Stratification issues in the primary system. Review of available validation experiments and State-of-the-Art in modelling capabilities. (StratRev)

NKS seminar, Armémuseum, 2009-03-26

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Project sponsored by NKS and NORTHNET

Outline

- StratRev – outline of the project
- Examples of known stratification issues in the primary system
- BWROG Workshop on Thermal Stratification (June 2008)
- Short about the review
- Possible continuation projects

StratRev
Work packages

I. Summarize known problems related to stratification and mixing phenomena in NPPs. (Input from End Users)

II. Review of existing experimental studies relevant for validation of stratification, natural convection and mixing in the RPV

III. Review of existing experimental studies relevant for validation of stratification in piping

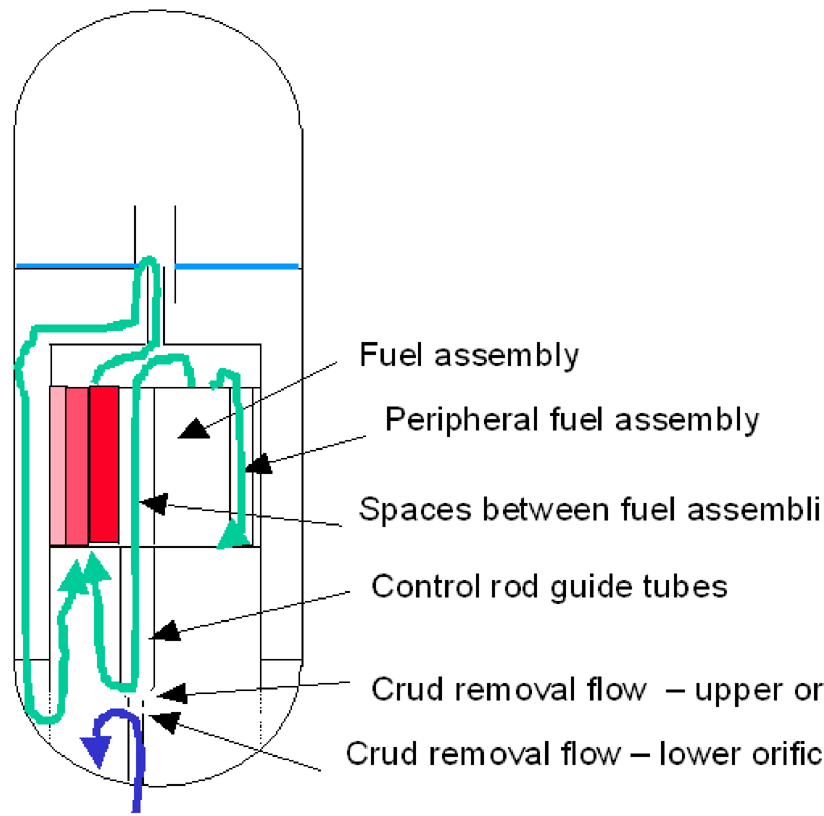
IV. Review of State-of-the-Art in modelling capabilities for stratification, natural convection and mixing in the RPV
   - Focus on CFD-methods

V. Organize a workshop on stratification issues in BWRs
   - Organized within the framework of BWR Owners’ Group (BWR-OG)
   - Älvkarleby, June 3-4, 2008

VI. Written report
   - Should include suggestions for possible continuation projects

Examples of stratification issues in the primary system
The HTG-event

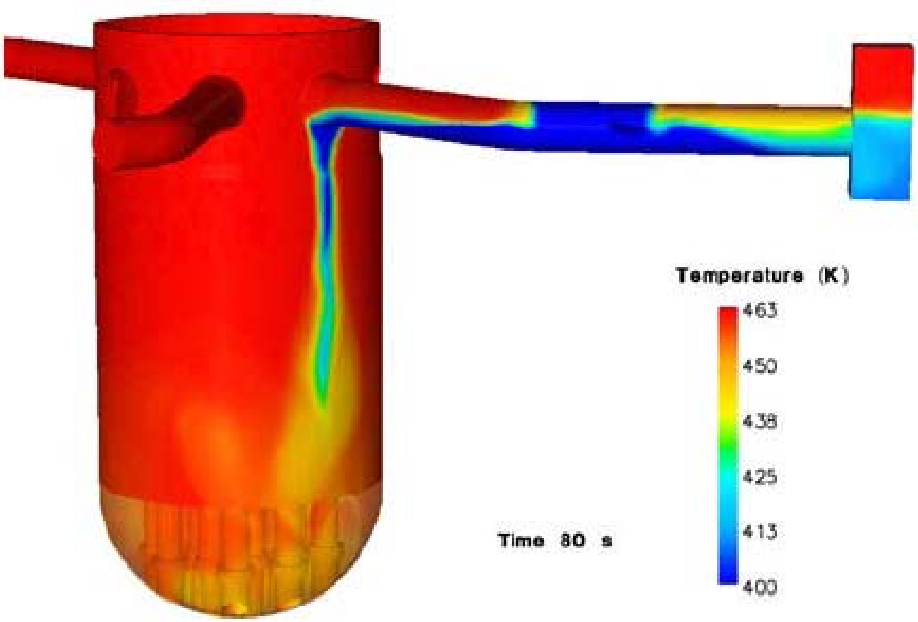
- The event can be separated into (at least) two separate issues
  1) Onset of stratified conditions
  2) Restart of pumps with a following thermal transient (PTS)
- Onset of stratified conditions
  - Cold water injection at lower plenum. Density differences enhance stratification
  - Momentum from natural circulation loops + turbulent mixing counteracts stratification
- Several natural circulation loops identified (multiple parallel channels and flow paths)
- Complex geometry
  - lower plenum
  - core (core power distribution also important)

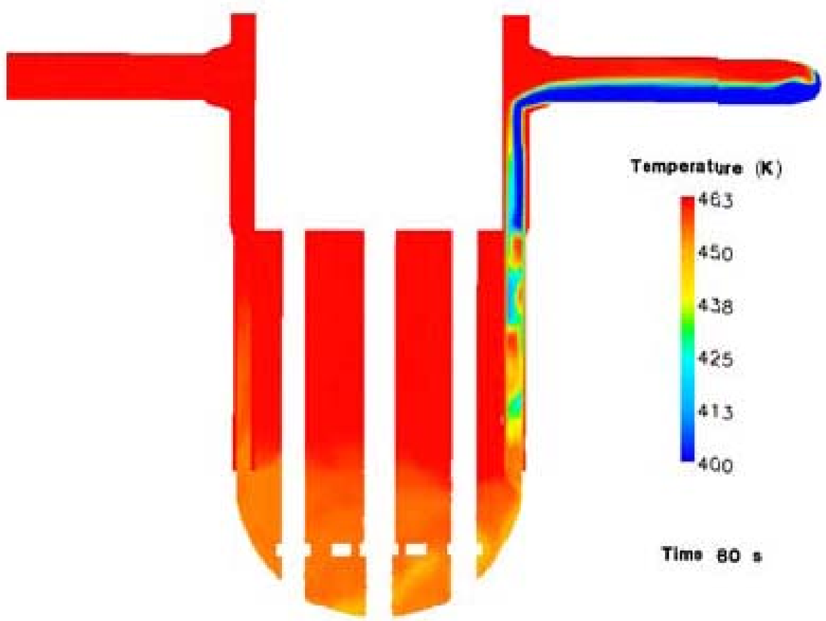


(Courtesy of OKG AB)

Examples of stratification issues in the primary system Downcomer

- Thermal striping during ECCS cold water injection in the hot leg and downcomer
- Oscillating cold water streaks generate thermal loads on the vessel wall

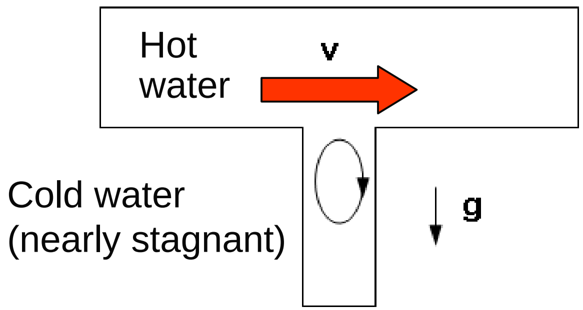


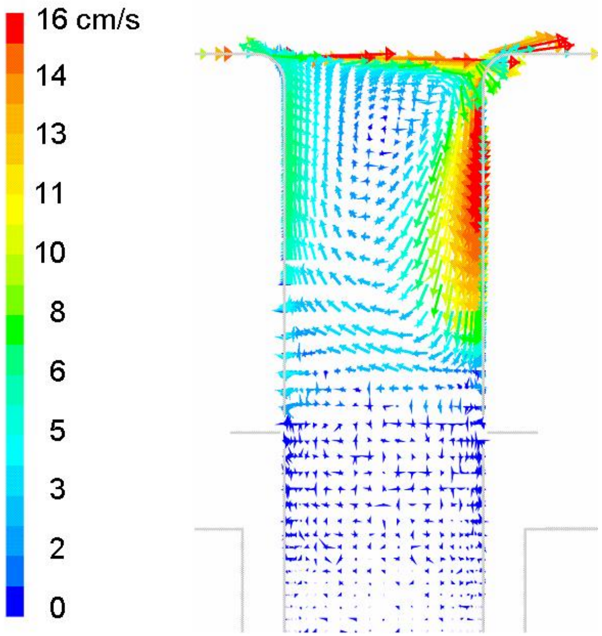


(Calculations from ECORA project, Sander Willemsen, NRG)

Examples of stratification issues in the primary system T-junctions with dead legs

- Stratification by cooling in the nearly stagnant branch pipe can be the primary cause of upcoming temperature differences
- Large-scale vortical structures create thermal fluctuations
- Heat conduction in the pipe wall can create natural circulation in the branch pipe
- Reduced turbulence level further away from the junction ($\Rightarrow$ transition to laminar flow can occur in the branch pipe)
- Prediction of turbulent mixing important (amplitudes and frequencies)

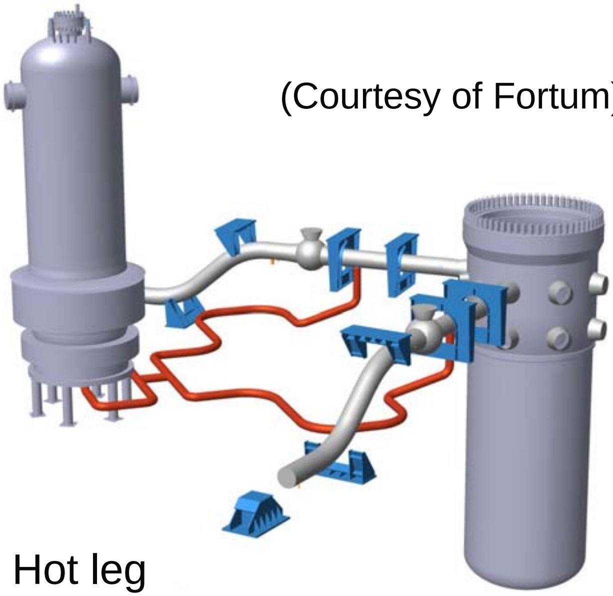




(Courtesy of VTT)

Examples of stratification issues in the primary system
Stratification in horizontal surge lines

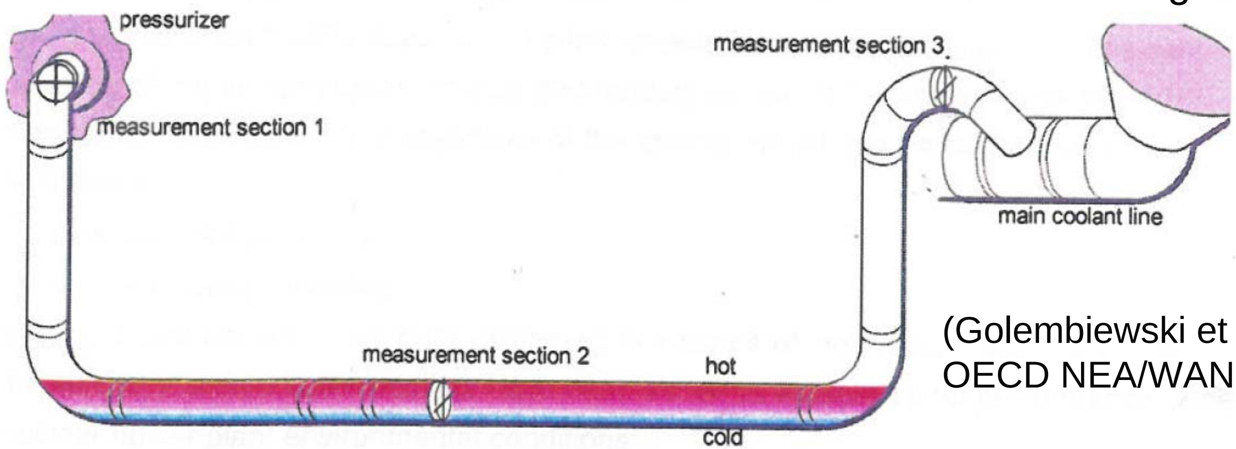
- Stratification in the horizontal parts of the surge lines (PWR)
- Cyclic temperature variations can occur during the sometimes slow fluid motion (low-freq. temperature oscillations)



(Courtesy of Fortum)

Pressurizer

Hot leg



(Golembiewski et al,
OECD NEA/WANO meeting 1998)

BWR-OG WORKSHOP ON THERMAL STRATIFICATION

ÄLVKARLEBY, SWEDEN

JUNE 3-4 2008

BWR-OG Workshop on thermal stratification
Some facts

- Approximately 50 participants
  - Germany 6; USA 5; Finland 5; Switzerland 3; England 1; Netherlands 1
- 17 presentations + final discussion
  - 8 presentations by utilities
  - 1 presentation by regulatory body
  - 2 presentations by code developers
  - 4 presentations by academia or research organizations
  - 2 presentations by BWR-OG
    (thermal stratification committee update + general info)
- Focus on BWR issues, but also PWR-related issues were discussed

BWR-OG Workshop on thermal stratification
Examples of plant issues related to stratification

- HTG-event in Oskarshamn 3 (Presentations by OKG and Westinghouse)
  - Stratified layer created by cold crud flow in combination with MCP’s switched off
- Cold water injection transient in NPP Krümmel
  - MCP’s switched off while cold water was injected during 14 minutes through the high-pressure injection system $\Rightarrow$ thermal loads on RPV and internals
- Stratification phenomena at NPP Gundremmingen
  - 1993: stratification in lower plenum (similar to the HTG-event)
  - Thermal stratification and evaporation inside a connection pipe to the main steam line
- Leibstadt NPP
  - Stratification in a horizontal feedwater line, especially at small flow rates during start-up
  - Stratification in the feedwater nozzles at small flow rates
  - Stratification at the RPV bottom during MCP trip
- Cooper Nuclear station
  - Reliability of temperature measurements based on the bottom head drain flow (stagnant water)

BWR-OG Workshop on thermal stratification
Comments at the final discussion

- **Stratification and mixing** are important phenomena that can occur, and it can also affect the integrity of systems and components
- The analysis of the various thermal transients described at the workshop showed small usage factors (thus a weak motivation for further studies)
- General interest for **improved understanding**
  - What can cause stratification? (forces that enhances stratification)
  - What counteracts stratification? (what is needed to break-up a stratified layer?)
  - There is a need to analyze several events/scenarios to gain understanding
- Possibility of reducing the operational restrictions can be a stronger driving force
  - Possible to avoid cold shutdown under certain circumstances?
  - Possible to reduce current restrictions on restart of Main Coolant Pumps?
- Important with similar technical specifications and limitations in different plants
- There is a lack of knowledge and procedures that should be applied following this type of events

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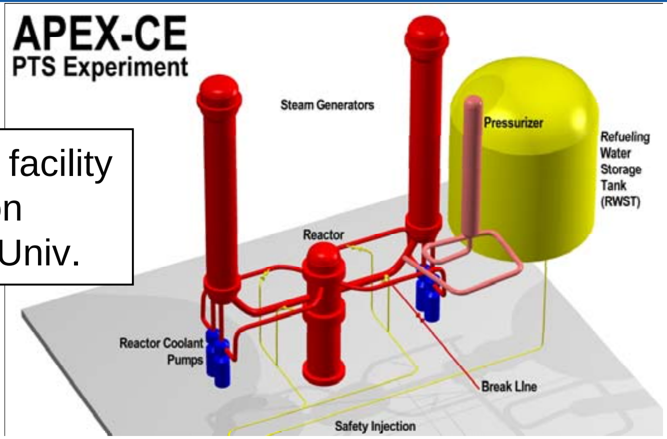
WP2. Experiments on stratification in the RPV

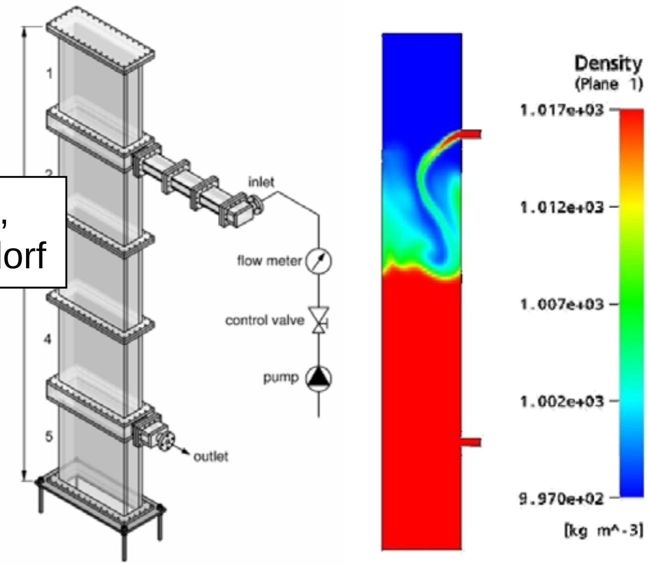
- Integral large scale experiments
  - Simulate complex conditions, e.g. natural circulation in realistic geometries
  - Often designed to develop and test passive safety systems and assessment of system codes

APEX facility
Oregon
State Univ.



- Separate effect experiments
  - Suitable for model development and code validation
  - Mixed convection studies
  - Breaking-up of stratified layers
  - Scale-up to plant conditions?

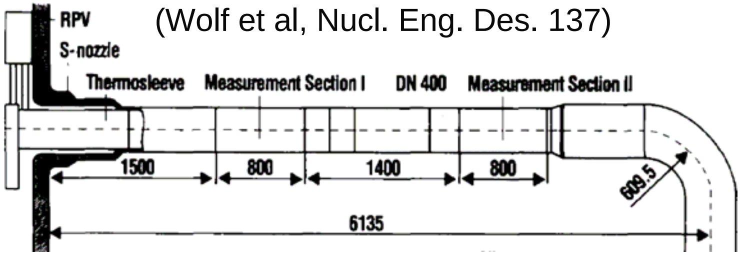
VeMIX facility,
FZR Rossendorf



(Da Silva et al, XCFD4NRS 2008)

<u>Comment</u>: Well-documented boundary conditions and flow field documentation required for accurate CFD-validation

WP3. Experiments on stratification in piping



(Wolf et al, Nucl. Eng. Des. 137)

- HDR-experiments (Germany ~1990)
  - Ex. Cold water injection into horizontal pipe and into the RPV
- ROSA experiment in the Large-Scale Test Facility (LSTF), Japan
  - Test ECCS water injection under natural circulation condition
- Plant data on stratification in surge lines
  - Temperature measurements at the outer pipe wall at different circumferential positions

Comment: Only limited possibilities for CFD code validation
(flow field information usually not available)

WP4. Modelling capabilities for stratification, natural convection and mixing

- Methods based on Computational Fluid Dynamics (CFD)
  - Potential to capture transient 3D phenomena, but computationally expensive
  - Require validation versus relevant experimental data
  - Some difficulties
    - Near-wall heat and mass transfer
    - Modelling turbulence and mixing
    - Buoyancy driven flows (e.g. natural convection)
    - Complex geometry (geometry simplifications) and effect of core power distribution
    - Scaling issues (from laboratory scale to plant conditions)
- Non-CFD prediction tools (BMIX++,TRACE,GOBLIN)
  - Computationally efficient
  - Limited ability to describe 3D effects and complex geometry
- Need to quantify modelling uncertainties

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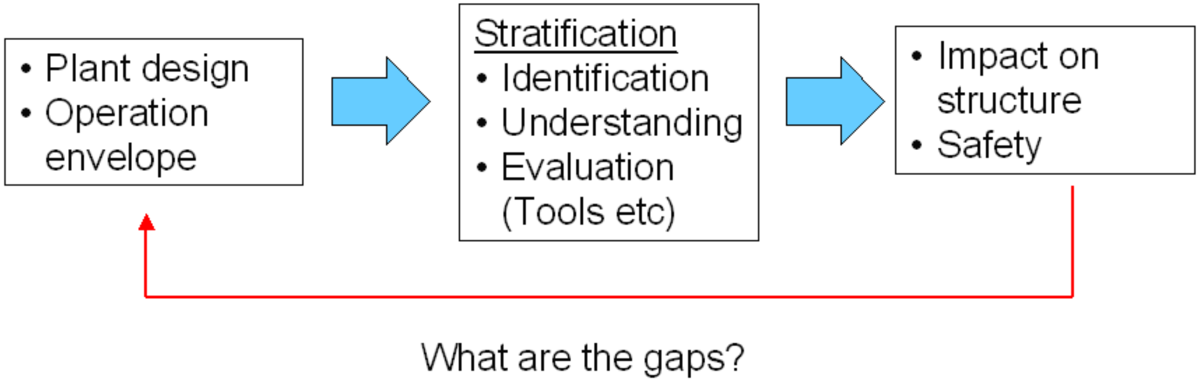
Possible continuation projects
Goals and objectives

- Ultimate goal: Development of procedure/methodology applicable for analysis of stratification related issues (BPG)
  - Regulators will be better prepared to substantiate the public safety
  - The utilities can reduce lengthy production losses if established BPG can be applied and thus shorten the time needed for analysis
- Assessment of the risk for safety concerns and available margins
- Development of knowledge and data bases for risk informed decision making
- Assessment of the prediction capabilities of various analysis methods (validation)
- Validation experiments
  - Separate-effect tests for validation of physical models
  - Integral tests for studying system behaviour and assessment of the effects of geometry simplifications
- Extension of the existing Best Practice Guidelines for CFD in nuclear safety applications (OECD/NEA)

Possible continuation projects
Questions to be addressed (to develop procedures/methodologies)



I. What is the possible impact on the structures?

– Assessment of the potential risk for structural damage with conservative assumptions about thermal loading
– Assessment using realistic thermal loading (requires more detailed analysis)

II. Can the event be prevented?

– Analyze possible scenarios and related operating procedures (cf. NOG-work)

III. What measures should we take in case of a stratification event?

– Validation of computational methods versus experimental data
– Formulate BPG

Concluding remarks

- Review of known plant issues related to stratification in the primary system, as well as current modelling capabilities and available experiments
- Stratification and mixing are important phenomena that can occur, and have the possibility to affect the integrity of systems and components.
- There is a lack of knowledge and procedures that should be applied following this type of events
- Questions to consider:
  - What is the possible impact of stratification events on the RPV structures?
  - What can be done to prevent the occurrence of thermal transients?
  - What measures should be taken in case of a stratification event?
- CFD is a (the) suitable tool to analyze the thermal loads that are localized in time and space, but validation needed
- Still not feasible to apply CFD to the entire RPV $\Rightarrow$ other methods (integral methods) still needed and should be developed
- Ranking of most interesting continuation projects requested from NORTHNET RM2 reference group