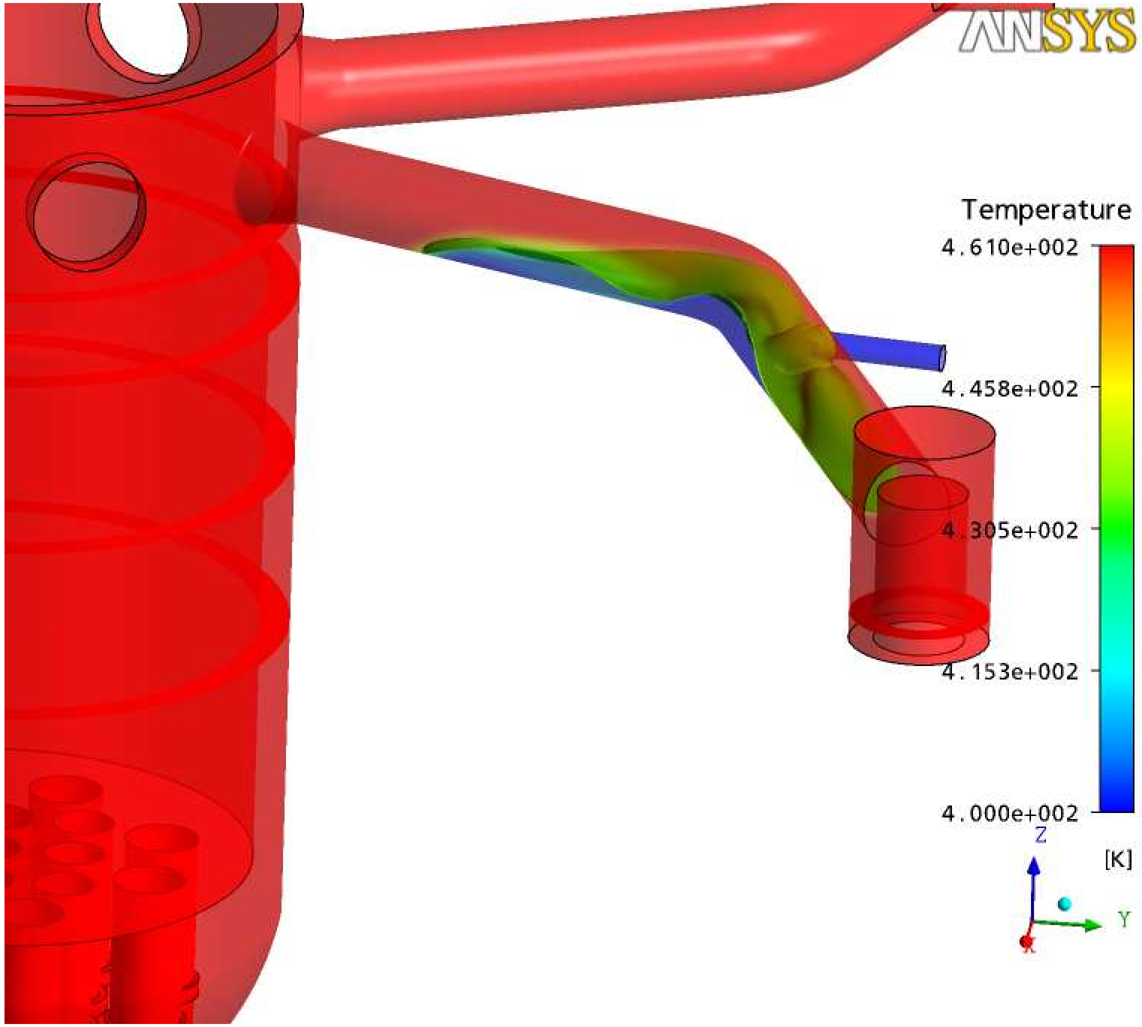
- Systematic validation on basic experiments, SETs and Its -> Validation matrix covering phenomena and scale
- Importance of preserving the link to large existing experimental data base
  - Integral system tests, e. g. BETHSY, PKL, LSTF, LOFT
  - Large SETs, e. g. UPTF
  - Empirical pressure loss and heat transfer correlations

Test Facility UPTF



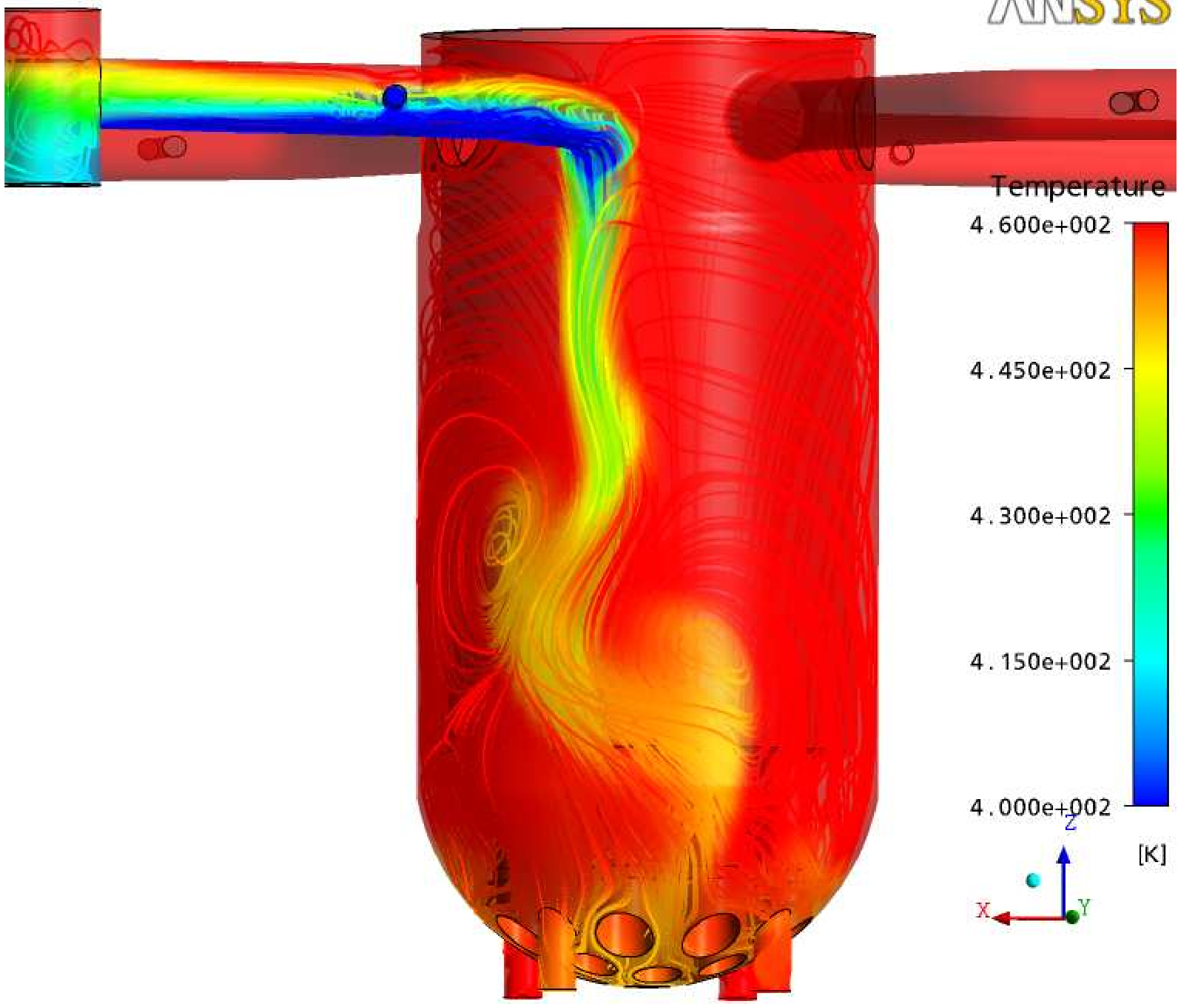
UPTF TRAM C Experiment: CFX Calculation

ECC-injection, time = 45 s



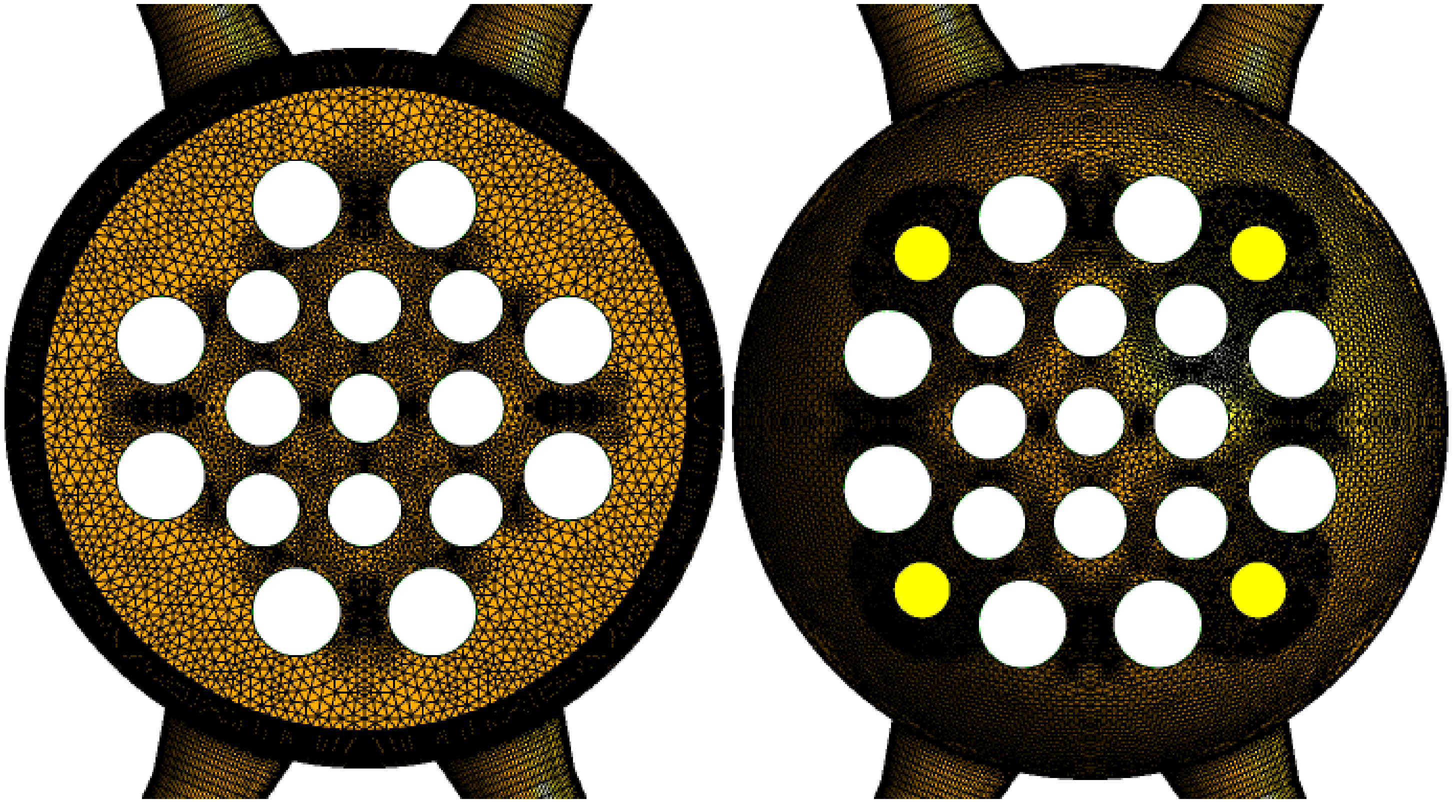
UPTF TRAM C Experiment: CFX Calculation

ECC-injection, time = 100 s



UPTF TRAM C Experiment: CFX Calculation

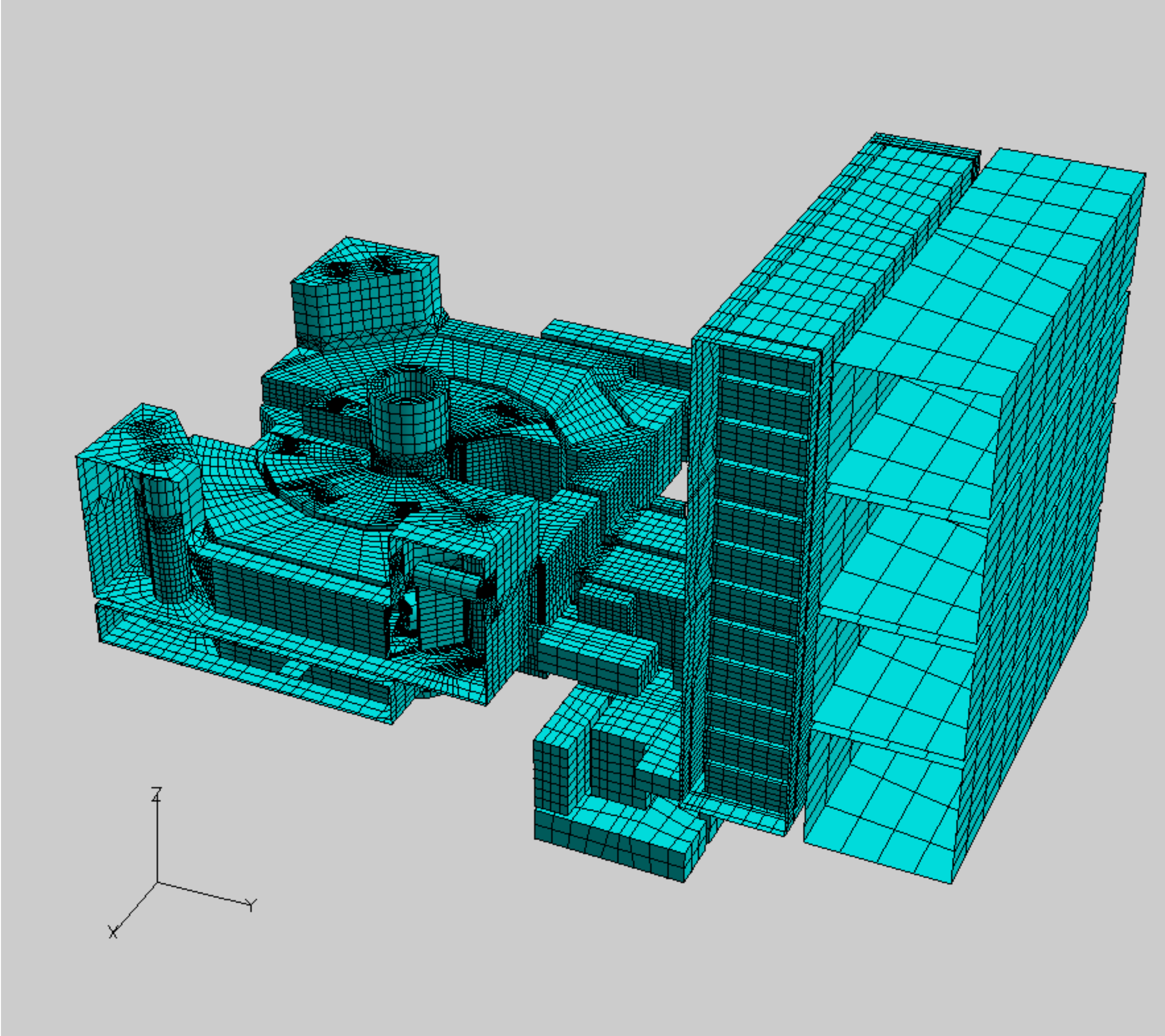
Top and bottom view of the lower plenum mesh



Reducing the User Influence

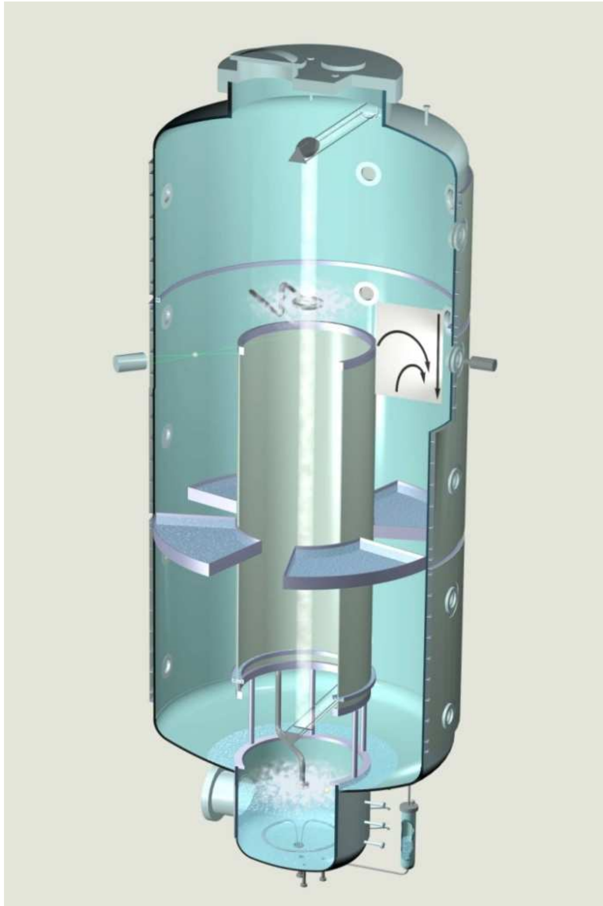
- Previous assessment of code predictions, e. g. benchmarks, ISPs, uncertainty studies, identified the “code user effect” as a major source of uncertainty
- A large part of the user effect could be traced back to nodalisation, esp. for coarse 3D or quasi-3D volume-and-junction arrangements
- CFD should contribute to mitigate this effect
- User effect remains important: high sensitivity to boundary conditions, choice of turbulence model, etc.
- BPGs have limitations in practice

WWER-440 Containment



Experimental Facility ThAI

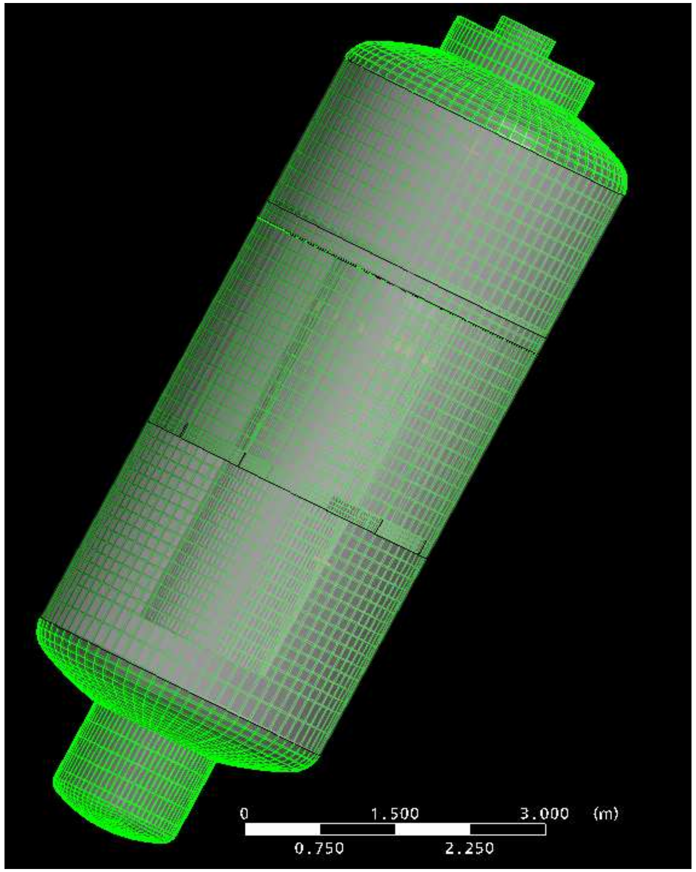
- ThAI-Facility:
  - Height: 9.2 m
  - Diameter: 3.2 m
  - Volume: 60 m³
  - Internals: Inner cylinder, blower, condensate tray
- Experiments for gas distribution stratification temperature condensation combustion, aerosols, iodine



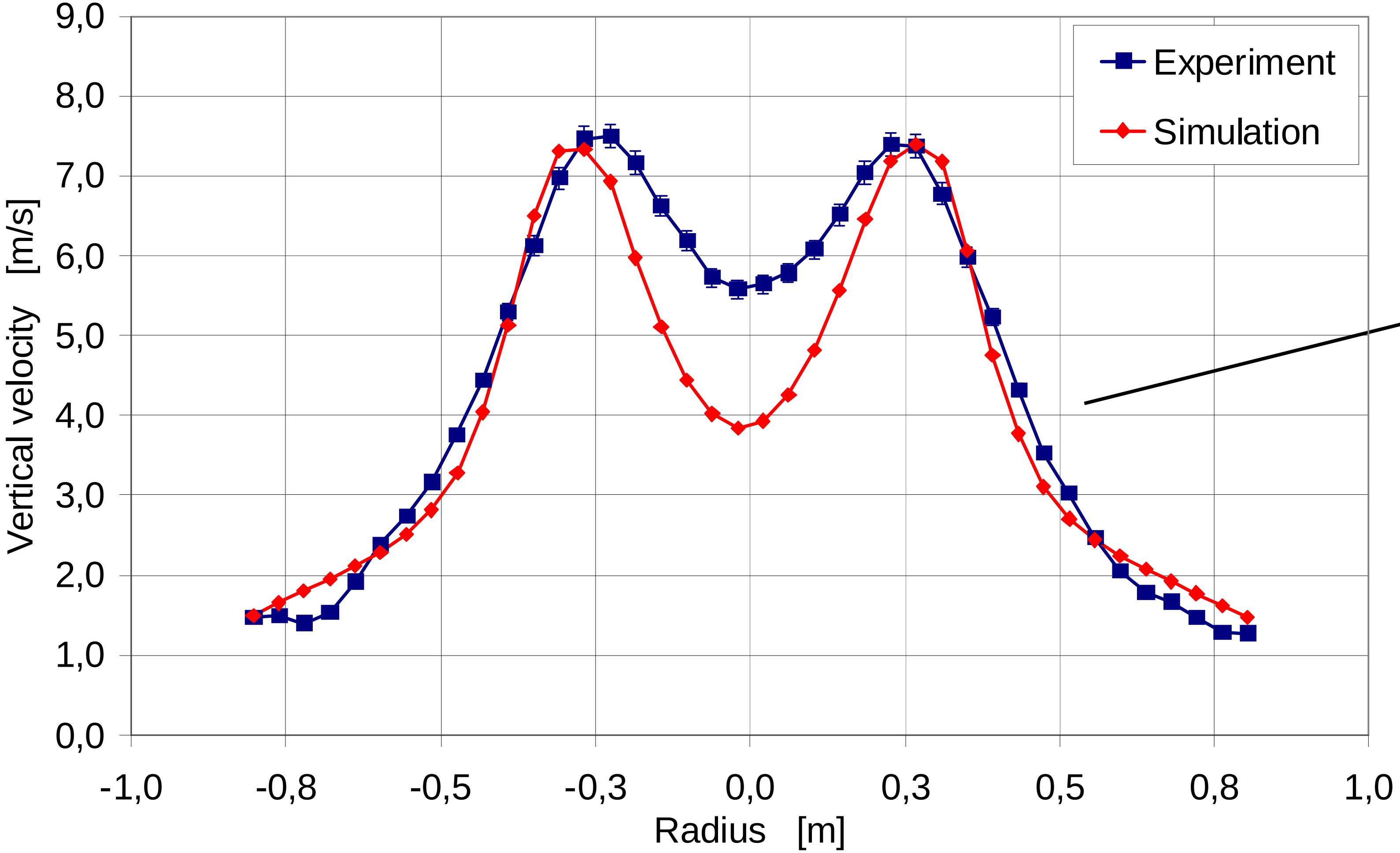
[Fig.: Becker-Technologies]

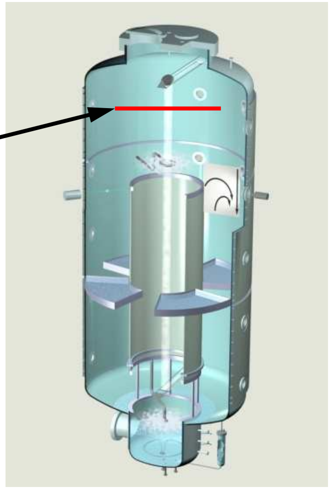
Test TH-18: Gas injection at high elevation

- Structured grids with 166.000 to 1.188.000 elements
- Mass flow at blower exit: 4.47 kg/s
- Different turbulence models used (k-ε, SST, SSG)

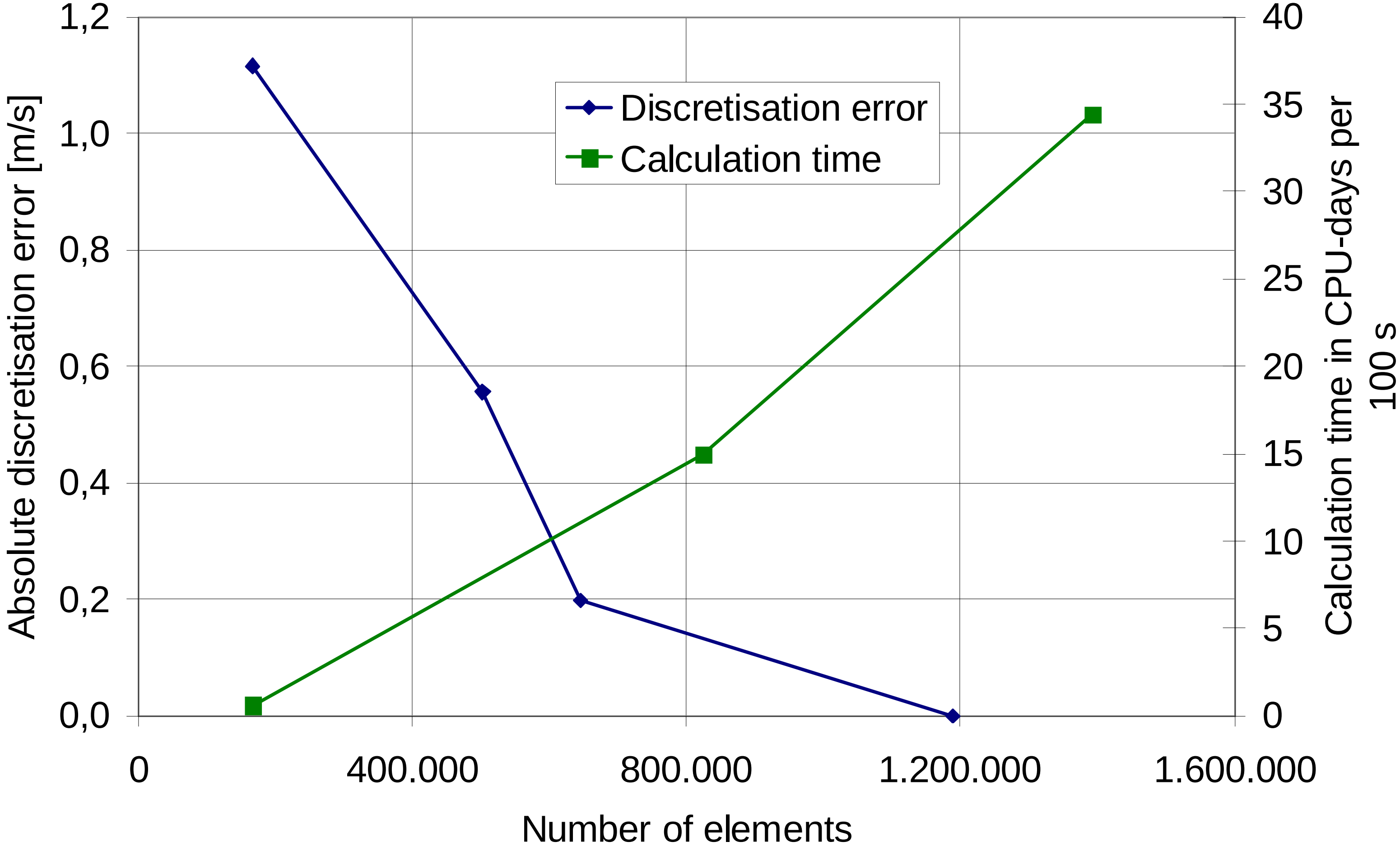


Vertical flow velocity at 8.0 m





Comparison of discretisation error and calculation time

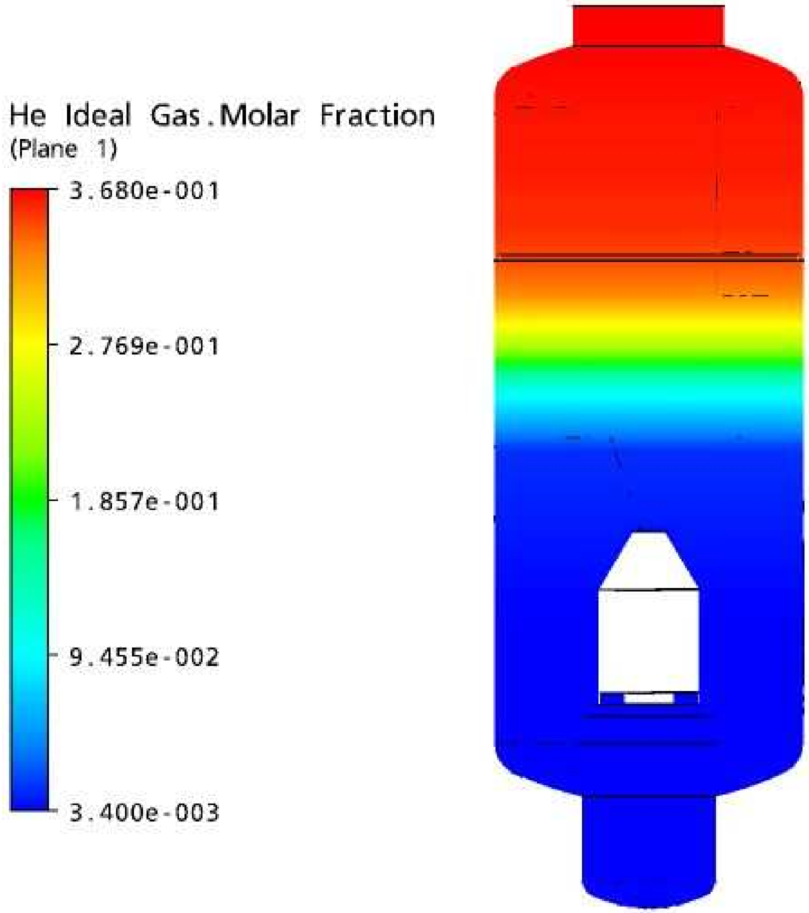


Investigating the Influence of Turbulance Models

- Variation of turbulence mode (2-equation models SST and k-ε)
- Variation of parameters (e. g. turbulent Sc-no., product-limiter etc.)
- Discussing the results with code developers and users

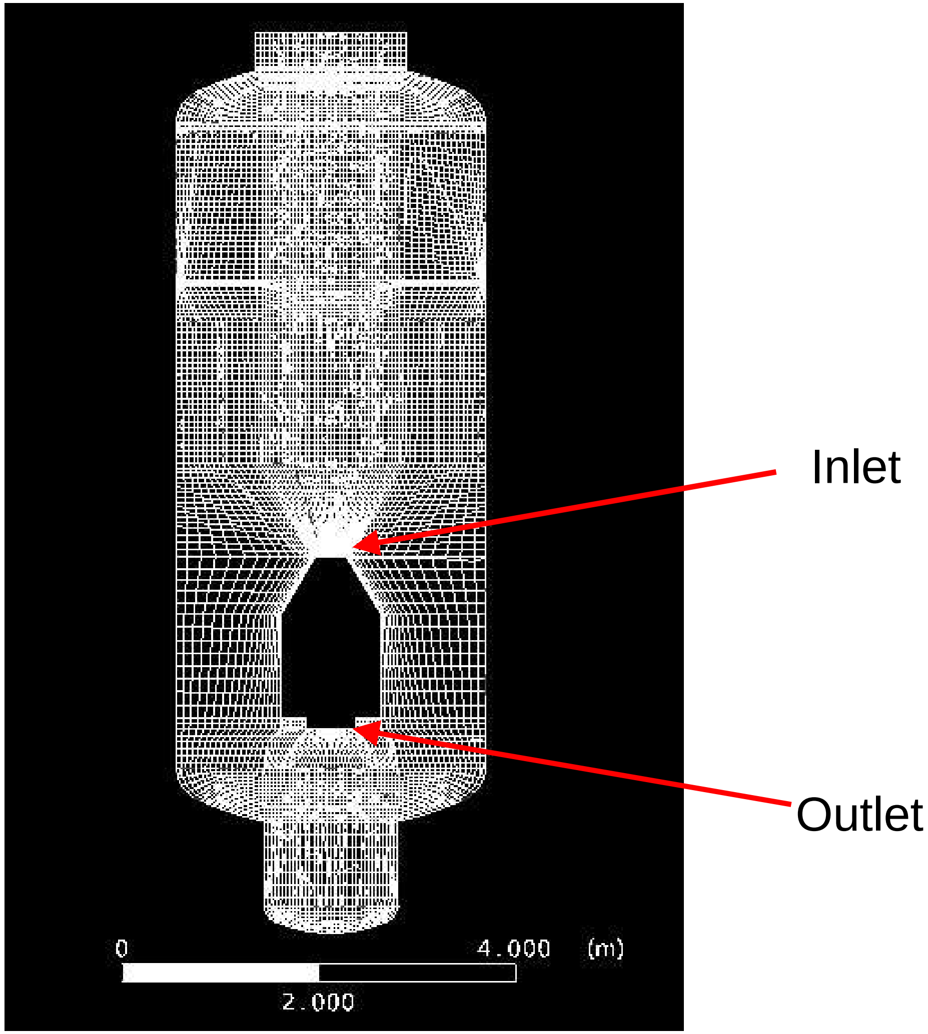
Test TH-20: break-up of stratified layer by a jet

- Test starts from a stable He-layer
- Jet from the blower erodes the layer
- He-concentrations measured at various locations and compared to calculation



CFX-Simulation of ThAI Vessel

- Blower not simulated, velocity profile at blower exit given as boundary condition
- Grid of 280.000 cells
- Grid variations show that refinement would be necessary, however, computing time is limiting



Questions to CFD Application

- CFD for everything?
  High effort in generating problem dependent models and speed of computation set limits; coupling with system scale or medium scale codes required

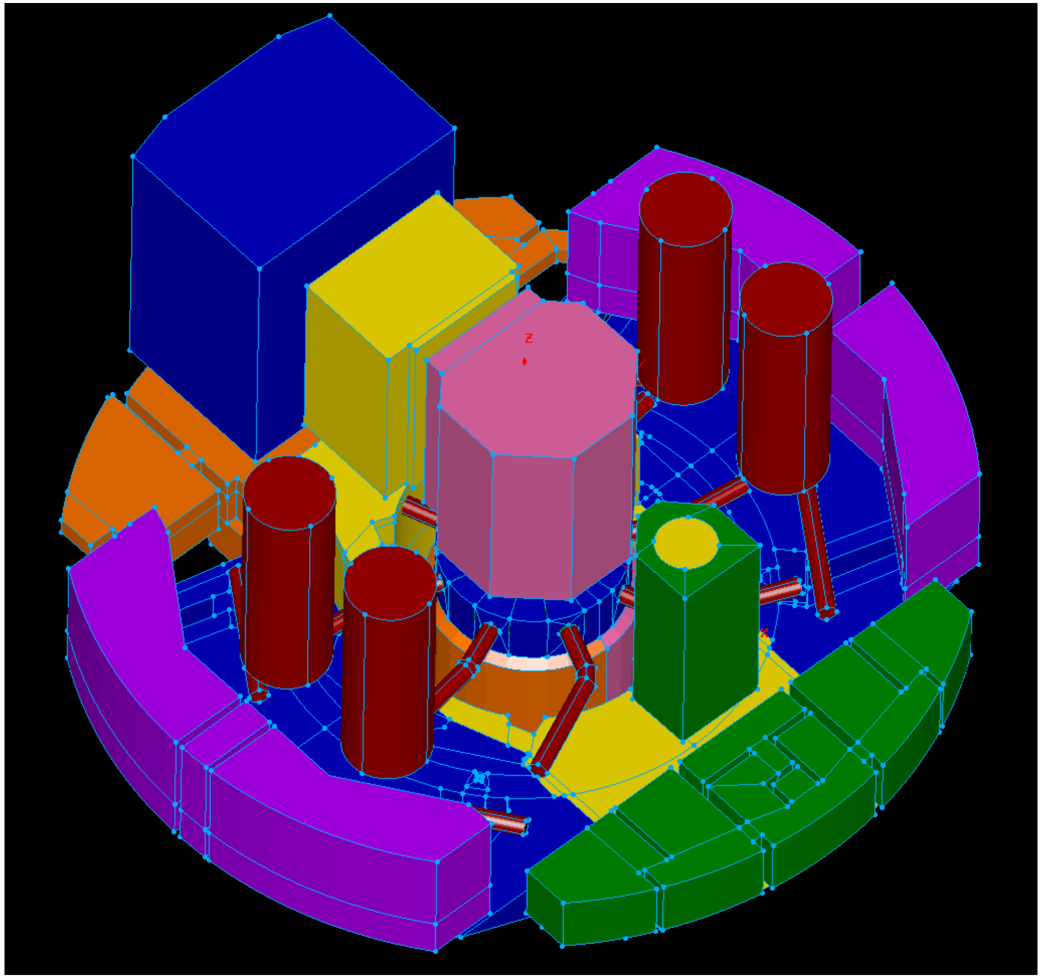
- One unique CFD code sufficient?
  - two-phase modelling not yet consolidated; benchmarking several codes has its merits
  - dedicated tools for specific problem areas will remain, e. g. electrical cabinet fires, fire-ball after aircraft crash

- Independence of safety assessment when using “commercial” codes?
  - User should know, the validation basis of models and limitations of applicability
  - BPGs must be applicable, uncertainty should be quantified

PWR Containment

Distribution of Air, Vapour and H_2

Generating the computational grid for a PWR containment (Konvoi type) is resource consuming



Co-operation

Huge task of developing, validating and sharing user experience requires a co-ordinated approach:

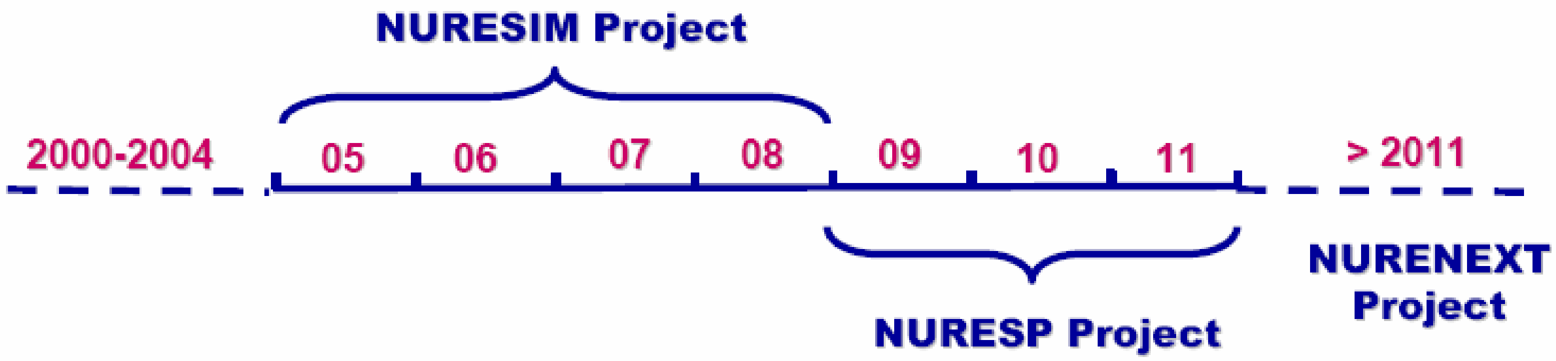
- Domestic, e. g. German CFD-network
- Europe:
  - Code platform NURESIM
  - SNE-TP: Strategic Research Agenda
  - OECD: Follow-up to GAMA activities
  - Sustainable forms of co-operation necessary

German CFD-Network & International Observers

The NURESIM roadmap

- 2000 – 2004: Genesis
  - ✓ 2000 – 2002: EUROFASTNET
    → 44 industrial needs for T/H R&D
  - ✓ 2001 – 2004: genesis of NURESIM
    (an integrated approach)

NURESIM: a single platform



- NURESIM Project: basis towards the target with first significant possibilities
- NURESP: consolidation + extension
- NURENEXT: confirmation + rationalization + further extension

Sustainable Nuclear Energy Technology Platform (SNE-TP)

Launched in Brussels on 21/09/07

A vision report *endorsed by 35 European organisations*

www.snetp.eu

Sustainable Nuclear Energy Technology Platform (SNE-TP)

But also, cross-cutting topics

- Safety
- Numerical simulation
- Education & training
- Material research
- Research infrastructures

Conclusion

- CFD is expected to resolve a number of present safety issues
- CFD will play an important role in designing future NPPs
- Accepting CFD for demonstrating safety requires thorough validation, including the existing large data base
- Attention has to be paid to the user effect by applying BPGs and uncertainty evaluation
- The huge task for developing, validating and applying CFD calls for sharing work and experience by sustainable forms of co-operation