ECORA
Evaluation of Computational Fluid Dynamics Methods for Reactor Safety Analysis

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Motivation

- Shortcomings of one-dimensional system codes in the simulation of three-dimensional, local flow and heat transfer phenomena
- Increased interest in application of three-dimensional CFD software as supplement to system codes
- High safety requirements in nuclear industry require consistent standards for use and assessment of CFD software
- Goals of ECORA:
  - Establish performance criteria for assessment of CFD software
  - Establish Best Practise Guidelines for application and use of CFD software

Objectives

- Assessment of CFD applications in reactor safety:
  - Flows in containment: PANDA experiments
  - Flows in primary system: UPTF experiments
- Best Practise Guidelines for reactor safety:
  - Starting point: ERCOFTAC Best Practise Guidelines
  - Adaptation to CFD application in for nuclear safety
  - Extension on assessment of experimental data
- Recommendations for improvements of CFD software
- Network of European ‘Centres of Competence for CFD Applications in Reactor Safety’
### Partner Programme

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<th>Country</th>
<th>Programme</th>
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<td>Gesellschaft für Anlagen- und Reaktorsicherheit</td>
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<td>AEA Technology GmbH</td>
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### Work Packages

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Project Structure

WP1: Establishment of Best Practice Guidelines

WP2: Evaluation of CFD Analysis of Primary Loop

WP3: Definition of Physical Models and Test Cases for PTS Analysis

WP4: Software Development and Verification

WP5: Software Validation

WP6: Evaluation of CFD Analysis of Containment

WP7: Analysis of Selected PANDA Tests

WP8: Evaluation of Application of CFD Codes to Reactor Safety

Best Practise Guidelines for CFD Simulations

- Types of errors and uncertainties:
  - Numerical errors: Solution or discretization errors, iteration errors, round-off errors
  - Model errors: Inadequacies of selected models
  - User errors: Lack of expertise in geometry and grid generation, definition of boundary conditions, selection of solver parameters, post-processing
  - Application uncertainties: Lack of information on geometry and boundary conditions (turbulence quantities, inlet profile shapes)
  - Software errors

- Provide procedures for quantifying and controlling errors and uncertainties
Procedures for Quantification of Errors

- Procedures for CFD simulations:
  - Definition of target variables: Representative, sensitive
  - Iteration errors: Residuals, global balances, target variables as function of iteration numbers or residuals
  - Spatial discretisation errors: Systematic grid refinement, variation of discretisation scheme
  - Time discretisation errors: Time step refinement, variation of discretisation scheme
  - Model errors: Strategies for model selection, assessment of experimental data, comparison to data
  - Uncertainties: Sensitivity studies, statistical analysis
  - Software errors: Verification, validation, interaction with developers

Application of Best Practise Guidelines

- Pump calculation:
  - Target variables: Efficiency, pressure rise
  - Quantification of iteration and solution error

- Courtesy: T. Hansen, AEA Technology GmbH
Quantification of Iteration and Solution Error

Best Practise Guidelines for Experimental Data

- Types of test cases:
  - Verification
  - Validation
  - Demonstration

- Standardized description of test cases:
  - Geometry
  - Boundary conditions
  - Initial conditions (unsteady flows)
  - Physical effects involved
  - Detail, consistency and accuracy of experimental data
  - Target variables
Primary System: Flow Phenomena

- Emergency Core Cooling (ECC)
- Single-phase flows:
  - Mixing of hot and cold water
- Two-phase flows:
  - Water jet into horizontal pipe filled with steam
  - Transport of water plugs
  - Free surface flows
  - Counter-current flow of steam and water

Primary System: UPTF Experiments
Primary System: UPTF Data

Containment: Flow Phenomena

- Physical models
  - Propagation and mixing of gases (steam, air and H₂)
    - Plumes
    - Impinging jets
    - Stratification
  - Chemical reactions (catalytic recombination)
  - Condensation
- Experiments in PANDA Test Facility
PANDA Experimental Facility

- Six cylindrical, large vessels (total 460 m$^3$). Two tower arrangement of the large vessels with large connection pipes.
- Broad variety of vessel and pool interconnections. Provides flexibility to easily adapt the facility for a variety of investigations.
- Well suited for large-scale thermal-hydraulic tests, especially for containment multi-compartment and 3-D effects.
- Main measurements: injected flow rates, vented flow rates, temperatures, gas concentrations at selected points of interest, velocities at selected points of interest.

SETH PANDA Tests – Free Plumes

- To investigate:
  - Plume features (steam in air or a mixture)
  - Effect of injection elevation on stratification stability
  - Influence of vent location on plume structure
  - Thermal/concentration front propagation in second vessel
- Varying parameters: elevation and outlet velocity of the efflux, initial fluid composition and location of venting.
Conclusion

- Improvement of quality of CFD calculations in reactor safety
  - ECORA Best Practise Guidelines
  - Assessment of shortcomings
  - Improvement of mathematical models

- Higher acceptance of CFD in reactor safety after ECORA

- 1st Step: Establishment of European ‘Centres of Competence for CFD Applications in Reactor Safety’

- Further information on ECORA: [www.domino.grs.de/ecora/ecora.nsf](http://www.domino.grs.de/ecora/ecora.nsf)