Qualification of ANSYS Software as a Framework of CFD and Multi-Physics Integration for Thermohydraulic Applications

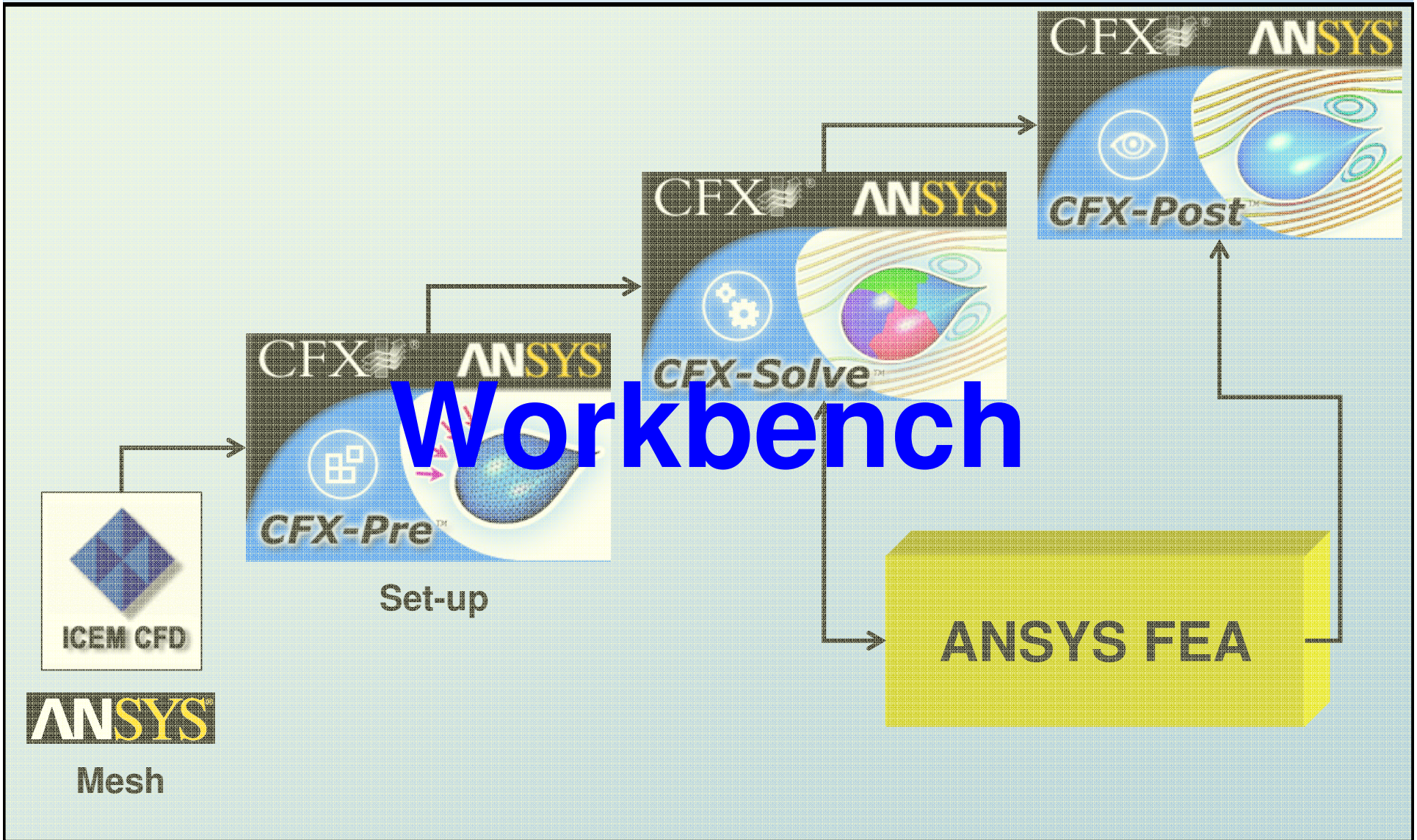
Thomas Frank
ANSYS Germany, 83624 Otterfing
Thomas.Frank@ansys.com

Overview

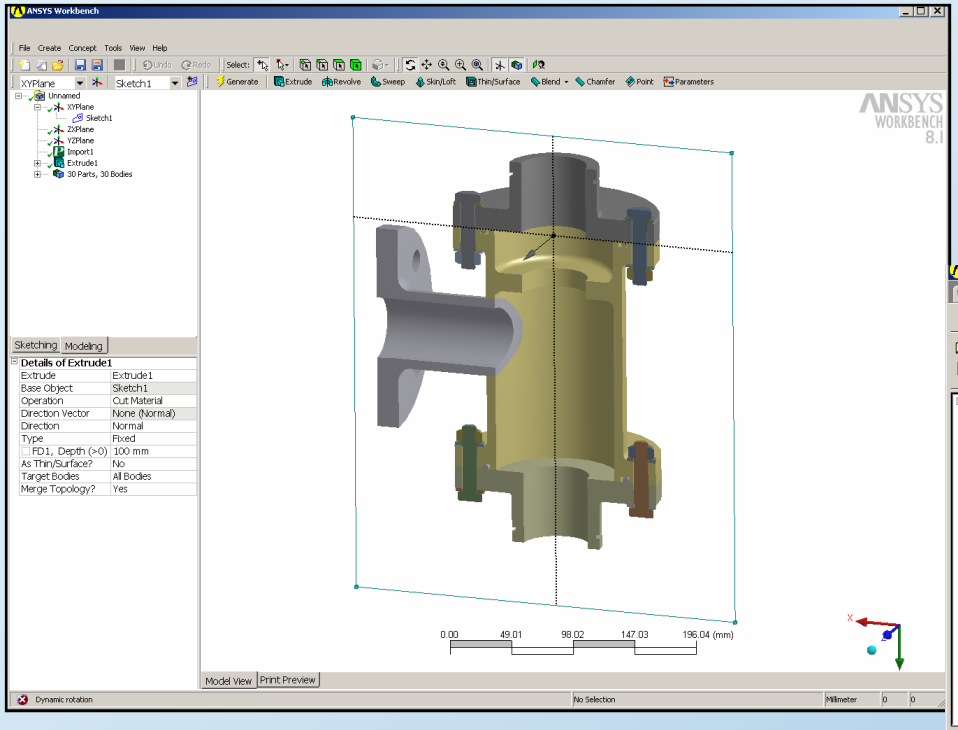
- ANSYS CFX & Workbench product overview
- ANSYS CFX Modeling Capabilities
  - Single and Multiphase Flows
  - Turbulence
  - Heat and Mass Transfer / Thermohydraulics
  - Code Coupling
- Solver Technology, Performance & Efficiency
- Code Maintenance, Education & Support
- Model Validation
- Applications in Nuclear Reactor Safety (NRS)
- Summary

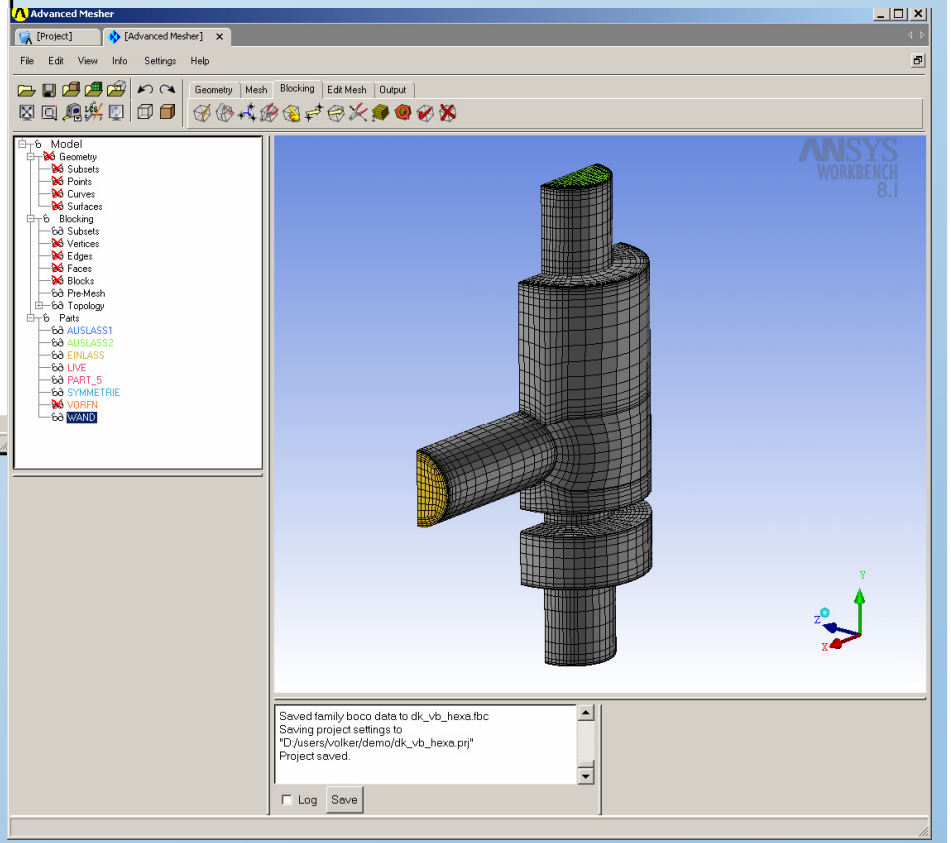
ANSYS & CFX in European NRS

CFX – Workbench Integration



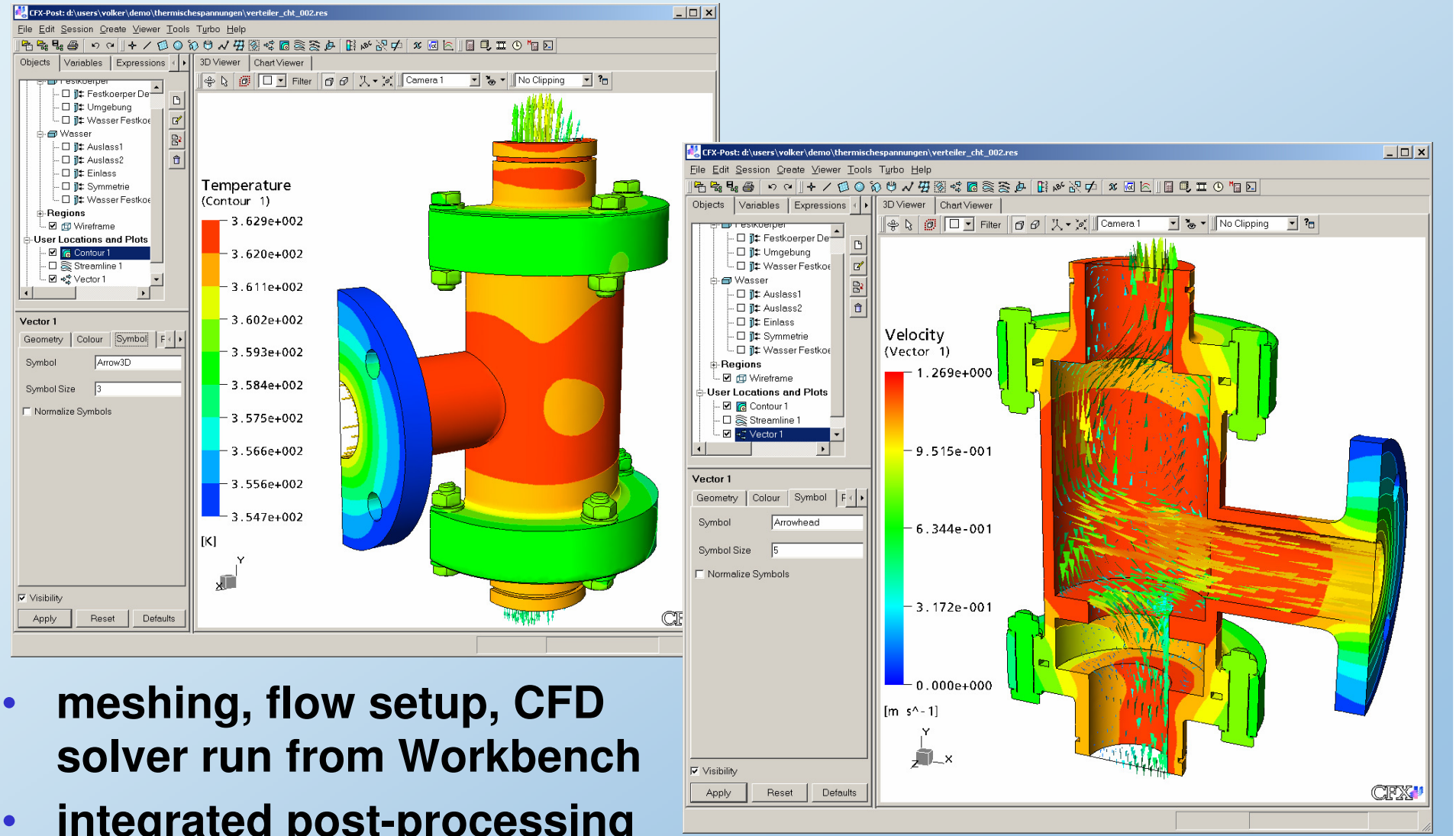
ANSYS Workbench





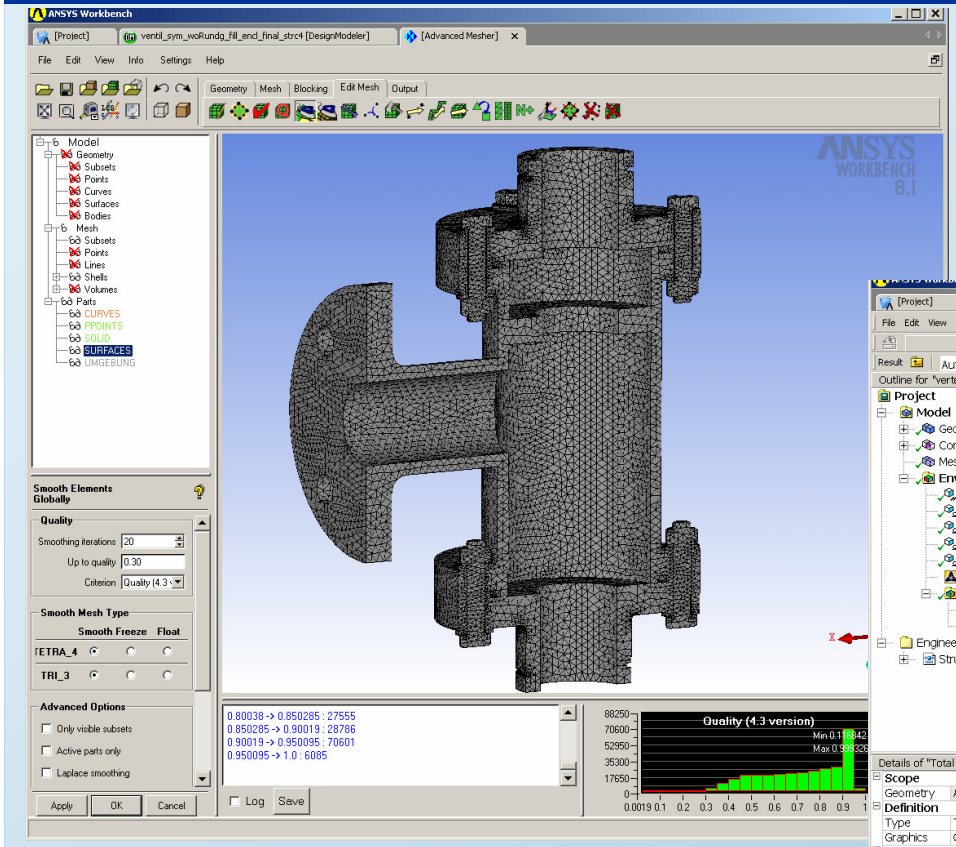
- single geometry representation
- full CAD integration
- fully parameterized model
- Unified Meshing Initiative (UMI)

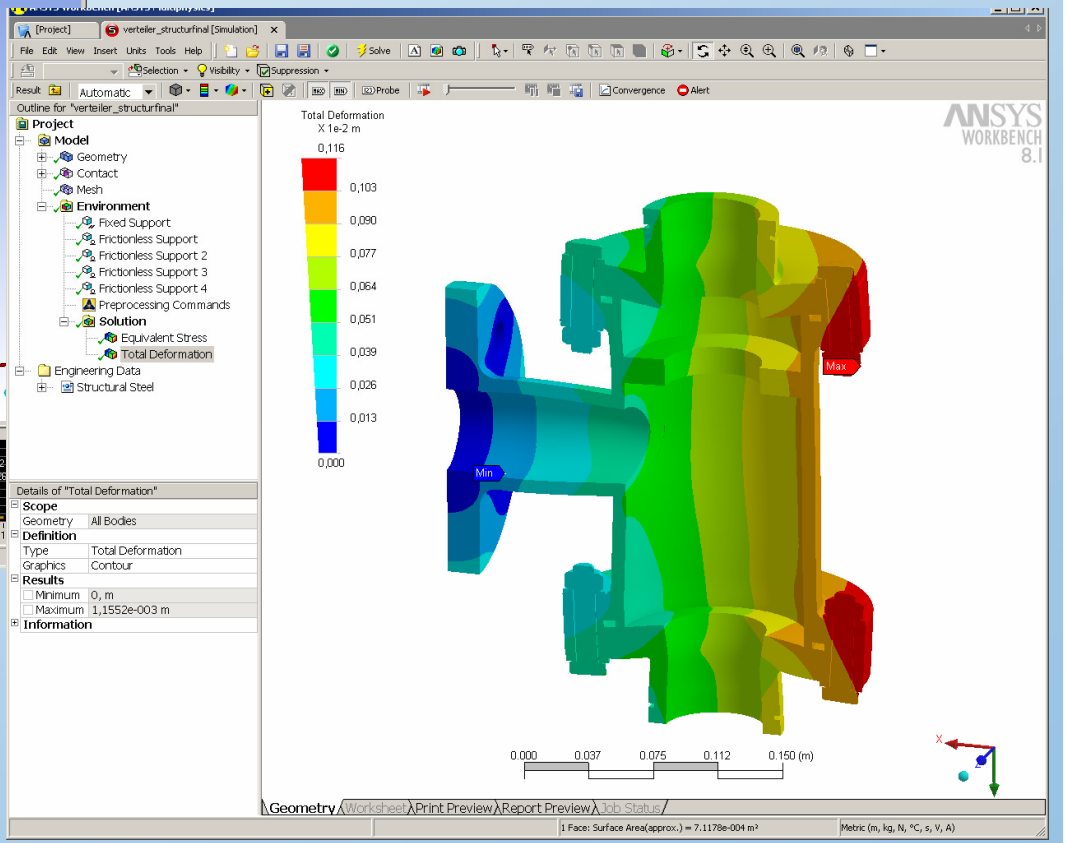
ANSYS Workbench



- meshing, flow setup, CFD solver run from Workbench
- integrated post-processing

ANSYS Workbench





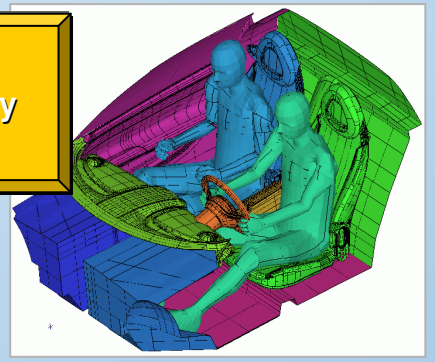
- CFD & CSM geometry
- CFD & CSM meshing
- CFD⇔CSM 2-way coupling

Multiphysics-Environment & FSI

ANSYS Multi-Physics

Heat Transfer

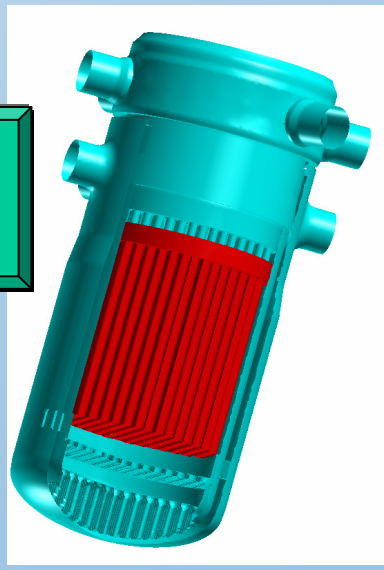
Electricity

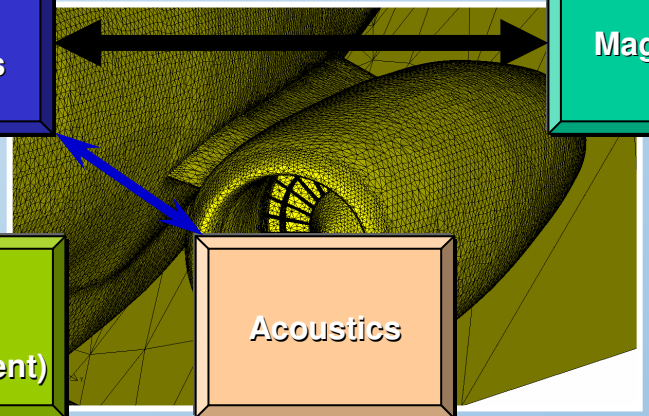


Solid Mechanics

Fluid Mechanics

Magnetism





1D Codes

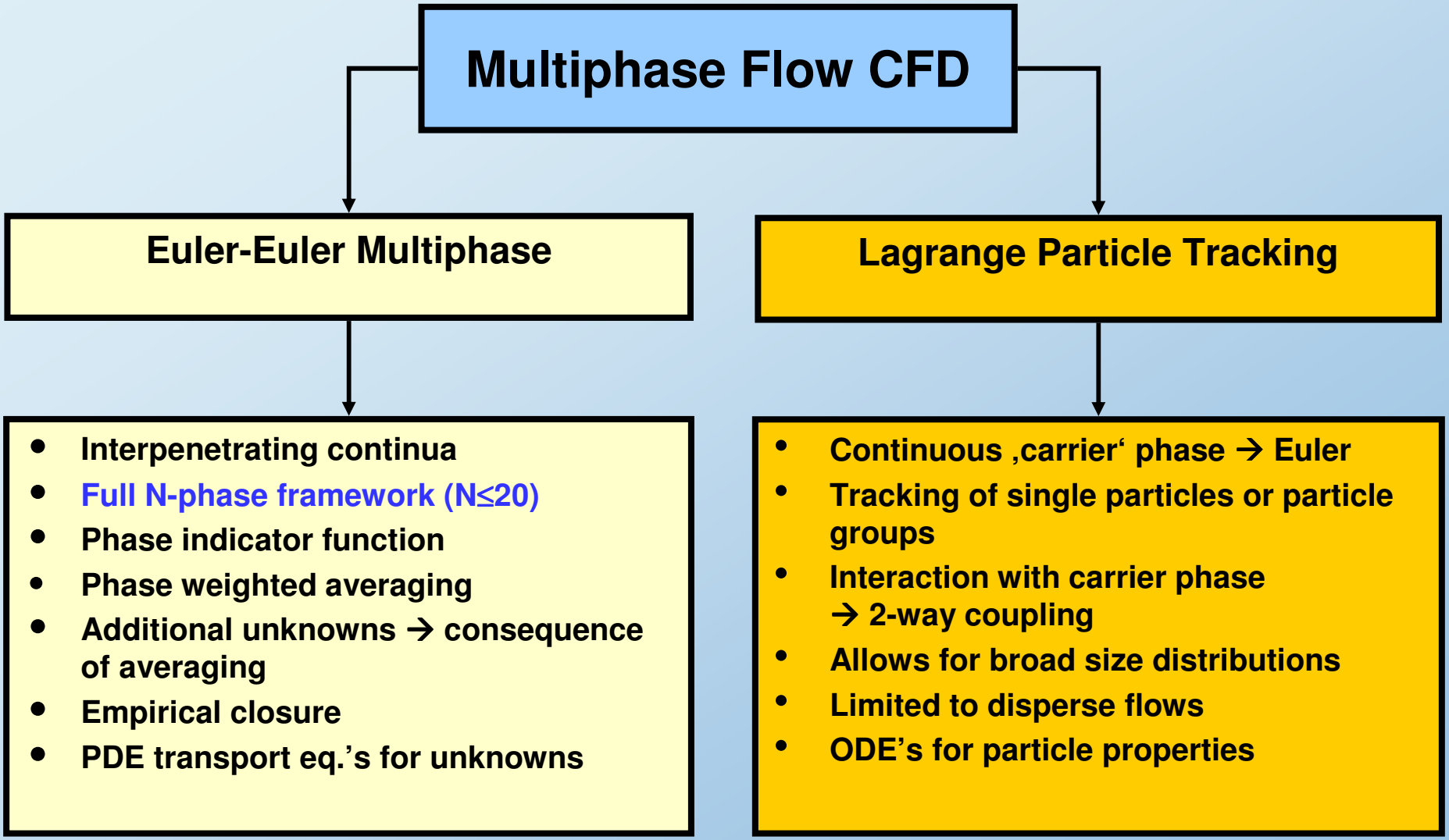
Neutron Kinetics (Development)

Acoustics

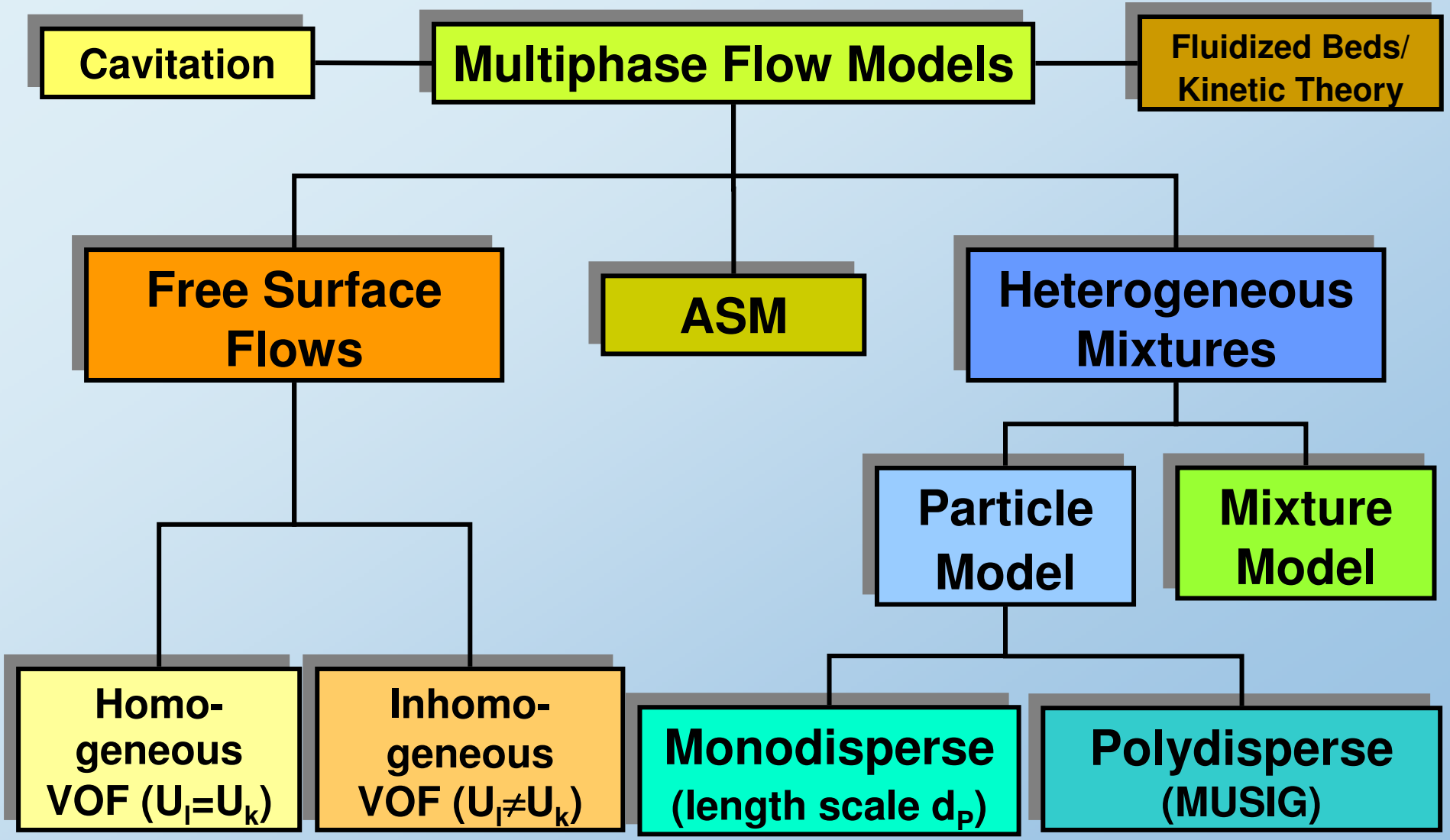
CFX Single Phase Capabilities

- Steady state & transient simulation
- Sub-, trans- and supersonic flows
- Wide variety of turbulence models (18+):
  - Standard k-ε
  - k-ω, SST
  - RSM (k-ε and k-ω based)
  - Algebraic RSM (EARSM)
  - Scale resolving turb. models (LES, DES, SAS)
  - …
- Material database, Multi-component fluid mixtures
- Chemical reactions, combustion models,…
- Conjugate heat transfer (CHT walls)
- Radiation

CFX Multiphase Flow Modeling



CFX Multiphase Flow Modeling



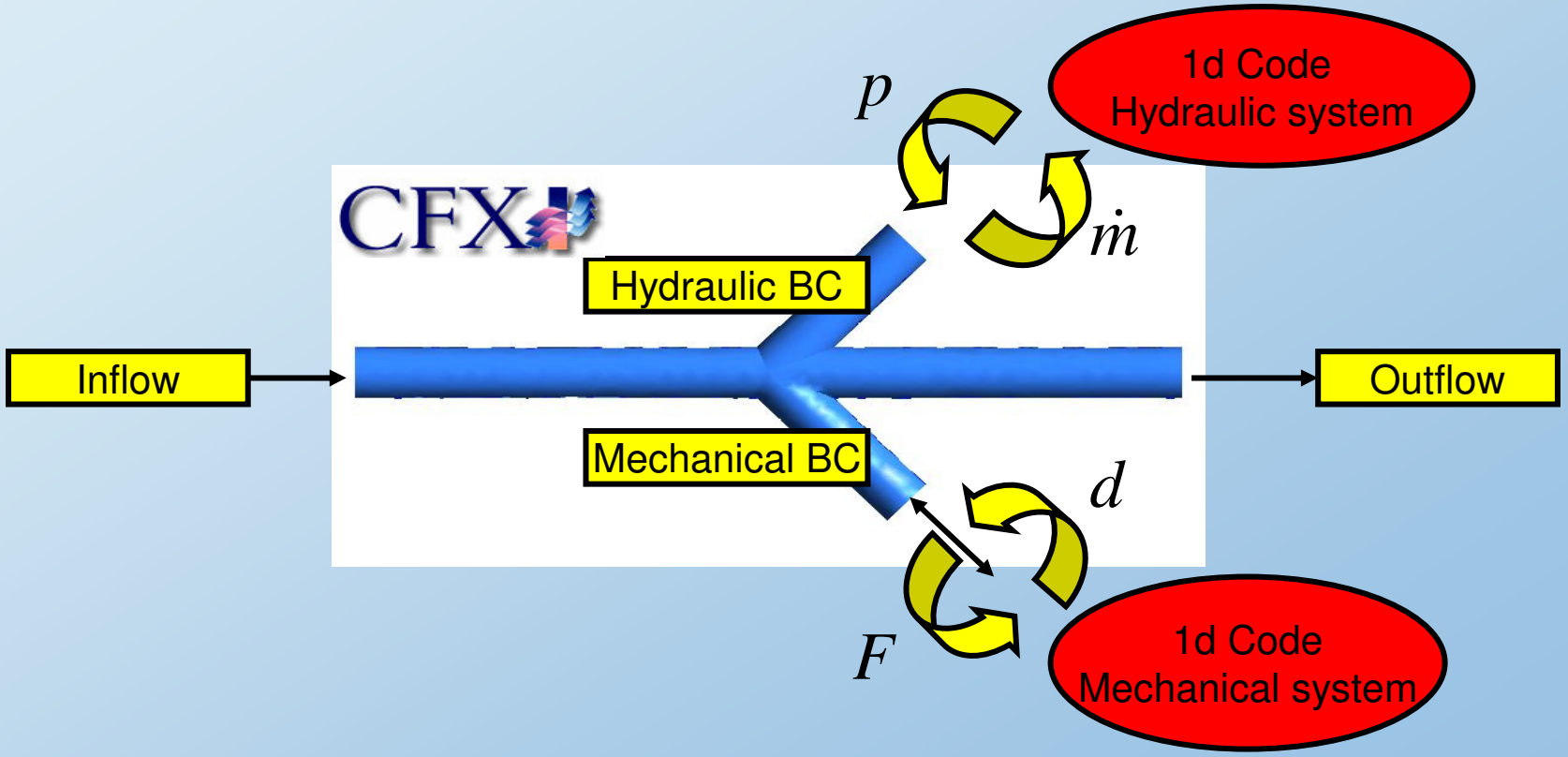
CFX Solver Models

- **Turbulence models, Transition**
- **Mixture models**
- **Eulerian multiphase:**
  full N-phase, homogeneous, inhomogeneo… Multicompon…
- **Free surface**
  surface tensi…
- **Lagrangian …**
- **Phase chang…**
  cavitation, bo…, evaporation, solid/liquid
- **Porous media models**
- **Real fluid models**
- **User-Fortran, CCL, User Customization**
- **Heat transfer models, CHT**
- **Radiation models:**
  P1, DTM, Monte Carlo, multiband, multigrey, specular, …ering, …ort
- **…dels:**
  …ultistep, kinetic, …ed, partially
- **… models**
- **Transient models**
- **2-way FSI** *(ANSYS WB, MpCCI)*
- **Moving Mesh**
- **Multi-domain physics**
- **More …**

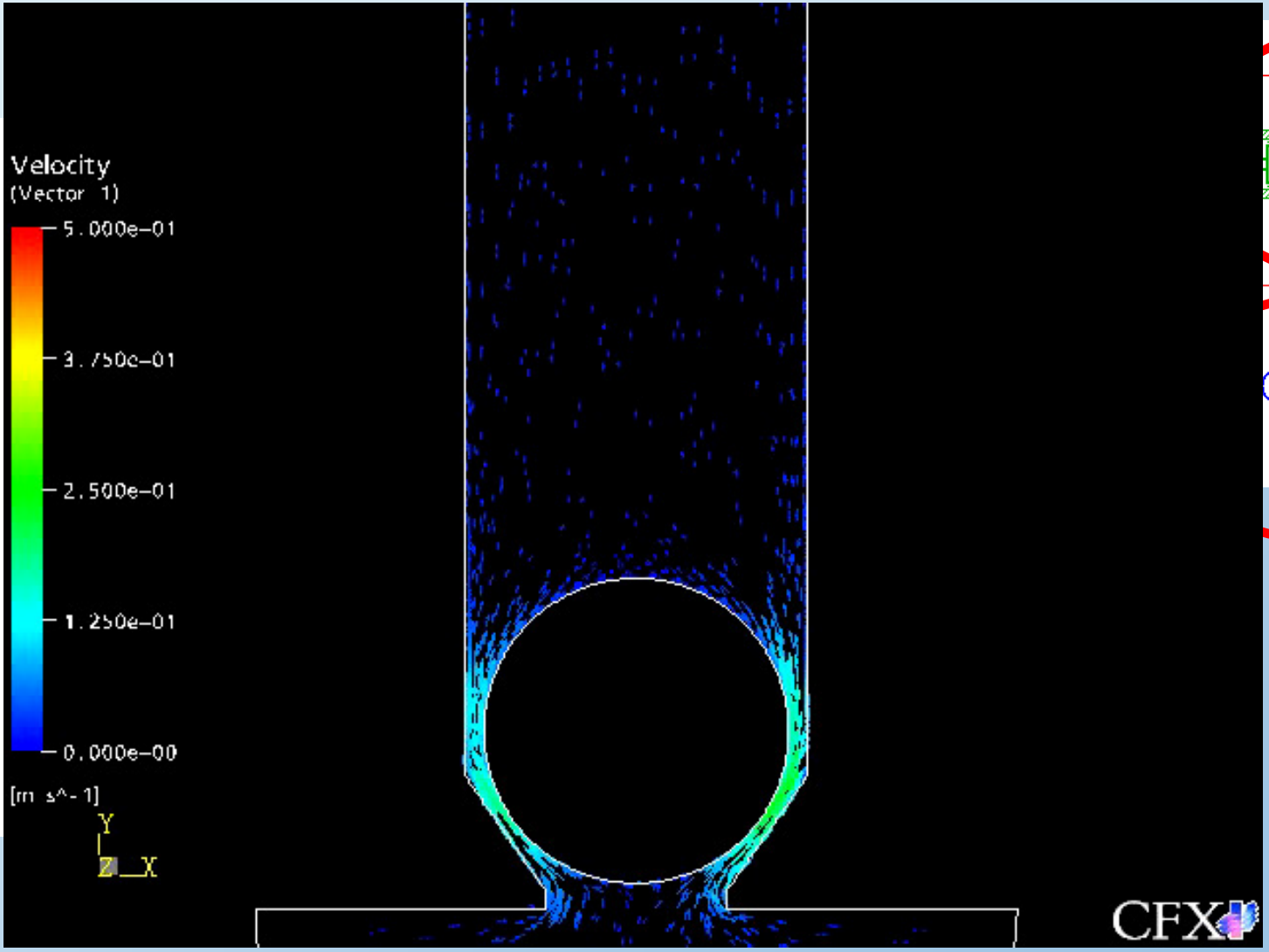
- **full feature matrix interaction**
- **fully parallelized (PVM, MPI)**
- **coupled solver**
- **algebraic multigrid (AMG)**
- **single & double precision**

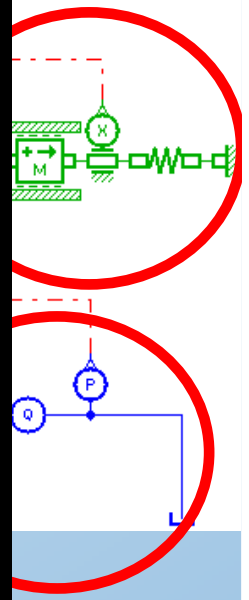
CFD ⇔ 1d-Code Coupling

- interfaces for CFX with AMESim / GT-Power
- mechanical / hydraulic BCs
- interfaces for ATHLET & RELAP-5 planed



Example: Opening Valve



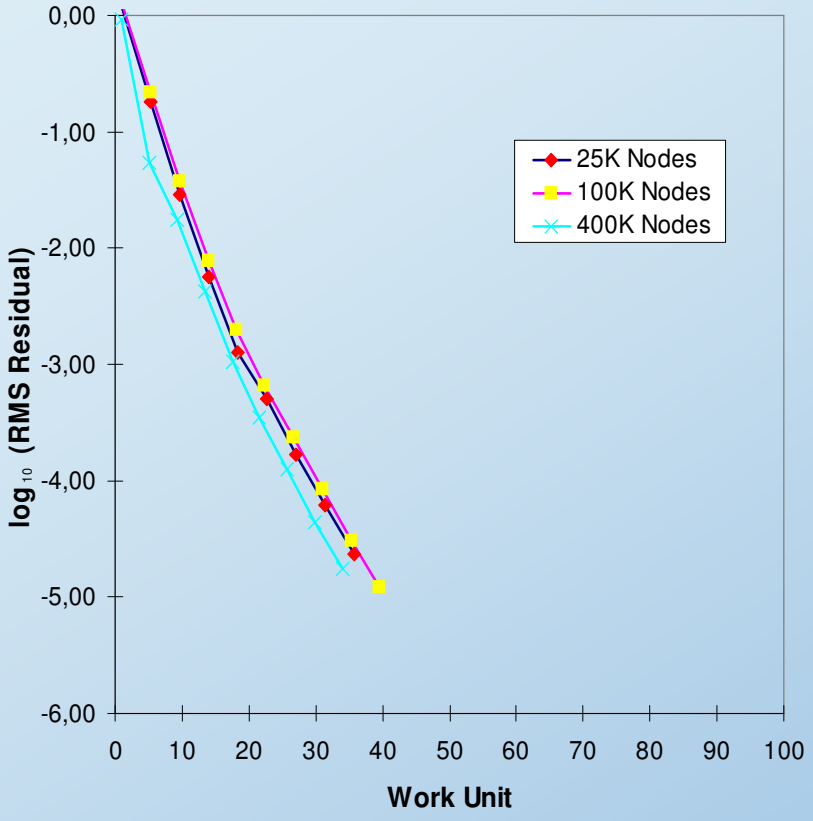


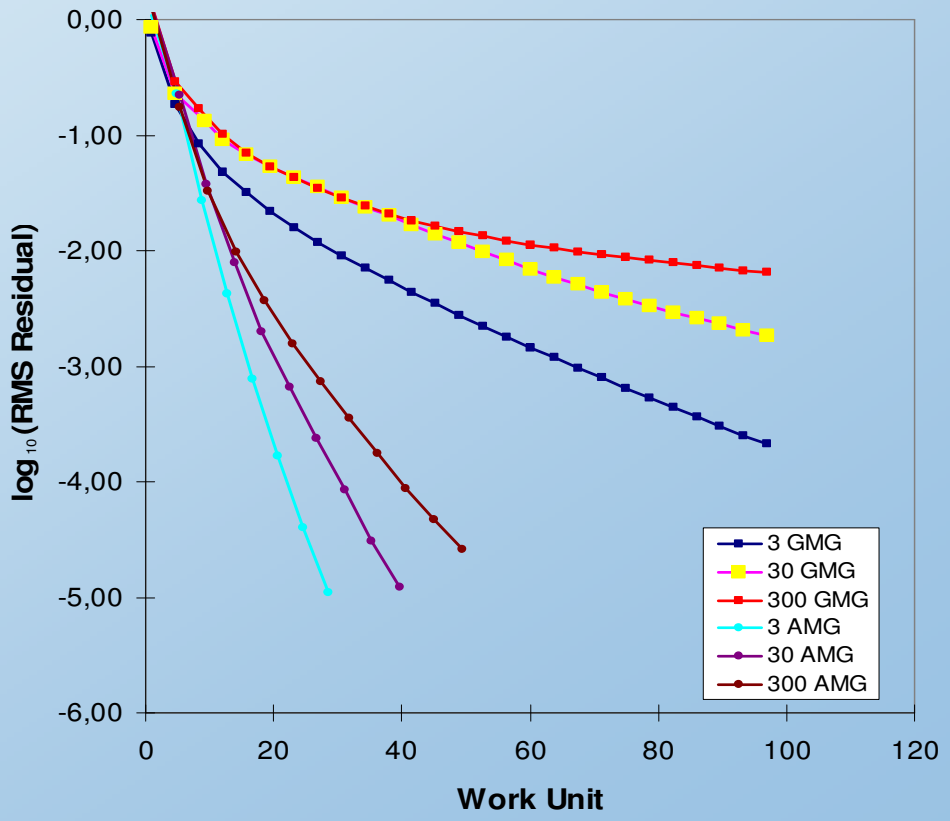
Solver Efficiency

- **CFX-5 coupled solver**
  - hydrodynamic system (U-V-W-P system of eq's)
  - coupled chemical reactions
  - coupled multiphase
- **Algebraic Multigrid Solver**
  - highly convergent
  - multigrid solver used by all models
  - enhanced robustness
  - effort grows linear with mesh resolution
- **Parallelization & High-Performance Computing**
  - fully and highly efficient parallelized solver (PVM, MPI)
  - memory scalability and speed-up
  - flexible partitioning methods
  - HPC architecture support (with limitations)

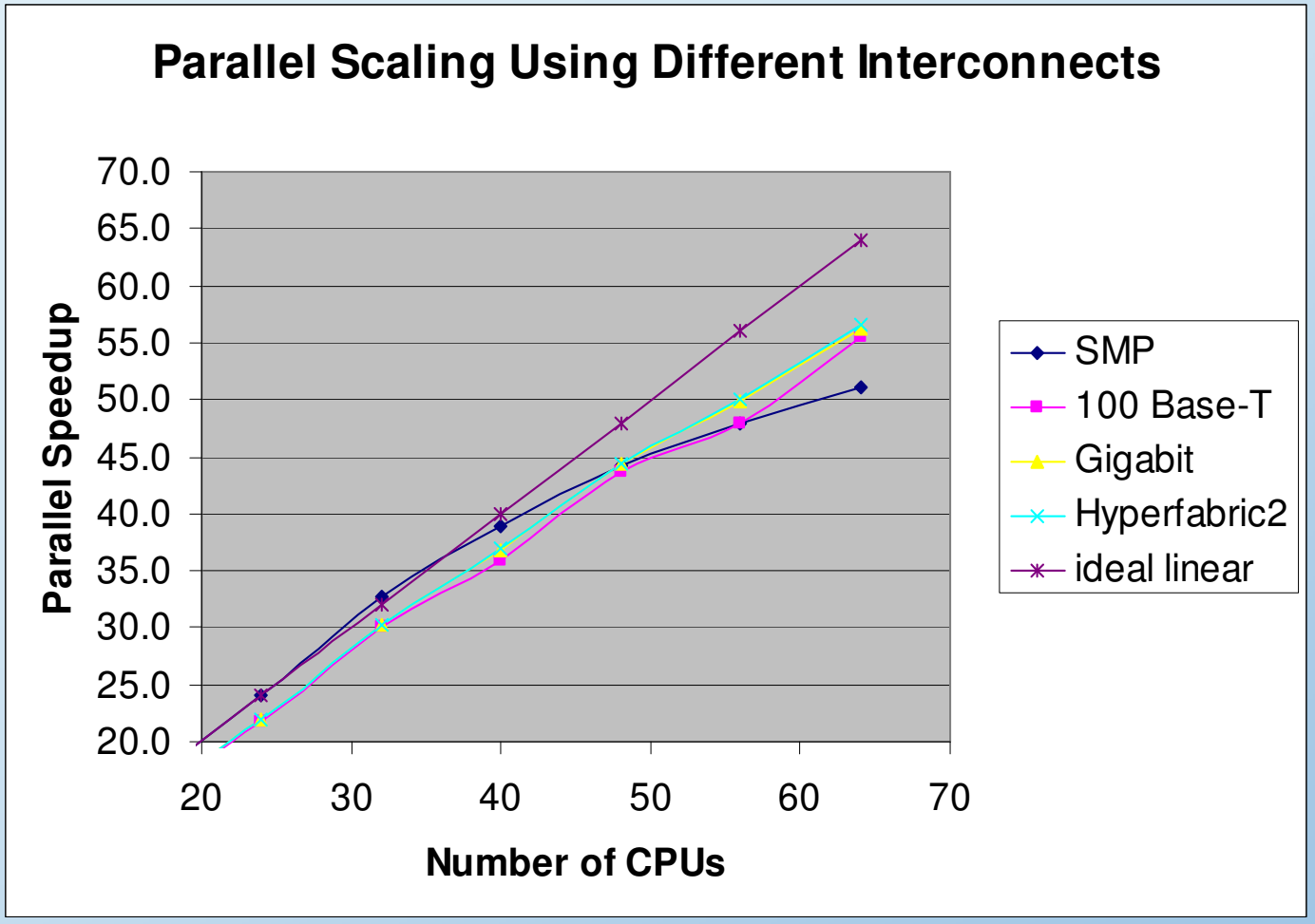
Algebraic Multigrid Solver

- **Grid refinement:**
  - **constant (linear) performance with grid refinement**
- **Sensitivity to grid aspect ratios:**
  - **aspect ratios: 3, 30, 300**
  - **AMG shows better performance then geometric multigrid**





Solver Efficiency: Parallelization



- Test results courtesy of Dr. M. Ehrig, HPTC
- PA 8800 superdome
- 80 million nodes
- Low data transfer algorithm

Code Maintenance, Support, Education & Training

- **Fully maintained commercial CFD code**
  - → extensive user documentation and tutorials, benchmark test cases, examples,…
- **Full user support & training**
  - @ ANSYS & In-house
- **Engaged in BPG for single and multiphase flows**
  - → ECORA, ASTRESA proposal
  - → ERCOFTAC, QNET-CFD, …
- **Education and training:**
  - → 4th Joint FZR & ANSYS CFX Short Course & Workshop on MPF in NRS, 26.-29. June ’06
  - → Regular CFX Seminars & Updates

Qualification of ANSYS Software

- Software engineering process according to strict guidelines derived in the project SEMPA
  (SEMPA – Software Engineering Methods for Parallel Applications)
- maintained Quality Assurance database
- QA defects are tracked until they are corrected by a developer and the solution is approved
- nightly execution of more then 350 regression tests for basic physical models on all ~10 supported hardware platforms
  → more then ~3500 simulation runs each day
- results of regression tests are compared to previously evaluated results
- failures / differences in regression tests are marked in a web interface and will be tracked by responsible developers immediately

Qualification of ANSYS Software (cont.)

- Internal database of automated validation test suites
  - stored with all mesh, input and output data
  - references are reliable experimental or analytical data
  - all validation material available to customers for own testing purposes on request
- Selected validation tests are repeated on new software versions
- 3 stages of Pre-Release testing:
  - Beta testing program with strong user participation
- Functional and acceptance testing of new software versions prior to release by internal testing group
- Participation in national/EU projects focused on validation of CFD models and codes

Model Validation

- large effort of ANSYS CFX in model validation
- participation in EU / national research projects:

- German CFD Network on Nuclear Reactor Safety Research

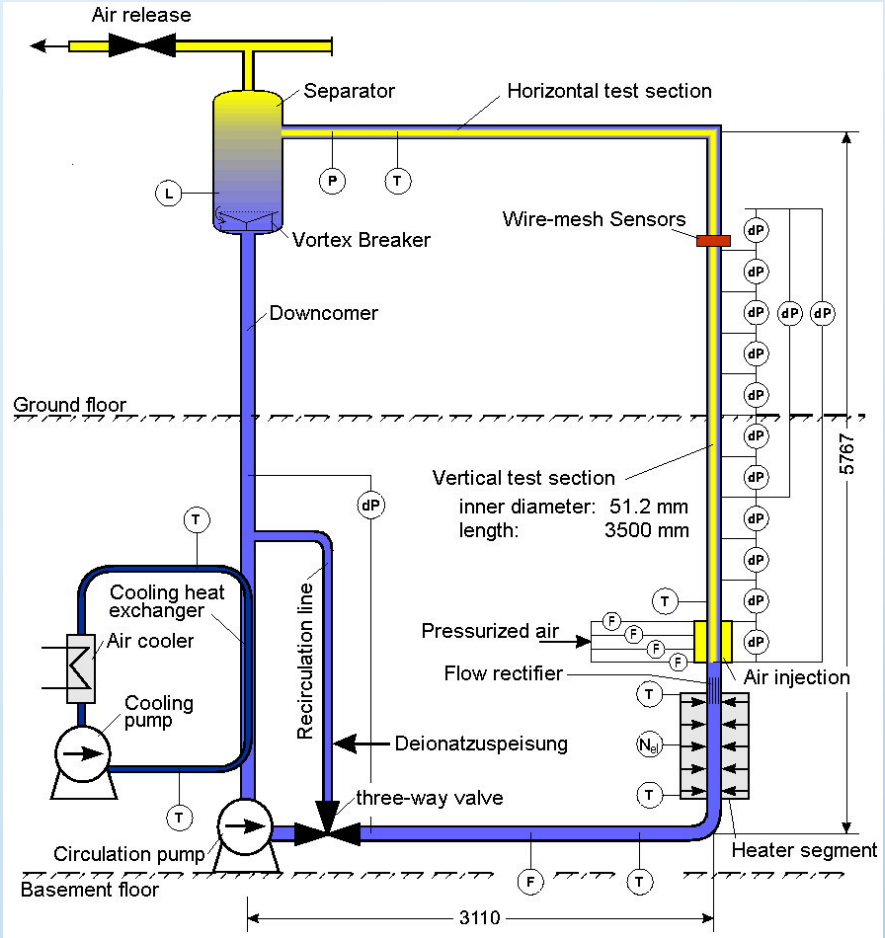
- Evaluation of Computational Fluid Dynamic Methods for Reactor Safety analysis

- Advanced 3d two-phase flow simulation tool for application to reactor safety

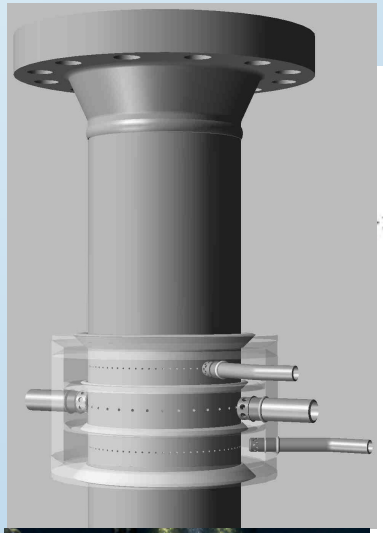
- Project on fluid mixing and flow distribution phenomena in the PWR primary circuit

… and much more, e.g. QNET-CFD, PRECCINSTA, EXPRO, ALESSIA, FLOMANIA, DESider, Cavitation

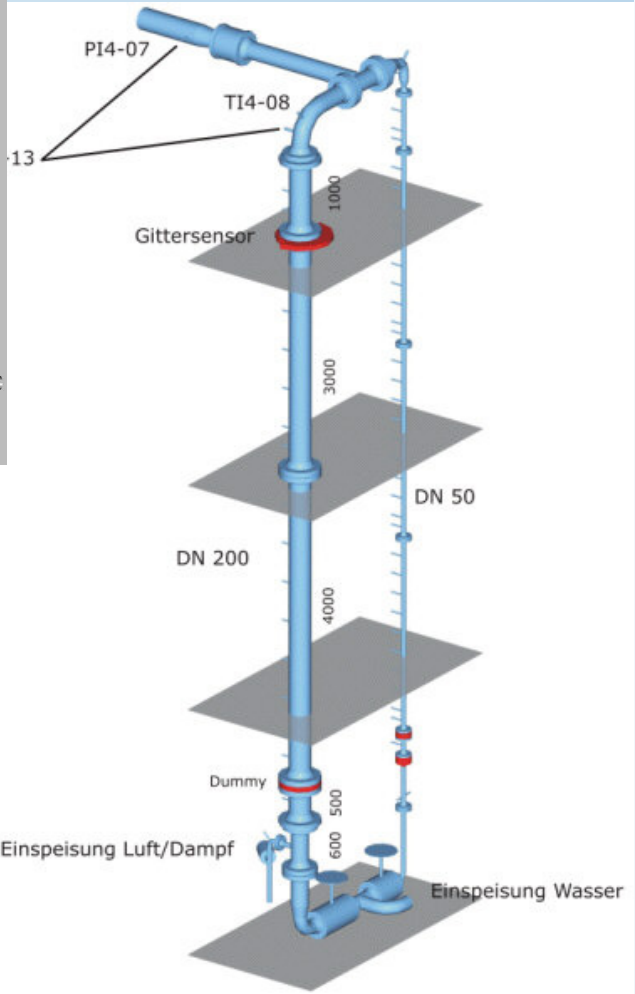
Bubbly Flow Model Validation
FZR MT-Loop and TOPFLOW Database



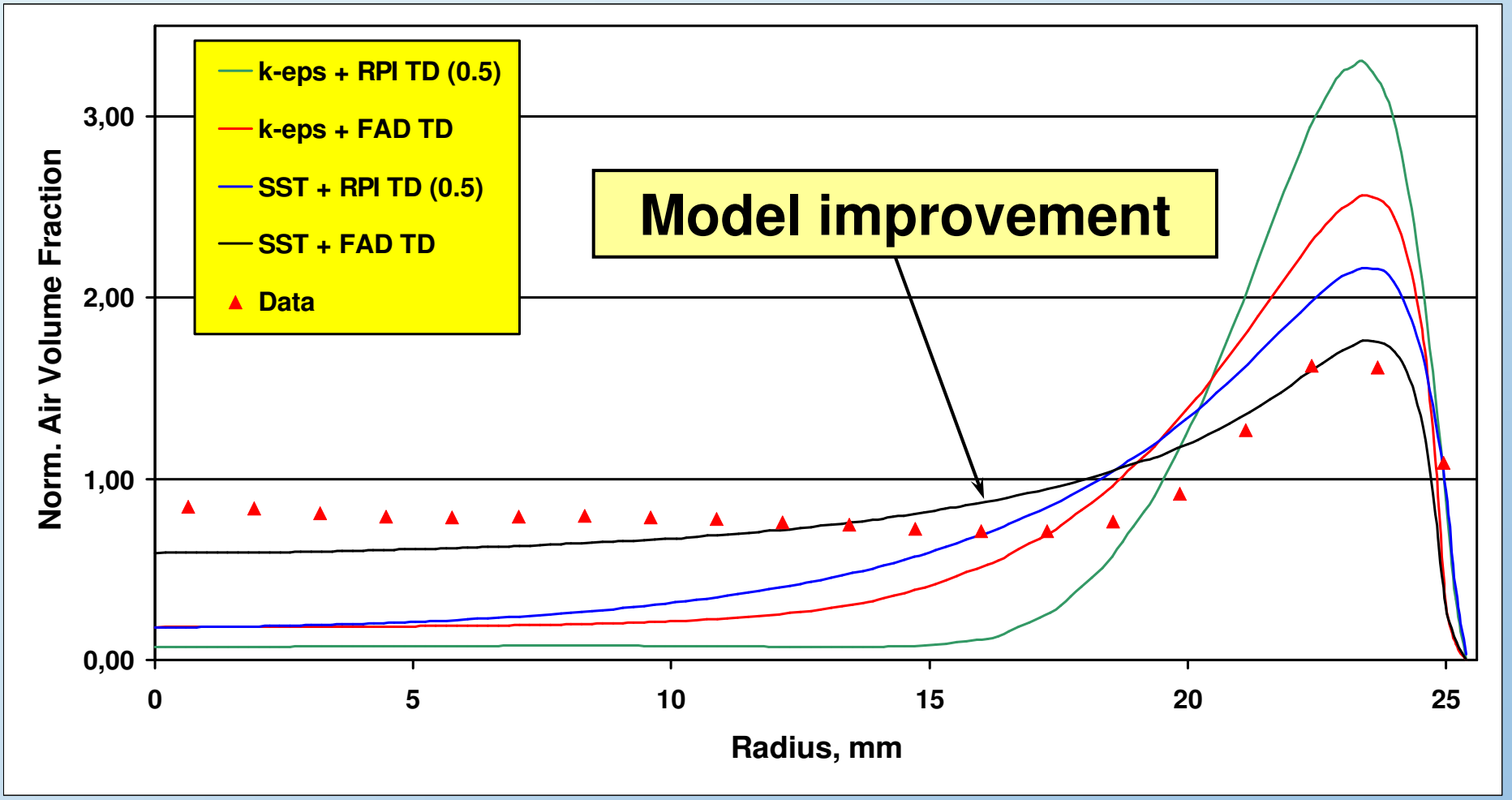
MT-Loop



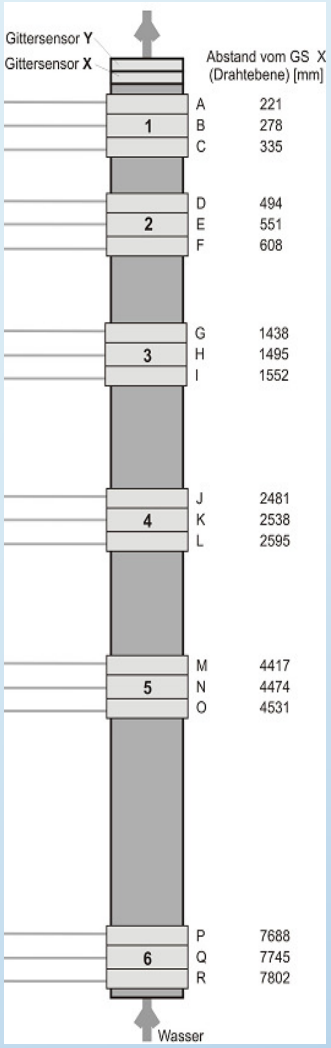
TOPFLOW

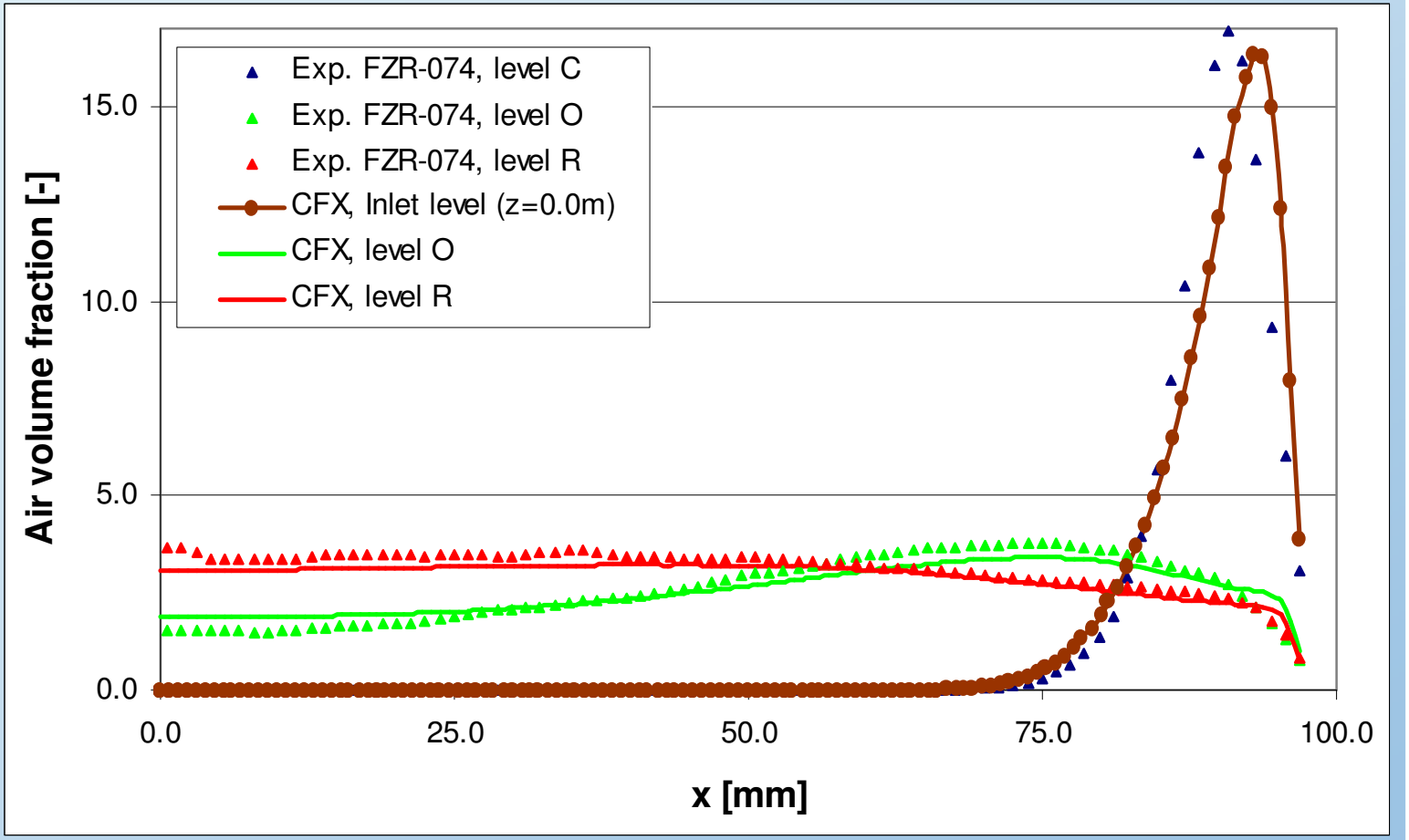


Validation: Bubbly Flows
Turbulent Dispersion Force

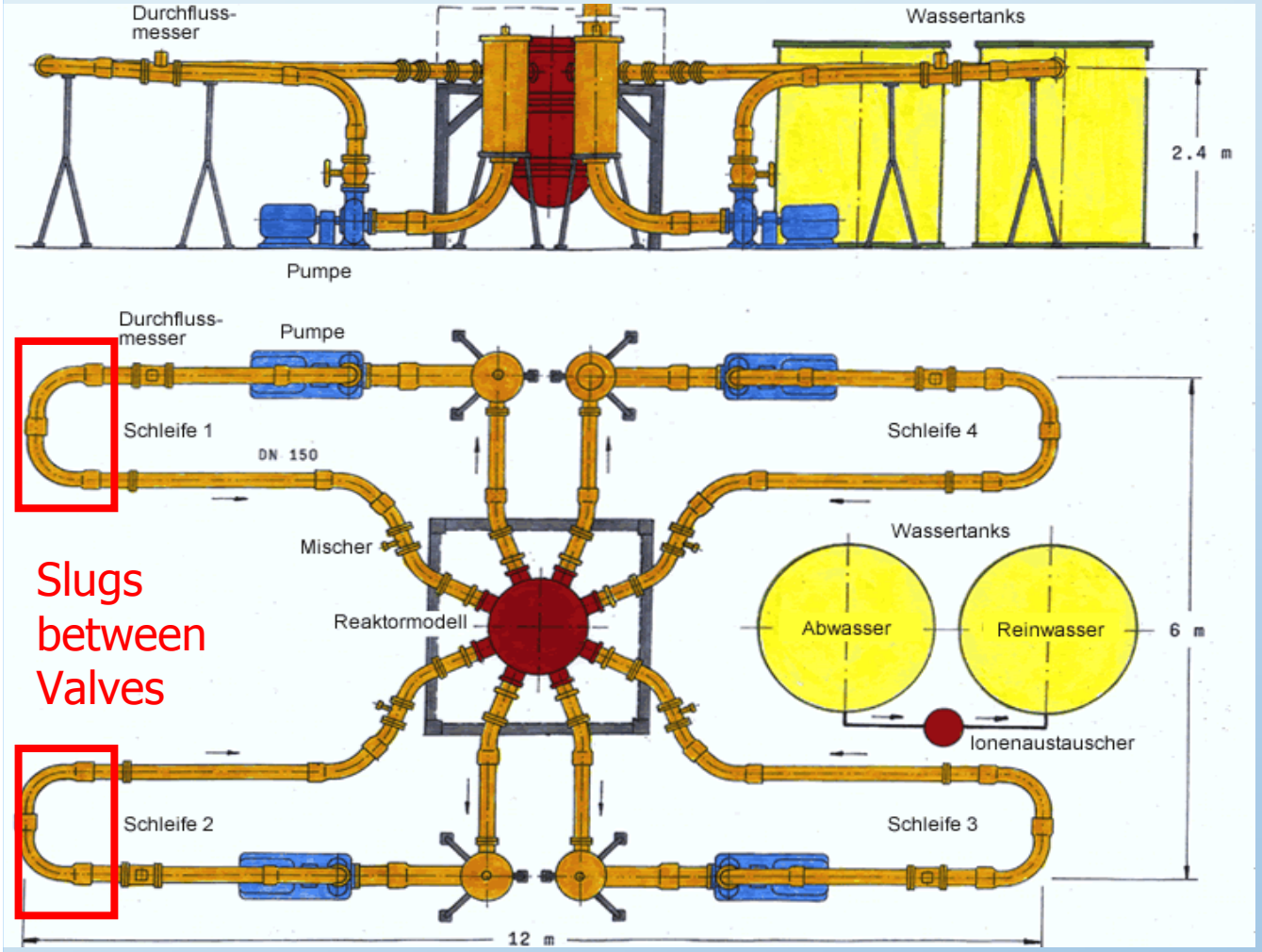


Validation: Polydisperse Flows
Inhomogeneous MUSIG Model



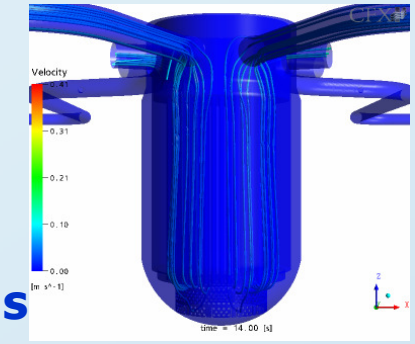


Boron Mixing Experiments at ROCOM Test Facility, FZR

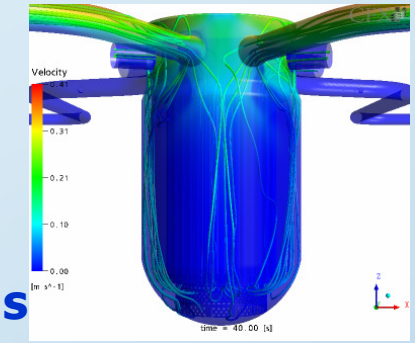


Scheme of the ROCOM test facility at FZ Rossendorf

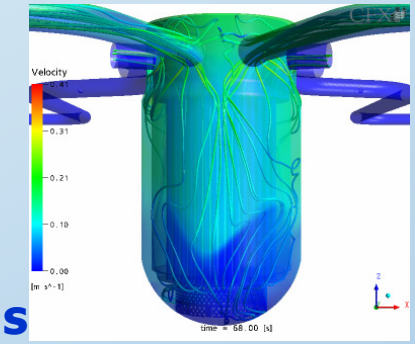
Transport of Slugs - Streamlines



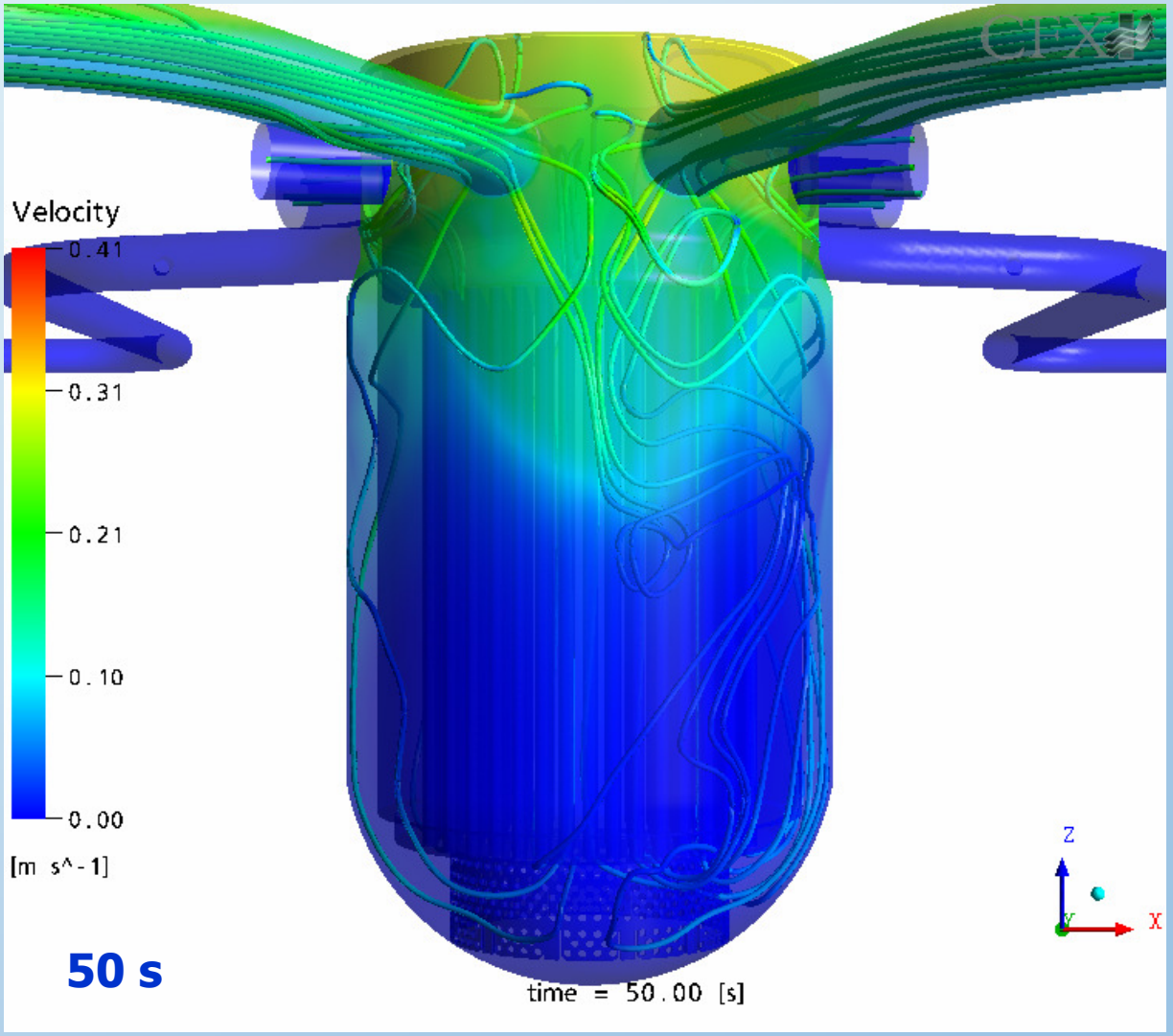
14 s



40 s



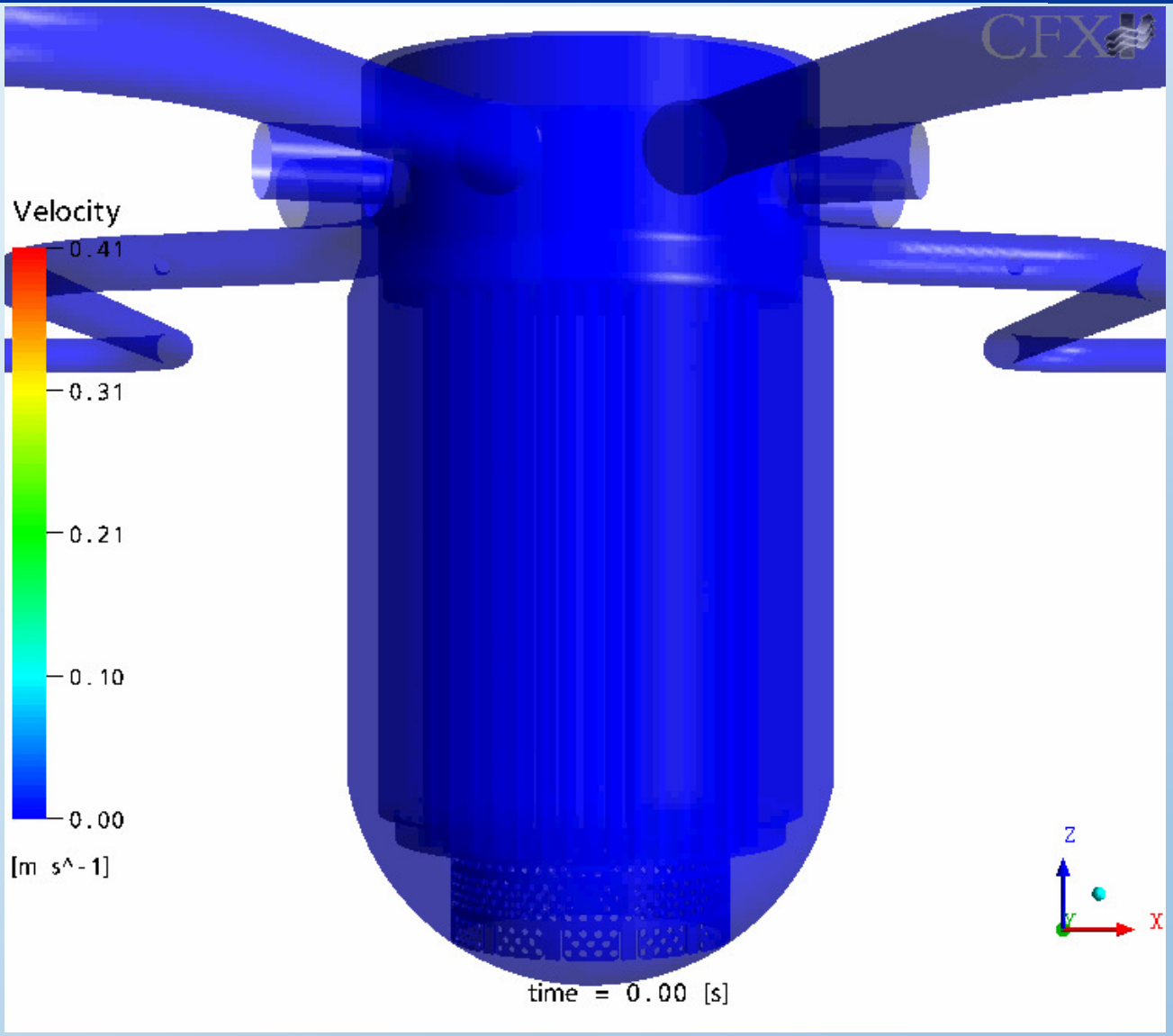
68 s



50 s

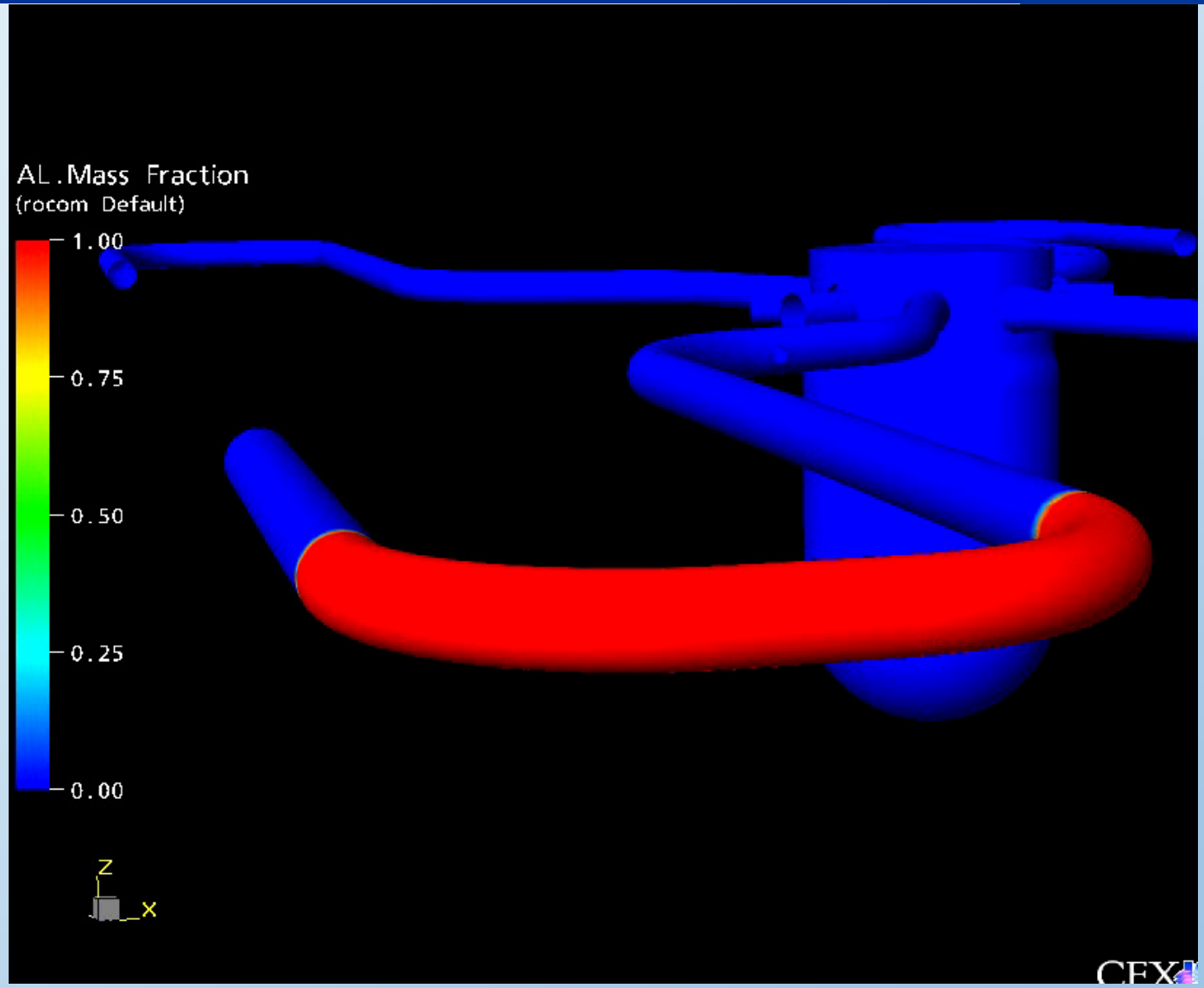
Courtesy of Th. Höhne, FZ Rossendorf

Transport of Slugs



Courtesy of
Th. Höhne,
FZ Rossendorf

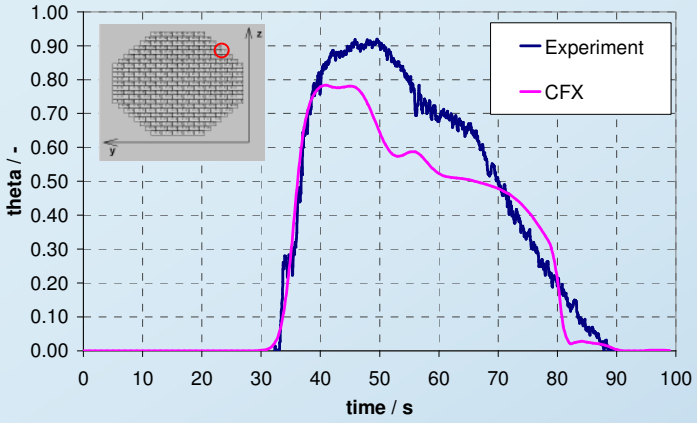
Transient Slug Mixing



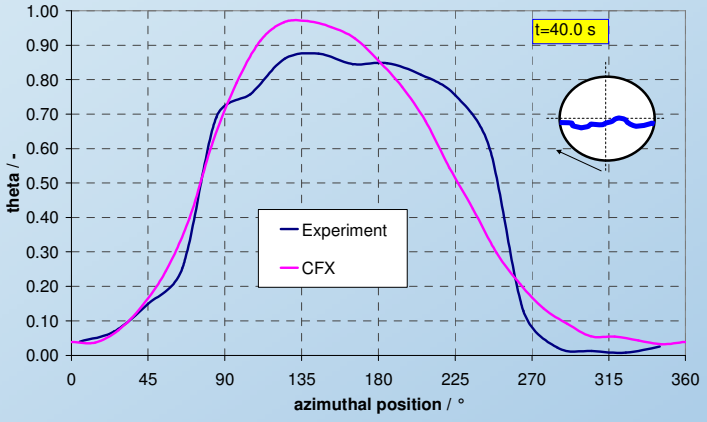
Courtesy of
Th. Höhne,
FZ Rossendorf

Quantitative Results of Slug Mixing

Reactor Inlet

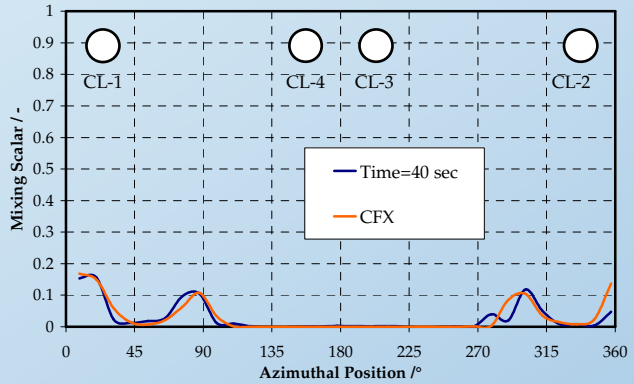


Local $\Theta_{x,y}(t)$ (42.5°)

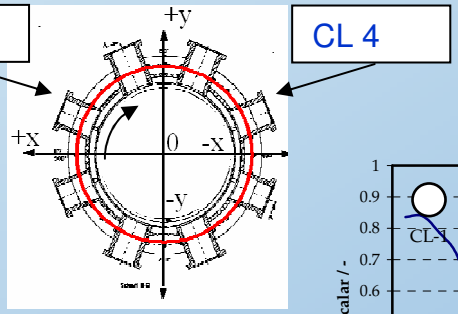


Θ_φ at 40 s

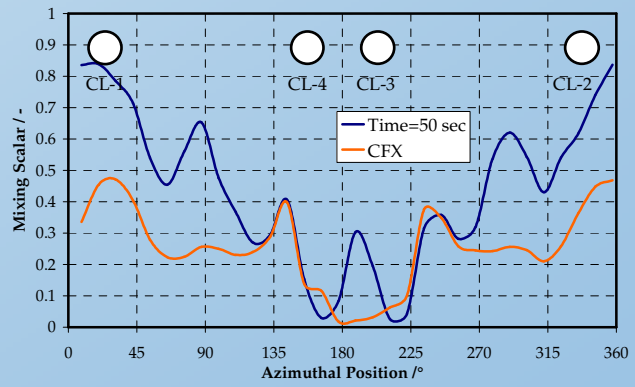
Upper Downcomer



Θ_φ at 40 s



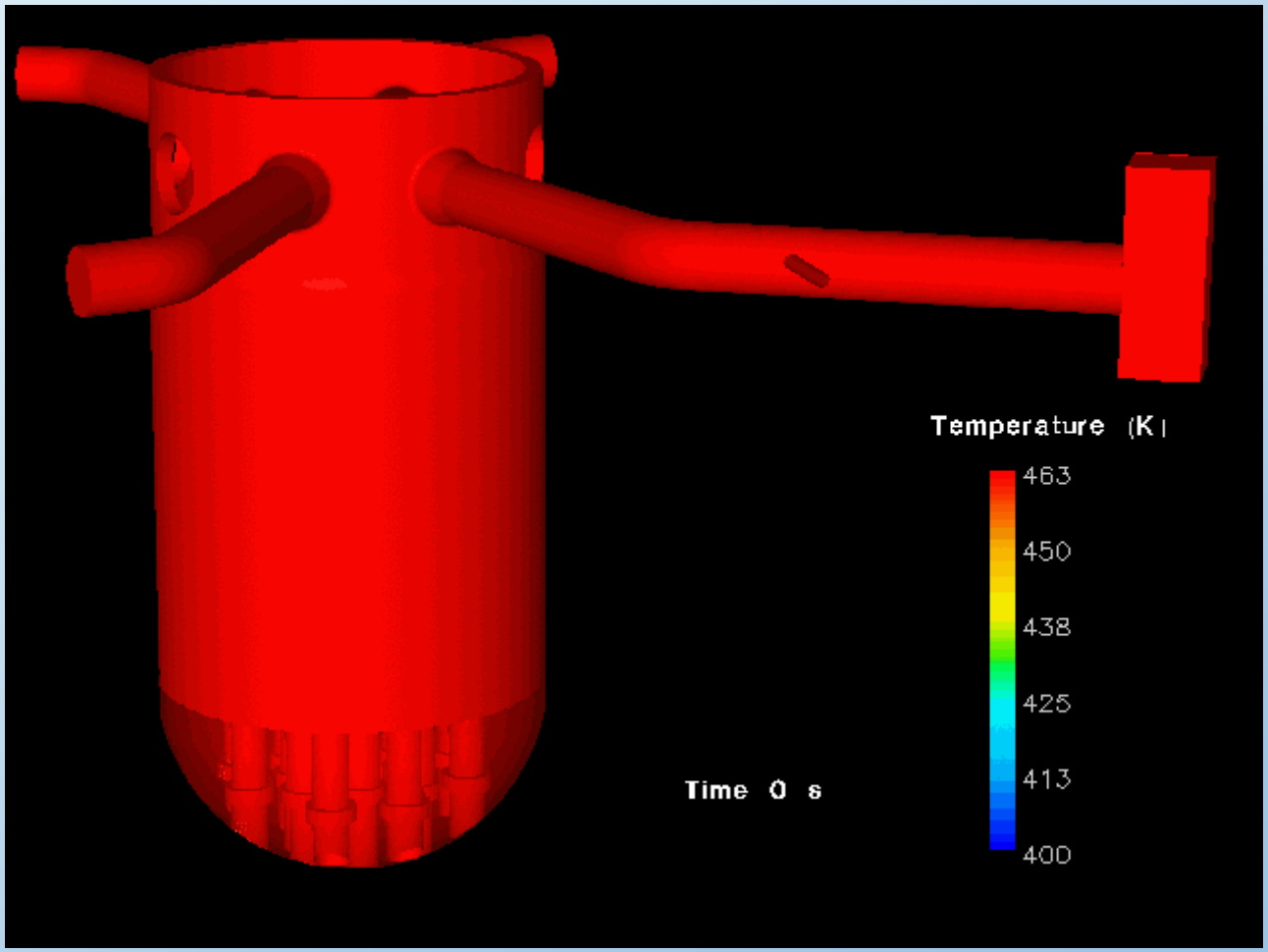
Courtesy of Th. Höhne, FZ Rossendorf



Θ_φ at 50 s

ECC Injection after SBLOCA

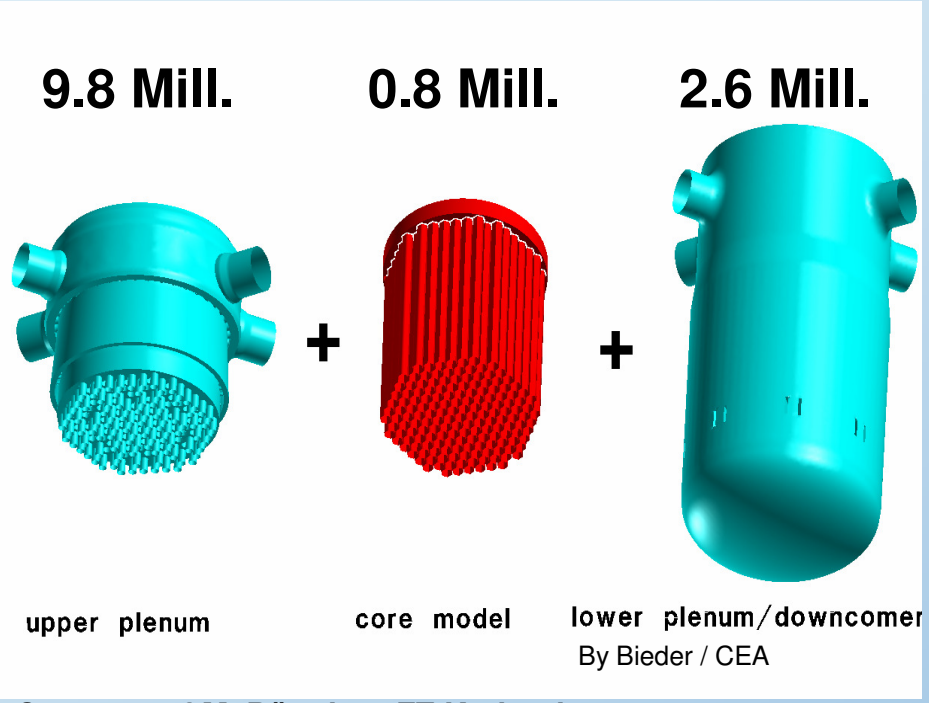
- UPTF demonstration case
- full-scale simulation of the primary system of the four loop 1300 MWe Siemens/KWU PWR
- Fluid-Fluid mixing in Cold Leg and Downcomer during ECC injection after SBLOCA
- Further UPTF cases investigated by GRS



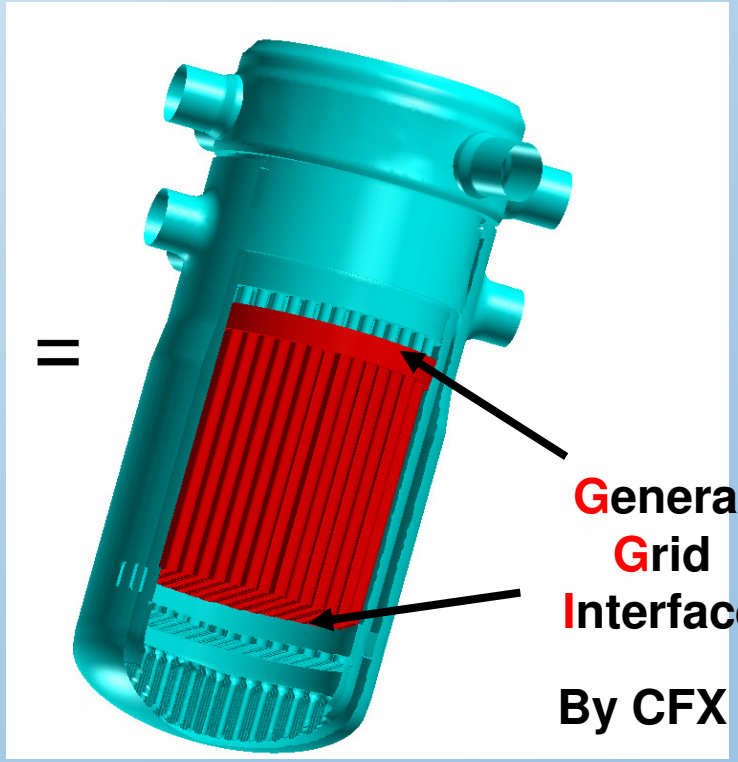
Courtesy of Sander Willemsen

VVER RDB Simulation

- Analysis of a VVER-1000 RDB (NPP Kozloduy, BG) OECD Coolant Transient Benchmark
- Temperature transient in a single Cold Leg
- Structures > 5mm resolved by the mesh



Courtesy of M. Böttcher, FZ Karlsruhe

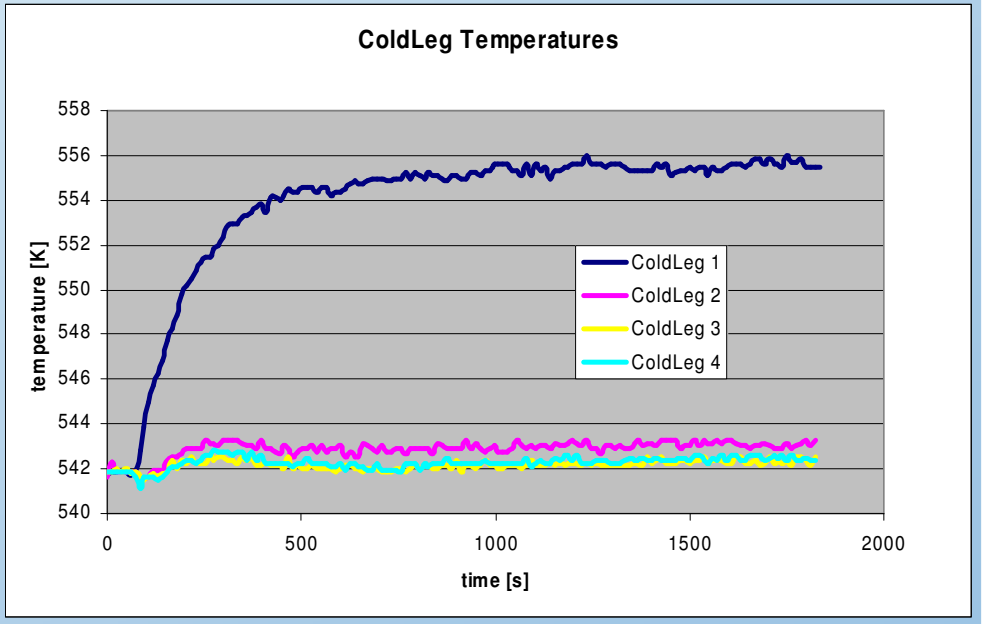


VVER Simulation

Initial and Boundary Conditions

281-286 MW Core Power Output (Assumption: linear increase up to t=1800s)

Loop No	Cold leg temp [°C]	Mass flow rate [kg/s]
1	268.6	4737
2	268.7	4718
3	268.6	4682
4	268.6	4834



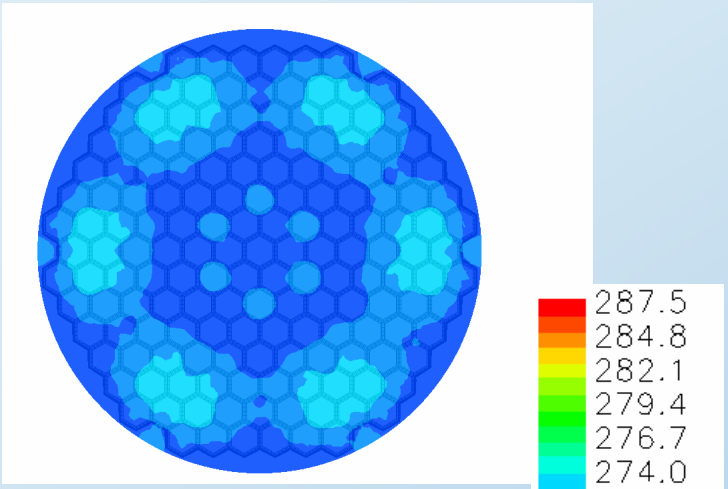
Courtesy of M. Böttcher, FZ Karlsruhe

Temperature Distribution in VVER during Temp. Transient

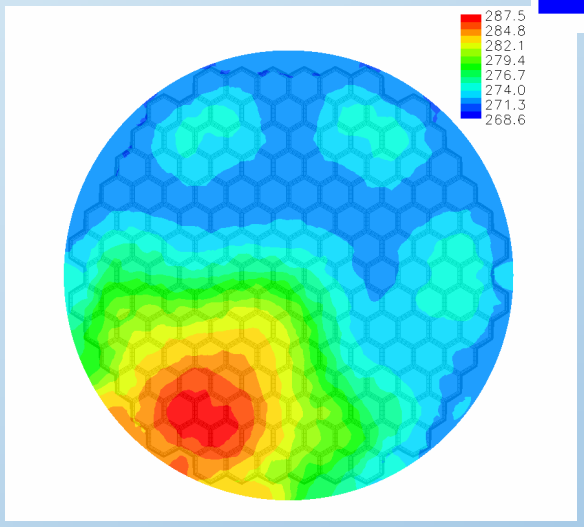
ANSYS

Core assembly outlet temperature

initial state:

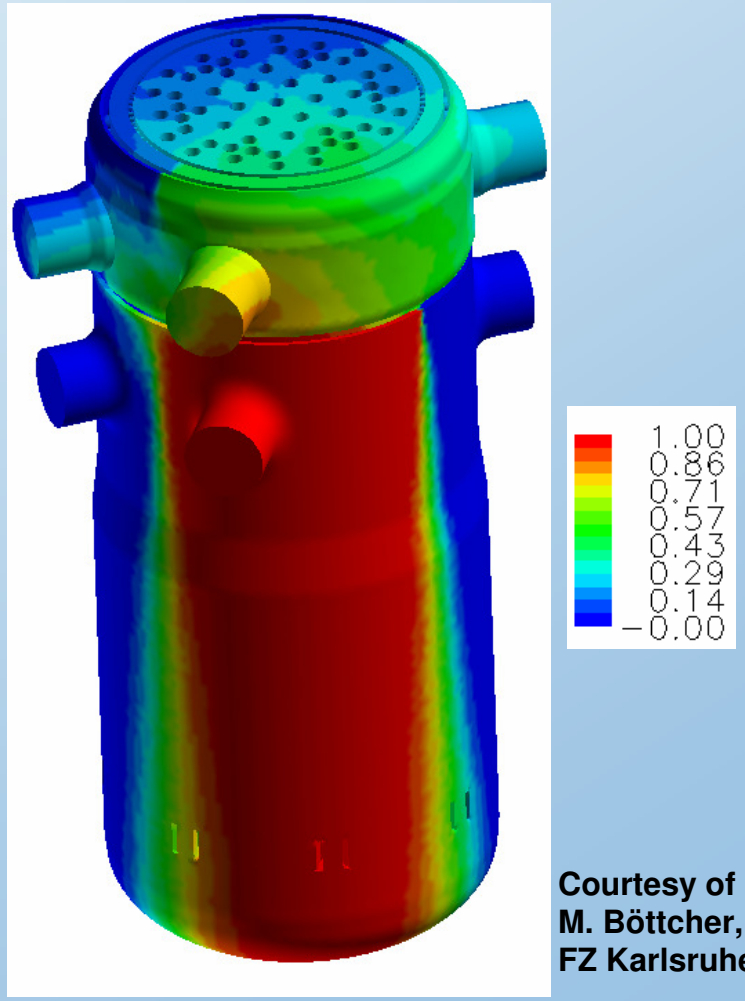


final state:



Temp [°C]

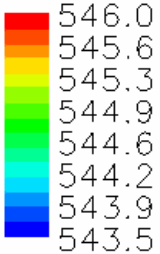
mixing coefficient



Courtesy of M. Böttcher, FZ Karlsruhe

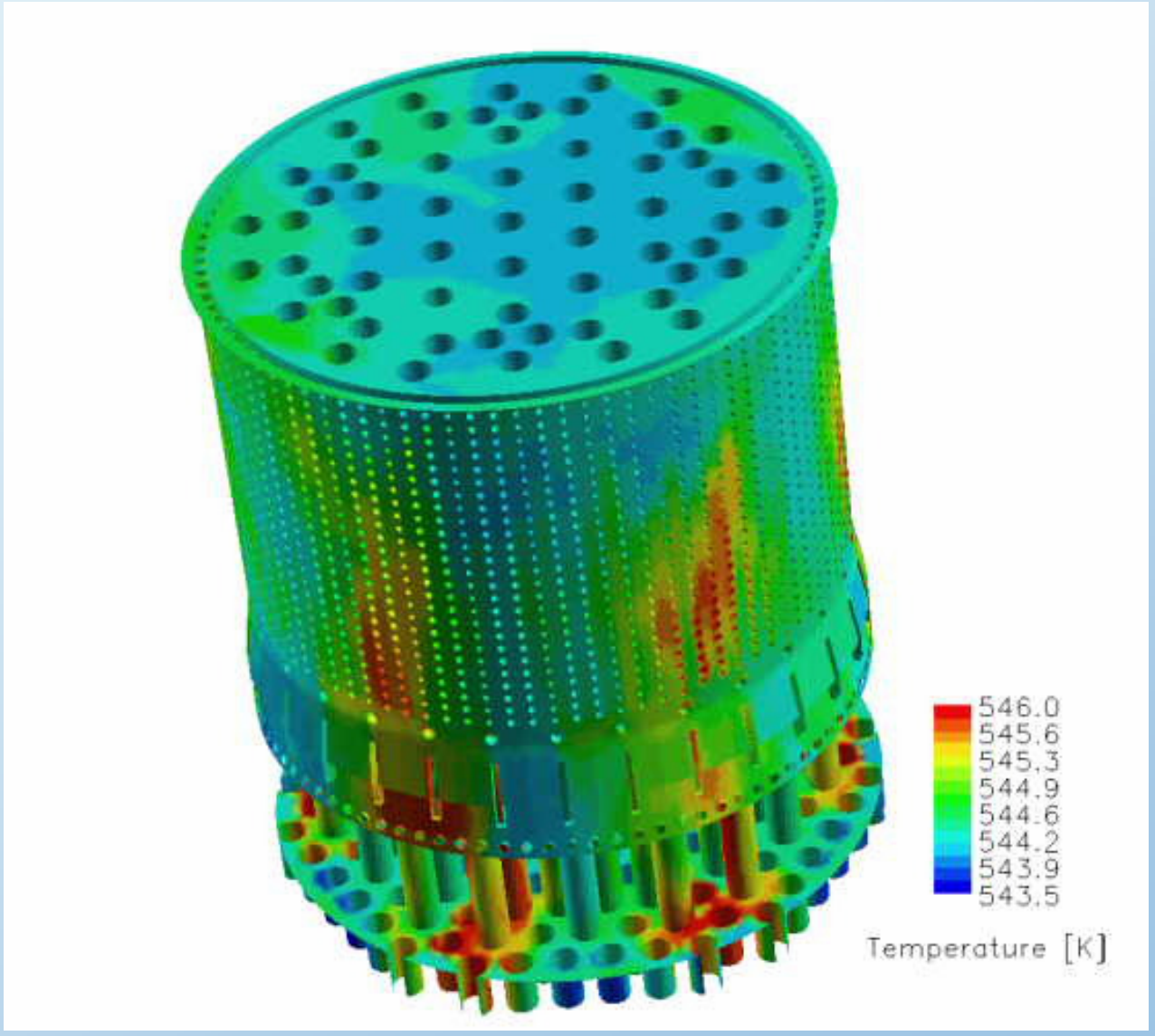
Cold Leg 3

Temperature Distribution in VVER RDB



Courtesy of
M. Böttcher,
FZ Karlsruhe

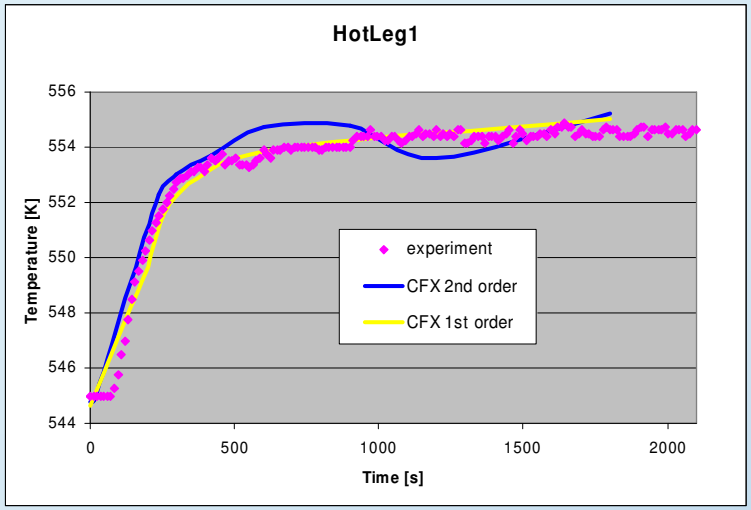
Temperature Distribution in VVER RDB

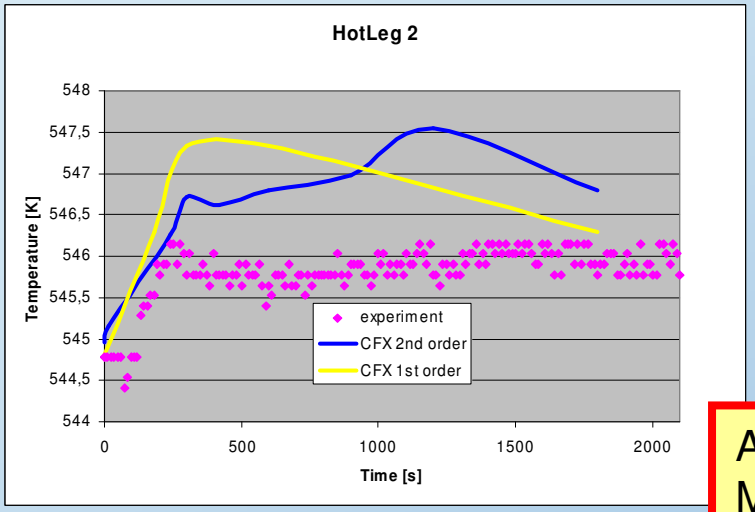


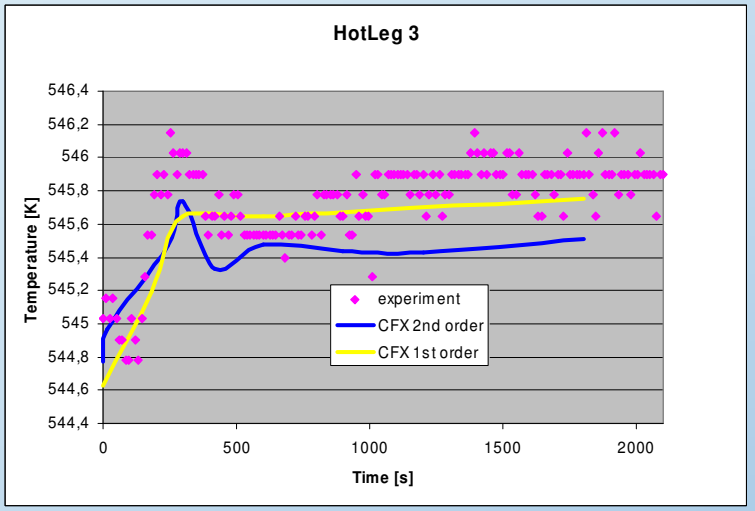
Courtesy of
M. Böttcher,
FZ Karlsruhe

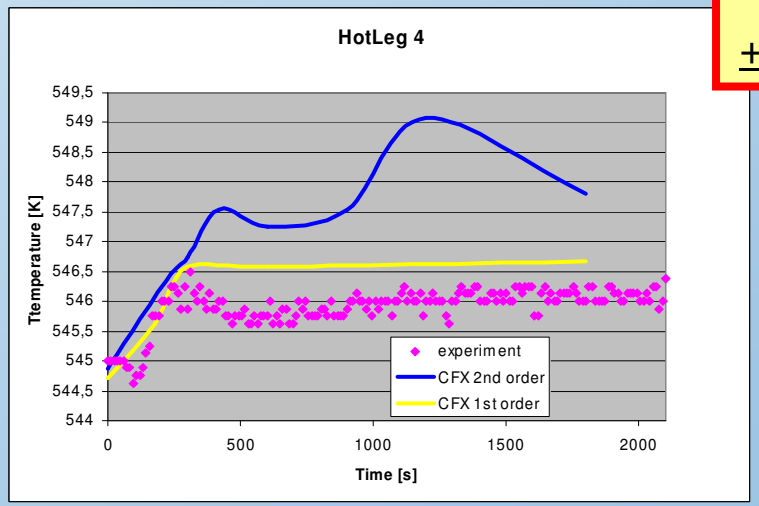
VVER Simulation – Hot Leg Temperature Transients

Temperature at Hot Legs 1-4









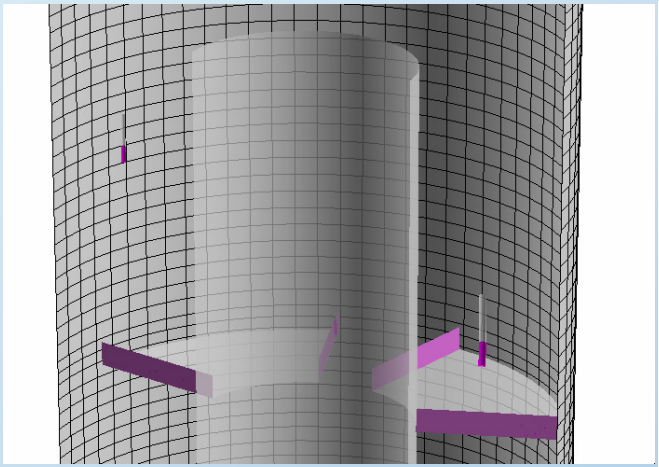
Accuracy of Measurements

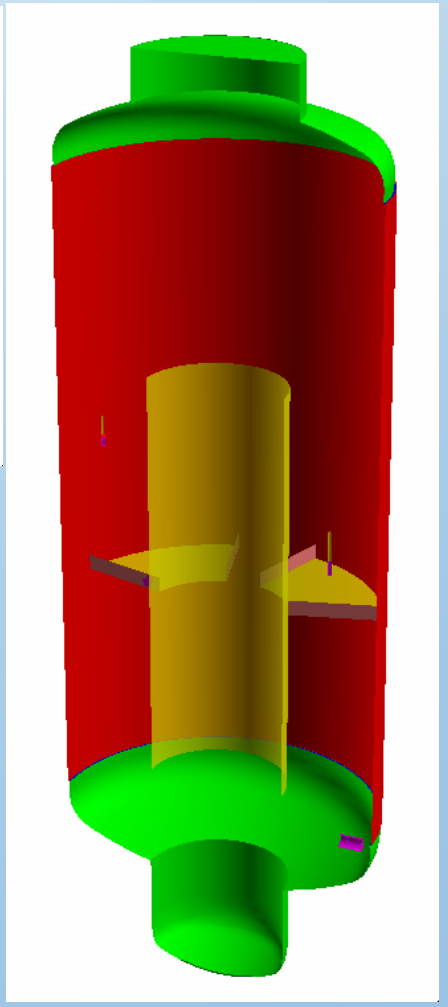
± 2K !

Courtesy of M. Böttcher, FZ Karlsruhe

Validation: ISP 47 (Step 2)

- ThAI test facility 60m^3
- four stages:
  - Helium injection
  - vertical steam injection
  - horizontal steam injection
  - flow dissipation
- 7700s duration of the experiment
- CFX 5.7 simulation
- 105664 grid cells, symmetry assumption

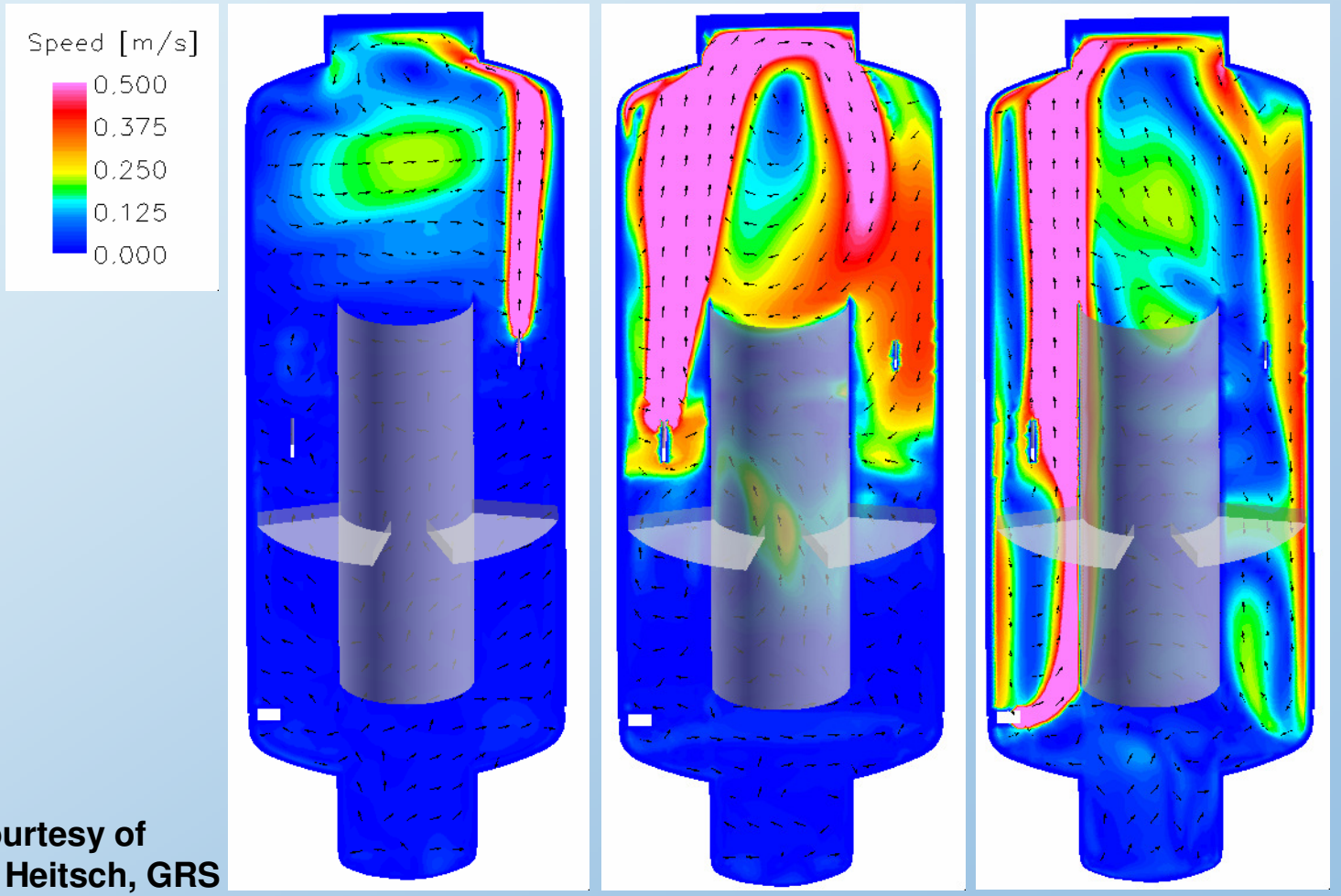




Courtesy of
M. Heitsch, GRS

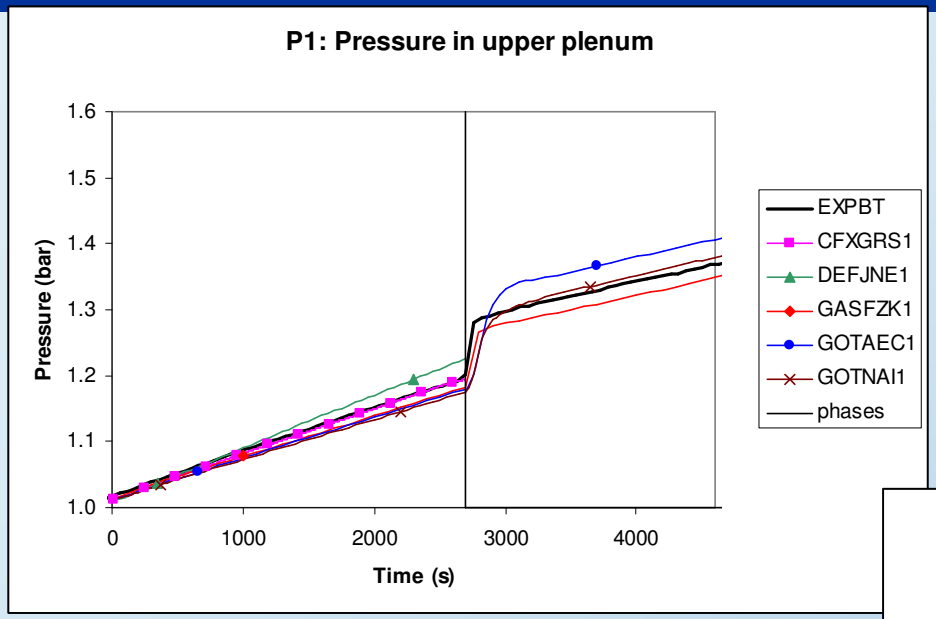
Validation: ISP 47 (Step 2)

- Velocity distribution at T=1000s, 3000s, 5500s

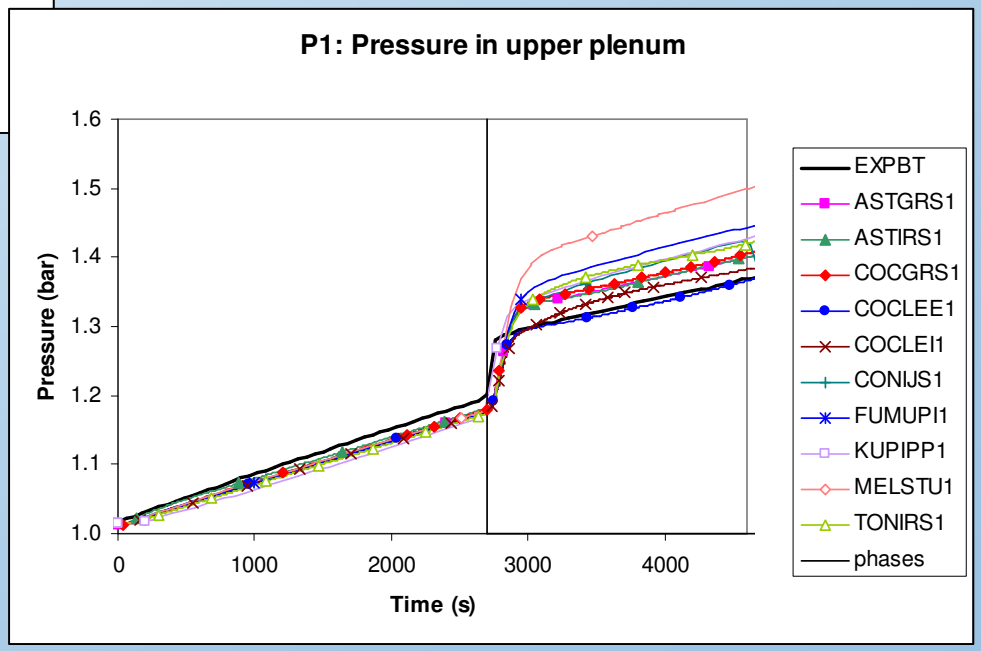


Courtesy of
M. Heitsch, GRS

Validation: ISP 47 (Step 2)

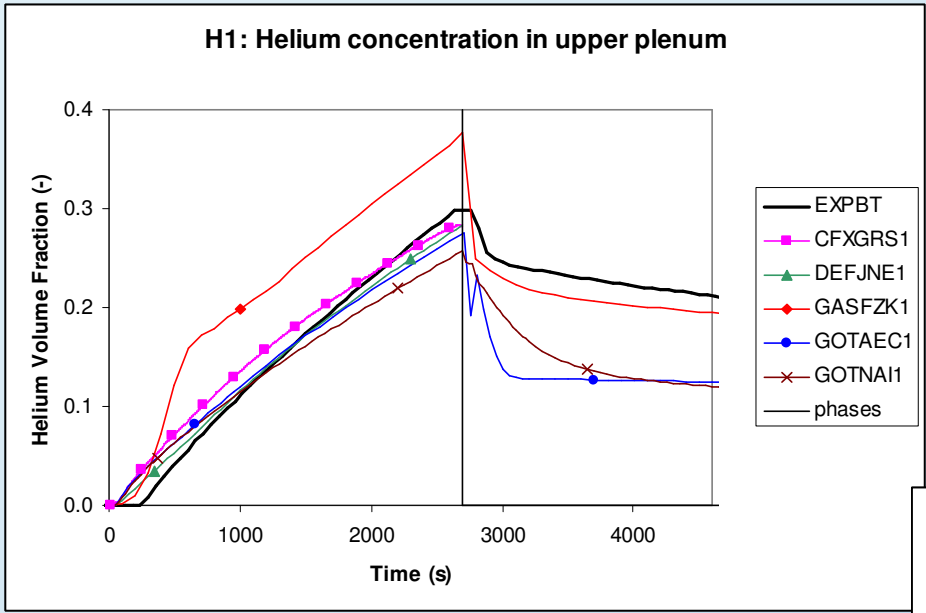


- good agreement of CFX simulation with measurements for 1st stage (Helium injection)

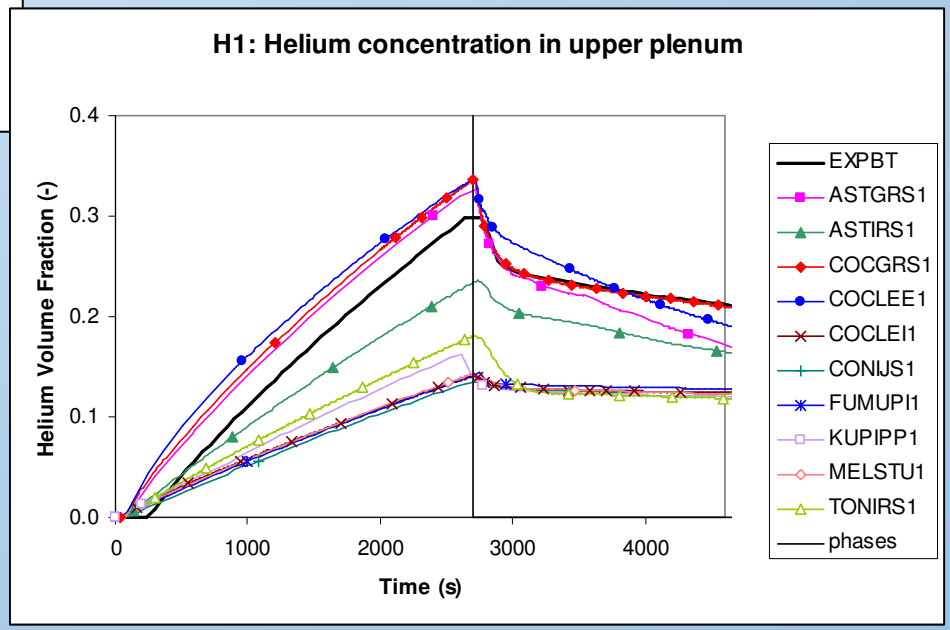


Courtesy of
M. Heitsch, GRS

Validation: ISP 47 (Step 2)



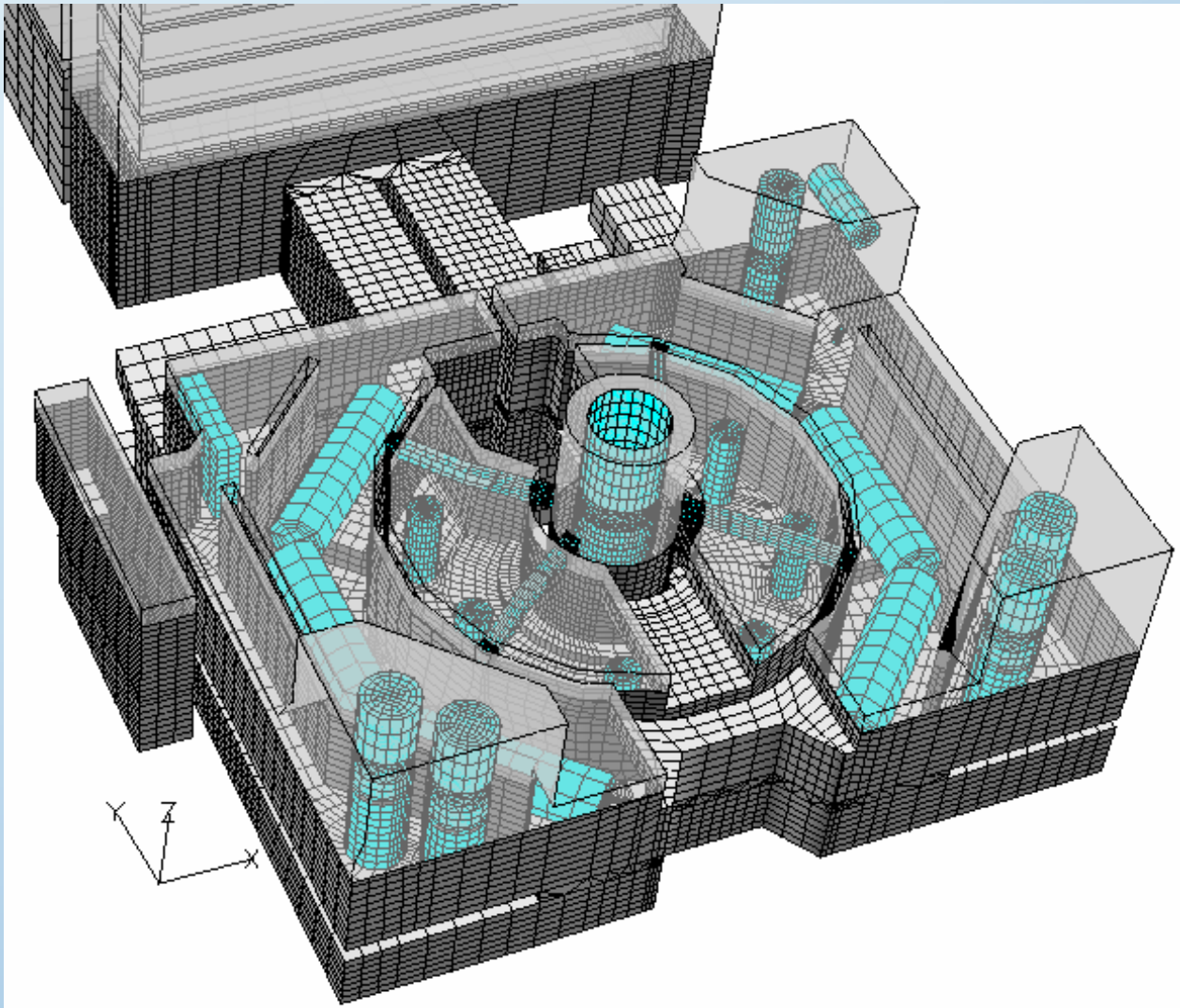
- **good agreement of CFX simulation with measurements for 1st stage (Helium injection)**



Courtesy of M. Heitsch, GRS

Containment Analysis
VVER 440-213 (PAKS)

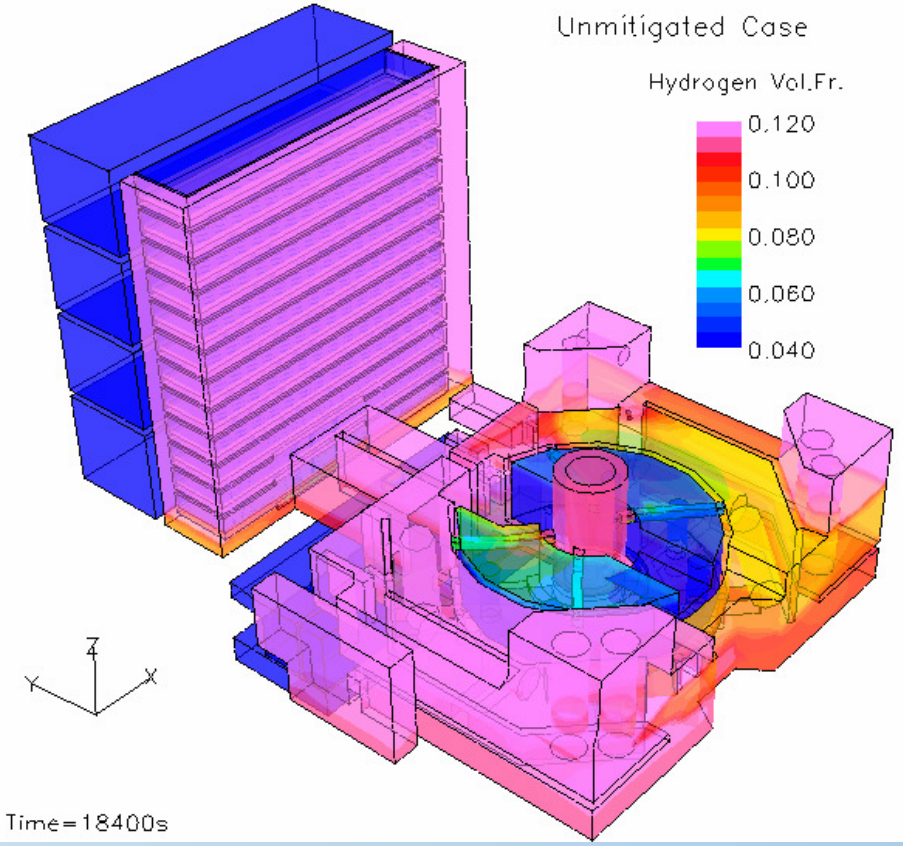
- LBLOCA with H_2 release
- 20 passive autocatalytic recombiners (PAR)
- bulk and wall condensation
- pressure peak suppression system
- 25 days on 8 processors (AMD)

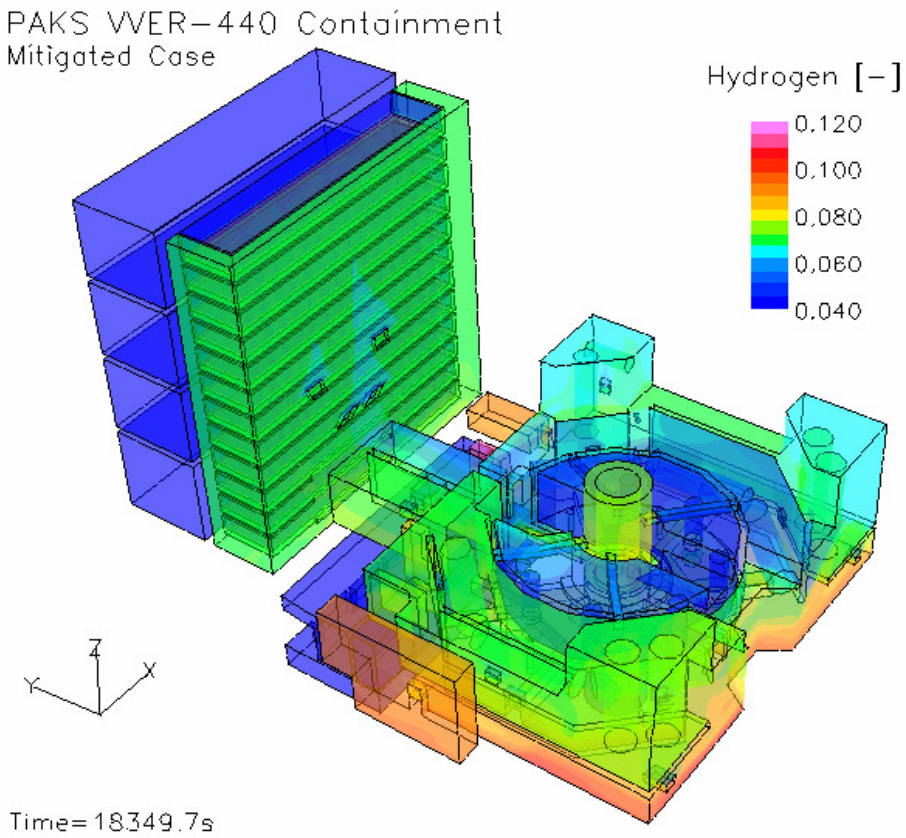


Courtesy of
M. Heitsch, GRS

Containment Analysis
VVER 440-213 (PAKS)

Effect of H_2 passive autocatalytic recombiners:





Courtesy of M. Heitsch, GRS

Summary

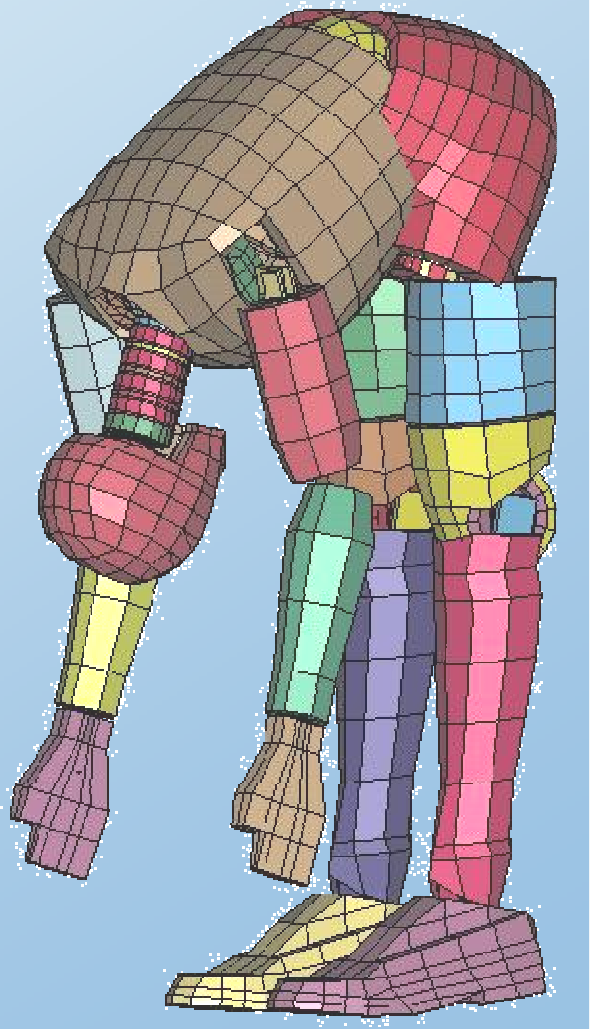
- ANSYS CFX – qualified software integration platform
- Multi-physics simulation environment:
  - CFD, Thermohydraulics
  - Fluid-Structure-Interaction (2-way FSI)
  - CFD – 1d-Code coupling
  - Radiation, Combustion, CFD – EMAG coupling
- Vast manifold of physical models
- Robustness, Scalability & Performance for large applications
- Maintained CFD code, Support & Education
- Large continuous effort in model dev. & validation
- Customer oriented development

ANSYS

ANSYS

CFX

ICEM CFD



Thank You!