Various Observations from MELCOR 1.8.6 Applications, Recommendations, and Suggestions

Jiří Duspiva

Nuclear Research Institute Řež, plc.
Nuclear Power and Safety Division
Dept. of Reactor Technology

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Outline

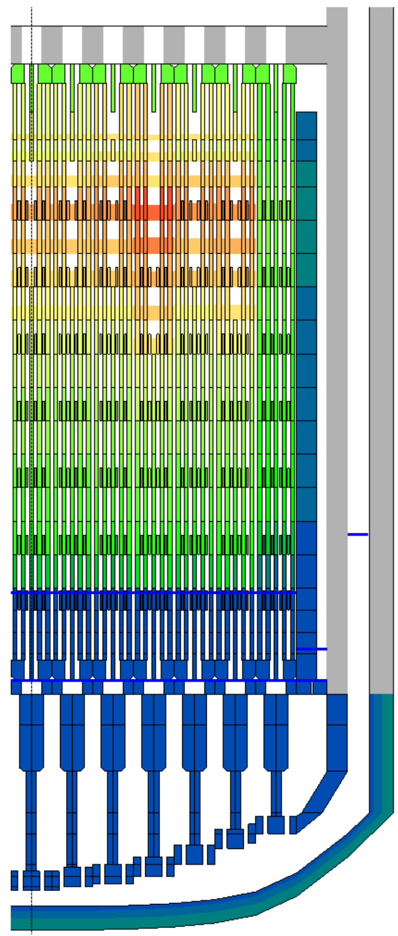
- Motivation
- Various Applications of Supporting Structures
- Modeling of Core Baffle
- IVR Modeling
- Other Topics
- Summary, Conclusions

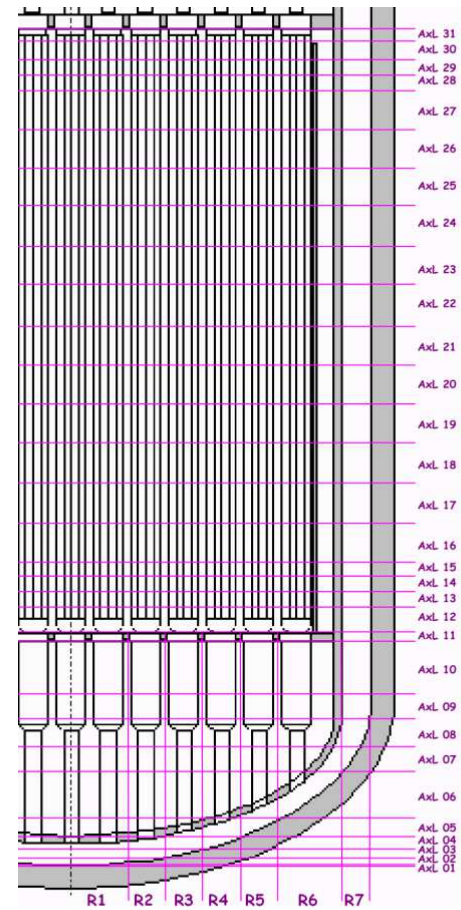
Motivation

- I have several observations from experiment and plant simulations
  - Mainly from abnormal terminations and their user solutions
  - New non-documented capabilities of MELCOR
    - Usually available only in appropriate BUG report
    - Latest release of MELCOR YU_3084 contains also updated manuals
- One of principal purpose of this meeting is exchange of user experience
- Number of contributions did not fully cover all two days
  - Main objective of this meeting is core and primary circuit
  - My colleagues would be able to present their effort in other MELCOR applications, but we preferred to keep main objective of this meeting

Various Applications of SS
Modeling of Grid Spacers

- This approach applied in Quench test simulations and VVER-1000 plant application
  - Only for IRTYP 'PWR' for MELCOR YT_1010 and newer if SH component used
- Failure criterion
  - Usually temperature criterion via. CF
  - User failure within CF
  - Very flexible if CF logic is sophisticated enough
- User defined type
  - Support of intact and PD
  - Self supporting option not recommended
- Penalty to user
  - Failure of each SS results in writing of RESTART and LISTING dump ⇨ too big restart and listing files (about 5 GB for plant simulation)
- Suggestion
  - To add user switch for each SS on writing of restart and listing in case of SS failure

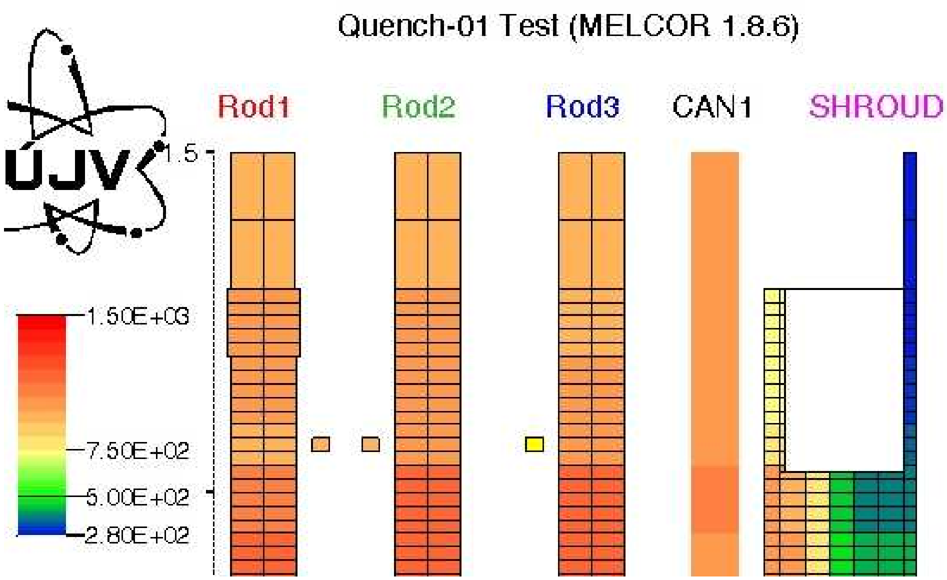




Various Applications of SS
Modeling of Grid Spacers (2)

- This approach can be applied only for IRTYP 'PWR' for MELCOR YT_1010 and newer if SH component used – Why?
- Problem identified in simulation of Quench-01 test with M186 YG (2006)
  - In cell of R3 with defined SH component (and bypass), SS is included in bypass part of cell and is not oxidized – Ar atmosphere
  - As consequence – SS has lower temperature – absence of oxidation positive feedback
- Assignment of SS in cell with distinguished channel and bypass
  - In case of PWR, it is important only for cells with SH component
  - Standard MELCOR approach
    - SS is in Bypass for BWR and PWR until YS version,
  - Modified approach, based on my request (starting with YT version)
    - SS is in bypass for BWR and PWRX
    - SS is in channel for PWR

Upper part of Quench facility

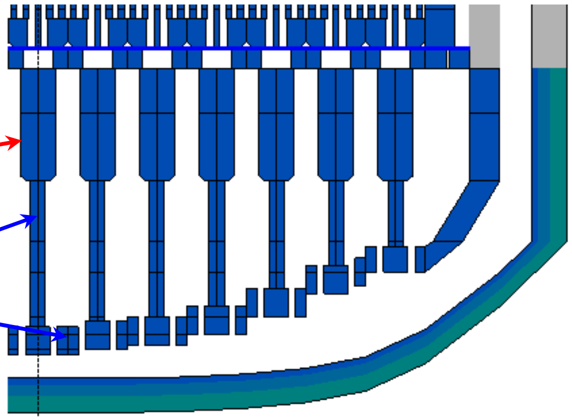


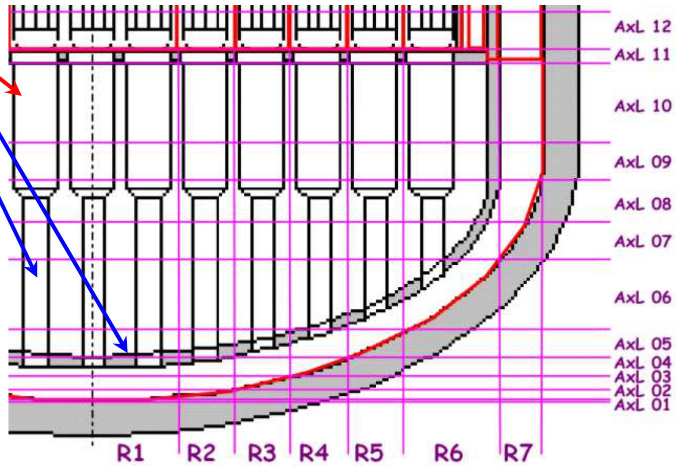
Various Applications of SS
Lower Plenum Structures

- MELCOR 1.8.6 allows significantly more detailed description of lower plenum and lower head
  - Nodalization of VVER-1000 very detailed
  - Supporting columns and core basket lower head modeled as user defined supporting structures
    - Upper part (hollow column) modeled with option – Intact
    - Lower part (solid column and lower head) modeled with options – Intact and Debris
- Original version used for both also option self-supporting (it keeps material until melting in original location)
  - Serious problems with abnormal termination

```
<Diagnostic Message>  Time= 7.2493E+03 Dt= 2.5103E-04 Cycle= 315946 (COR)
  ERROR IN SUBROUTINE CORDBD
  SUBCYCLE TIME STEP HAS BEEN REDUCED BELOW MINIMUM
  CORRN1   (or routine called by it) requested  a SYSTEM fallback
  SYSTEM TIME STEP REDUCED TO 0.1000E-11
```

  - Debugging identified problem in cell with small mass of conglomerate debris on SS with zero mass of intact material





Various Applications of SS
Lower Plenum Structures (2)

- Observations from debugging of abnormal termination called from CORBDB routine, debugging performed with version YT_1010 and also executables YU_2798 tested (termination at the similar time with identical message)
- Problem comes from routine COREU3, called by routine CORRN1 called by CORDBD, with error flag 995
- Mass balance of identified problematic cell 411

CELL 411	UO2	ZR	ZRO2	STEEL	ST OXIDE	B4C	INCONEL
SUP-STR		0.	0.	0.	0.		
	0.	0.	1.925E-5	0.	2.49E-21	0.	0.
NONS-STR		0.	0.	0.	0.	0.	
	0.	0.	0.	0.	0.	0.	0.
MP-OXIDE	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
MP-METAL	0.	0.	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.	0.	0.
P-DEB	88.62	0.	3.825	0.	0.	0.	0.
	7.098	13.43	9.828E-1	5.094	6.798E-2	7.477E-2	3.296E-4

*** LOAD (kg) CARRIED BY SUP-STR = 1.9248E-05

- Temperature of this supporting structure is 2058.91 K and TPD is 2169.32 K ($\Delta T > 100K$)
- Because temperature of this SS is less than melting temperature of ZrO2, it is not converted into PD or molten pool – Failure criterion was met, but Self-Supporting option keeps material until it is molten, even it is only conglomerate debris without any intact material

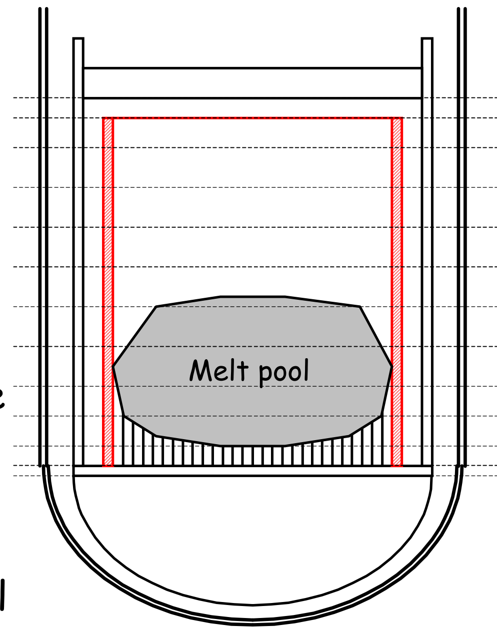
Various Applications of SS
Lower Plenum Structures (3)

- The only change of SS type (absence of Self-Supporting) overstepped this problem
- General remark – mass 2.49E-21 kg is very unrealistic (non-physical consequence of double precision programming)
  - In other cases I saw relatively often masses in order 10^{-40} kg and the lowest value was 10^{-324} kg
    - Fraction of atomic nuclei mass is physical nonsense
  - It should be eliminated with conversion to PD, based on any threshold (0.1 g ?)
- My conclusion and recommendation
  - Types of supporting structures with selfsupporting behaviour – PLATEG, PLATEB and USER with SELF option – those can't be recommended, because they could cause above described troubles
  - Types of supporting structures without selfsupporting behaviour – PLATE, COLUMN and USER without SELF option – those are recommended for overcome of this trouble
- This problem reported as BUG328 (recent status – New ?!?), same problem also reported as BUG345 with source code change and status – Resolved, but
  - My testing showed continuation of the problem after application of proposed change in source code, but status is still Resolved !!! (my reporting of non-successful testing is from April 2009)

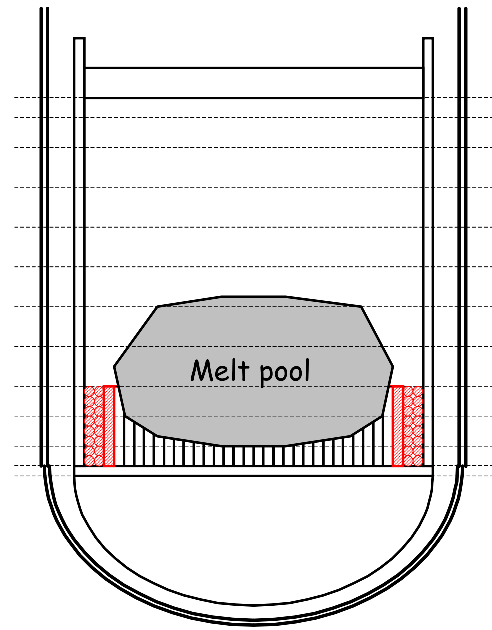
Shroud Degradation

- **Behaviour of core baffle (SH) without former structures**
- Shroud failure in middle or lower elevation results in collapse and conversion of whole remaining shroud above failure into particulated debris
- Huge structure of shroud (ID about 4 m and L about 4 m in VVER-1000) is during one time step (0.01 to 0.5 s – usual dt) converted into spheres with OD in order of 10^{-3} to 10^{-2} m
- Disagreement in comparison with TMI-2 evolution and local shroud penetration
- Relevant also for Quench test simulation

The only MELCOR Modeling until YT_1010 version



Before SH failure

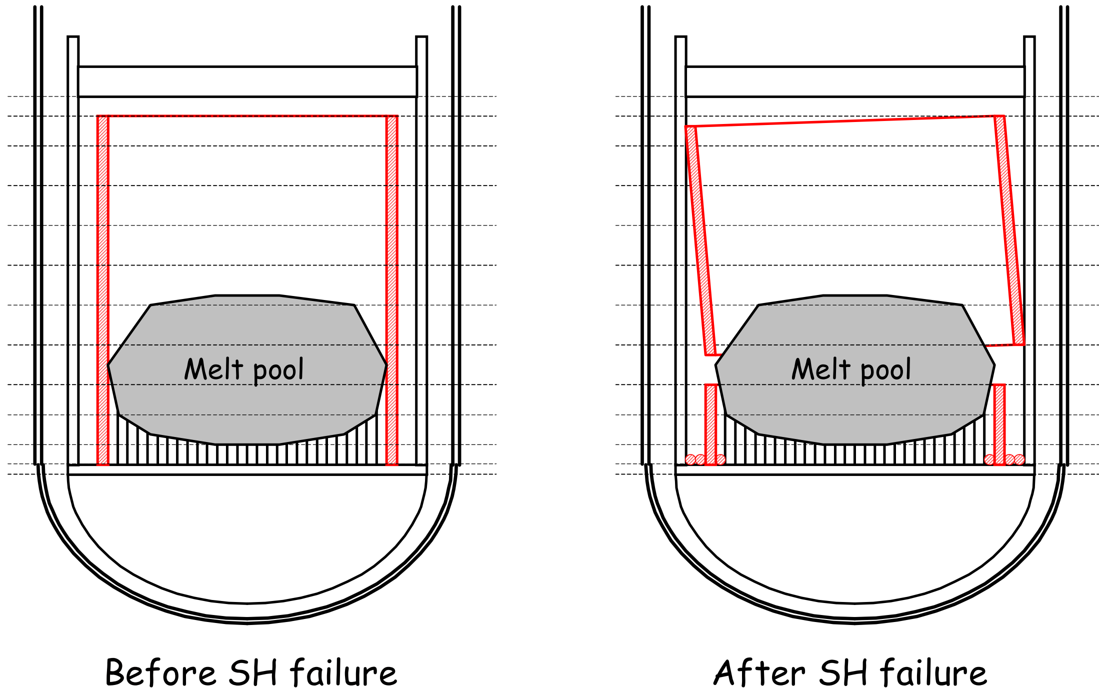


After SH failure

Shroud Degradation (2)

- Real situation will lead into "neglectable" movement of upper part of shroud
  - Failure will not occur in whole perimeter (as in MELCOR), but locally as TMI-2
- Suggestion (2006)
  - To change default conditions of SH degradation into self-supporting in each AxL
  - SH above failure will stay in original position with original surface and thickness and possibility to be heated up and oxidize
- New input row in YT_1010 CORijjSH with two possible input values
  - 'FORMERS' – SH is supported by former structures (default)
  - 'FIXED' - SH in a cell will not collapse until it fails locally

More Realistic SH Behaviour



In-Vessel Retention Scenario
Modeling of Cavity

- In vessel retention is one of important severe accident management strategy
  - Mainly for small and medium sized reactors (below ~1000 MWe)
- MELCOR 1.8.6 has significantly improved modeling capability related to IVR important phenomena
  - Molten pool in core and lower plenum (stratified)
  - Detailed modeling of lower head wall including cylindrical part
- What kind of analyses can be performed with MELCOR 1.8.6?
  - Analyses of plant response on successful application of IVR strategy
    - User has to be careful, because only CORSOR FP release model is available for in-vessel phase (based on experiments with solid pellets, but used also for release from molten corium)

BUT

  - MELCOR is not suitable code for any feasibility study of IVR strategy
    - MELCOR can not answer question on preservation of lower head integrity

In-Vessel Retention Scenario
Modeling of Cavity (2)

- Cavity subdivided into more CVs
  - Modeling of flow conditioner
- Run was terminated with following error message

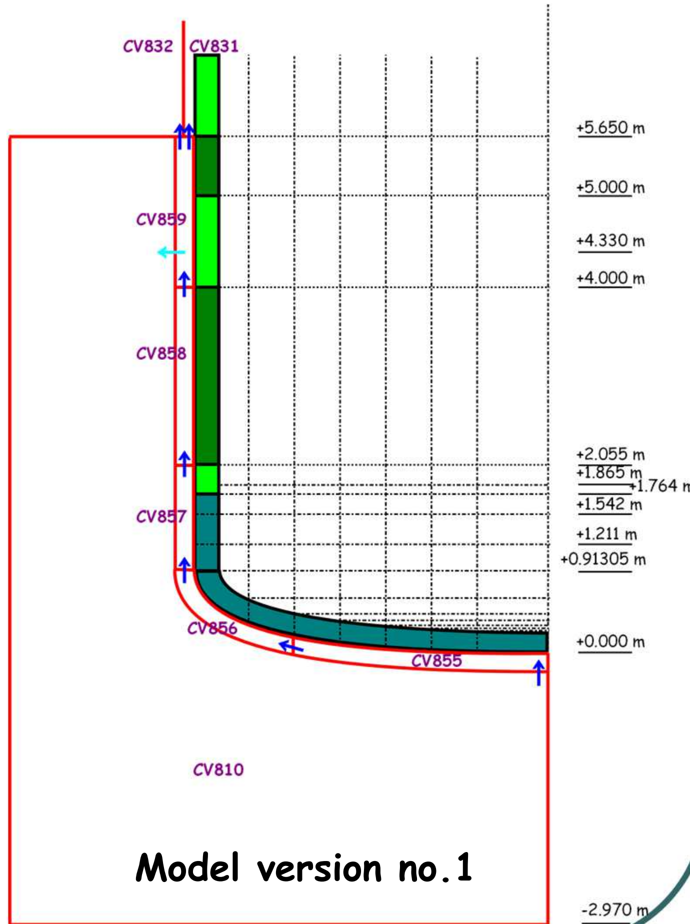
In diganostic file:

```
ERROR TRAPPED IN SUBROUTINE CVHMDR
PACKAGE COR GENERATED TOO LARGE AN ATMOSPHERE ENERGY SINK
VOLUME NUMBER = 855
ENERGY LEFT = 0.00000E+00 ENERGY SINK =-3.87413E-13
```

- Result checking showed no atmosphere in CV855

VOLUME NUMB	VOLLIQ M**3	VOLFOG M**3	VOLVAP M**3	VIRVOLLIQ M**3
855	3.267E+00	0.000E+00	0.000E+00	-8.882E-16
858	2.473E+00	5.960E-20	5.731E-16	-4.441E-16

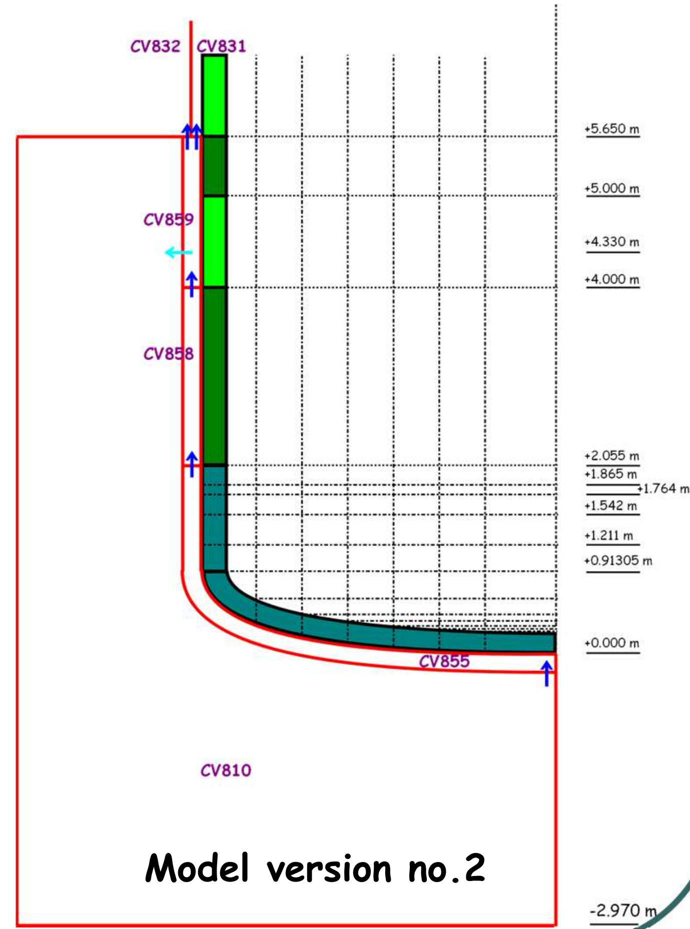
- Reason of abnormal termination was heat transfer to ATM of CV855, which does not exist
- Next step – simplification of nodalization



Model version no.1

In-Vessel Retention Scenario
Modeling of Cavity (3)

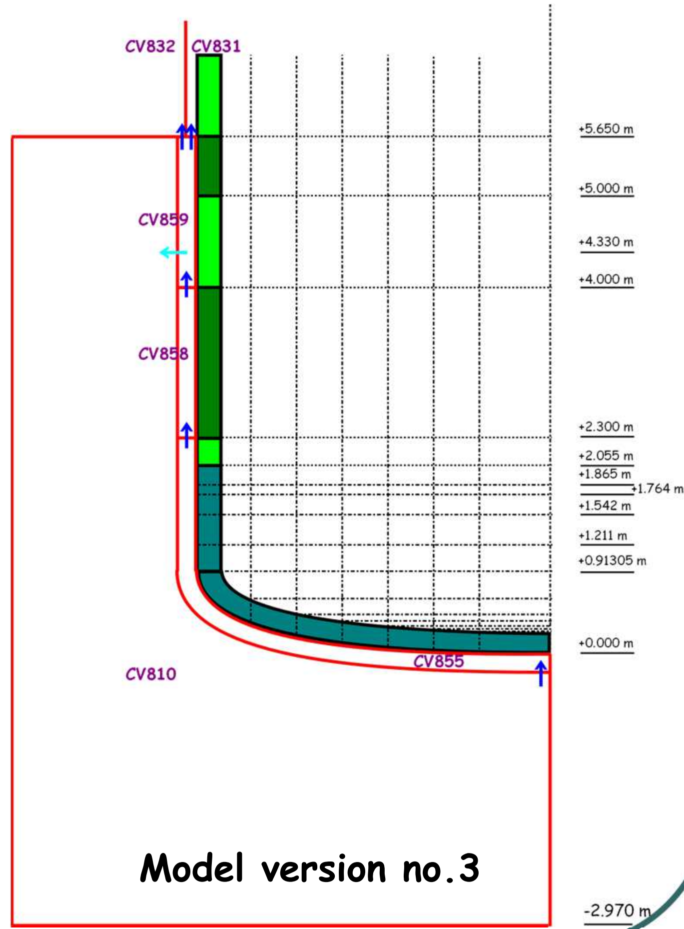
- Model simplification
  - Original CV855, CV856 and CV857 merged into new CV855
- Run again terminated with the same error message and the same reason
  - The only difference in some runs – volume of ATM was in order 10^{-10} m^3
- Whole CV855 is in contact with LH wall only, which is part of COR package
  - Constant heat transfer coeff. to ATM (SC1246(1) default 10 W/m^2K)
- Further modification
  - Enlargement of CV855 above top of LH modeled in COR package



Model version no.2

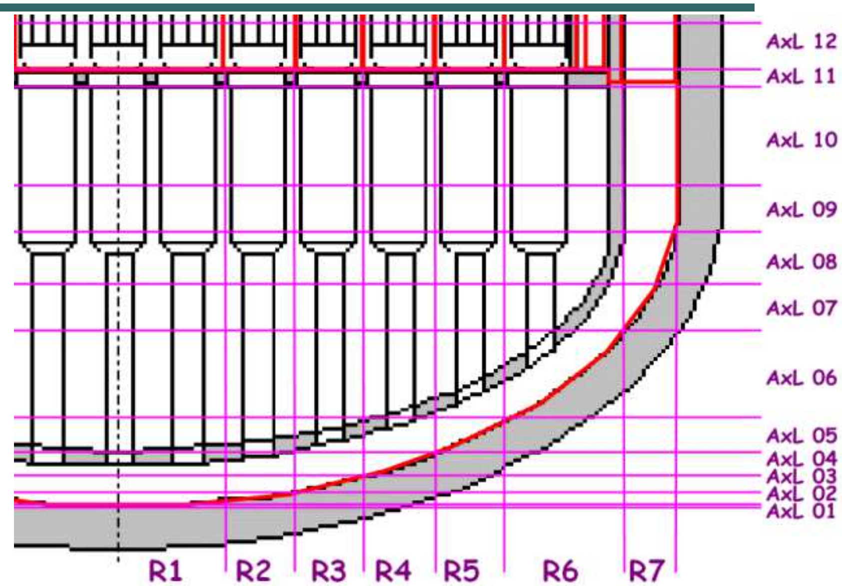
In-Vessel Retention Scenario
Modeling of Cavity (4)

- 2nd modification
  - Enlargement of CV855 above top of LH modeled in COR package
- This model improvement was successful, because ATM was exposed by HS
- User recommendation
  - Top of CV in contact with lower head wall of COR package has to be above top of modeled lower head wall
- Suggestion to SNL
  - To check algorithm for heat transfer from COR lower head wall into ATM, mainly in case of tiny atmosphere volume
- BUG report on this topic was not yet created



In-Vessel Retention Scenario
Freezing of ATM in Lower Head

- The 2nd trouble related to simulation of IVR scenario is related to situation inside of lower head
- Lower plenum is simulated with 1 CV
- During late phase of core degradation, temperature in LP CV dropped to very low values and finally run was terminated due to T_{ATM} 273.15 K (found in listing file)
  - Fluid temperatures in all COR cells associated to this CV were very high with few exceptions – AxL 10
    - It behaved similarly for several hundred seconds



AxL	R1	R2	R3	R4	R5	R6	R7
11	3214.25	3207.32	3200.54	3191.28	3195.36	3174.17	
10	394.58	3207.17	738.45	3190.95	3195.23	332.44	311.13
9	2991.16	2991.19	2991.19	2991.19	2991.19	2991.13	2829.01
8	3113.00	3113.00	3113.00	3108.73	3090.62	3068.08	3028.92
7	3113.00	3113.00	3103.55	3061.60	2990.00	2897.79	2879.45
6	3090.09	3056.70	2984.68	2877.13	2679.37	2306.94	
5	2962.46	2897.91	2769.75	2571.58	2199.15		
4	2774.71	2648.07	2453.64	2132.19			
3	2519.82	2325.48	1999.33				
2	2215.64	1870.00					
1	1754.53						

In diganostic file:

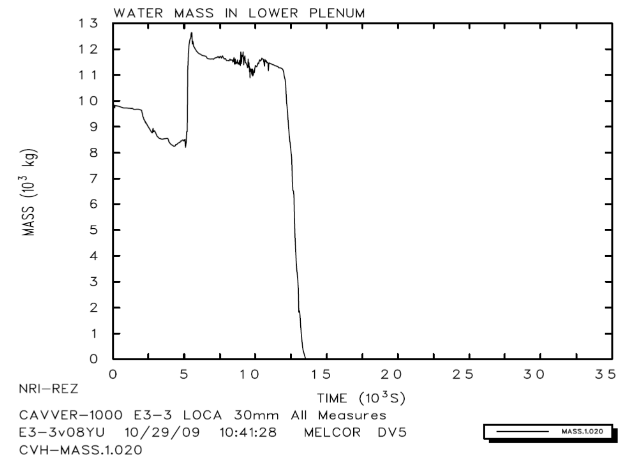
```
Attempted cycle advancement was unsuccessful
DT REDUCED BELOW DTMIN FROM PACKAGE CVH
DTrequest= 5.801500E-13 DTmin= 1.000000E-12
```

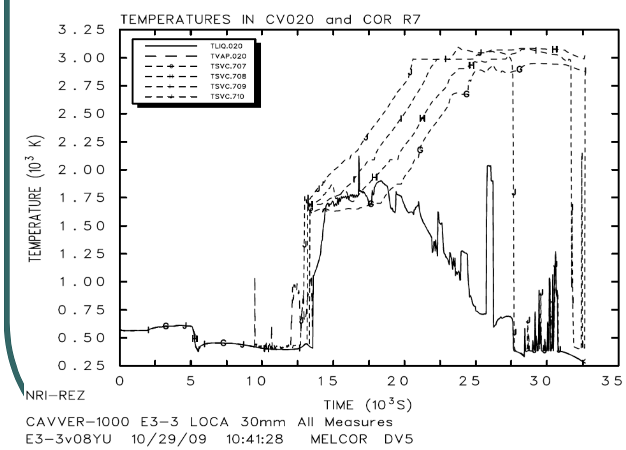
In extended diagnostic file:

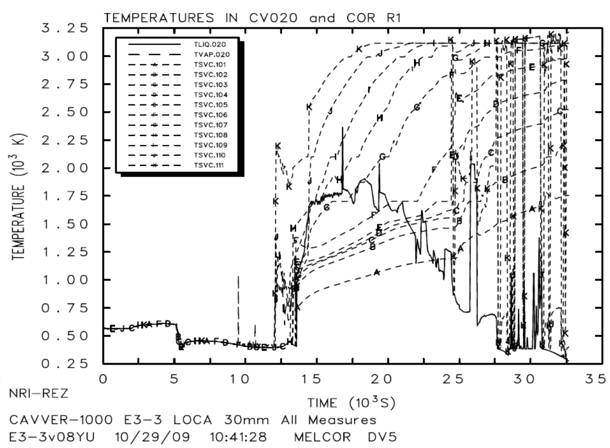
```
Error in equilibrium thermo routine CVTWGE
Called from near-equilibrium thermo routine CVTNQE
For Volume  20
```

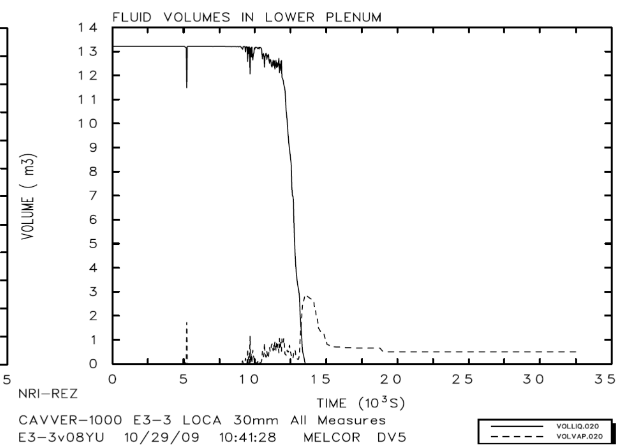
In-Vessel Retention Scenario
Freezing of ATM in Lower Head (2)

- Scenario with primary circuit depressurization and cavity reflooding
- COR fluid temperature evolutions very chaotic
  - After water boil off (~15 000 s)
  - Volume is practically fully occupied with particulated debris and/or melt



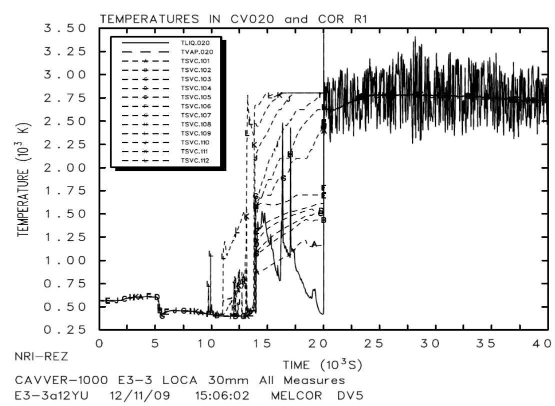


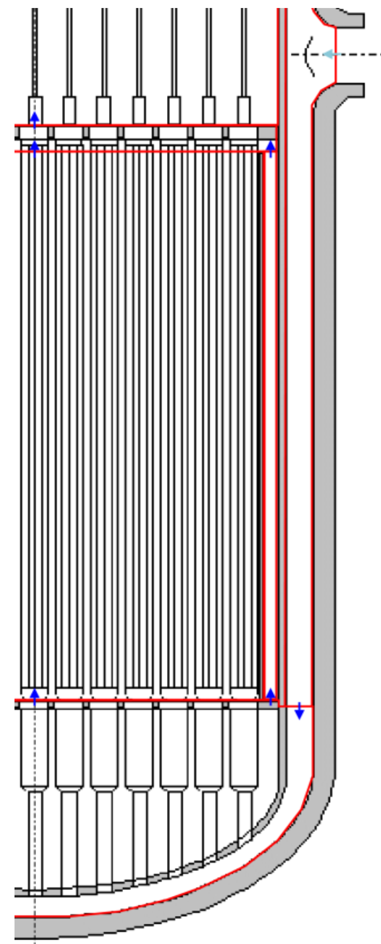




In-Vessel Retention Scenario
Freezing of ATM in Lower Head (3)

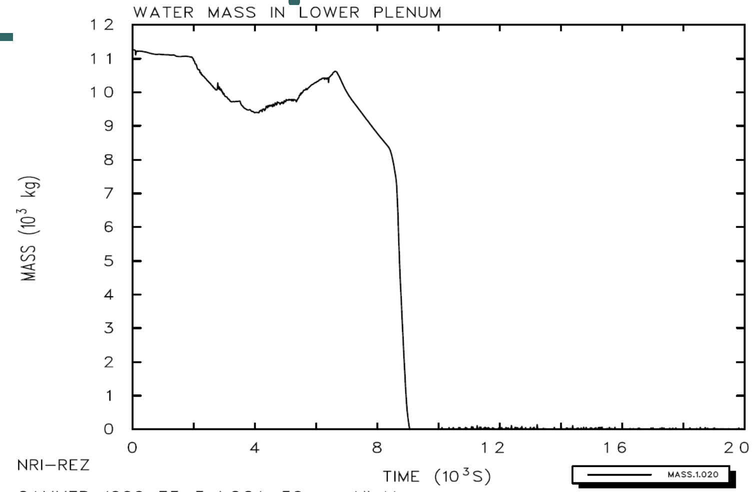
- Possible reasons
  - Fluid flows into lower plenum oscillate, but summarized very low downward flow predicted
  - CV top border in accordance with level of molten pool
  - Tested attempts
    - Extension of LP CV with the aim to enlarge fluid volume – no success
    - Switch off stainless steel oxidation (slightly endothermic reaction) – no success
    - Switch off dT/dz model at time 20000 s (ITDZ on CORTST01 row) was successful step
      - Core is empty (no structure), LP is full of melt ⇨ no need for axial T profile



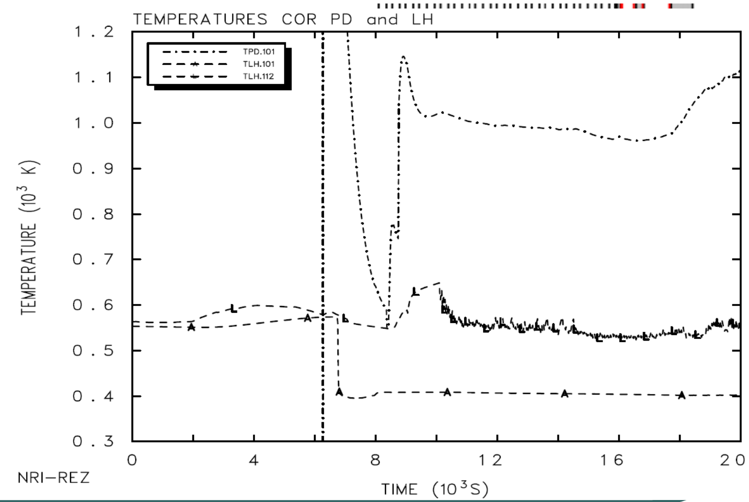


In-Vessel Retention Scenario
Another Problematic Topics

- Relocation of PD into LP results in starting of boil off, enhanced after 2nd relocation
- After LP dry out – heat up of LH
- Beginning of water income significantly changes LH inner surface temperature evolution
- Condensed water is drained to LP (water coming from down-comer during late phase with LP full of molten corium)
    - Water is added to bottom of LP CV
    - This water strongly influences heat transfer between debris/melt and lower head wall

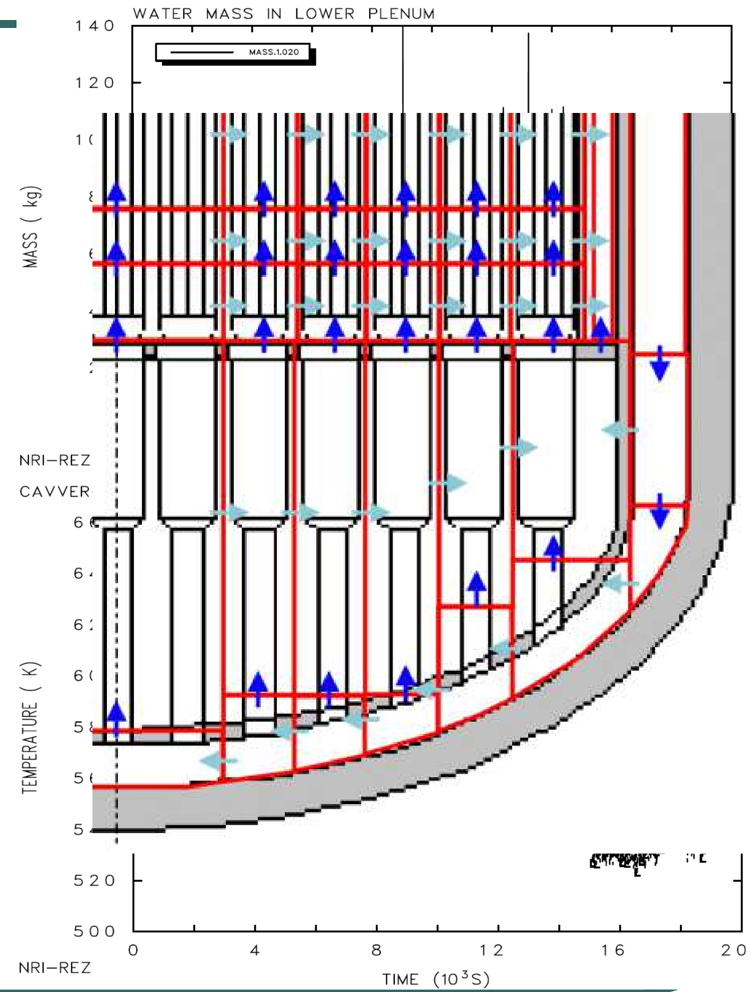


CAVVER–1000 E3–3 LOCA 30mm All Measures



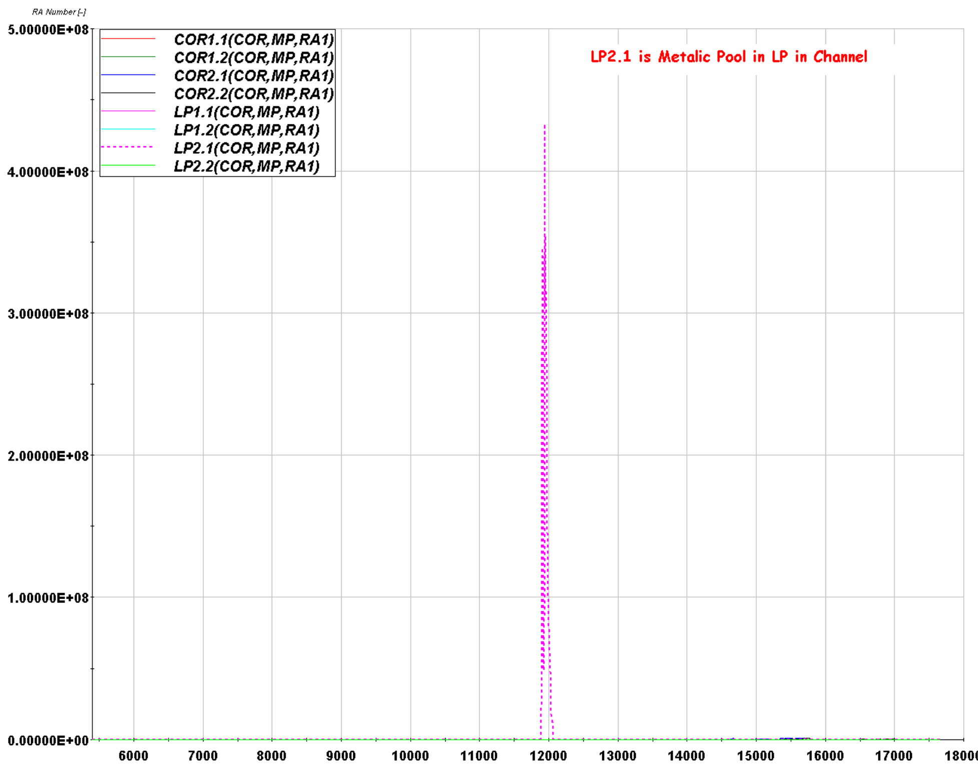
In-Vessel Retention Scenario
Another Problematic Topics (2)

- Condensed water is drained to LP (water coming from down-comer during late phase with LP full of molten corium)
  - Water is added to bottom of LP CV
  - This water strongly influences heat transfer between debris/melt and lower head wall
- This behavior is unrealistic
- Idea for detail LP nodalization
  - CV full of debris in R7 would terminate water penetration into bottom of LP
  - Not realized due to troubles with ATM freezing



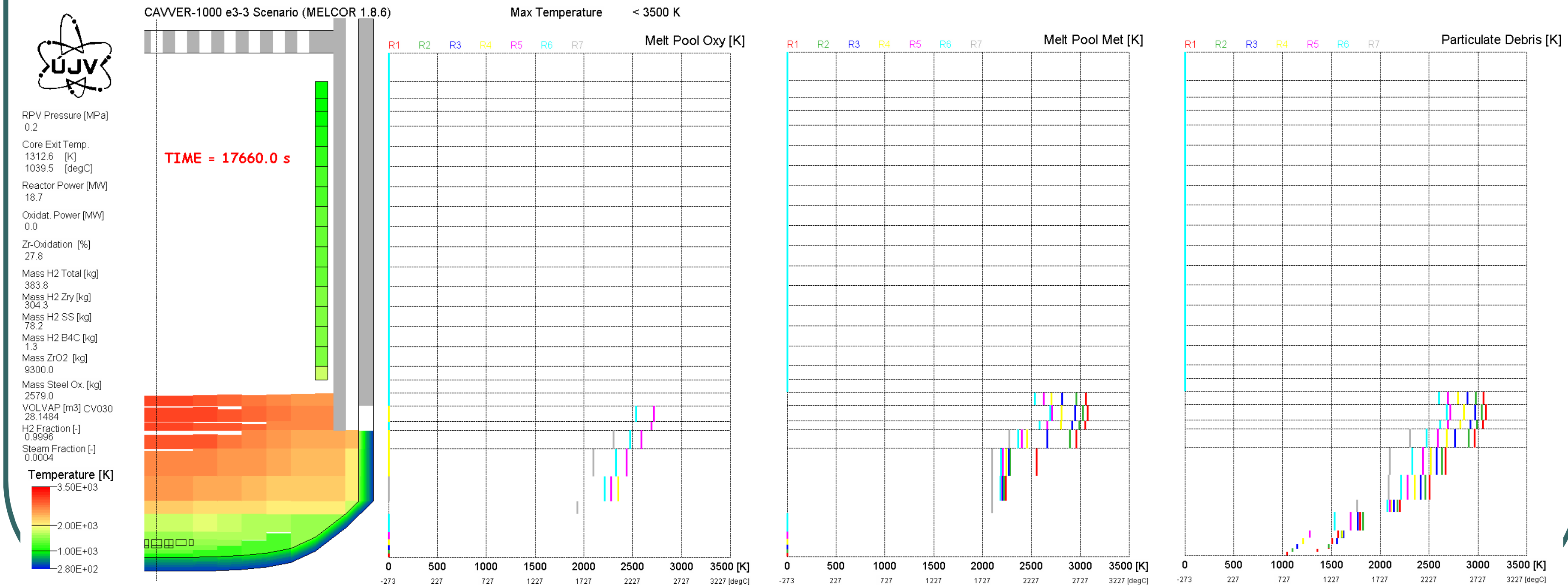
In-Vessel Retention Scenario
Molten Pool Modeling

- Very important parameter for correct modeling of molten pool in LP is Rayleigh Number
- It is strongly influenced by material property definition
- Default standard definition of materials for COR
  - Existence of Molten pools is predicted
  - Ra number is predicted with unrealistic value



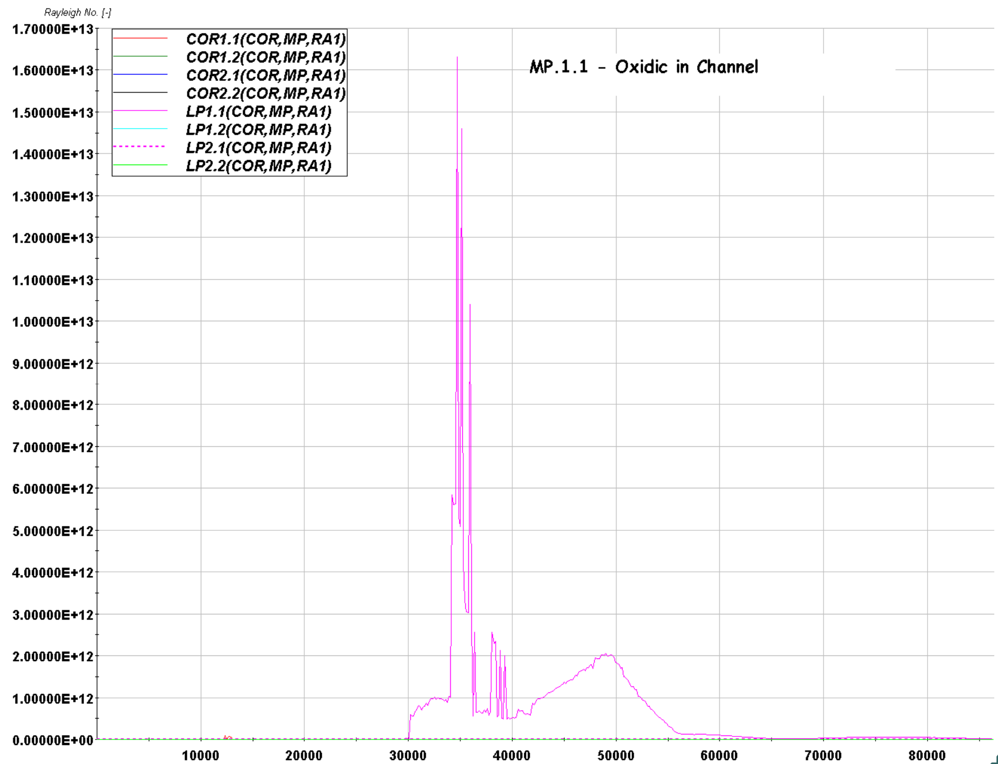
In-Vessel Retention Scenario Molten Pool Modeling (2)

- Molten pools predicted, but Ra is not calculated



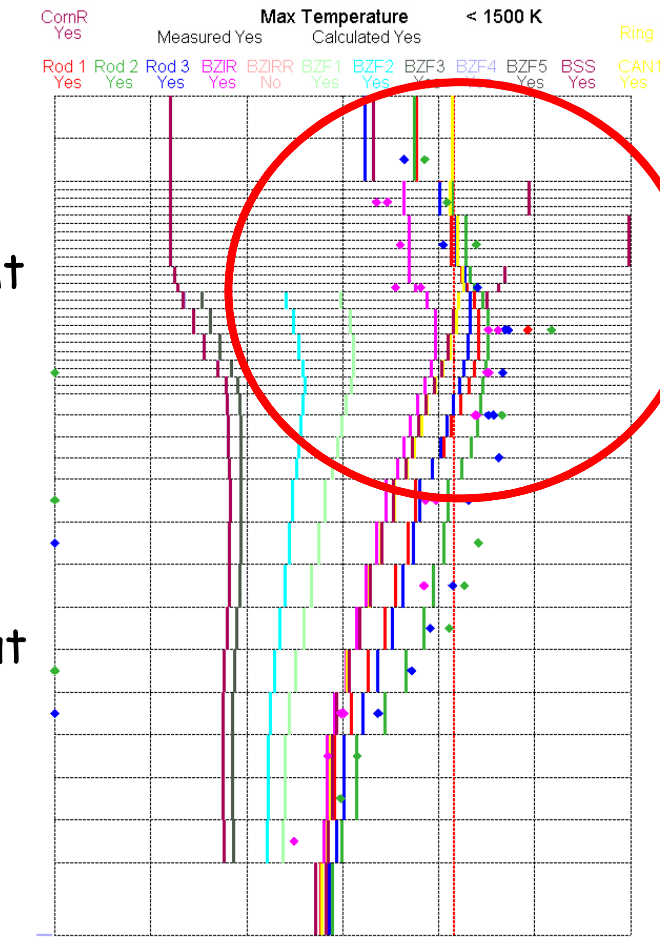
In-Vessel Retention Scenario
Molten Pool Modeling (3)

- Application of non-standard definition of material properties in COR package results in more realistic prediction of molten pool
  CORMAT1 UO2 UO2-INT
  CORMAR2 ZRO2 ZRO2-INT
- This redefinition changes only melting temperature of those materials
  - Simulation of eutectic reaction
  - Similar approach is used in control rod modeling for B4C and SIC



Other Topics
Input Reading by MELCOR 1.8.6

- Overheating of corner rods (NR) in Quench-01 simulation with MELCOR 1.8.6 YG (2006)
  - During the initial period, material of NS in cells above heated zone is burnt during a few seconds – very strong positive feed back from oxidation, although initial temperature is very low
  - More detail results checking showed that the temperature escalation starts with exceeding of oxidation cut off limit temperature
- Resolved during M2.0 Workshop
  - Support by R. Cole



Other Topics
Input Reading by MELCOR 1.8.6 (2)

Input data

Column No.86

* ijj	ASFU	ASCL	ASOS	ASCN	ASSS	ASNS
COR33006	4.48431E-02	5.26845E-02	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
COR32906	7.07141E-02	1.27328E-01	0.00000E+00	0.00000E+00	0.00000E+00	1.42974E-02
COR32806	2.93205E-02	3.88430E-02	0.00000E+00	0.00000E+00	0.00000E+00	5.92819E-03
COR32706	4.07037E-02	5.39233E-02	0.00000E+00	0.00000E+00	0.00000E+00	8.22972E-03
COR32606	1.44878E-02	5.17914E-02	0.00000E+00	0.00000E+00	0.00000E+00	2.92922E-03

Input data read and re-written in MELGEN listing

	* ijj	ASFU	ASCL	ASOS	ASCN	ASSS	ASNS
2342	COR33006	4.48431E-02	5.26845E-02	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2343	COR32906	7.07141E-02	1.27328E-01	0.00000E+00	0.00000E+00	0.00000E+00	1.42974E-02
2344	COR32806	2.93205E-02	3.88430E-02	0.00000E+00	0.00000E+00	0.00000E+00	5.92819E-03
2345	COR32706	4.07037E-02	5.39233E-02	0.00000E+00	0.00000E+00	0.00000E+00	8.22972E-03
2346	COR32606	1.44878E-02	5.17914E-02	0.00000E+00	0.00000E+00	0.00000E+00	2.92922E-03

Input data proceeded – only 85 columns

```
=================================================
EDIT OF CORE CELL COMPONENT SURFACE AREAS (M**2)
=================================================
   SECOND ROW FOR SHROUD REFERS TO CORE BARREL SIDE
----  -------- -------- -------- -------- -------- -------- -------- --------
330    4.484E-2 5.268E-2    0.        0.        0.        0.        0.        0.
                            0.        0.
329    7.071E-2 1.273E-1    0.        0.        0.        1.430     0.        0.
                            0.        0.
328    2.932E-2 3.884E-2    0.     2.136E-2     0.        5.928     0.        0.
                            0.     2.263E-2
327    4.070E-2 5.392E-2    0.     2.966E-2     0.        8.230     0.        0.
                            0.     3.142E-2
326    1.449E-2 5.179E-2    0.     1.056E-2     0.        2.929     0.        0.
                            0.     1.118E-2
```

User must carefully check data in MELGEN and/or MELCOR listing file – **don’t trust your input only, but check how code handles data**

Other Topics
Not-Quite Equilibrium Model

- M186 YU_2911 release - not-quite-equilibrium option now used by default for a volume with a "tiny" pool or atmosphere
  - My testing of YU_2911 on Quench-11 resulted in run-time error in cvtnqe routine due to activation of this not-quite-equilibrium option (disabled in YT version) – no information to users in relation with YU release about its activation
  - This NQE model can be deactivated by SC4408 using definition SC44081 4408 1000000.0 1
    but this possibility was described only in update of SC4408 definition, which was only attached to BUG68 report – now available in latest version of MELCOR User's Guide (YV release)
    - Each of magnitudes of this parameter controls some model and its original description describes only 6 model option – max value 111111.0, default in YT 1000000.0, in YU 0.0, recently 7 options possible and described in M186 YV UG

Other Topics
Fission and Decay Power Absorption

- Modification of SC1311 definition (fission and decay power absorption) – repetition of suggestion from MCAP2008 and EMUG2008
  - To allow independent definition of SC1311 and SC1321 per ring
    - Very important for PWR core with SH component defined
  - What is plan of SNL concerning this topic?

Other Topics
Fission and Decay Power Absorption (2)

- 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 values 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 Surry*	VVER-1000 with SH	VVER-1000 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 Surry*	VVER-1000 with SH	VVER-1000 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

[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

Other Topics
New SH Control Variables

- These control variables are described in BUG73 report, but not included in latest updated UG (YV release in Jan 2010)
  - COR-MZRO2-CNI /c/ Intact oxide mass on inner surface of BWR canister (the part not adjacent to control blade) in cell n. (units = kg)
  - COR-MZRO2-CNO /c/ Intact oxide mass on outer surface of BWR canister (the part not adjacent to control blade in cell n. (units = kg)
  - COR-MZRO2-CBI /c/ Intact oxide mass on inner surface of BWR canister adjacent to the control blade) in cell n. (units = kg)
  - COR-MZRO2-CBO /c/ Intact oxide mass on outer surface of BWR canister adjacent to the control blade in cell n. (units = kg)
  - COR-MSSOX-SHI /c/ Intact oxide mass on inner surface of PWR core shroud (SH) in cell n. (units = kg)
  - COR-MSSOX-SHO /c/ Intact oxide mass on outer surface of PWR core shroud (SH) in cell n. (units = kg)
- Testing in Sept 2008 (probably with YP version) showed that COR-MSSOX-SHI control variable represents mass of ZrO2, if SH material is Zr (Stainless Steel is default material for SH)
  - Generally – redefinition of default material does not change name of control/plot variable name of appropriate COR component

Other Topics
New Plot Variables

- New plot variable was added in some release (YP or earlier?)
- 'PWR' IRTYP – only one additional plot variable
  - COR-DROXD-CL.nnn /p/ thickness of oxide on CL outer surface of cell nnn? (units = m)
- 'BWR' IRTYP
  - COR-DROXD-CN.nnn /p/ thickness of oxide on CN inner surface?
  - COR-DROXD-CNB.nnn /p/ thickness of oxide on CN outer surface?
  - COR-DROXD-CB.nnn /p/ thickness of oxide on CB inner surface?
  - COR-DROXD-CBB.nnn /p/ thickness of oxide on CB outer surface?
- Description of these plot variables is not included in any User's Guide including the latest one
  - Description included here is my understanding only!
  - I did not find anything at MELZILLA, but I found these variable in keyword list

Summary, Conclusions

- Several cases of user troubles and their solutions presented
  - Some of them solved by user, but only as preliminary solution and they need code modifications
- New MELCOR capabilities were emphasized, because they were described only in BUG reports, source code or sample case inputs
  - Some users still use older versions of MELCOR
    - Some troubles can appear during utilization of new version
  - Latest release of MELCOR YV_3084 (Jan 2010) includes also draft (updated) versions of User's Guide and Reference Manual
- Suggestions included – some of them repeated

End of Presentation

Thank You for Your Attention