Overview of
MELCOR Activities in NRI Řež

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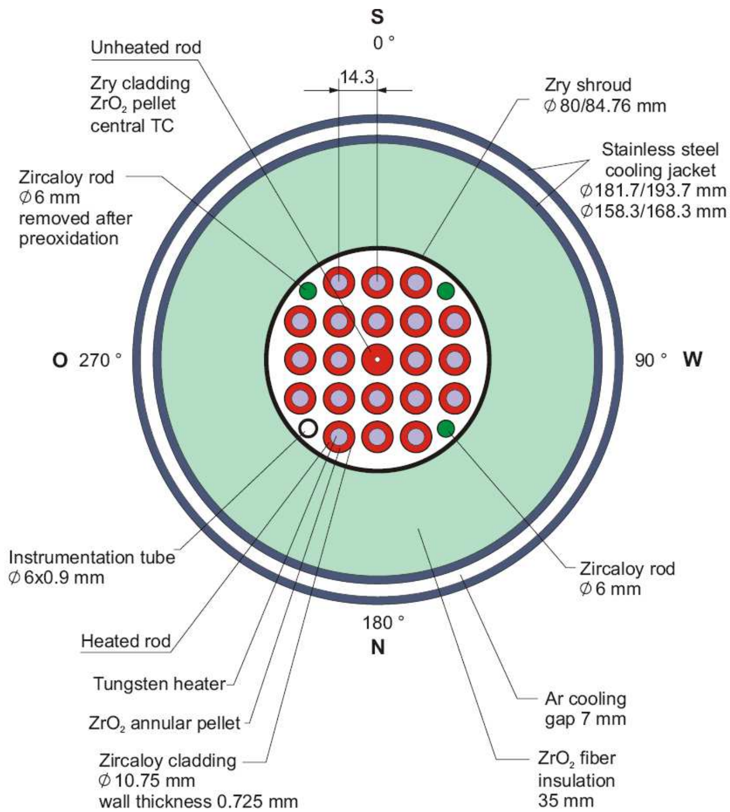
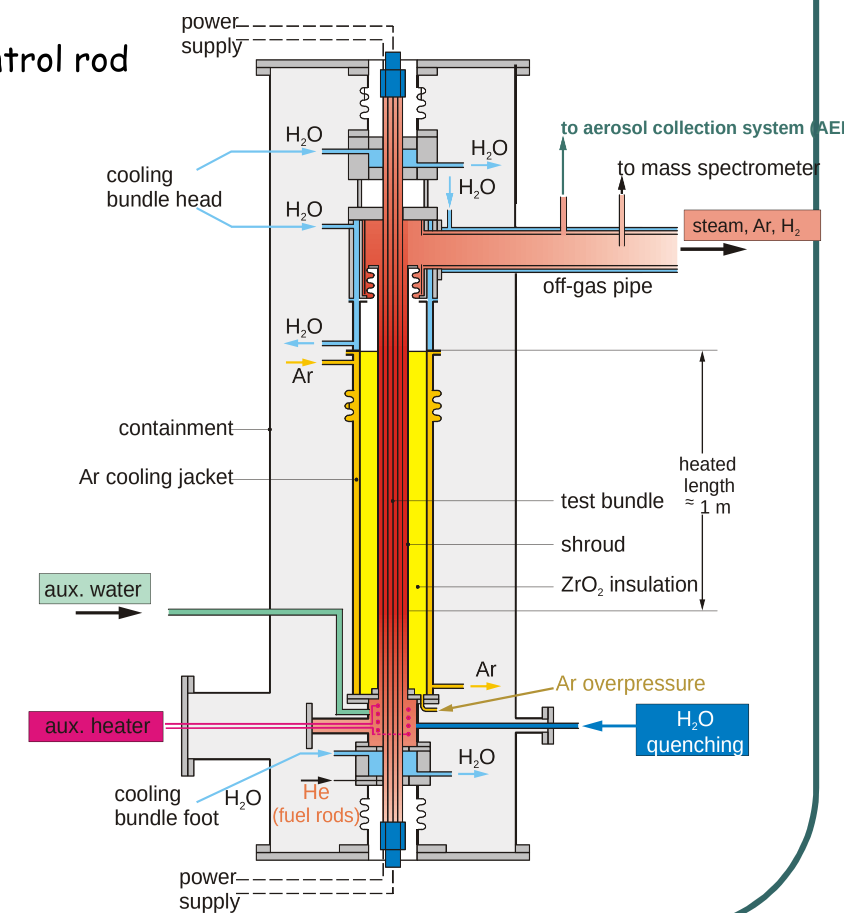
Outline

- Validation on Quench-11 Test
- Conversion M185 ⇨ M186
- Overview of Other Experiment Simulations
- Plant Applications

Quench Facility Description

- PWR Bundle
  - 20 heated rods + 1 unheated or (B4C or SIC) control rod





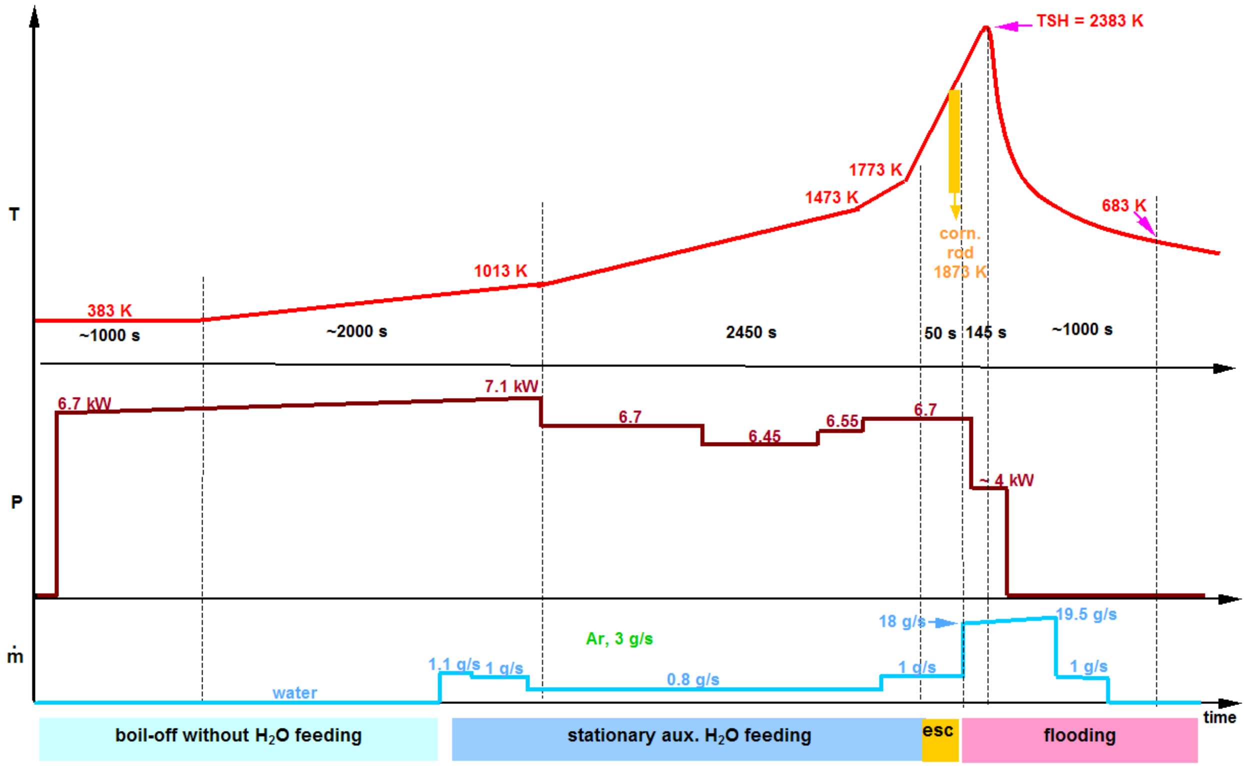
Quench-11 Test
Experiment Conduct

Main characteristics of Quench-11 tests

- Quench medium – Water
- Flooding rate – 18 g
- Initial temp. – 2040 K
- Max. ZrO_2 before flooding – 170 μm
- Max. ZrO_2 layer thickness – completely oxidized
- H2 generation before/during cooldown – 9/132 g

Shroud and bundle were significantly degraded

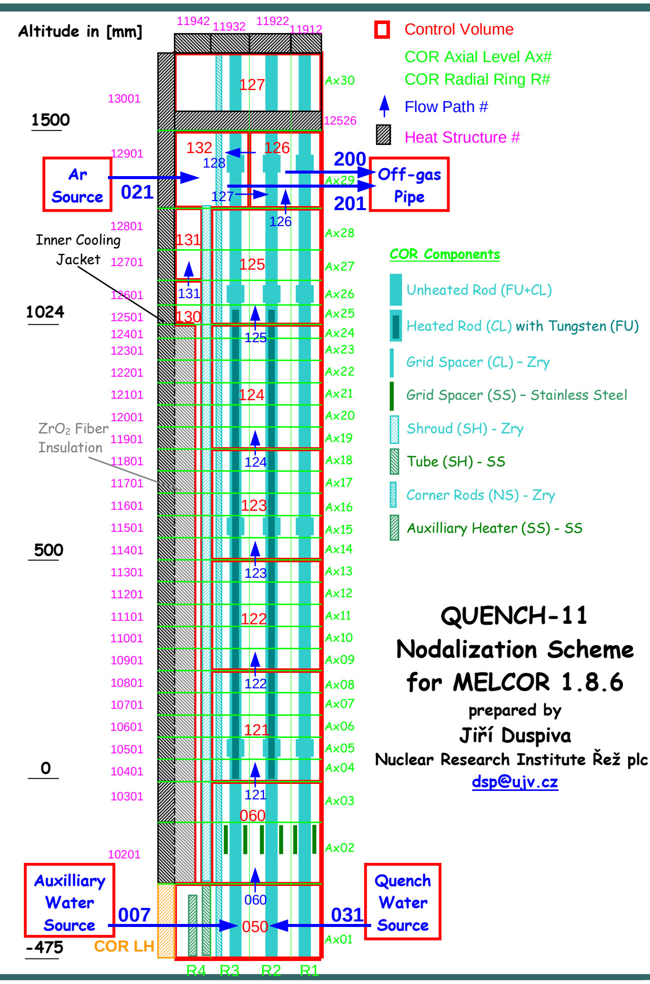
- **Shroud failure at 850 mm**



[SR] A. Stefanova, P. Groudev, M. Steinbrueck, L. Sepold and J. Stuckert, SARNET Benchmark on Quench 11, Specification report, FZKA Internal Report, NUKLEAR 3409, SARNET-CORIUM-008, July 2006

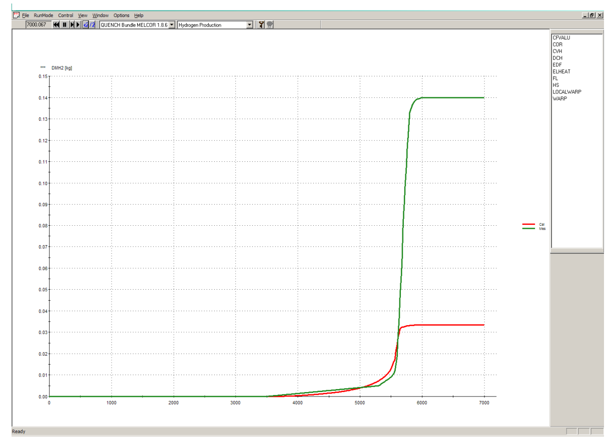
Quench-11
Bundle Nodalization

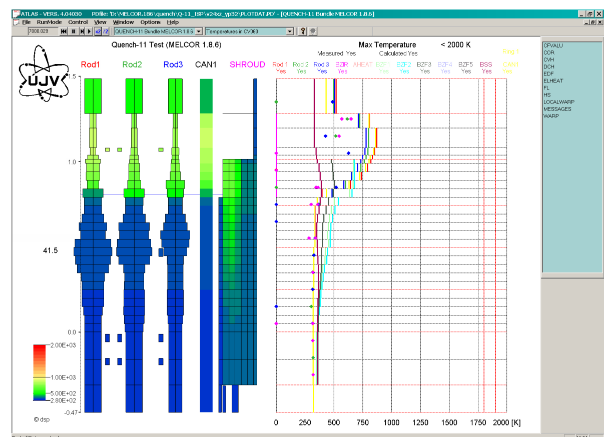
- Final nodalization for MELCOR 1.8.6
  - 4 Radial rings
    - 4th ring only in 1st axial level
  - 30 axial nodes (newly defined altitudes from 0.0 to 1.092 m, upper and lower plenums remain unchanged)
  - New SHROUD component in MELCOR 1.8.6 and bypass volumes
  - Simplified off-gas pipe in comparison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





[Dsp] Duspiva J.: Implication of MELCOR Code Validation on Quench Tests to Code Development, 13th International QUENCH Workshop, Karlsruhe, Germany, October 20-22, 2007

[Ste] Stefanova A. et Al.: SARNET Benchmark on QUENCH-11, Final Report, FZK Karlsruhe, FZKA-7368, SARNET CORIUM P008, March 2008

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]

[Gau] Gauntt R.O., et al., "MELCOR Computer Code Manuals", Vol.1 User's Guide, Vol.2 Reference Manuals. Version 1.8.6. NUREG/CR-6119, Rev.3, SAND2000-2417/1 and 2, September (2005)

Sensitivity Matrix
Table of Sensitivity Cases

Parameter	Acronym	Unit	Default	Basic	Sens 1	Sens 2	Sens 3	Sens 4	Sens 5	Sens 6	Sens 7
COR00003	FCNCL	none	0.25	0.10	0.25	0.40	0.60				
COR00003	FCELR	none	0.25	0.20	0.25	0.40	0.60				
COR00005	REFRZ	W/m2-K	1000.0	1000.0	100.0	300.0	600.0	1500.0	2000.0	3000.0	5000.0
COR00008	DRCLMN	m	0.0001	0.0001	0.0	0.00001	0.001	0.01			
COR00012	VFALL	m/s	1.0	1.0	0.01	0.1					
SC1132-1	TRDFAI	K	2500	2800	2500	2890					
SC1132-2	TRDMAX	K	3100	3100	2500	2890					
SC1131-1	DZXMN	m	0.00001	0.00001	0.0	0.0001					
SC1131-2	TZXMX	K	2400	2400	2100	2200	2600				
SC1131-3	DSXMN	m	0.001	0.001	0.0	0.00001	0.0001				
SC1131-4	TSXMX	K	1700	1700	2100	2400					
SC1131-5	DZXMN1	m	0.00001	0.00001	0.0	0.0001					
SC1131-6	TZXMX1	K	2100	2400	2100	2600					
SC1141-1	DTBRK	s	1.0	1.0	0.1						
SC1141-2	GAMBRK	kg/m-s	1.0	1.0	0.1	5.0					
FLnnnBk	FLBLK	none	not appl.	not appl.	applied						

Green – case with the highest hydrogen generation

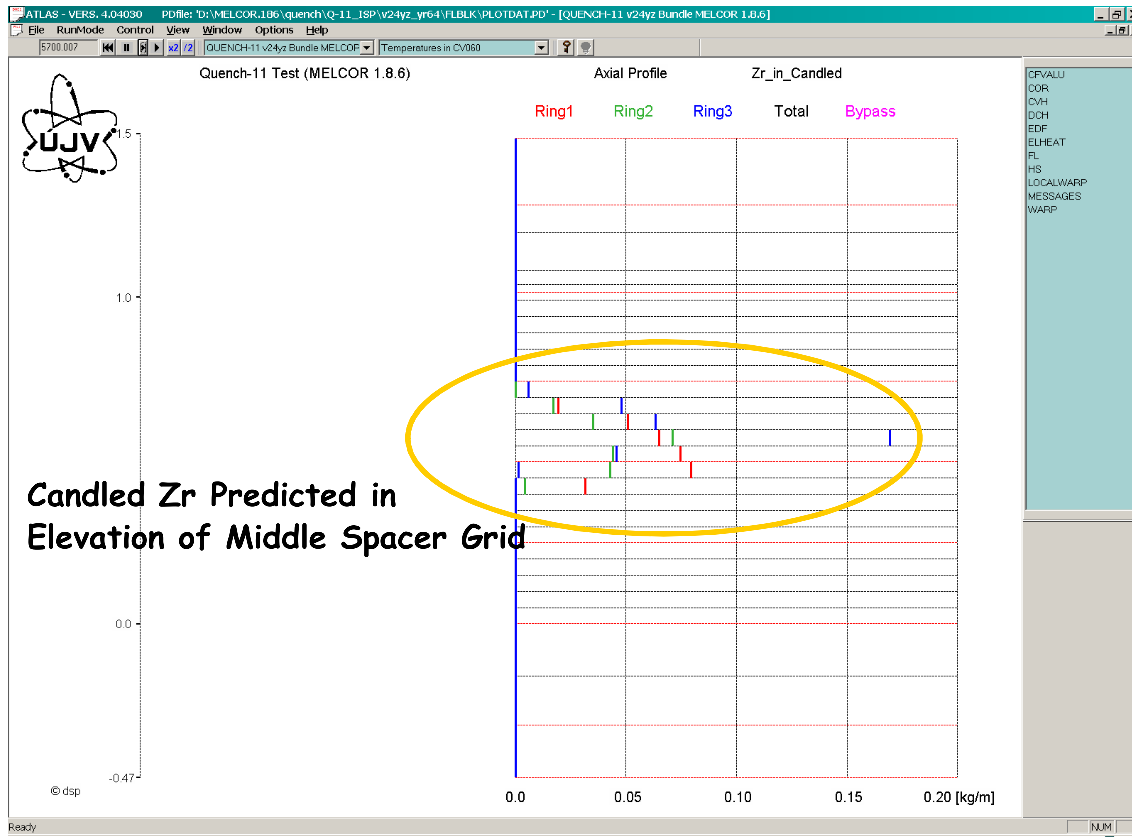
Red – case with the lowest hydrogen generation

- 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_REFRZ-3_TZXMX-3
  - FLBLK_REFRZ-5_TZXMX-3
  - Final case: FLBLK_GAMBRK-1_TZXMX-3_VFALL-1_REFRZ-6_FCELR-3_FCNCL-3 (acronym **X4**)

New ATLAS Screen Developed

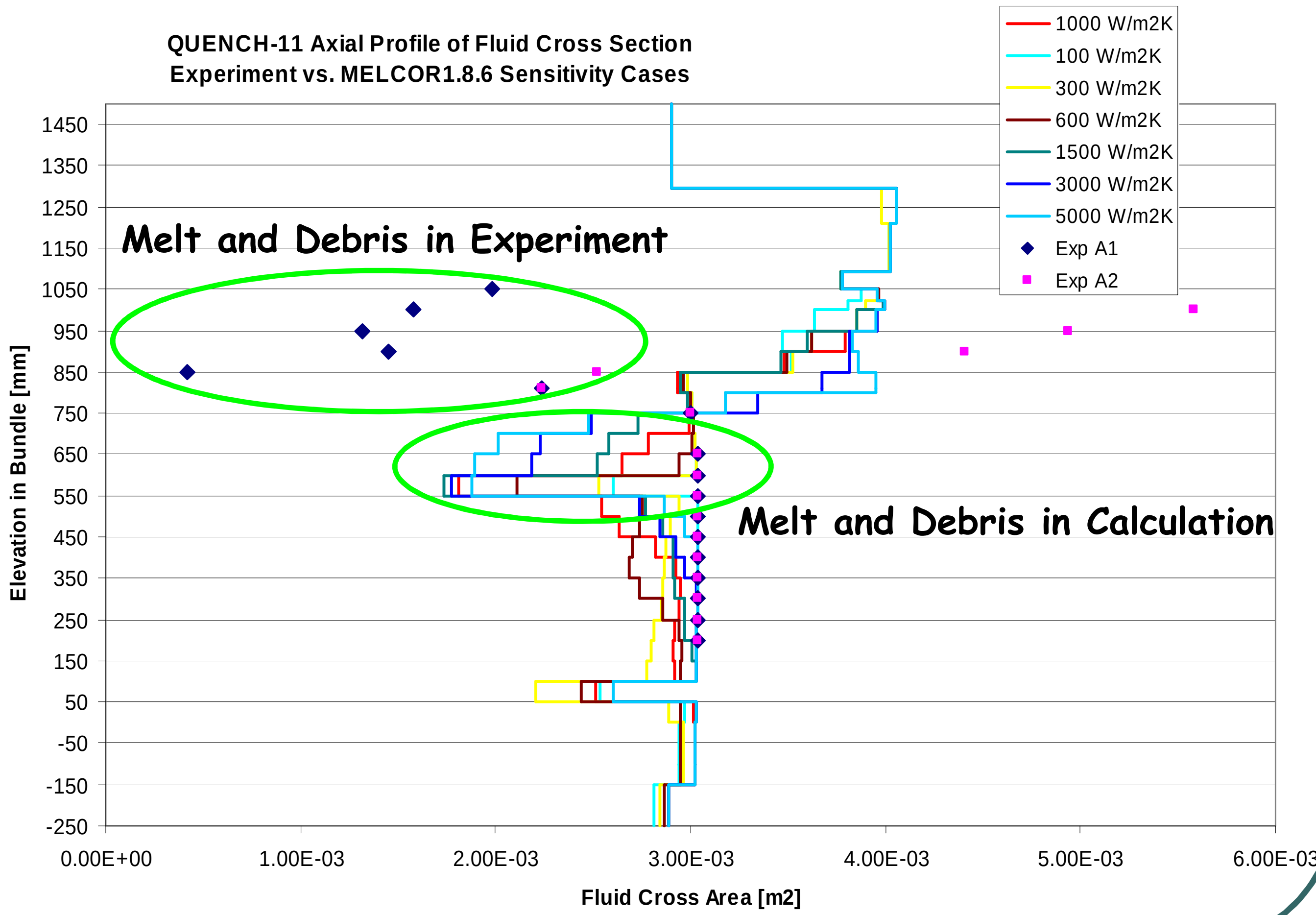
- New screen for ATLAS postprocessor was developed to visualize evolution of profiles
  - Specific masses per rod [kg/m]
    - Candled Zr or ZrO_2 on
      - Cladding
      - Shroud
      - Fuel (ZrO_2) pellets
    - Particulated debris of Zr or ZrO_2
    - Intact plus candled Zr or ZrO_2 in component
      - Cladding
      - Shroud
      - Fuel (ZrO_2) pellets
  - Fluid flow area [m^2]
    - Per radial ring
    - Total
- Assessment of profile evolution
- Not possible to compare more cases in one figure

Specific Mass of Candled Zr on Cladding per Rod at 5700 s
Results of FlnnnBk Sensitivity Case



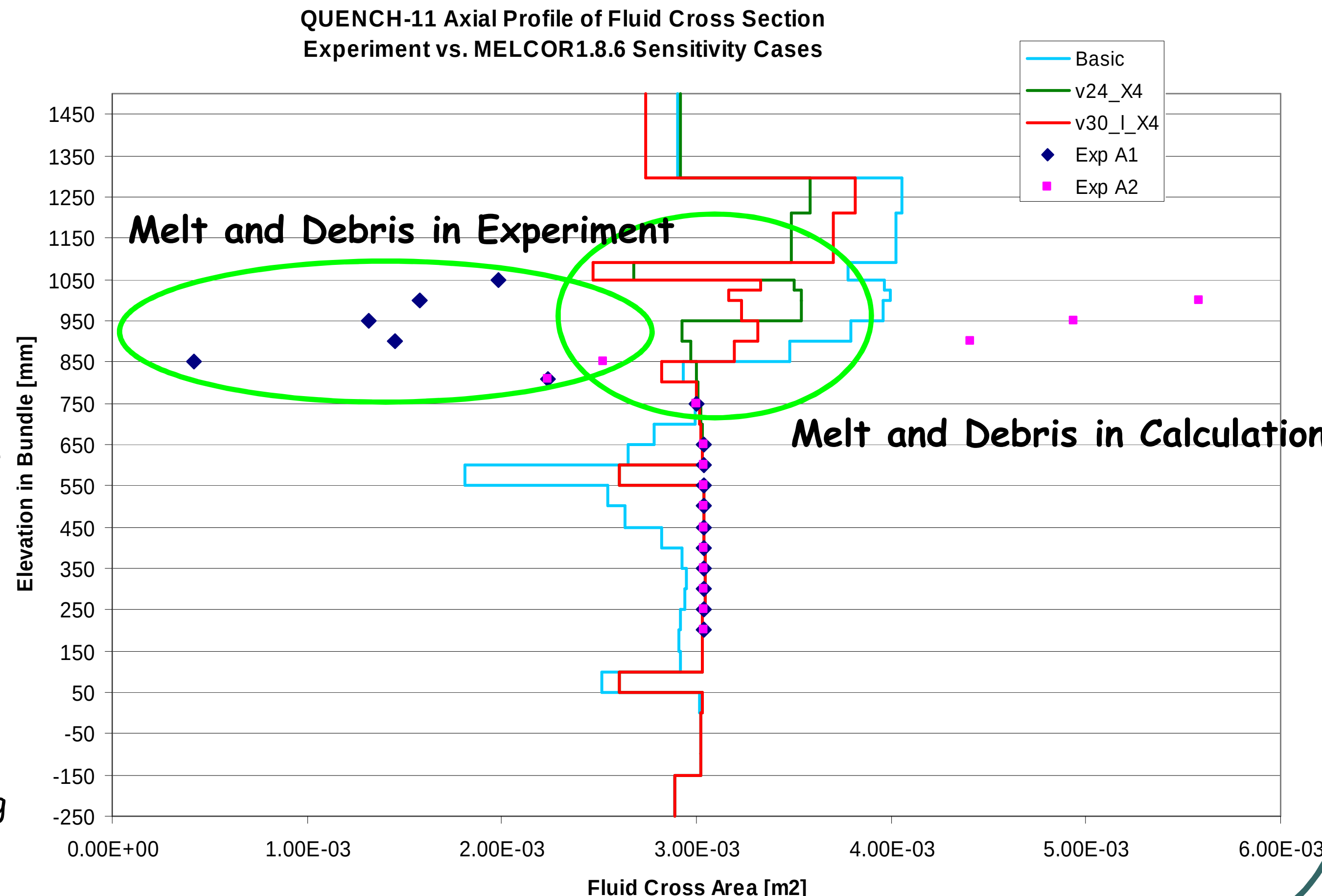
Sensitivity Test on COR00005 Candling Heat Transfer Coefficients

- 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



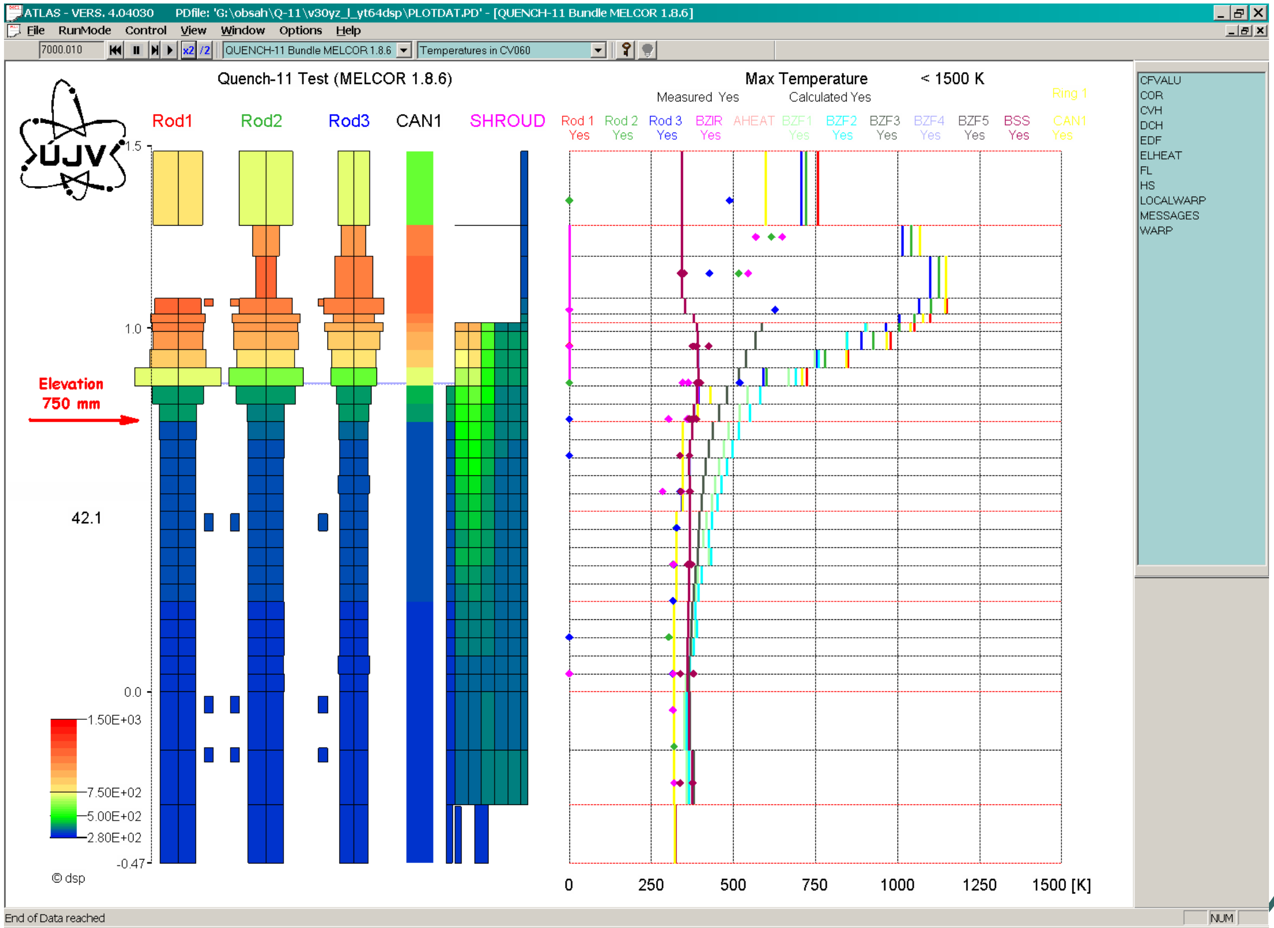
Sensitivity Tests
Final Cases

- 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



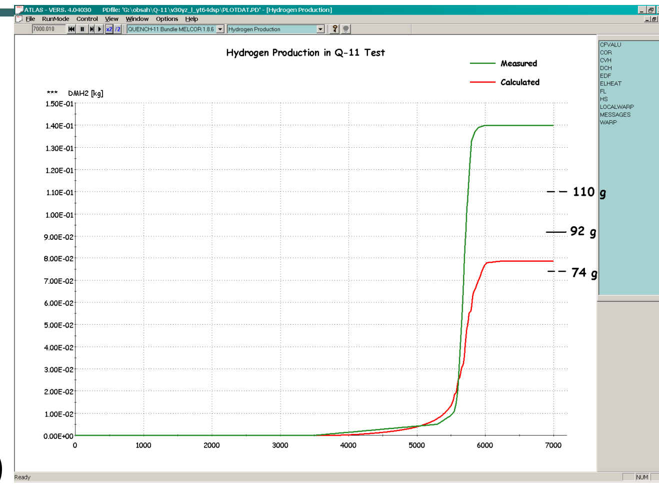
Sensitivity Tests
Final Bundle Configuration

- 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

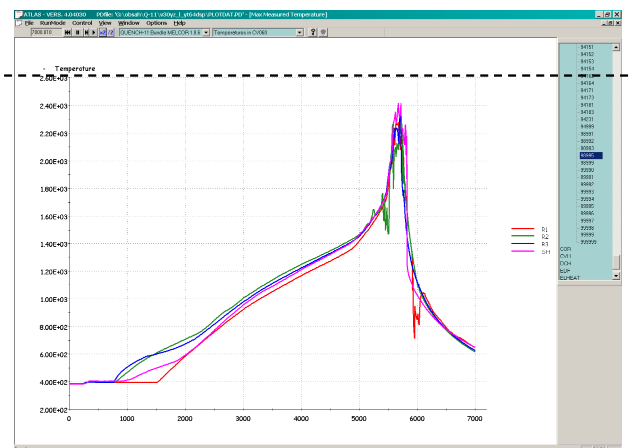
Measured

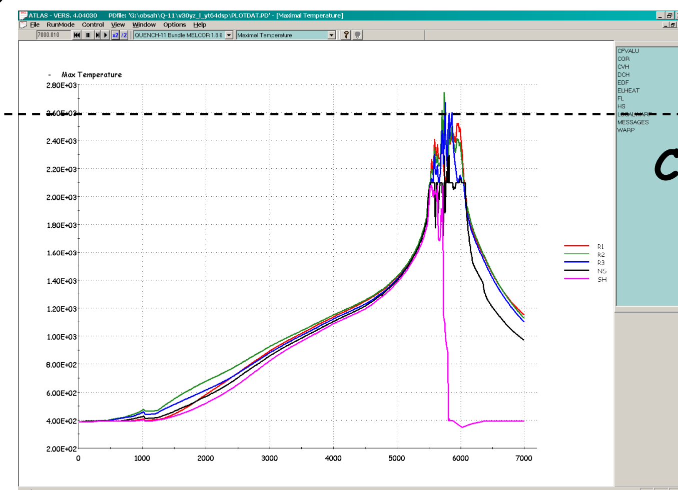
R1

R2

R3

SH





2600 K

Calculated

R1

R2

R3

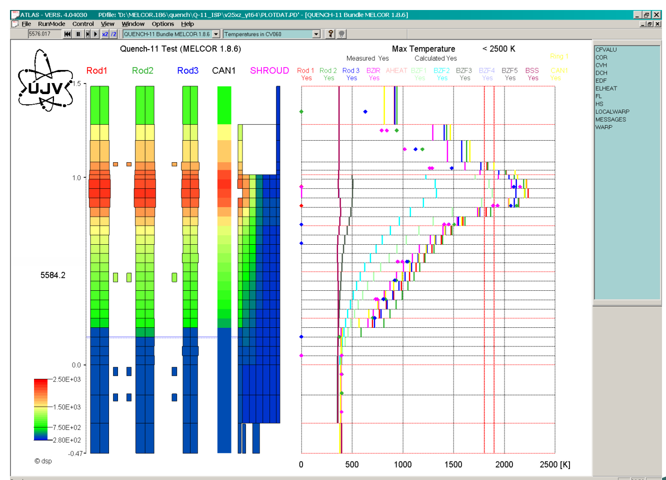
SH

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

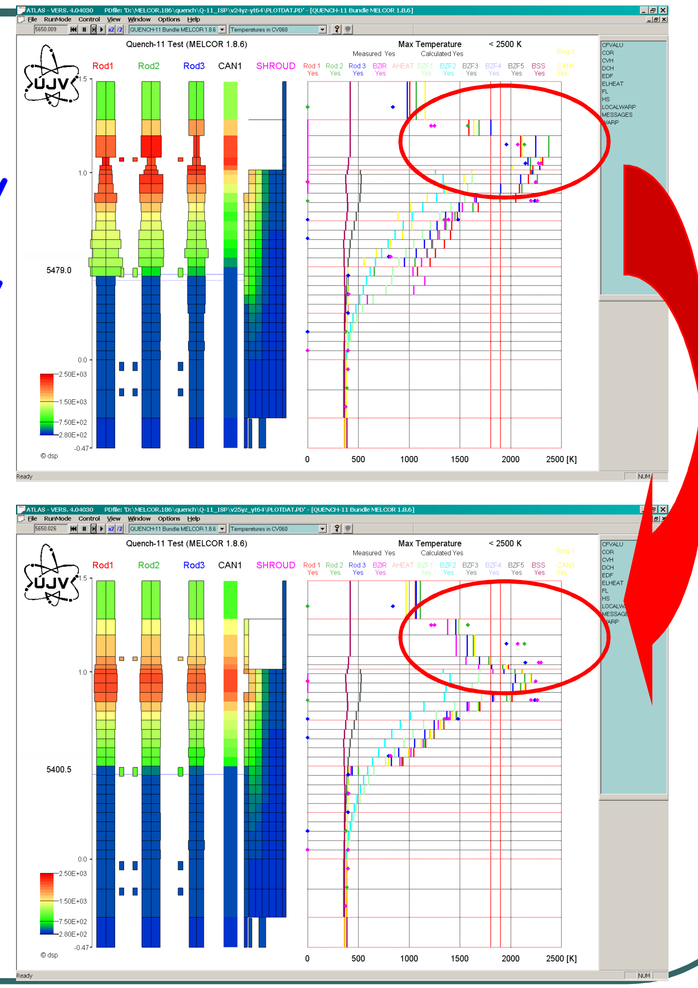


Sensitivity Tests
Impact of SH Self-supporting (2)

- 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 ALLOWEREPLACE 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)

MELCOR 1.8.6 Plant Applications
Steady State

- 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])

[San] R.L.Sanders: Fission Product Gamma Heating of Core Structures for MELCOR, Letter Report, Oak Ridge National Laboratory, ORNL/NRC/LTR-94/42, January 17, 1995

MELCOR 1.8.6 Plant Applications
Suggestion

- 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

Material	Default	PWR	VVER-1000	
		Surry*	with SH	without SH
UO2	0.9	0.8106	0.81998	0.81998
Zr	1.0	0.1746	0.07864	0.17747
CR	1.0	0.0094	0.00002	0.00002
SS	1.0	0.0054	0.10136	0.00253

Material Absorption Efficiency

Material	Default	PWR	VVER-1000	
		Surry*	with SH	without SH
UO2	0.500	0.500	0.500	0.500
Zr+ZrO2	0.541	0.541	0.192	0.433
CR	0.565	0.565	0.005	0.005
SS+Steel Ox.	0.234	0.234	0.200	0.450

* [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

Test	Flooding rate [g/s]	Initial temp. [K]	H_2 generated before/during reflooding, [g]	Code/Version used	Comment
Quench-01 Feb 26, 98	52	1830	36/3	MELCOR1.8.5 MELCOR1.8.6 ICARE2	Tuning up
Quench-03 Jan 20, 99	40	2450	18/120	MELCOR1.8.5 ICARE2	
Quench-06 Dec 13, 00	42	2060	32/4	MELCOR1.8.5	ISP-45 Blind
Quench-07 Jul 25, 01	15	2100	66/120	MELCOR1.8.6	B_4C Control Rod
Quench-11 Dec 8, 05	18	2040	9/132	MELCOR1.8.6 MELCOR2.1	SARNET Blind Benchmark

- 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
    - Cntn response and ECCs for RELAP5 (+ REMIX) analysis of primary and secondary circuits
  - Loss of coolant accident in specific rooms
    - Cntn 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 Cntn 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

Summary, Conclusions (2)

- 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