Overview of
MELCOR Activities in NRI Řež

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Outline

- Validation on Quench-11 Test
- Conversion M185 $\Rightarrow$ M186
- Overview of Other Experiment Simulations
- Plant Applications
Quench Facility Description

- **PWR Bundle**
  - 20 heated rods + 1 unheated or (B4C or SIC) control rod
Main characteristics of Quench-11 tests

- Quench medium – Water
- Flooding rate – 18 g
- Initial temp. – 2040 K
- Max. ZrO₂ before flooding – 170 µm
- Max. ZrO₂ layer thickness – completely oxidized
- H₂ generation before/during cooldown – 9/132 g

Shroud and bundle were significantly degraded
- Shroud failure at 850 mm

Quench-11
Bundle Nodalization

- Final nodalization for MELCOR 1.8.6
  - 4 Radial rings
    - 4th ring only in 1st axial level
  - 30 axial nodes (newly defined altitudes from 0.0 to 1.092 m, upper and lower plenums remain unchanged)
  - New SHROUD component in MELCOR 1.8.6 and bypass volumes
  - Simplified off-gas pipe in comparison with older models
Simulation of Q-11 with MELCOR

Contribution to Q-11 Benchmark

- Conclusions from the MELCOR 1.8.6 simulation presented at the 13th International QUENCH Workshop [Dsp]
  - Summary prepared as contribution to Benchmark Final Report [Ste]
- Main conclusions related to MELCOR 1.8.6 simulation within Benchmark
  - Significant underestimation of hydrogen generation due to
    - Absence of melt oxidation (only less than 2 % of candled Zr oxidized)
    - Relocation of shroud upper part into bypass with Ar atmosphere
    - Intensive downward relocation into colder parts of bundle
  - Final bundle configuration
    - Main mass of refrozen material predicted in area of middle grid spacer (550 mm) instead of above 750 mm
    - This could be influenced by user ⇒ Sensitivity Analysis


Sensitivity Matrix
Overview of Parameters

- Test matrix consists of 16 input parameters with 3 to 7 optional values
  - COR00003 ... Radiative Exchange Factor CN (SH) to CL
  - COR00003 ... Radiative Exchange Factor Radially out of Cell
  - COR00005 ... Candling Heat Transf. - Refreezing for all materials
  - COR00008 ... Critical thickness of unoxidized Zry
  - COR00012 ... Velocity of Falling Debris
  - SC1132(1) ... ZrO$_2$ relocation for CL
  - SC1132(2) ... Fuel rod relocation temp. regardless of composition
  - SC1131(1) ... Min ZrO$_2$ thickness required for hold up of melt
  - SC1131(2) ... Max ZrO$_2$ temp. permitted for hold up of melt
  - SC1131(3) ... Min SX thickness required for hold up of melt
  - SC1131(4) ... Max SX temp permitted for hold up of melt
  - SC1131(5) ... Min ZrO$_2$ thickness required for hold up of melt in CN (SH)
  - SC1131(6) ... Max ZrO$_2$ temp permitted for hold up of melt in CN (SH)
  - SC1141(1) ... Core Melt breakthrough Candling - time step
  - SC1141(2) ... Core Melt breakthrough Candling - melt flow per width
  - FLnnnBk ... Flow Path blockage by candled and frozen melt

- More detail description of each of parameters is included in [Gau]

# Sensitivity Matrix

## Table of Sensitivity Cases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Acronym</th>
<th>Unit</th>
<th>Default</th>
<th>Basic</th>
<th>Sens 1</th>
<th>Sens 2</th>
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**Green** - case with the highest hydrogen generation  
**Red** - case with the lowest hydrogen generation  
- MELCOR 1.8.6 YR used for this sensitivity study  
- Results assessed also from final configuration point of view  
  - Fluid cross area profile - new ATLAS window and Excel sheets used  
- Additional sensitivity cases defined based on the matrix results  
  - FLBLK_REFR2-3_TZXMX-3  
  - FLBLK_REFR2-5_TZXMX-3  
  - Final case: FLBLK_GAMBRK-1_TZXMX-3_VFALL-1_REFR2-6_FCELER-3_FCNCL-3 (acronym X4)
New ATLAS Screen Developed

- New screen for ATLAS postprocessor was developed to visualize evolution of profiles
  - Specific masses per rod [kg/m]
    - Candled Zr or ZrO₂ on
      - Cladding
      - Shroud
      - Fuel (ZrO₂) pellets
    - Particulated debris of Zr or ZrO₂
    - Intact plus candled Zr or ZrO₂ in component
      - Cladding
      - Shroud
      - Fuel (ZrO₂) pellets
  - Fluid flow area [m²]
    - Per radial ring
    - Total
- Assessment of profile evolution
- Not possible to compare more cases in one figure
Sensitivity Test on COR00005 Candling Heat Transfer Coefficients

- Default values
  - 1000 W/m²K
- Sensit. cases
  - 100 W/m²K to 5000 W/m²K
- Exp A1 [Ste]
  - Area to intact SH inner diam.
- Exp A2 [Ste]
  - actual posttest SH dimensions

![QUENCH-11 Axial Profile of Fluid Cross Section Experiment vs. MELCOR1.8.6 Sensitivity Cases](chart.png)

- Melt and Debris in Experiment
- Melt and Debris in Calculation
Sensitivity Tests
Final Cases

- Calculated with M186 YT_1010 version (+ elheat)
- Modification of input parameter and sensitivity coefficient definitions resulted in correct prediction of axial location of frozen melt and debris
  - Profile of calculated results influenced by bypass fluid volume counting towards

![Chart showingQUENCH-11 Axial Profile of Fluid Cross Section Experiment vs. MELCOR1.8.6 Sensitivity Cases](chart.png)

- Melt and Debris in Experiment
- Melt and Debris in Calculation
Sensitivity Tests
Final Bundle Configuration

- Main mass of candled material is located in correct elevations above 750 mm
Sensitivity Tests
Hydrogen Generation

- Very good agreement in H2 generation
  - Calculation 79 g
  - Experiment 92 g (for prototypical materials, with ±20 % uncertainty)
- Overprediction of maximum temperatures
  - Early collapse of SH at Zr melting temperature (2098 K), but in experiment shroud max T is about 2400 K
  - Collapse of SH component influences heat losses from bundle (M186 YT_1010 version)

2600 K 2600 K
Measured Calculated
R1 R1
R2 R2
R3 R3
SH SH
Sensitivity Tests
Impact of SH Self-supporting (1)

- Time 5576 s
  - One dt after failure of SH
- Collapse of SH component influences heat losses from bundle
  - Identical temperature profiles until SH failure

Supported by SH node below only

Self-Supported SH
Sensitivity Tests
Impact of SH Self-supporting (2)

- Time **5650 s**
  - About 74 s after SH failure
- Collapse of SH component influences heat losses from bundle
  - Significantly lower temperatures in case with non-failed (self-supported) nodes
  - Impact on hydrogen generation

**Supported by SH node below only**

**Self-Supported SH**
Summary of Q-11 Simulation

- Simulation of QUENCH tests with MELCOR 1.8.6 (valid mainly for Quench-11 test)
  - Good agreement of boil-off and stationary phases
  - Acceptable agreement in temperature response during transient
  - Hydrogen generation during transient and reflooding phases
    - Underestimated in original calculation for SARNET Benchmark due to
      - Standard oxidation kinetics is applied also for melt and debris
      - Collapse (conversion into debris) of shroud above break elevation
      - Tuning up of selected parameters resulted in better agreement with experimental results
- Application of MELCOR code to Quench test demonstrated its capability to model reflooding also in plant applications, but
  - Some modifications of the code were needed for fulfillment
- Final definition of input parameters and sensitivity coefficients based on sensitivity study (X4 case)
  - FLBLK yes, GAMBRK 0.1 kg/m-s, TZXMX 2600 K, VFALL 0.01 m/s, and REFRZ 3000 W/m2-K
  - Exclusion of FCELR and FCNCL, because they are design specific
Influence of Validation to Code Development

- User's feedback is recently provided mainly via user's suggestion at the MCAP Annual Meetings and bug reporting
  - New bug reporting tool for MELCOR - BUGZILLA presented at MCAP2007
- Suggestion to code modification, improvement or further development
  - Spacer grid modeling as SS - assignment of SS into channel part of core cell with shroud or canister component - it is changed in YR version (released in summer 2007) for PWR (tested on Quench-07 simulation)
  - SH degradation - to stay up part of shroud above its failure elevation - SH is supported by FM components ⇒ problem only if FM is absent, but it could be a case for some plant designs - new input row is added in YT version (released at beginning of 2008)
  - Absence of plot variables for SH oxide layers - added in YT version
  - Steam starvation parameter - could be replaced by molar faction if each COR cell is represented by own CV (not realistic for Quench facility) - added in YT version
  - To add specific model for melt oxidation - general agreement with suggestion, but its solution will take more time
Conversion of Plant Input VVER-1000 Reactor

- Conversion of MELCOR 1.8.5 input model for VVER-1000 reactor performed in two steps
  - Application of pre-prepared convertor (Add-In application for MS Excel developed by SNL team)
    - Mainly definition of new axial levels in bottom head
    - It puts new data into separated file and requests input row “ALLOWREPLACE” - this is not my preferred approach
      - Colleague modified part of input file and nothing happened, because this ALLOWREPLACE was active and the same input row was included later again
  - Creation of new input from original version for M185 based on convertor data
    - To keep each input row only one time (no replacement)
    - To keep user friendly sorting of input file
    - To define new Shroud component
      - Core baffle was modeled as SS in M185 model in separate radial ring (reduction of number of radial rings)
Each plant calculation is initiated with steady state
  • Usual start time at -3600 s or -1000 s
This approach applied also for newly developed M186 model of VVER-1000 reactor (PWR option for IRTYP on COR00002 row)
  • Correct initialization assumed, but during few first time steps control functions opened pressurizer safety valves due to overpressurization of primary circuit
    • First idea - newly defined FLs in RPV have wrong loss coefficient
      • Their modifications had no impact
    • Detail result processing identified cause of overpressurization
      • Very intensive boiling in core bypass (modeled as bypass in outer most radial ring in core with shroud component)
      • Source of heat is done by fission and decay power absorption in shroud
        • Default definition of SC1311, SC1312, SC1321, and SC1322 take into account only fuel rods, grid spacers, guide tubes, and control rods, but shroud contain huge mass of steel and significantly change redistribution of fission and decay heats escaping fuel rods (Defaults are based on ORNL/NRC/LTR-94/42 report [San])

Default definition of SC1311, SC1312, SC1321, and SC1322 is correct for radial rings without shroud, but it is incorrect for outer ring with shroud.

- Redefinition based on [San] methodology with taking into account of shroud mass will result in unrealistic values for radial rings without SH and realistic for outer ring with SH only - See table ☐

Suggestion on systematic solution
- Recent version of SC1311, SC1312, SC1321, and SC1322 defines values for all rings together, but using of matrix with independent value per ring would enable to take into account differences of rings with and without SH component

Original format **SC1311 (i)**  i is material parameter

New format **SC1311 (r,i)**  r is Ring, i is mat.parameter

Preliminary solution applied for VVER-1000 input data
- Reduction of Material Absorption Efficiency for SS and Steel Oxide
  - Steel is used only for CR cladding and SH
  - Influence of CR heat up due to reduction of absorption in CR cladding neglected

Fission power - SC1311 and SC1312 based on [San] methodology

### Absorption Fractions and Participation flags

<table>
<thead>
<tr>
<th>Material</th>
<th>Default</th>
<th>PWR Surr*</th>
<th>VVER-1000 with SH</th>
<th>VVER-1000 without SH</th>
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### Material Absorption Efficiency

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* [San] Appendix C
MELCOR Validation
Simulation of Experiments

- **Phebus FPT-1 (ISP-45)** - Integral analysis with MELCOR 1.8.5
- **KAEVER (ISP-44)** - MELCOR 1.8.5
- **RTF** - test from ISP-41 - MELCOR 1.8.5
- **QUENCH test** - Matrix of test on next slide
- **THAI-13, TOSQAN, MISTRA (ISP-47)** - MELCOR 1.8.5
- **CCI-1,2,3 Test** - OECD MCCI Project - MELCOR 1.8.5
- **LOFT LP-FP-2** - MELCOR 1.8.6
- **THAI HM2 test** - OECD THAI Project - MELCOR 1.8.5, 1.8.6, and 2.1
- **PANDA (ISP-42)** - MELCOR 1.8.5
- **SVUSS** (Bubble condenser facility) - MELCOR 1.8.5
- **EREC** (VVER-440/213 Cntn facility) - MELCOR 1.8.5

- **Code to Code comparison** - some experiments mainly with ASTEC
### Matrix of Quench Tests Simulated with MELCOR Code

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<tr>
<th>Test</th>
<th>Flooding rate [g/s]</th>
<th>Initial temp. [K]</th>
<th>H\textsubscript{2} generated before/during reflooding, [g]</th>
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<th>Comment</th>
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- **Own input model developed in NRI for simulation of Quench bundle test with MELCOR code**
  - Input model for ICARE2 was taken over and modified
  - Application of sophisticated result visualization technique - ATLAS postprocessor (GRS, Germany)
  - Future activities - Quench-13 (SIC Control Rod)
Plant Applications

- **DBA (MELCOR 1.8.5, conversion to MELCOR 1.8.6 on going)**
  - Pressurized thermal shocks for VVER-440/213
    - Ctn response and ECCs for RELAP5 (+ REMIX) analysis of primary and secondary circuits
    - Loss of coolant accident in specific rooms
      - Ctn response
- **Severe Accidents (latest activities only)**
  - 5th FWP (OPTSAM, LPP, EVITA...), SARNET in 6th FWP (CORIUM, ASTEC)
  - PSA-2 Topic
    - PSA-2 study NPP Dukovany (VVER-440/213)
      - 2nd PSA-2 update 2002
      - 3rd PSA-2 update 2006
    - Support for PSA-2 NPP Temelín (VVER-1000)
      - Analyses of SA progression and source term estimation
  - Study on FP and aerosol retention on leak paths
  - Improvement of SAM programs for Dukovany and Temelín NPP
    - In-vessel corium retention (Dukovany)
    - Hydrogen mitigation (Dukovany + Temelín)
      - Decoupling of RCS and Ctn models from whole plant analysis
      - Application of Sigma (FA) and Lambda (DDT) criteria
Summary, Conclusions

- Simulation of Q-11 test with MELCOR 1.8.6 showed that support of developers is necessary condition for reasonable validation
  - Suggestion of code improvement and further development
  - Support concerning of code or input clarification
    - Some input definitions are not unambiguous or some input are not documented
      - Generally or documented only in BUG reports on MELZILLA

- Collaboration between users and developers is reasonable only for recent versions
  - NRI uses M186 for validation since 2006 and for plant applications since 2008
  - NRI tests M2.1 for Q-11, THAI, and VVER-1000
EMUG is meaningful for NRI if information exchange is concentrated on actual versions – M186, M2.1, and M185 as well
- Some users still use M184 and older versions

NRI sees membership in CSARP/MCAP as key condition for above mentioned conclusions
- Many of problems in older versions solved in new versions
- Some “new” modeling approaches or input parameter definitions for older versions only imitate changes in new version
- Some best practices are applicable only in latest versions
Next EMUG Proposal

- **Date of EMUG meetings**
  - **MCAP** is held on September
  - **EMUG** is few month later with closing of contributions at the end of October (this year)
    - Identical contributions assumed
  - Proposal for next meetings - February to April
    - Half year period between two consecutive EMUG - MCAP meetings

- **Location**
  - NRI could host one of future EMUG Meeting
End of Presentation

Thank You for Your Attention