A Comparative Assessment of similar Experiments by means of CFD

- Buoyancy Driven Mixing Processes

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European Review Meeting on Severe Accident Research
Marseille, France, March 24 – 26, 2015

Supported by:

Federal Ministry for Economic Affairs and Energy

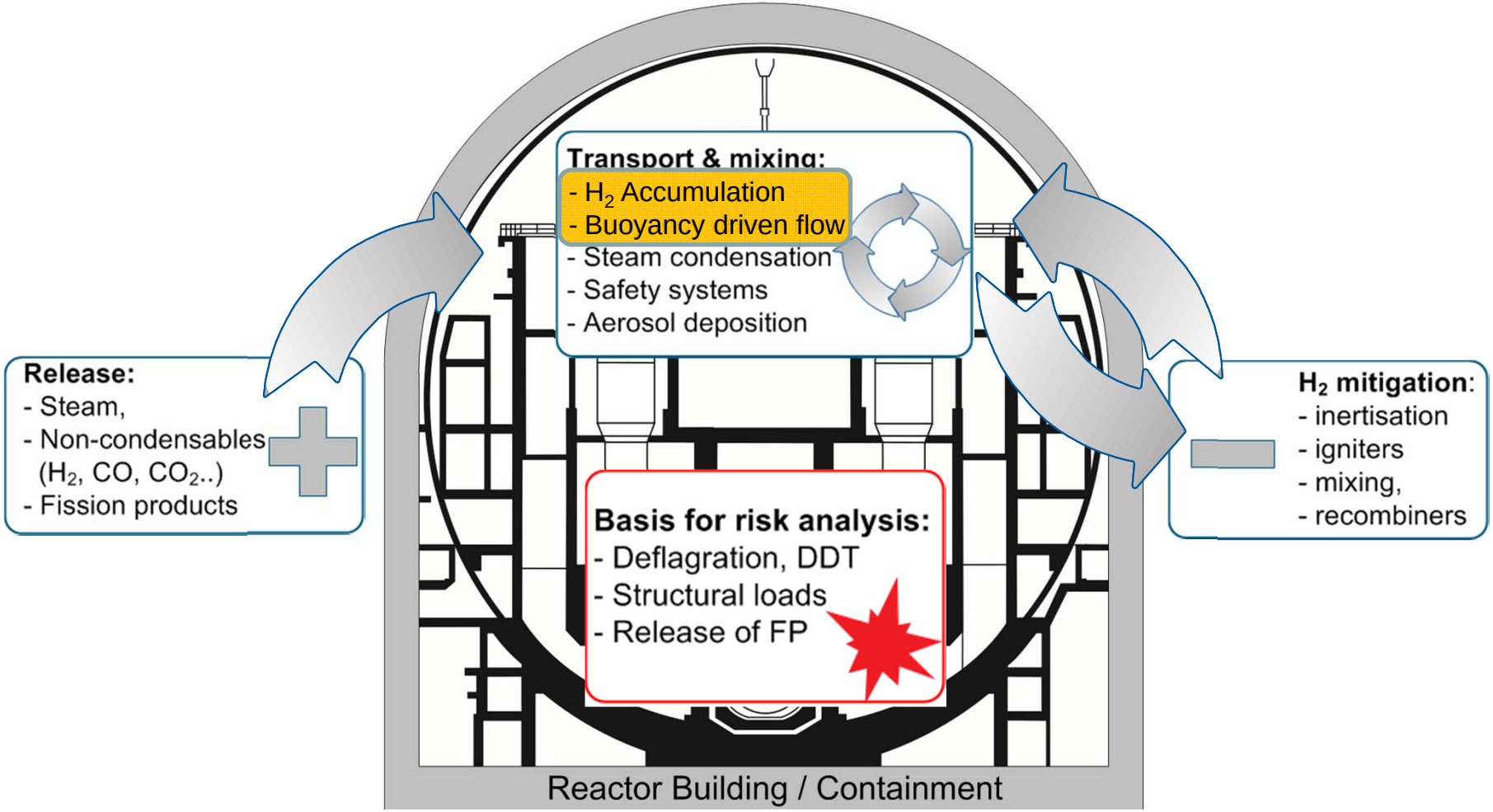
on the basis of a decision by the German Bundestag

Project No. 150 1407

Outline

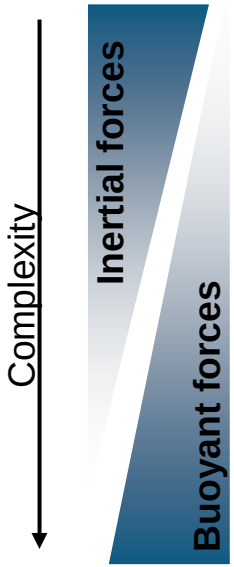
- Background & Strategy
- Comparative Simulations
  - *Data Basis*
  - *Modeling Approach*
  - *Results*
- Summary & Conclusions

Simulation Task – Predicting Hydrogen Risk during SA



H_2 Transport & Mixing Inside Containment Compartments

- Are driven by pressure and density differences
- ➢ Categorize validation series:



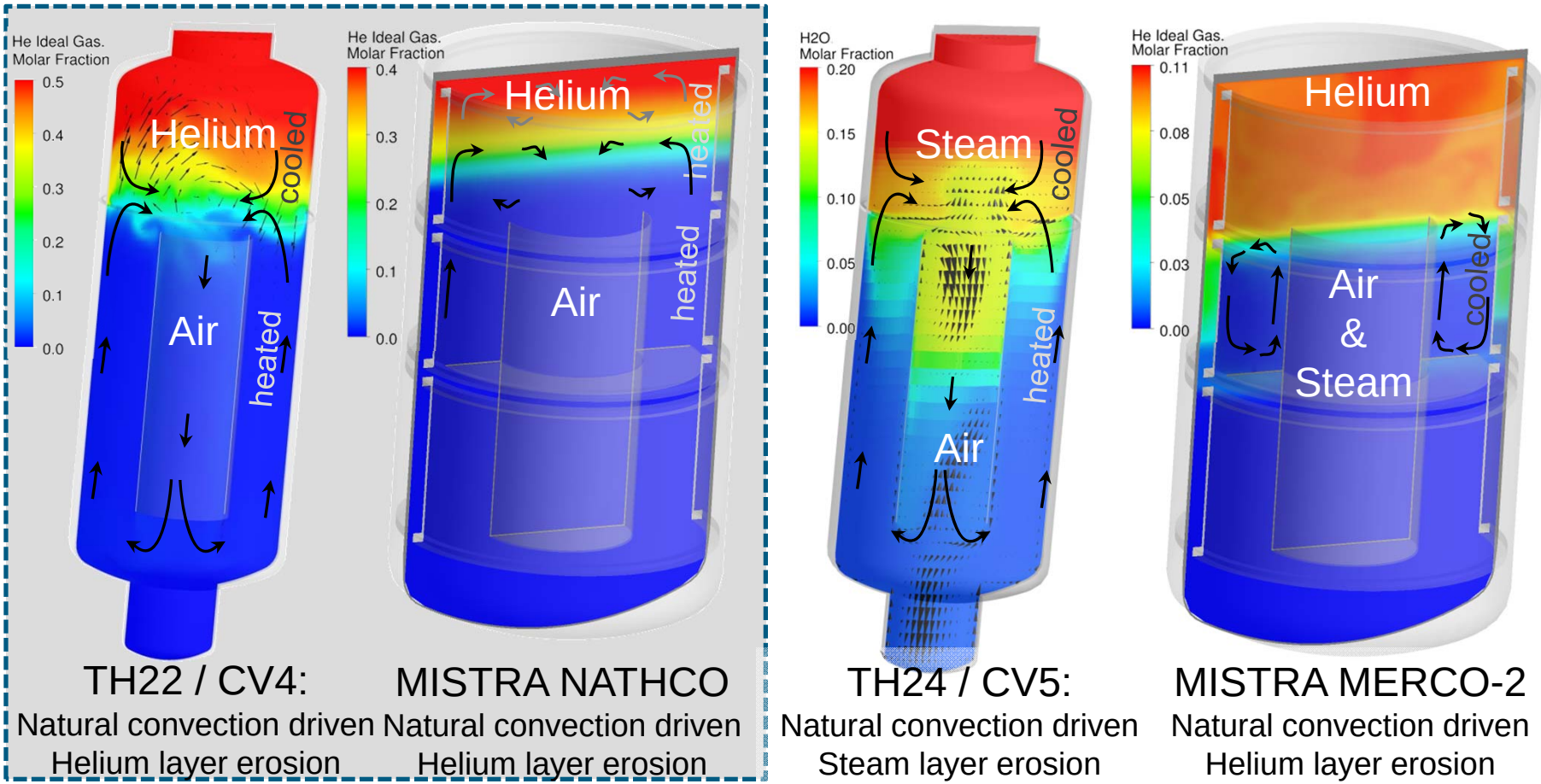
(1) Dominant inertial forces (Fr>1) **test series 1.1**
blow-down, directed flow, close to application of existing models

(2) superimposed inertial and buoyant forces (Fr~1) **test series 1.2**
early accident phase, buoyancy enhanced or opposed flow

(3) Dominant buoyant forces
late accident phase, global 3D random flow, **test series 2.1**
locally strong feedback of passive safety systems **test series 2.2**

- ➢ Identical modeling approach,
- ➢ 2 simulations, one ‘blind’ with specified one ‘open’ with measured IC’s & BC’s

Test Series 2.1 – Global Natural Circulation Mixing



TH22 / CV4:
Natural convection driven
Helium layer erosion

MISTRA NATHCO
Natural convection driven
Helium layer erosion

presented today

TH24 / CV5:
Natural convection driven
Steam layer erosion

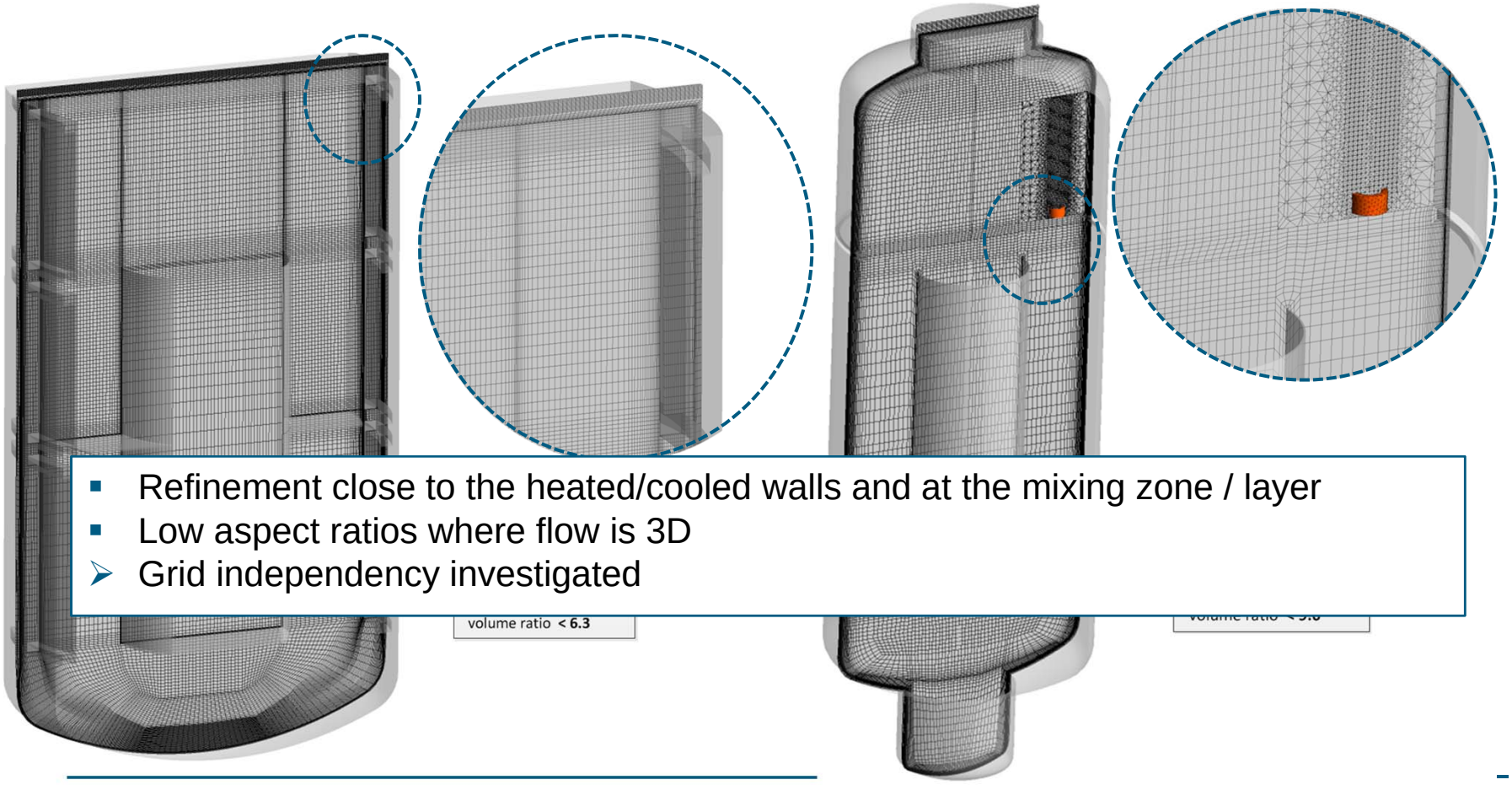
MISTRA MERCO-2
Natural convection driven
Helium layer erosion

(📖 Fischer 2010, Abdo et al., 2010 and 2012; Schmidt et al.,2014)

‚Standard' CFD Model – Physics

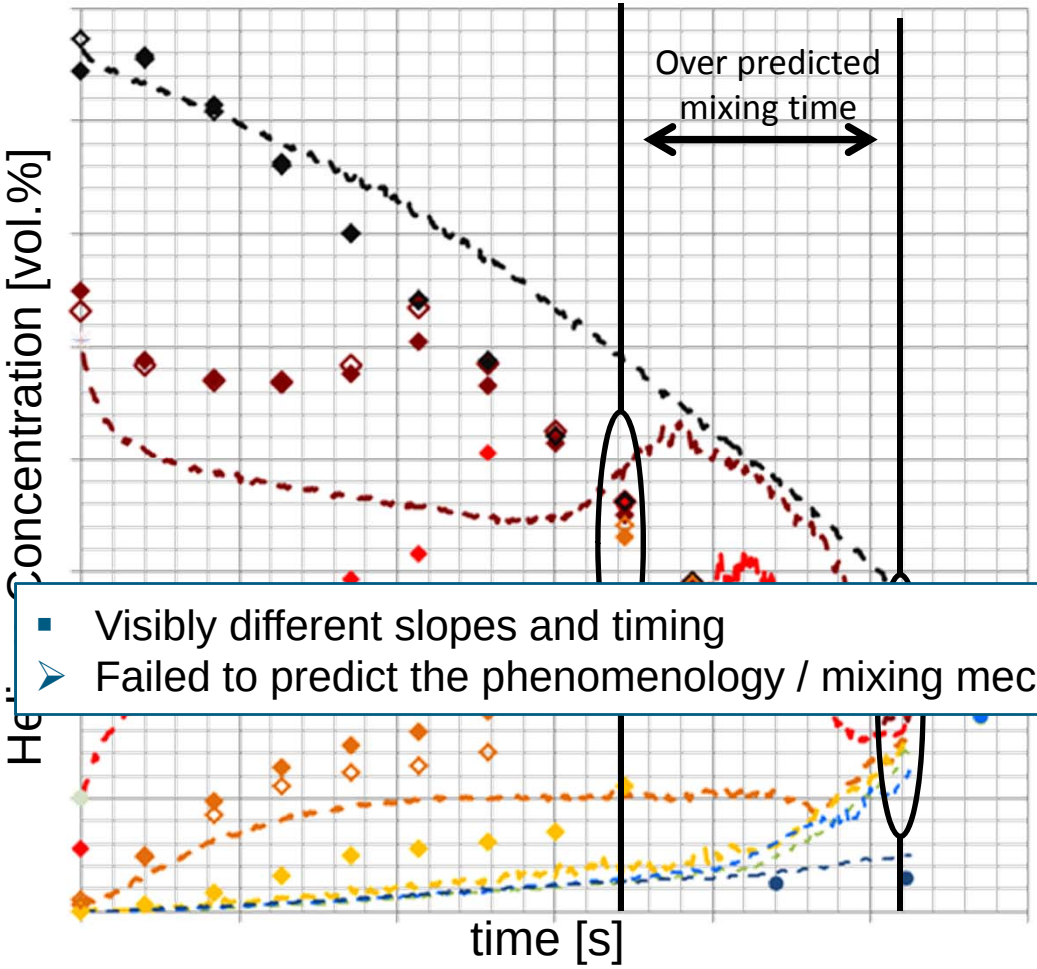
- U-RANS, total energy and species transport equations
- k-ω-SST model
  - incl. buoyancy turbulence production und dissipation
    $Sc_t = 0.9$, $Pr_t = 0.9$
- ideal gas equation of state
- temperature dependent fluid properties
- thermal radiation
  - Monte Carlo, 200.000 histories,
    participating media: $\alpha_{steam}=1.0$, $a_{Air/He/H2}=0$,
    $\varepsilon_{Wall}=0.6$, $\varepsilon_{adiabatic}=0$ (reflecting)
- walls:
  - automatic wall treatment
  - conjugate heat transfer
  - thermal BC: T_{sec}+HTC

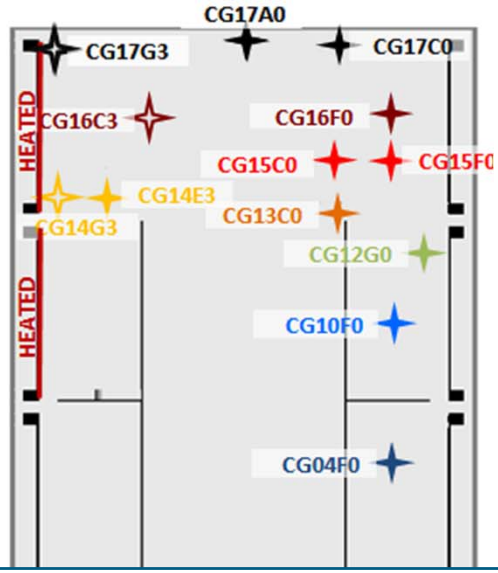
Numerical Grids - MISTRA & THAI



- Refinement close to the heated/cooled walls and at the mixing zone / layer
- Low aspect ratios where flow is 3D
- ➢ Grid independency investigated

Results NATHCO (idealized conditions)

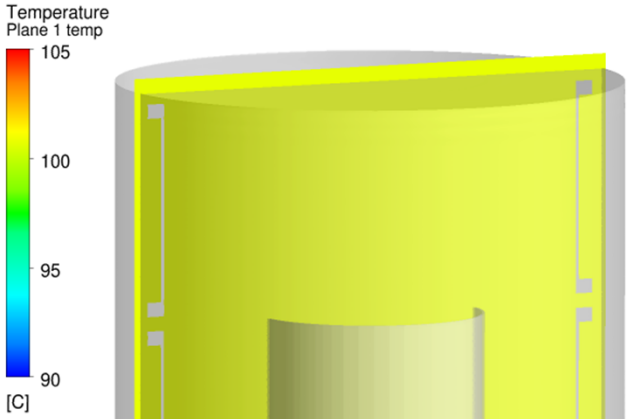




- Visibly different slopes and timing
- ➢ Failed to predict the phenomenology / mixing mechanism

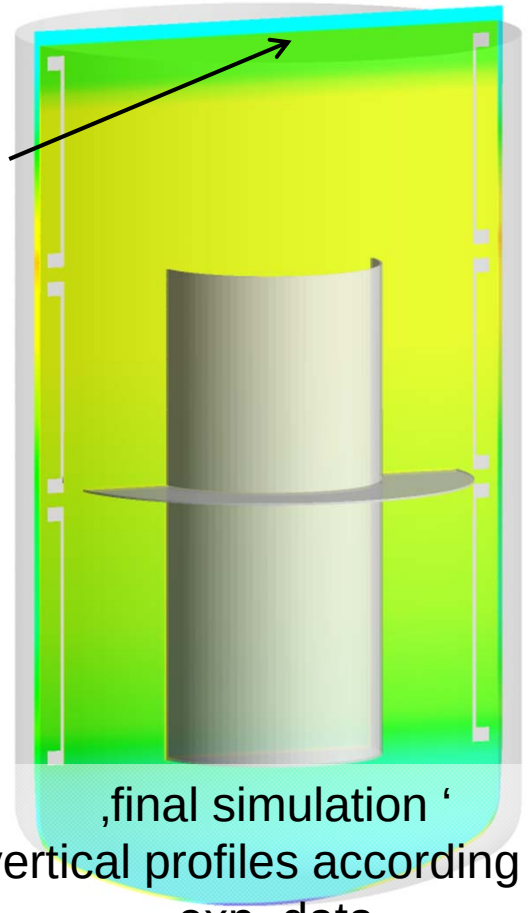
◆ **Experiment**
--- **CFX (ideal init. wall temps)**

NATHCO – Thermal Initialization



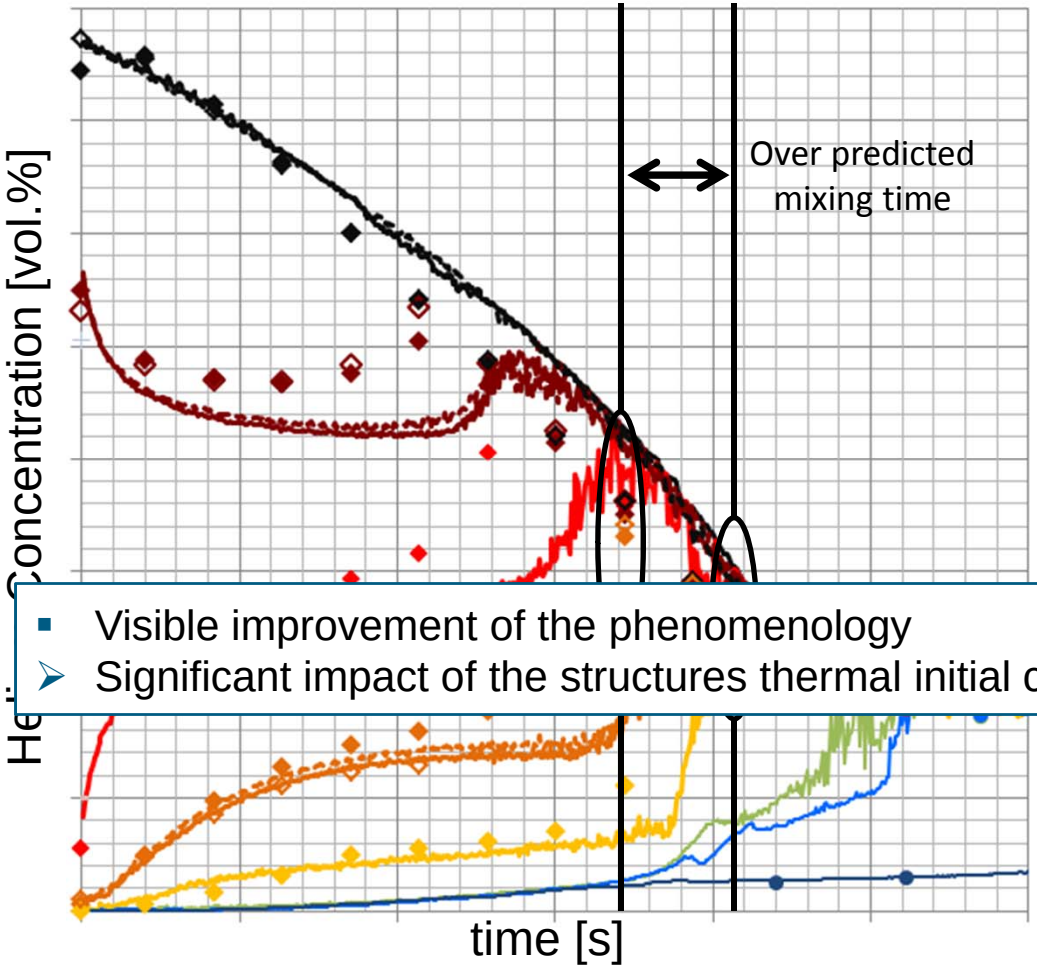
‚initial simulation'
average temperature
according test protocol

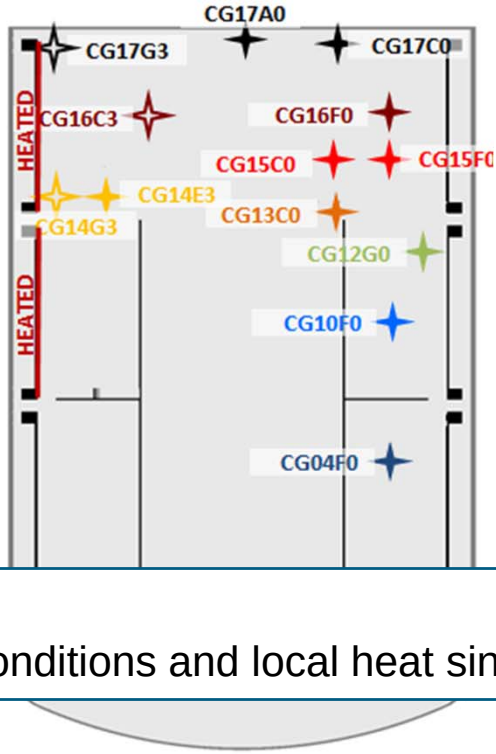
Heat losses /
heat sink



‚final simulation '
vertical profiles according to
exp. data

Results NATHCO (real test conditions)

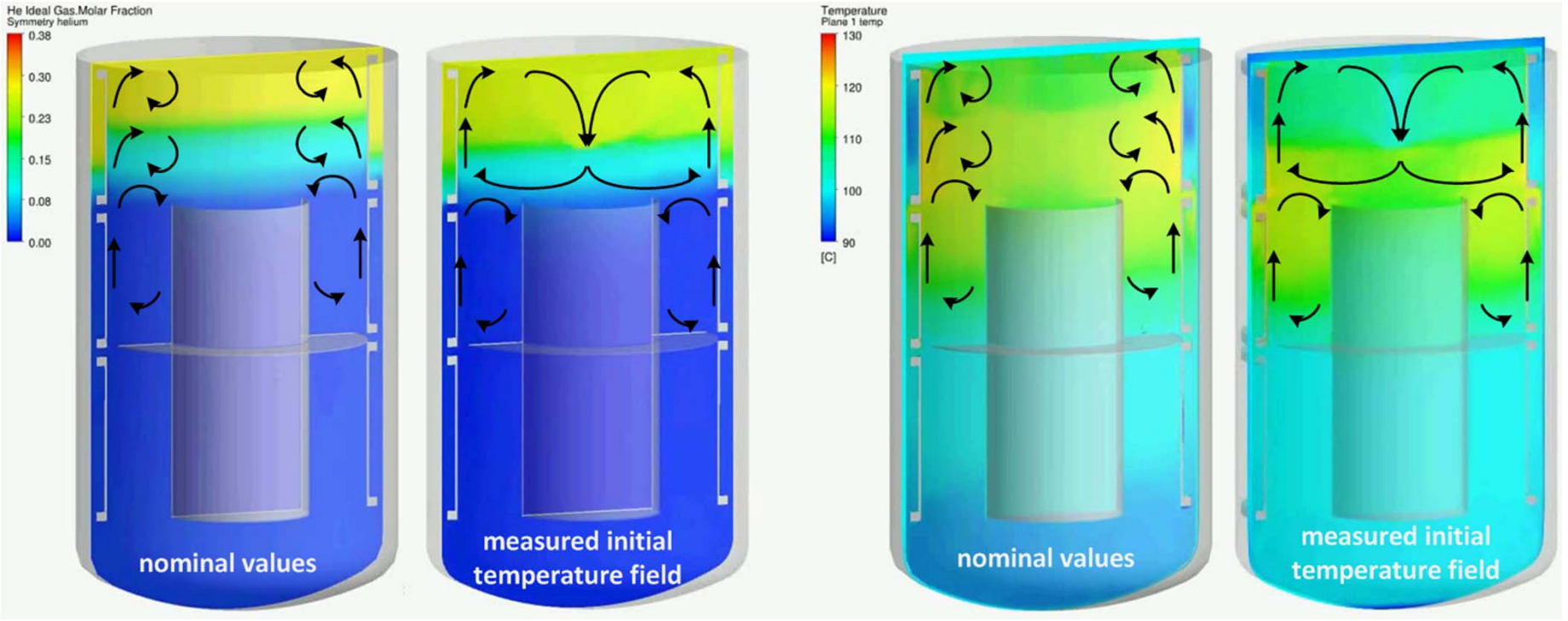




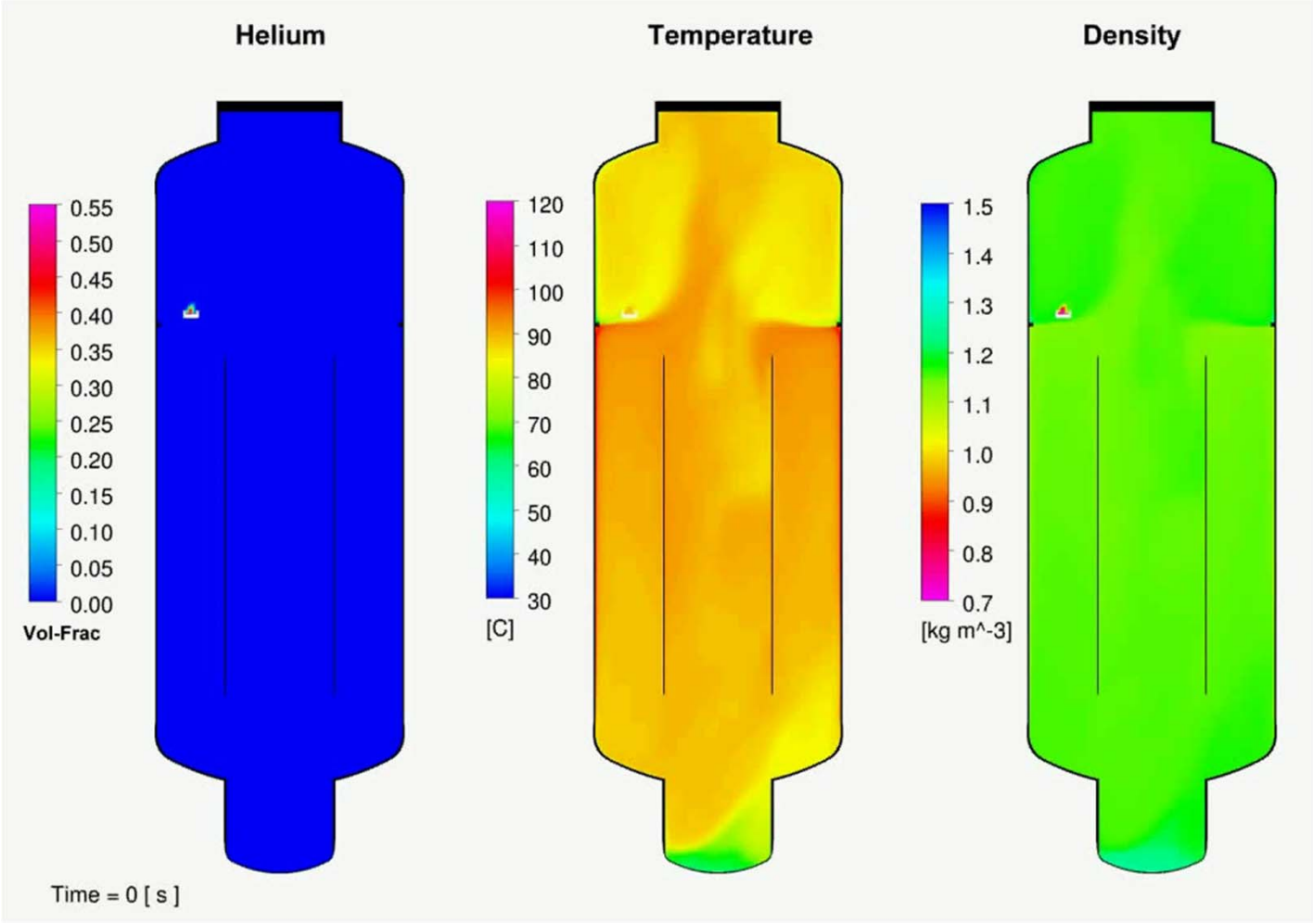
- Visible improvement of the phenomenology
- ➢ Significant impact of the structures thermal initial conditions and local heat sinks

◆ **Experiment**
--- **CFX (ideal init. wall temps)**
— **CFX (real init. wall temps)**

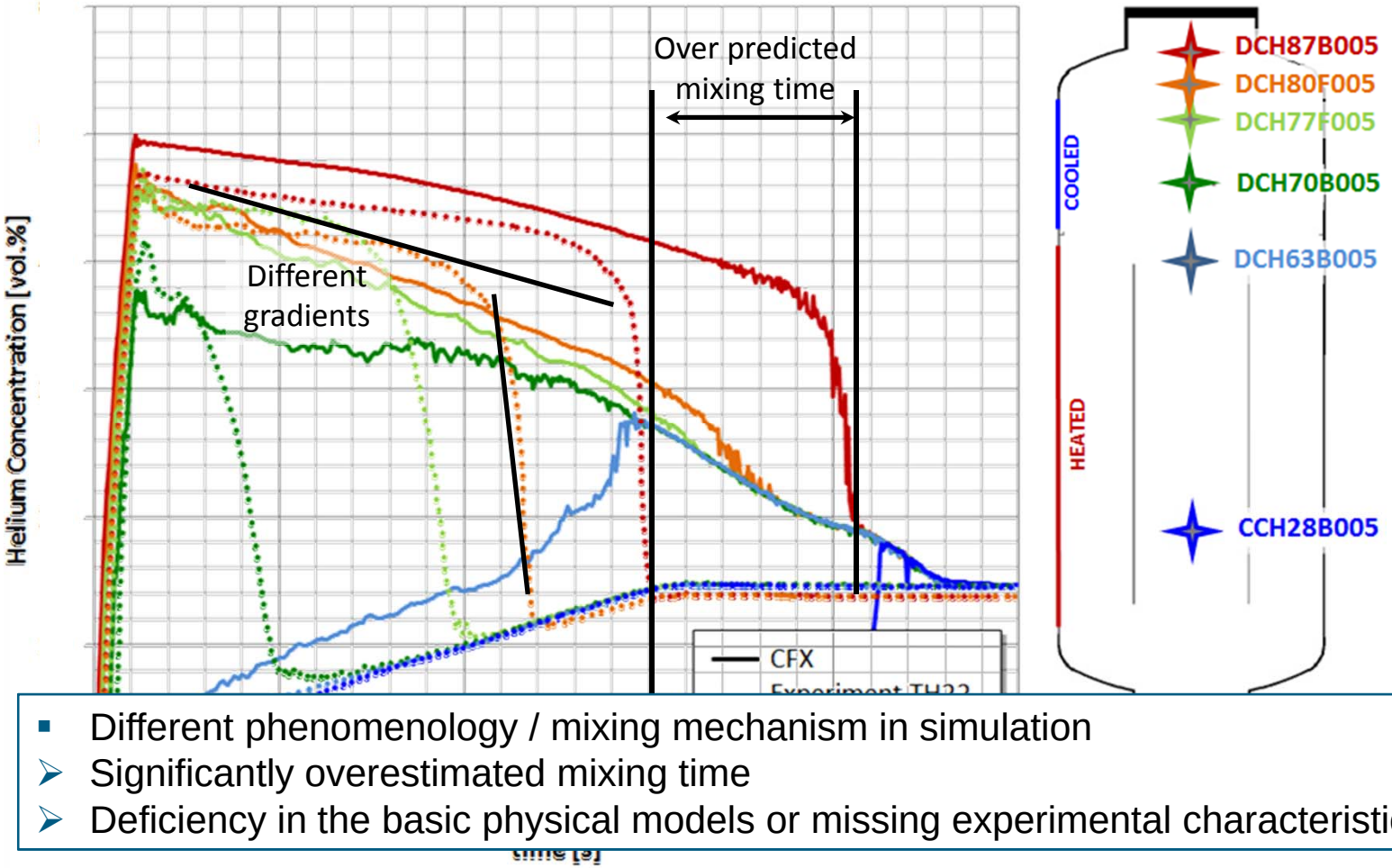
NATHCO – Effect of the Thermal Initialization



TH22 experimental transient (‚best' result)



Ergebnisse TH22 (ideal conditions)



- Different phenomenology / mixing mechanism in simulation
  - ➢ Significantly overestimated mixing time
  - ➢ Deficiency in the basic physical models or missing experimental characteristic?

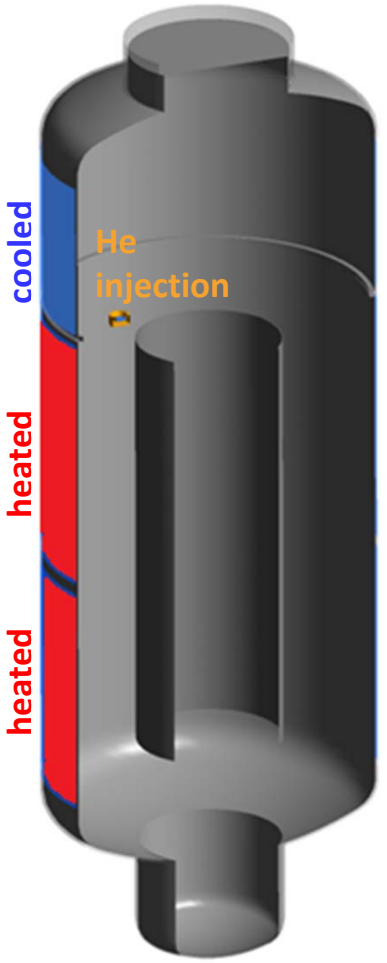
TH22 – Revision of IC & BC

Improved thermal boundary conditions

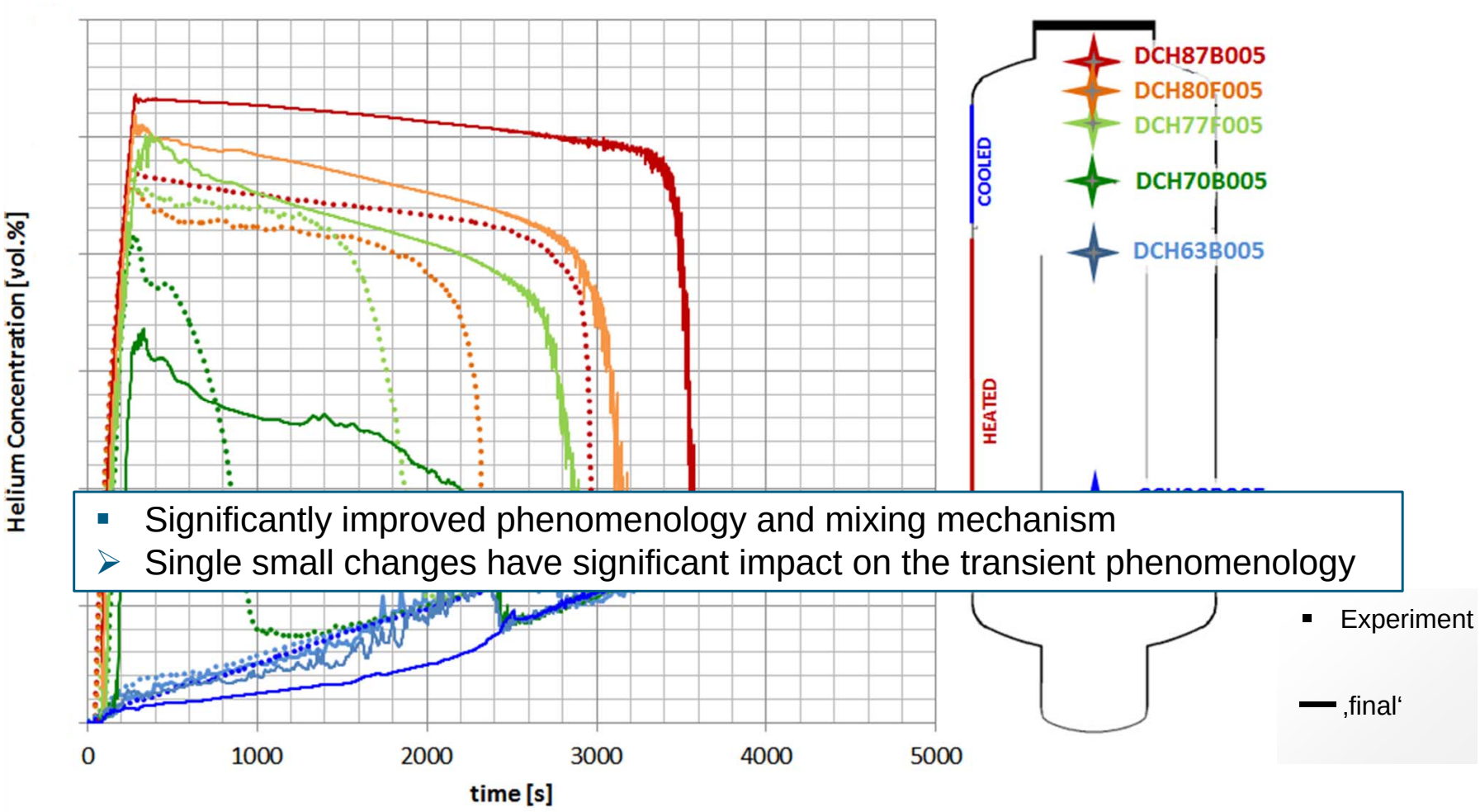
- Heated / cooled walls:
  - o *Temperature + HTC instead of fixed temperature*
  - ✓ *Heat fluxes checked*
- Other structures (heat sinks):
  - ✓ *Temperature checked*
  - ➢ *Visible effect of radiation model*

Improved initial helium distribution:

- *2D inlet boundary instead of volumetric point source*
  - ➢ *Impact on initial helium distribution*
  - ➢ *Low effect on other variables (u, v, w, T, k, ω)*

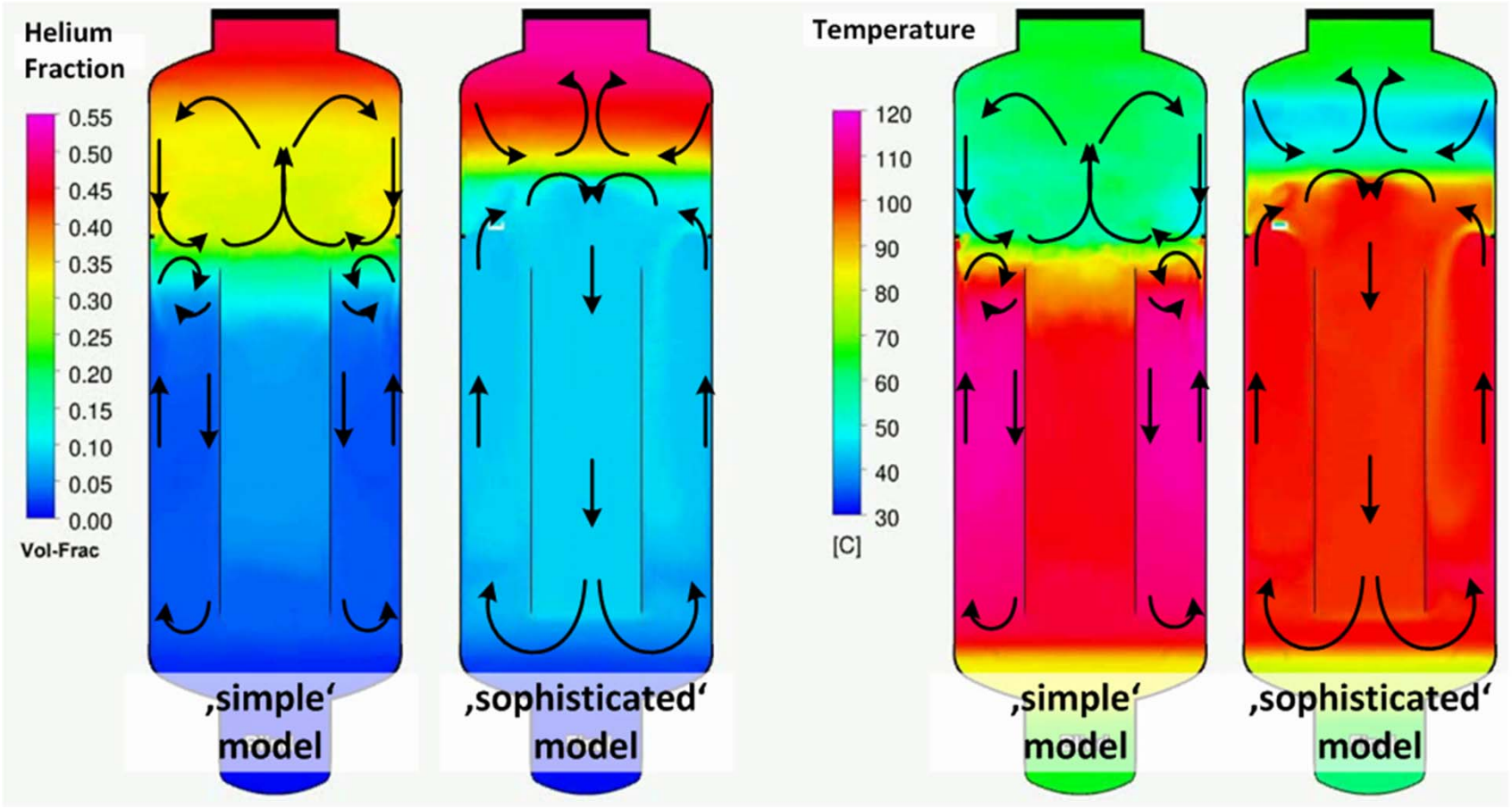


Ergebnisse TH22 (real conditions)



- Significantly improved phenomenology and mixing mechanism
- ➢ Single small changes have significant impact on the transient phenomenology

TH22 – Effect of IC and BC



Test Series 2.1 – Summary & Conclusions (1)

CFD can predict complex 3D natural circulation driven flows and mixing processes
However, CFD is a boundary value problem, i.e.:

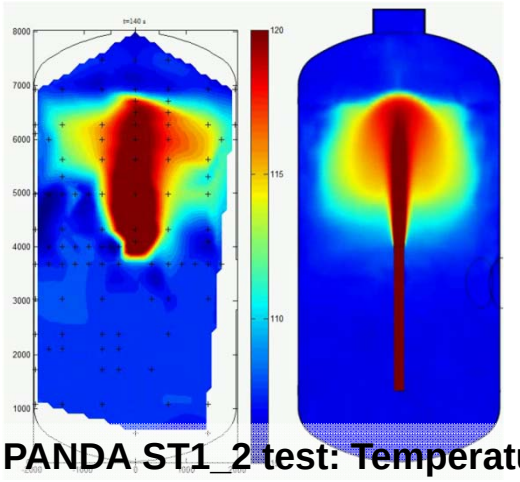
- Avoid definition of fixed wall temperatures or fixed heat fluxes and limit both by the definition of an external temperature and HTC
- Avoid wall functions and use a fine boundary layer resolution to predict correct gas-wall heat transfer
- Specify the initial structure temperature field consistent to the test (structures represent local heat sinks and thermal inertia).
- Consider thermal (gas) radiation for a consistent prediction of internal structure temperatures and gas-wall heat transfer

Single minor model simplifications (user decisions)
may multiply up to a significant effect on the transient duration and phenomenology.

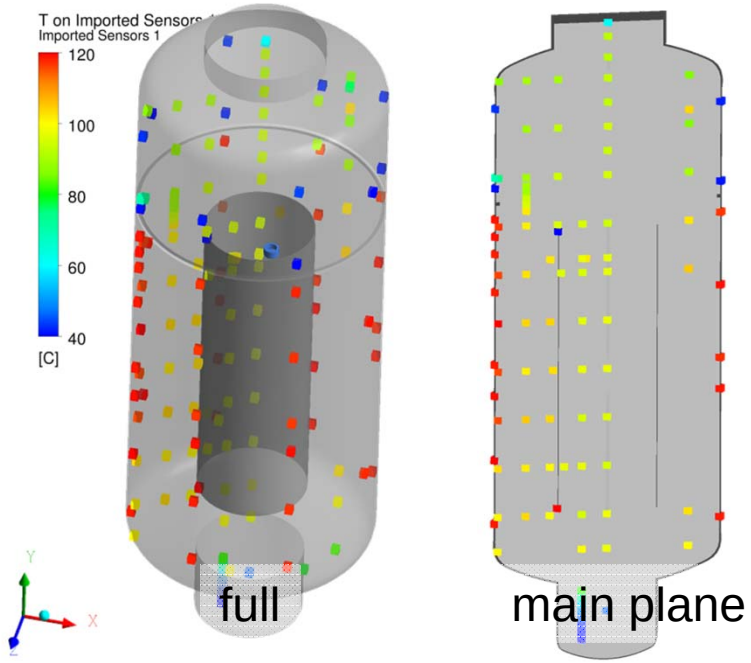
Test Series 2.1 – Summary & Conclusions (2)

For model validation:

- No experimental characterization of the flow field and mixing mechanism available
- Detailed validation of the heat balance and temperature field necessary
- Make use of all available measurements
  In-house development of an ‚import filter‘
  for exp. data in CFX (Pre & Post)



PANDA ST1_2 test: Temperature map provided by PSI vs. simulation

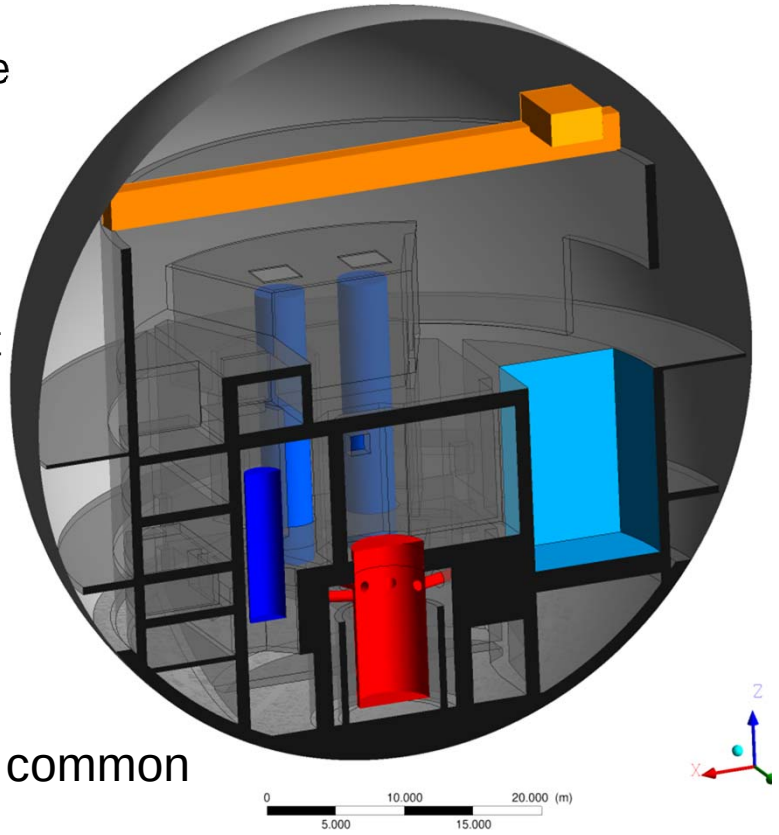


Test Series 2.1 – Summary & Conclusions (3)

For the simulation of containment flows:

- ✓ The consistent prediction of test cases indicate that there are no important physics missing in the ‘standard’ model
- Need for a reliable estimate of initial (non-uniform) structure temperatures in particular if only a time window of the transient is analyzed
- Need to consider all structures thermal inertia (distributed het sinks) and flow resistance
- ➢ It is impossible to define a conservative treatment for the initial (concrete) structure temperature field

⇨ Strong ‚user-effect‘ possible. Need for a common approach & ‚Best Practise Guideline‘



GRS, 2014

Acknowledgements

The continued development of CFD models for prediction of H_2 mixing and mitigation is performed in close cooperation with RWTH Aachen University and funded by German Federal Ministry of Economic Affairs and Energy (Project No. **1501407**)

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Special thanks to the experimental teams for their efforts in conducting and documenting the test series. We acknowledge the support of the different funding bodies.

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