Karlsruher Institut für Technologie

Mini-Pool Reactor

to determine interaction and mass transport of oxygen and other impurities in flowing LBE

Design and Design supporting CFD calculations

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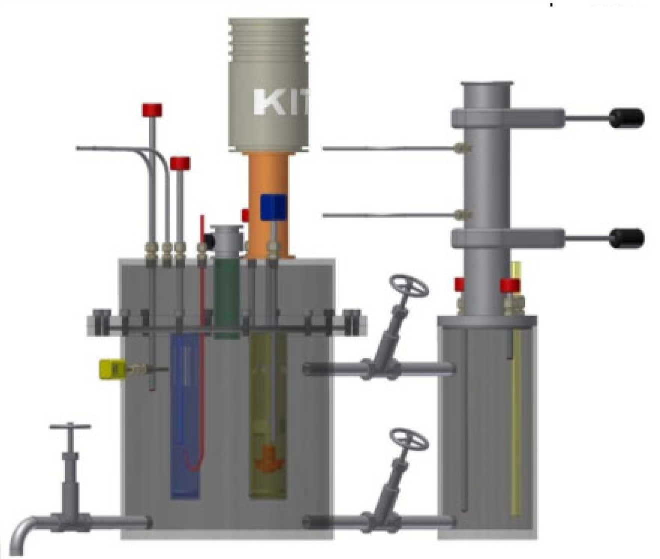
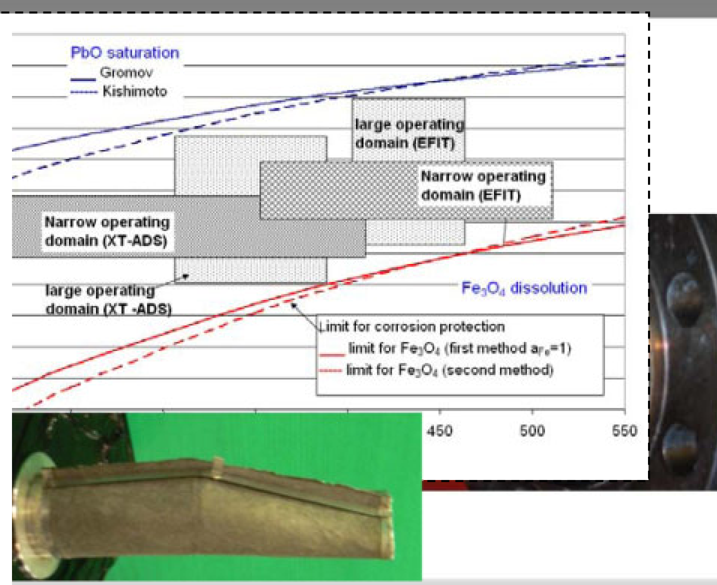
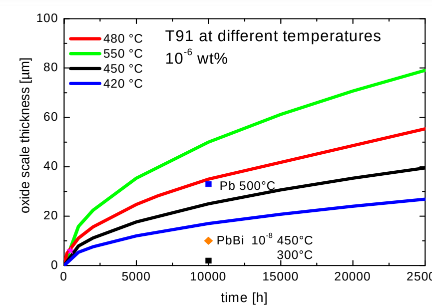






$$wt_{o,B} = F_B \cdot \rho_{ox} \cdot \delta_B \cdot 4 \cdot \frac{M_o}{M_{Fe3O4}}$$

$wt_{o,B}$ = weight of oxygen (oxidation)

F_B = total surface of cladding

δ_B = thickness of oxide scale

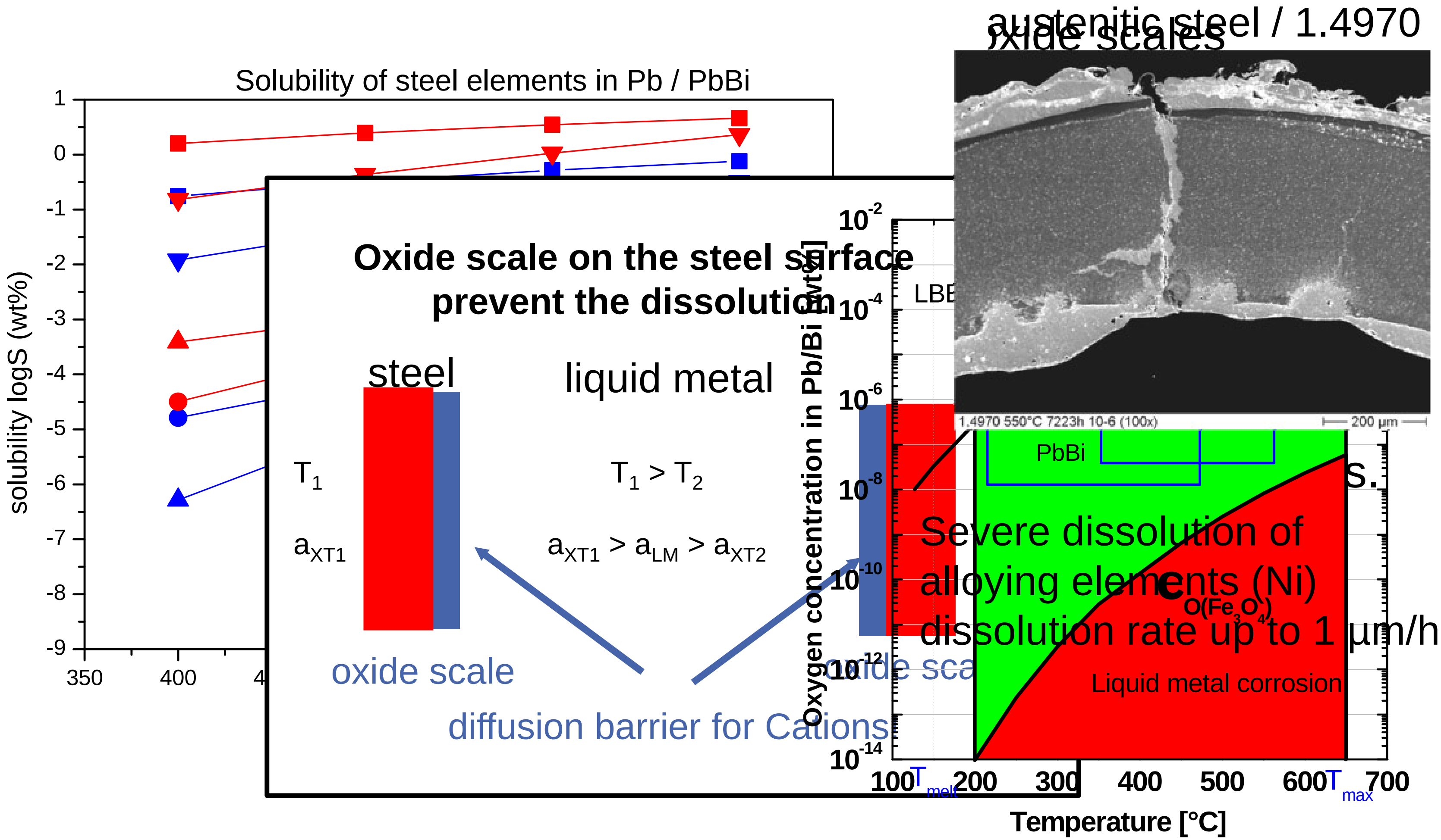
ρ_{ox} = density of oxide scale

M_o, M_{Fe3O4} = molecular weight of oxygen and Fe_3O_4

- Outline
  - Introduction
  - Questions addressed – Experiments foreseen - Pre-design
  - Design oriented CFD
  - Summary and next steps

Oxygen – Why relevant for Pb alloy cooled ADS?

- Solubility of metals in liquid Pb PbBi - W, Ta<<Fe, Cr<Al<Ni



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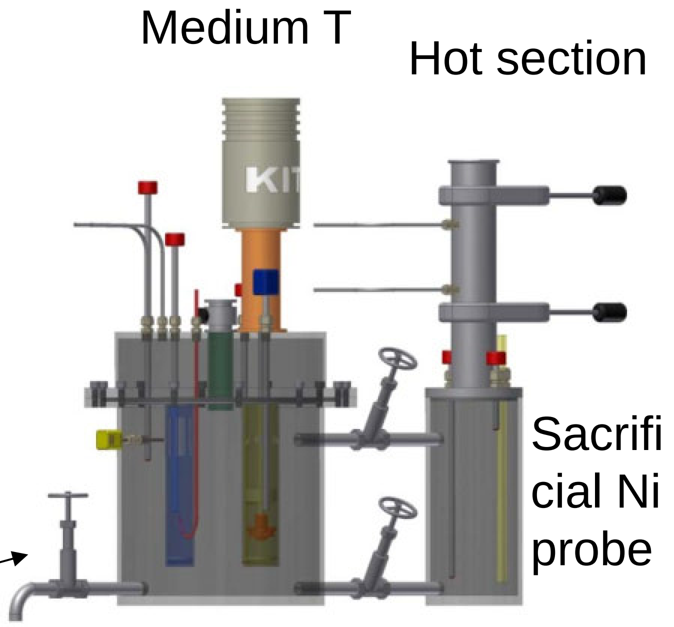
Modular Mini-Reactor Pool for

Corrosion, Mass Transport and Filtering

Experimental test cases

- Normal operating conditions: reference cover gas environment
- Cover gas leak & gas/solid entrainment
- HEX-leak (water vapour)
- THEADES crud & filtering
- Sacrificial Nickel probe
- Filter performance

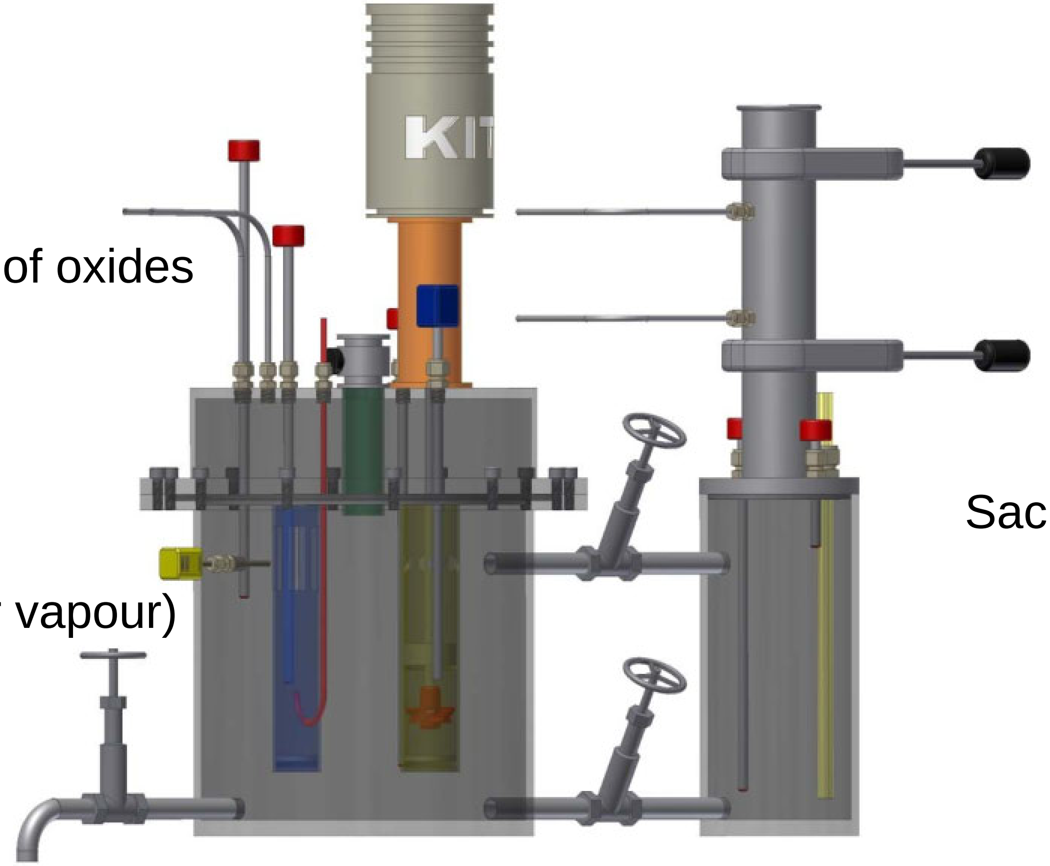


CFD Studies

- Thermohydraulic characterisation
- Mass transport & sources
- Influence of environment gas & solid oxides

Modular Mini Reactor Pool

Instrumentation:
Oxygen sensors with thermocouples
Cold probe
Ultrasound doppler
floating gauge - local level (pressure, velocity)
Level sensor

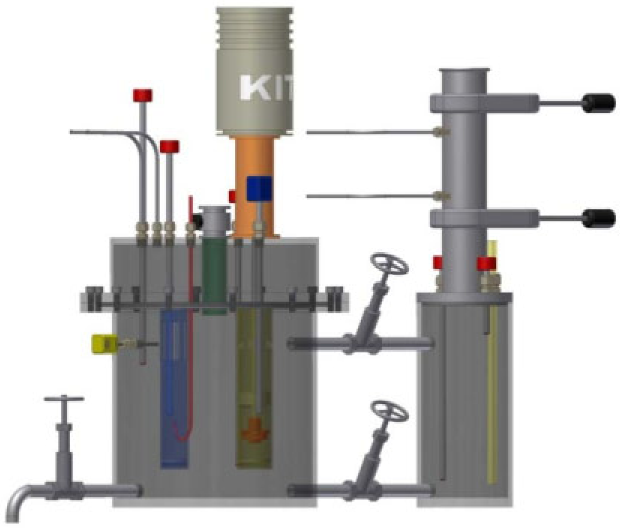


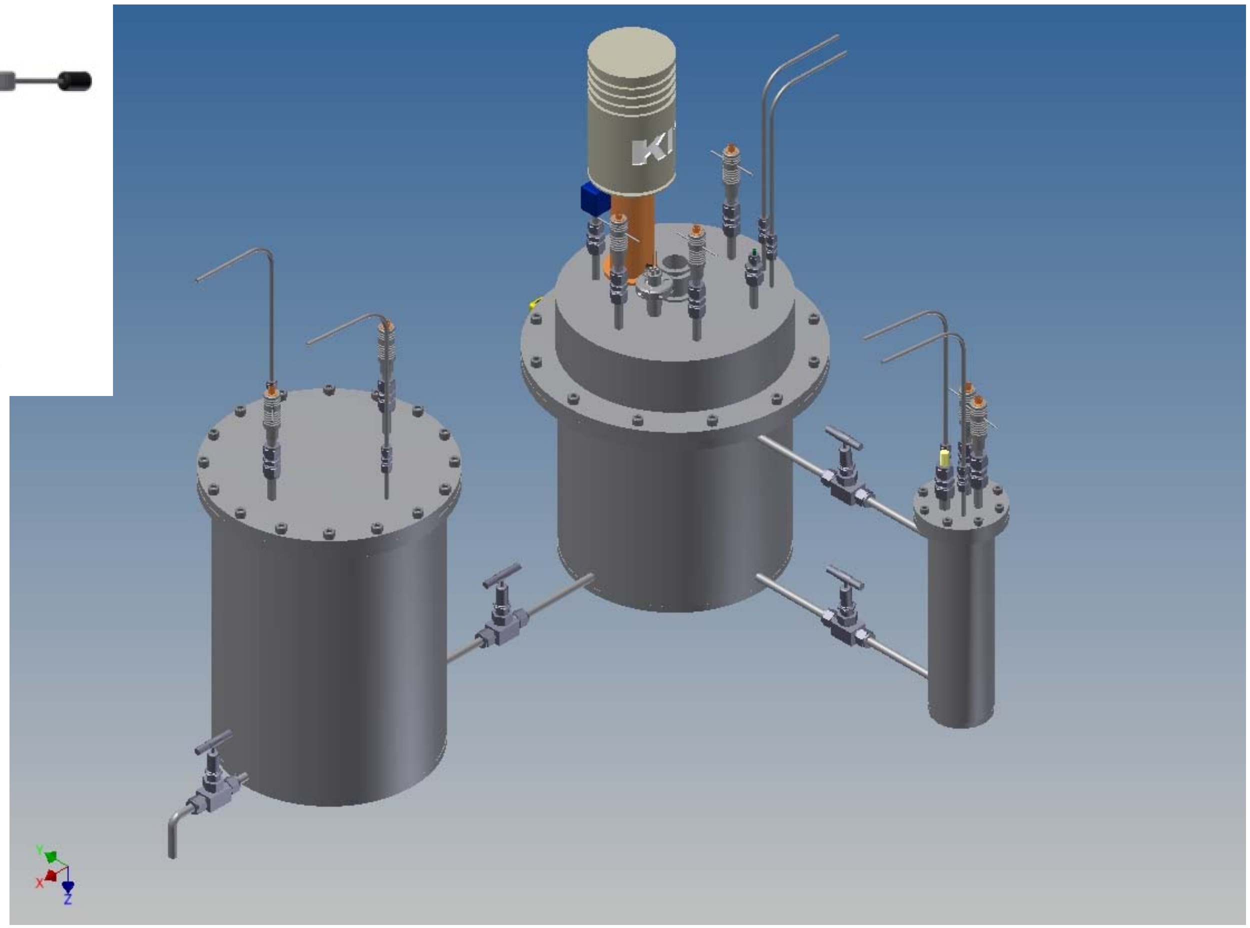
Entrainment of oxides

HX-leak (water vapour)

Sacrificial Nickel probe

Modular Mini Reactor Pool – 1st design changes



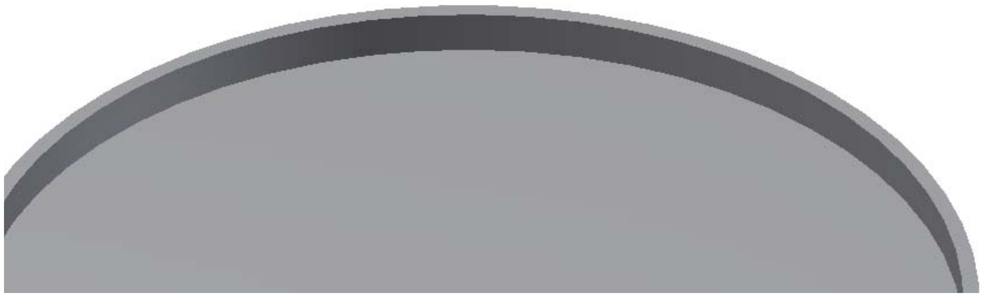


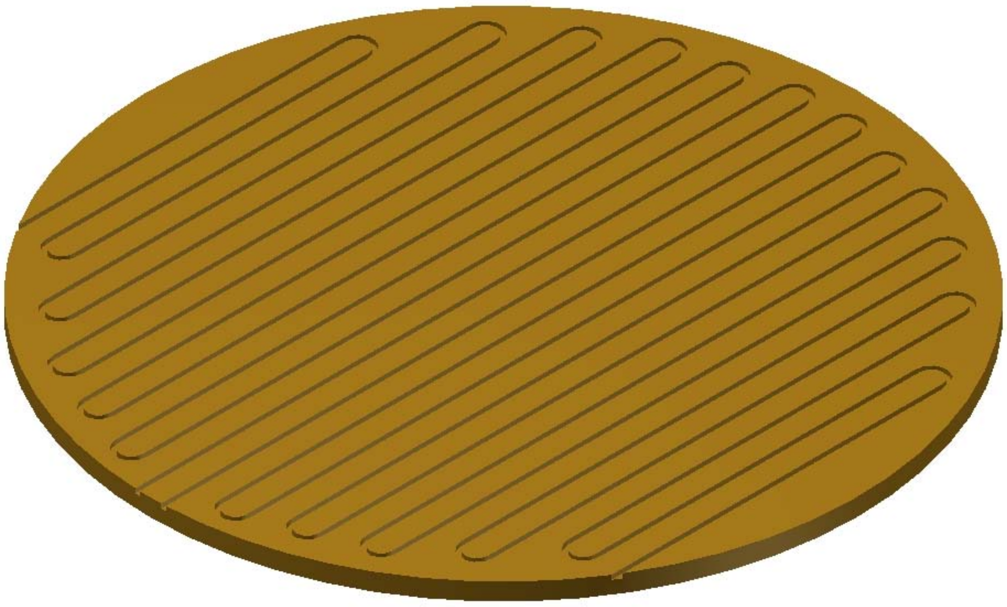
Now - 3 pots:

Conditioning
Experimental
Hot - Sacrifcial Ni

1st Design Phase
Heating system is designed – all „pots“ are manufactured

6KW total heating power
Temperature up to 650°C





Design-supporting CFD

1st step

Aim: Support the design - location of sensors and internal

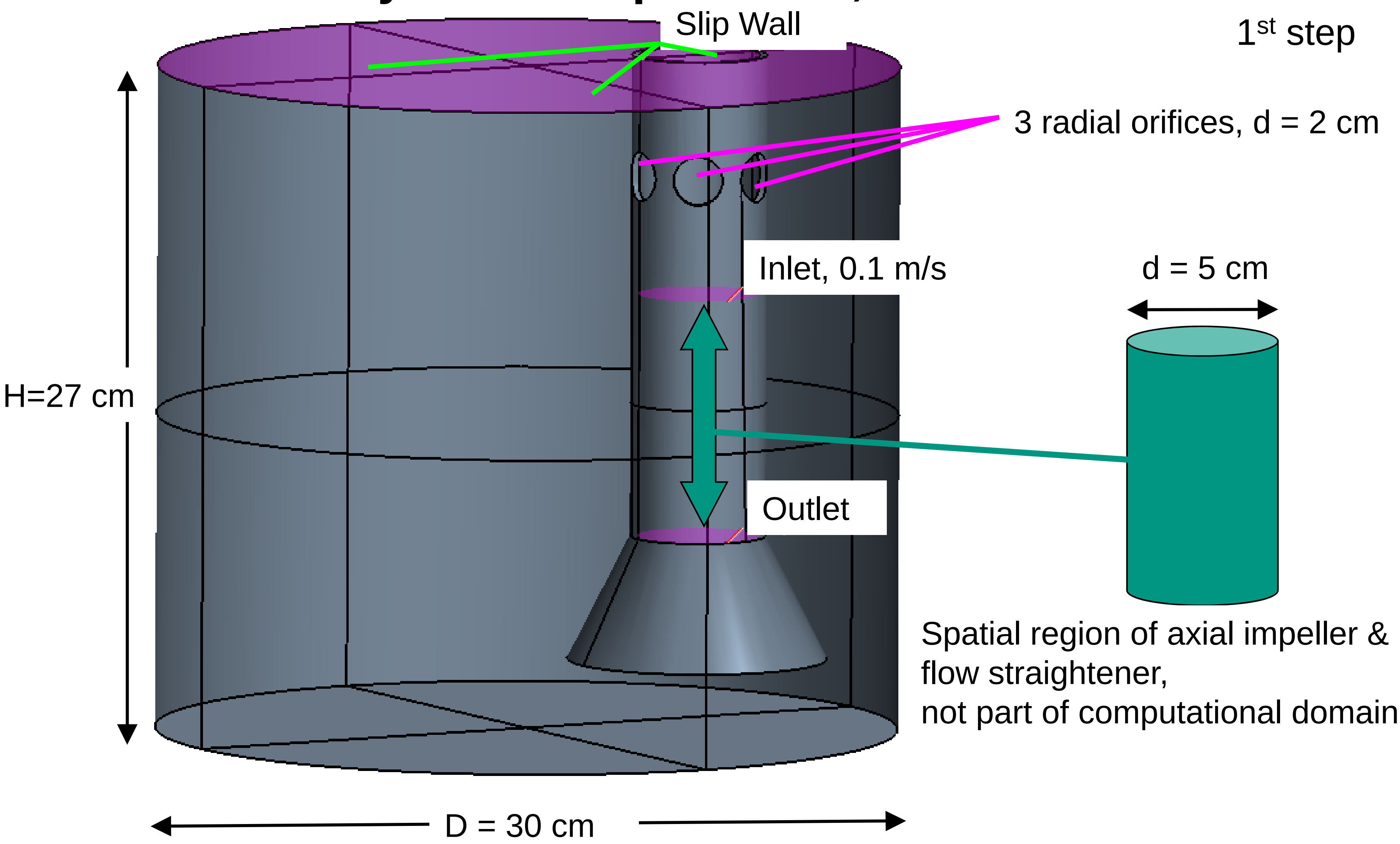
- Evaluation of design based on fluid mechanical aspects
- Identification of main flow patterns & regimes

- Adopted strategy:
  - Force asymmetry of flow field with choice of geometry and boundary conditions (do not rely on existence of large scale symmetry of flow field)
  - Flow field should contain regions with
    - Strongly directed, fast flow → mainly/definite convective transport
    - Stagnant flow, dead water regions → mainly/definite diffusive transport

- CFD-Software: STAR-CCM+ 6 (CD-adapco)

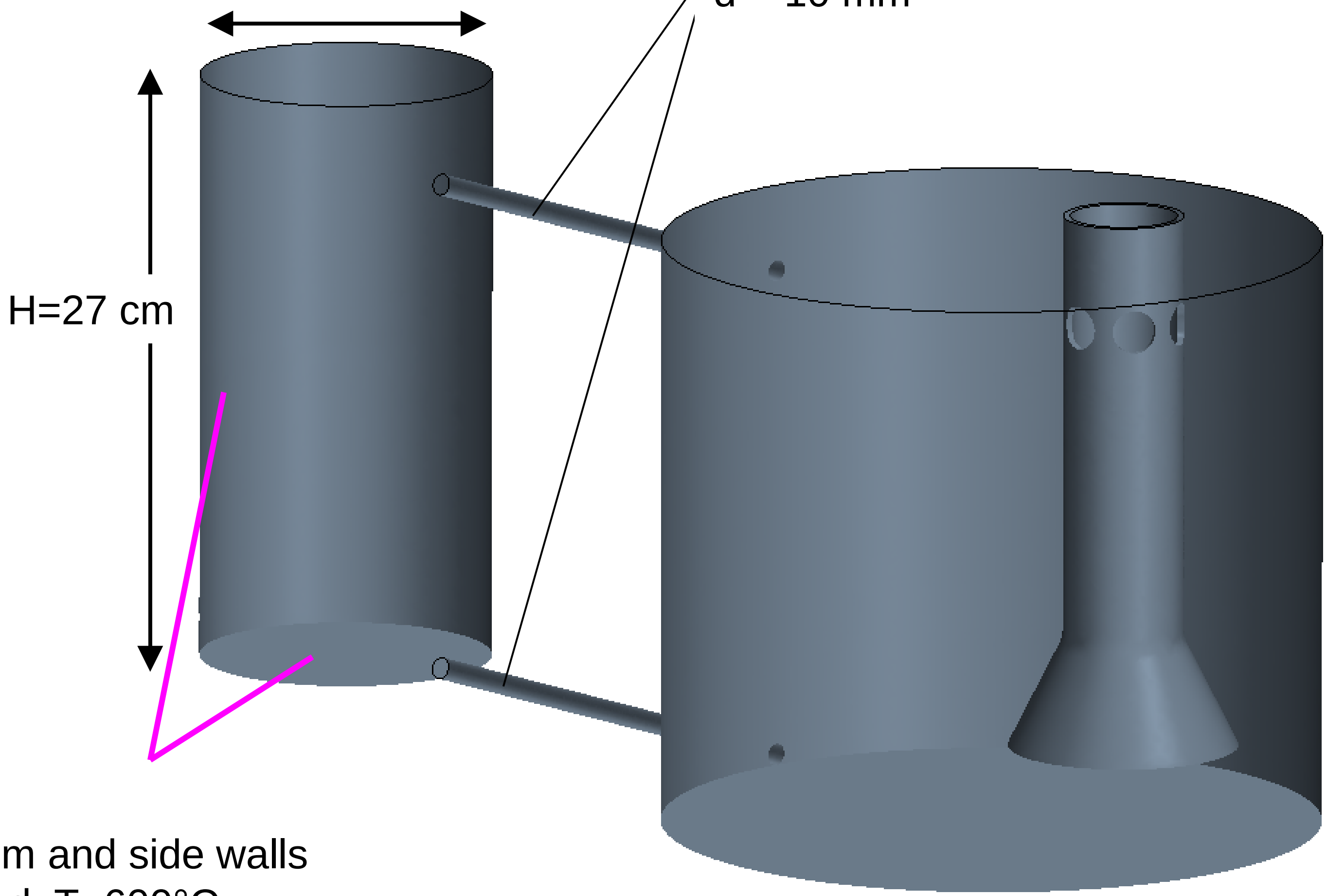
"CFD-Geometry" of main pool/tank, T=400°C

1st step



Main pool with auxiliary heated tank (sacrificial Ni at 600°C)

1st step



Bottom and side walls heated, T=600°C

Numerical Settings

1st step

- Finite-Volume Spatial Discretization
- Polyhedral mesh

- Stationary solver
- Segregated flow model, pressure-velocity coupling by SIMPLE method
- Convection scheme: 2nd order upwind

- Fluid: LBE with constant fluid properties at T=400°C

- Reynolds-Averaged Navier-Stokes Equations (RANS)
- Incompressible, Buoyancy accounted for by Boussinesq approximation

- Realizable two-layer k-epsilon turbulence model

Results with auxiliary heated tank @ T=600°C

1st step

- Mean flow velocity in connection pipes approx. 0.14 m/s
- Flow direction according to natural convection loop
- Low flow velocity in heated tank
- Core of large scale vortex in similar position as in simulation without heated tank

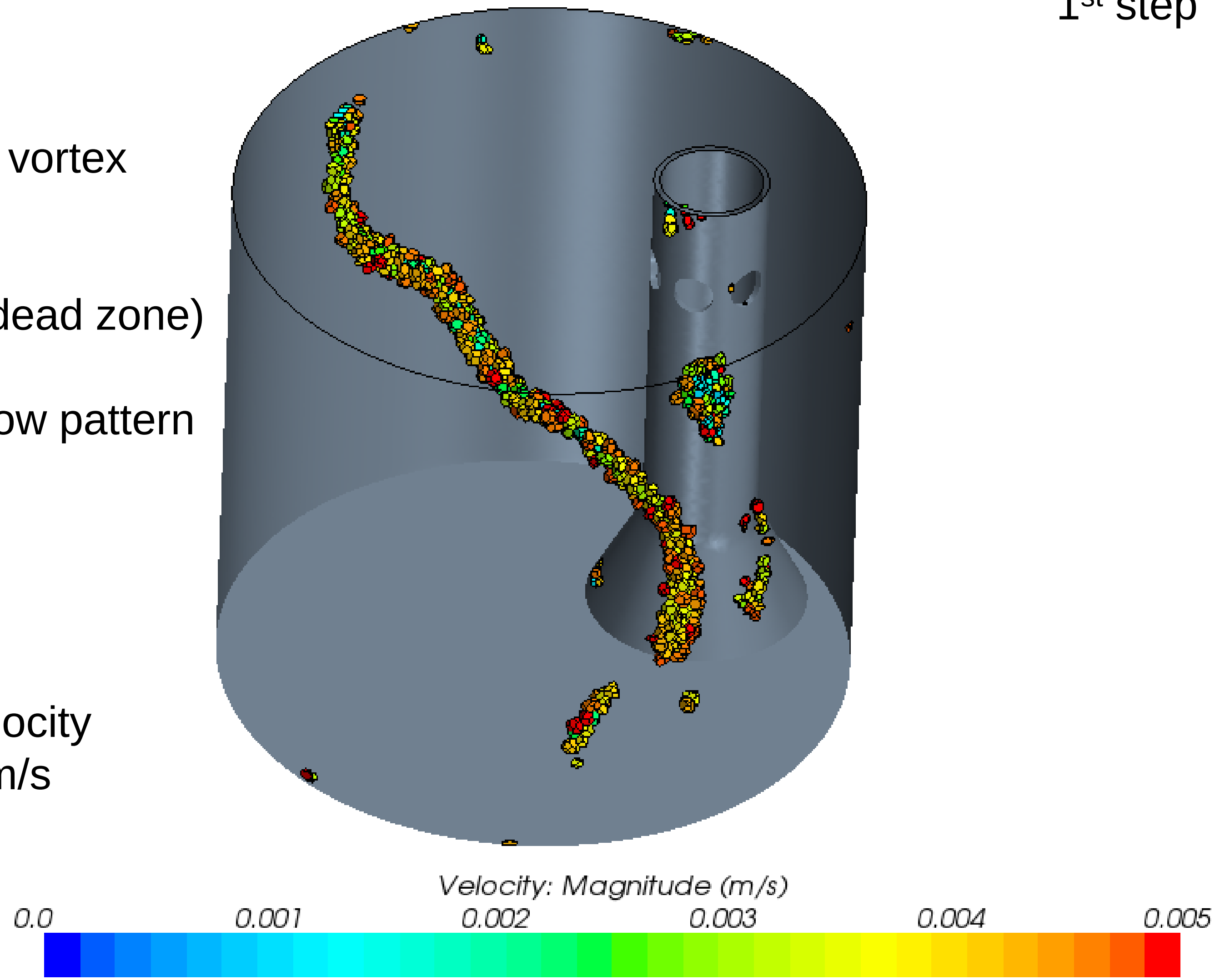
Main Flow Patterns, T=400°C: Core of Large-Scale Vortex

1st step

Stable large – scale vortex

Possible position of
oxygen sensor (for dead zone)

Stable assymetric flow pattern



Only cells with velocity
magnitude < 5 mm/s
are shown

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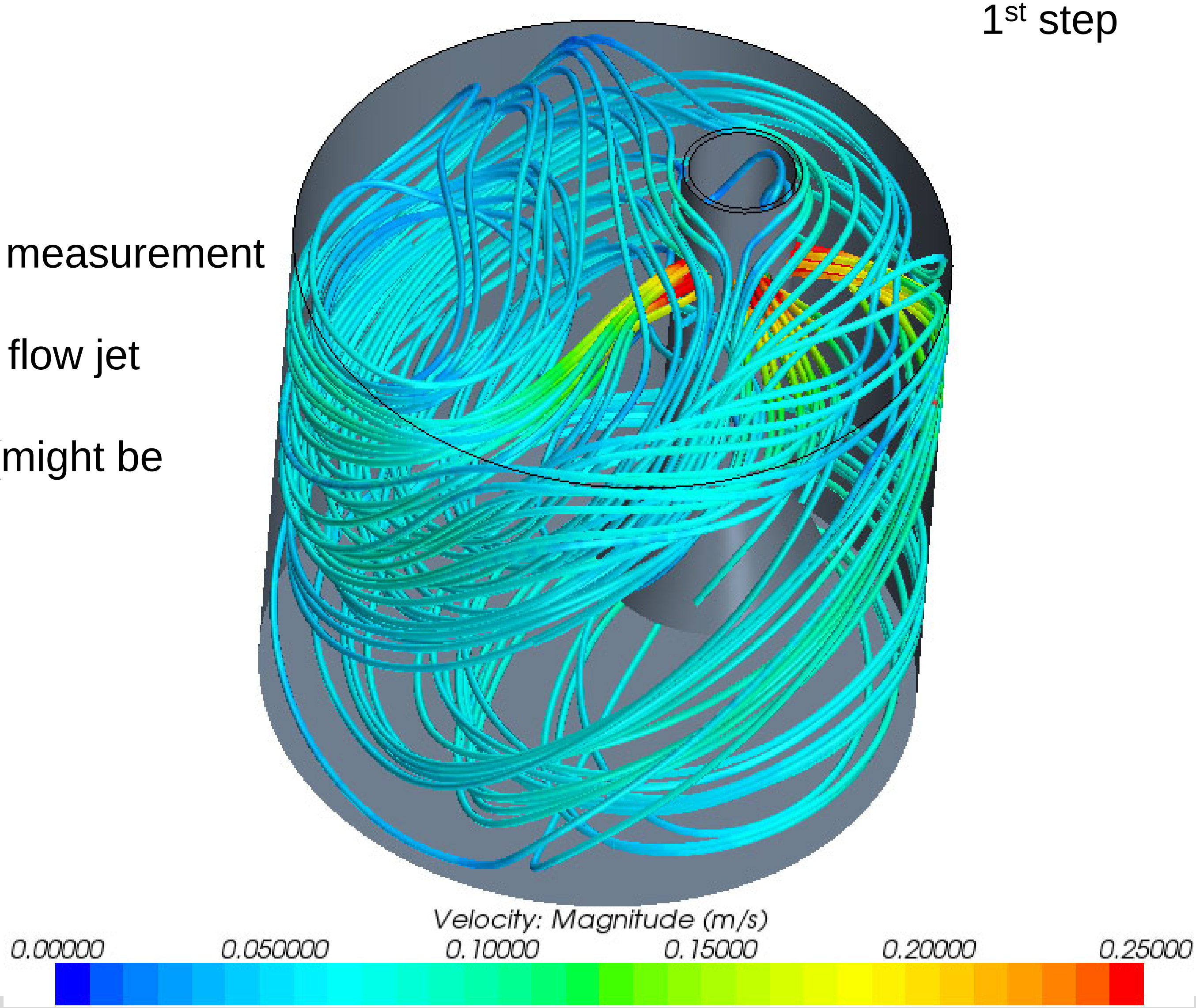
Main Flow Patterns, T=400°C: Fast Jets from Orifices

1st step

Stable flow jets
To be used for velocity measurement

oxygen sensors along flow jet

1 in stable dead zone (might be supported by design)



Design-supporting CFD – 2nd step

Aim: Support the design by

- Evaluation of design based on fluid mechanical aspects
- Identification of main flow patterns & regimes
- Choice of location of sensors (concentration & velocity) and internals

- Adopted strategies:
  - Force asymmetry of flow field with choice of geometry and boundary conditions (do not rely on existence of a large scale symmetry)
  - Realize properly defined boundary conditions
  - Flow field should contain regions with
    - Strongly directed, fast flow → mainly/definite convective transport
    - Stagnant flow, dead water region → mainly/definite diffusive transport

- CFD-Software: STAR-CCM+ 6 (CD-adapco)

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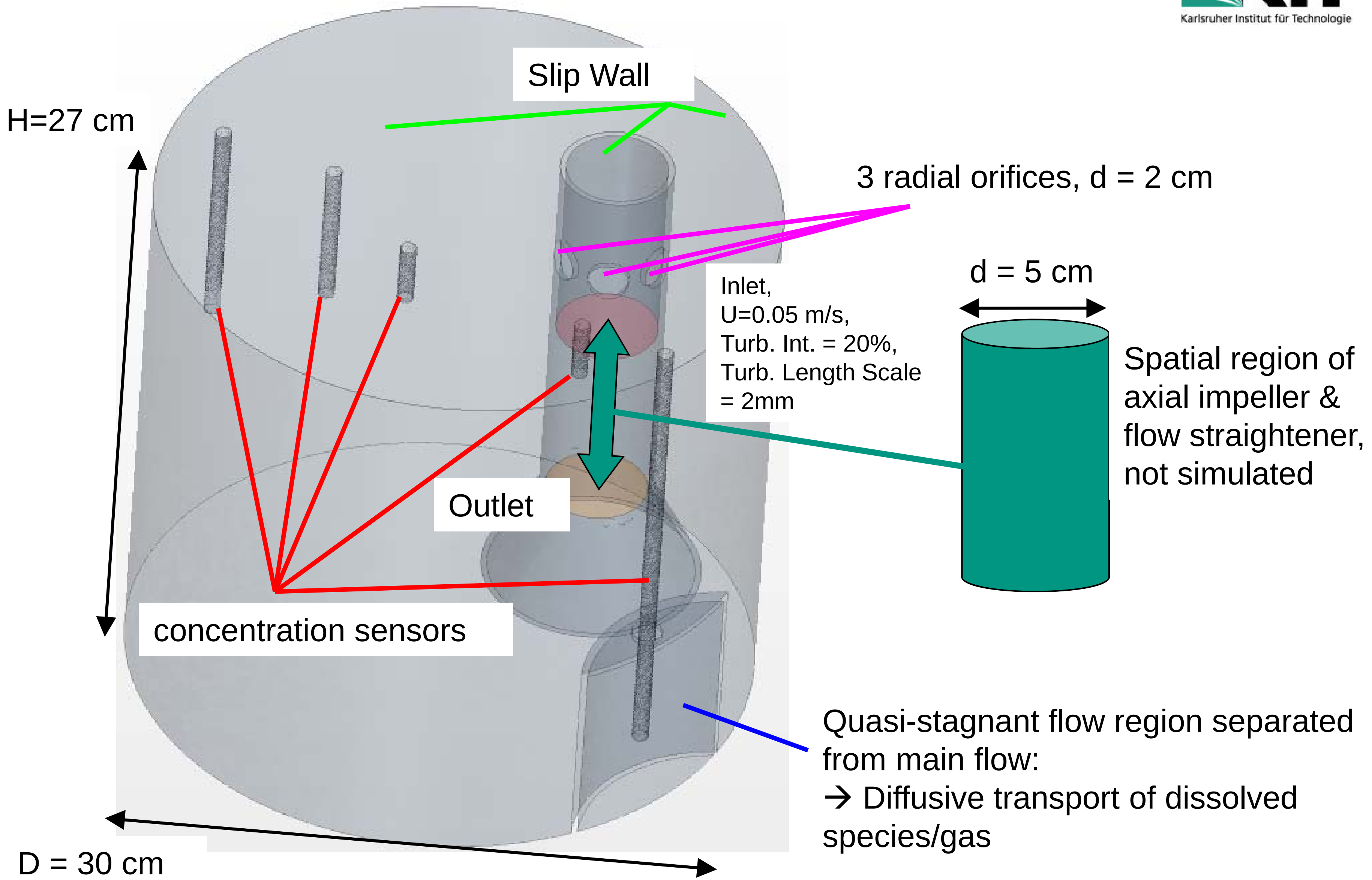
"CFD-Geometry" of main pool/tank, T=400°C



Numerical Settings – no changes

- Finite-Volume Spatial Discretization
- Polyhedral mesh

- Stationary solver
- Segregated flow model, pressure-velocity coupling by SIMPLE
- Convection scheme: 2nd order upwind

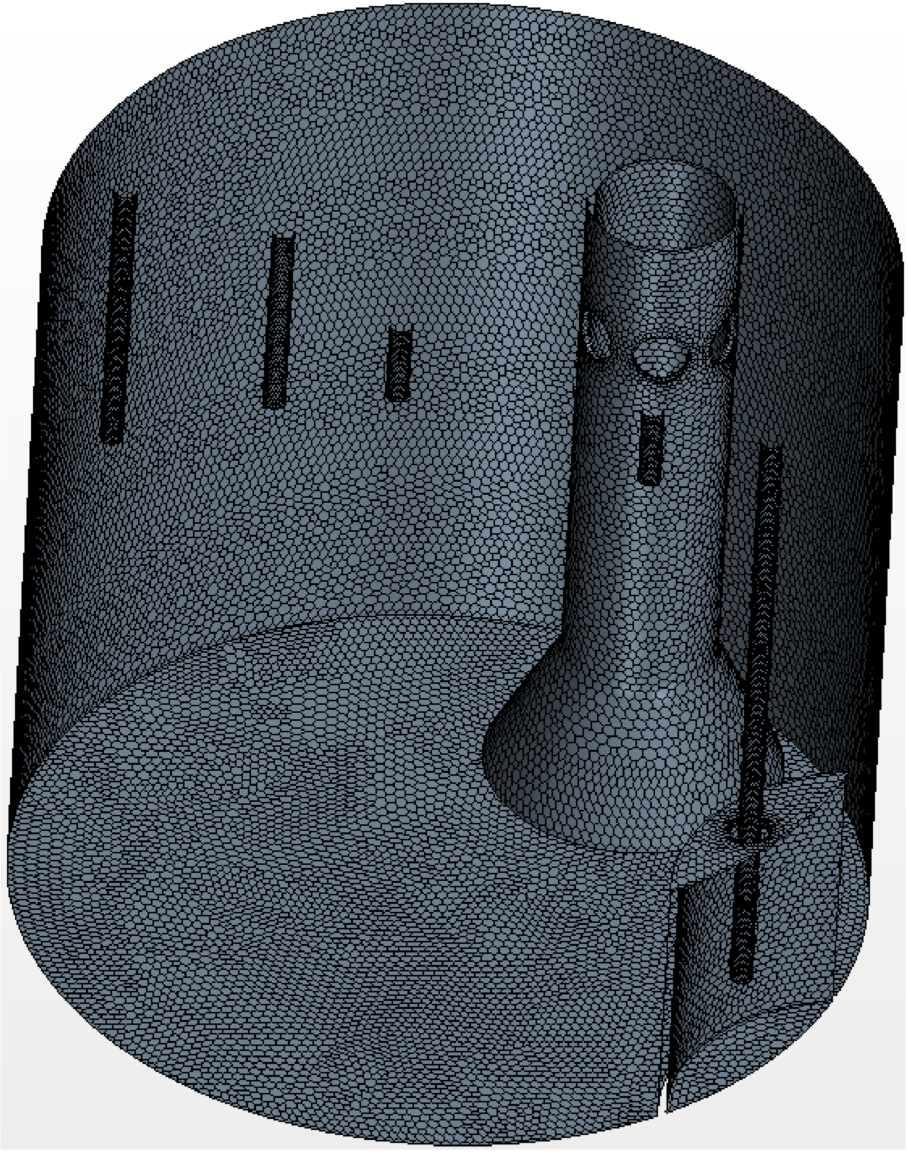
- Fluid: LBE with constant fluid properties at T=400°C

- Reynolds-Averaged Navier-Stokes Equations (RANS)
- Incompressible

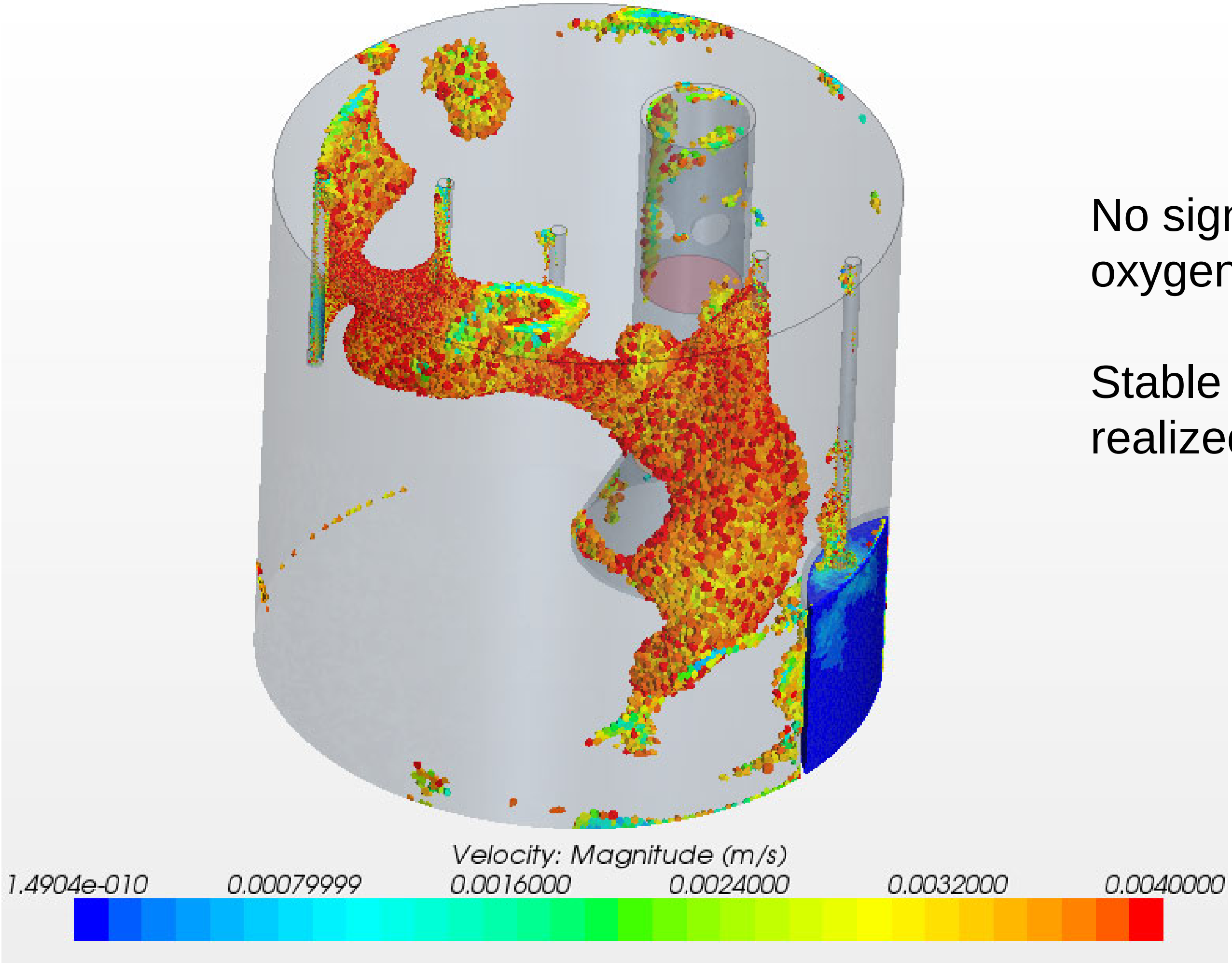
- Realizable two-layer k-epsilon turbulence model

Exemplary computational mesh

- 680,000 polyhedral cells



Main Flow Patterns, T=400°C:
Stable Large-Scale Low-Flow-Speed region



No significant change by oxygen sensors

Stable stagnant region realized by design

Only cells with velocity magnitude < 4 mm/s are shown (4mm/s is ~10% of characteristic circumferential speed, the max. flow speed in the jets is ~ 150 mm/s)

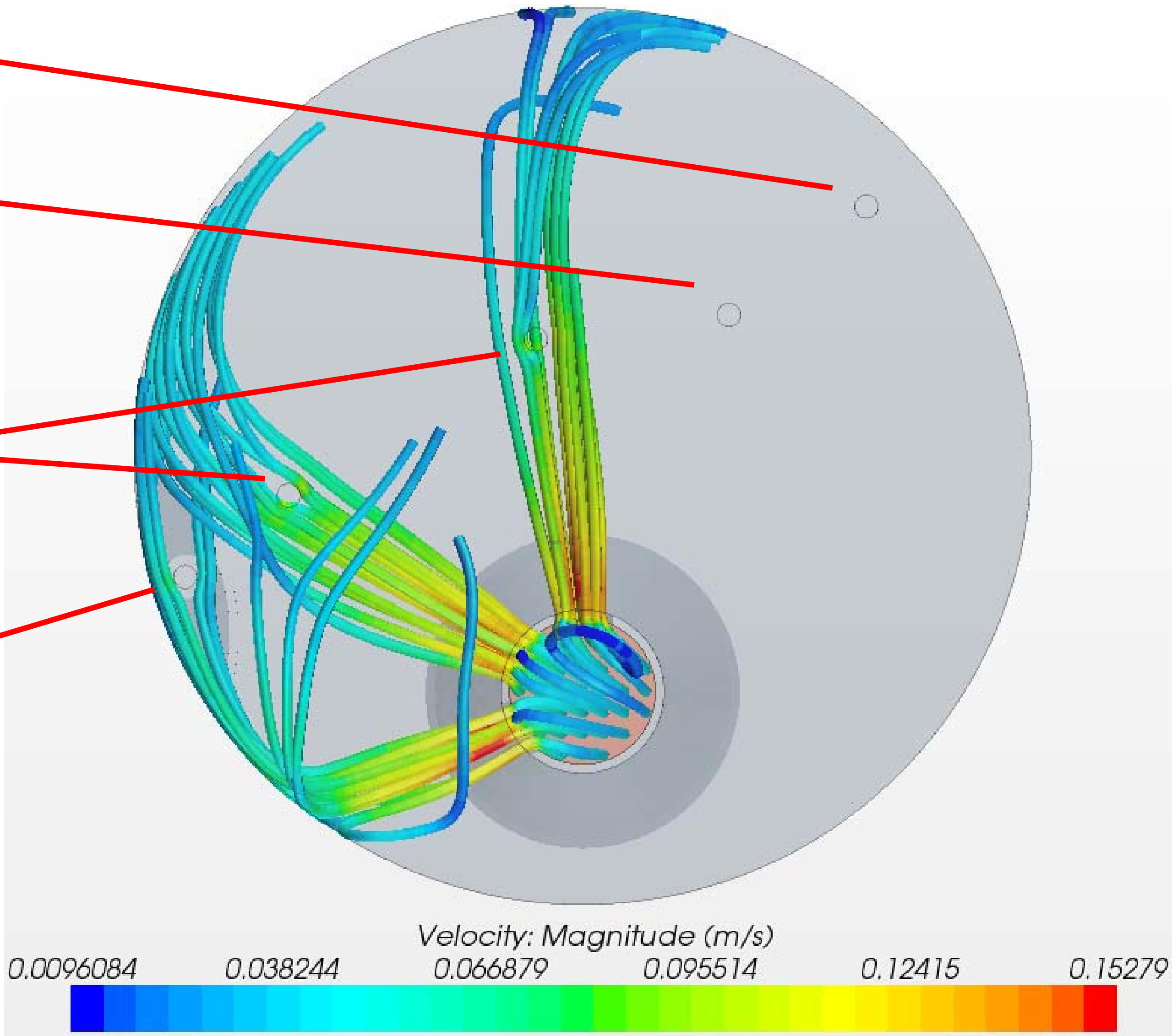
Main Flow Patterns, T=400°C: Fast jets from orifices

1 oxygen sensor in circumferential flow

1 oxygen sensor in core of global low-speed region

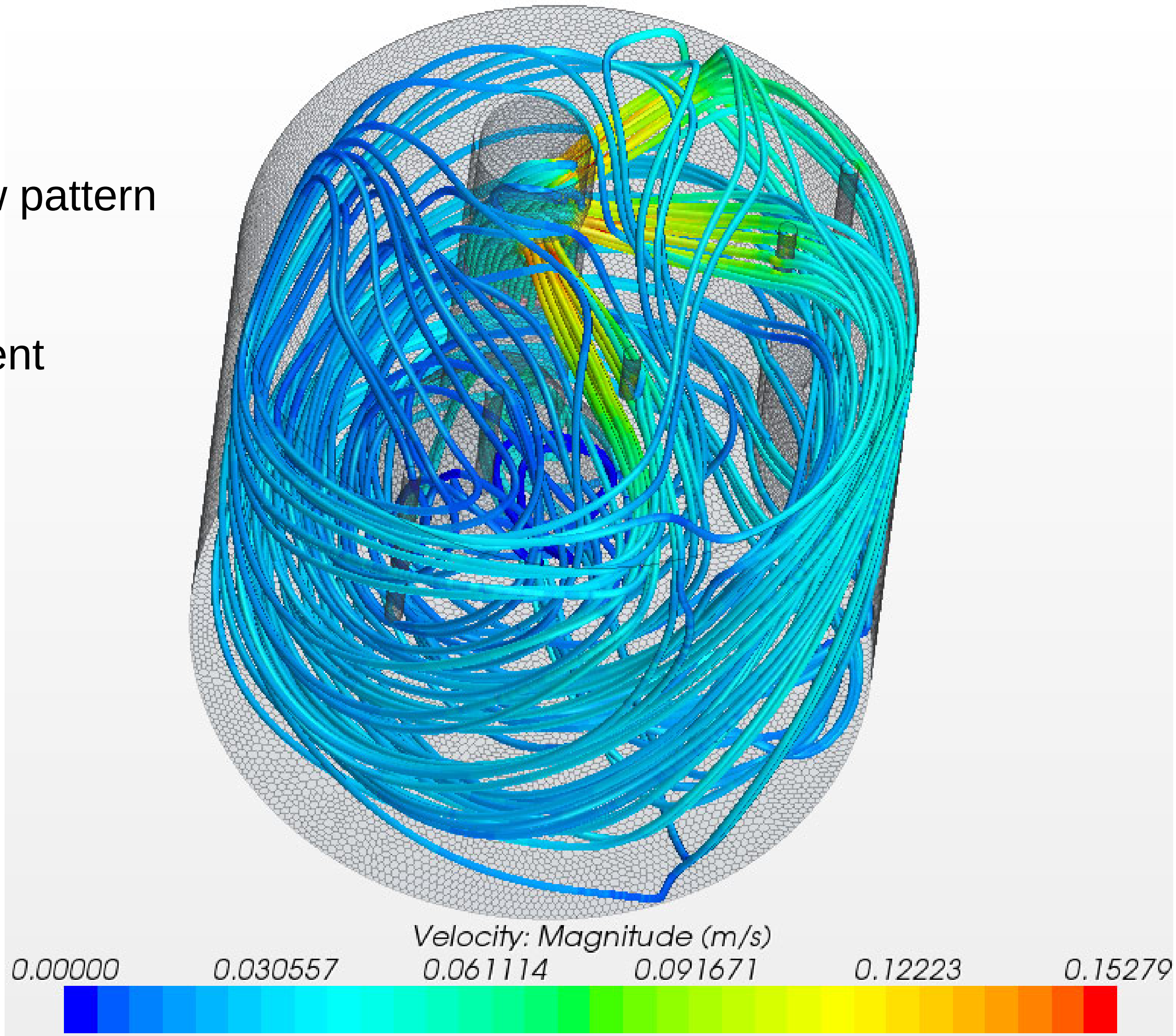
2 oxygen sensors in jets

1 oxygen sensor in dead water pocket



Main Flow Patterns, T=400°C: Large scale circumferential flow structure

Stable circumferential flow pattern
Important for experiments
- oxygen transport
- Flow measurement
- etc.



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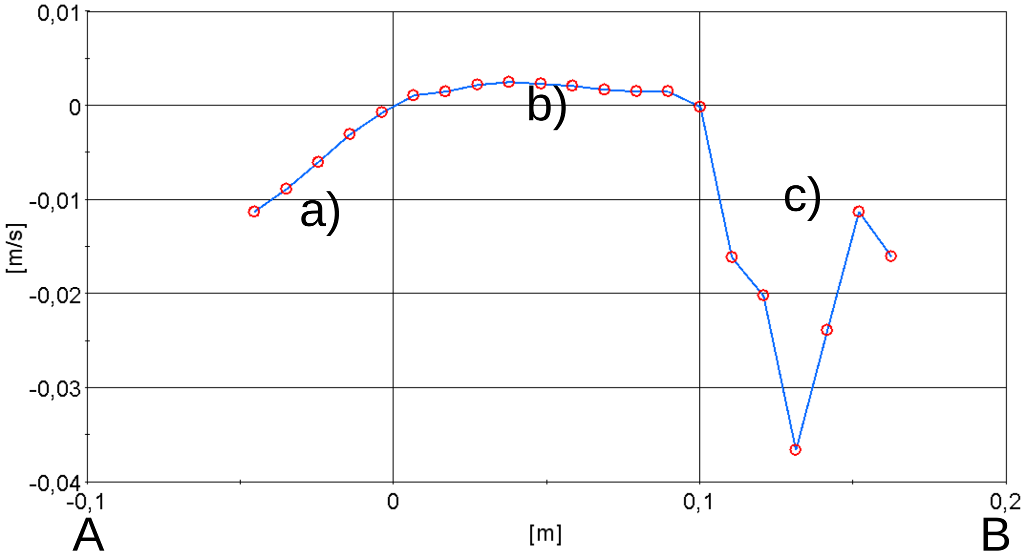
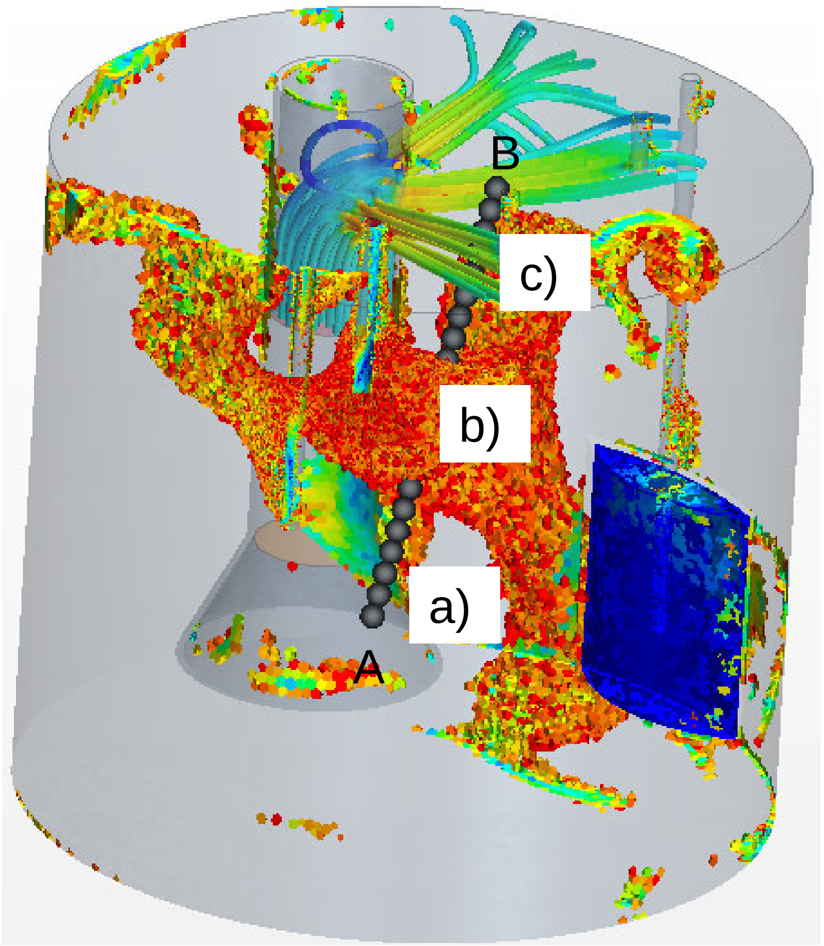
Main Flow Patterns, T=400°C:
Location of measurement lines of flow velocity by **Ultrasonic Doppler Velocimetry UDV**

Location of measurement line chosen according to following criteria:

• upwardly inclined direction (allowing escape of air bubbles)

• identification of
a) main circumferential flow velocity, direction is know
b) low speed region,
c) fast jet





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Summary and next steps

- Pre-design ready - pots are manufactured
- CFD results in location of sensors and 1st design details
- „Internals“ can now be constructed

Next design relevant CFD calculations:

- Characterization of impeller and flow straightener:
  homogenity of flow, turbulence intensity, turbulent length scale
- Characterization of flow around oxygen sensors
  (turbulent vortex street?)
- Unsteady simulations with time-resolved transport of dissolved species from cover gas atmosphere
- Simulations including all internals and auxiliary hot tank with sacrificial Ni probe

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A. Class, C. Schroer , F. Lang

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