РОССИЙСКАЯ АКАДЕМИЯ НАУК
безопасного развития атомной энергетики
RUSSIAN ACADEMY OF SCIENCES
Nuclear Safety Institute (IBRAE)

Overview of MELCOR Code Activities in IBRAE RAN

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EMUG Meeting, April 15, 2014
VUJE a.s.
Bratislava, Slovak Republic

Outline

- MELCOR 2.1 code performance improvement strategies
  - Optimization and refactoring
  - Swapping algorithms
  - Loop-based parallelization
  - Numerical solvers modernization
  - COR and RN1 packages overlap mode
- MELOR 2.1 code verification and validation on the Lower Head Failure (LHF) experiments

MELCOR 2.1 Performance Improvement

- **Refactoring**
- **Swapping algorithms**
- **Loop-based parallelization**
- **Numerical solvers modernization**
- **COR and RN1 packages overlap mode**

MELCOR 2.1 Performance Improvement

- **Refactoring**
- Swapping algorithms
- Loop-based parallelization
- Numerical solvers modernization
- COR and RN1 packages overlap mode

- Global data have been replaced with local copies.
- Testing of these changes has shown noticeable speedup on the tests.

Test case	Rev. 5250, sec	Rev. 5441, sec	Speedup, %
BWR/Mark I SBO	26196	22296	15
PWR LBLOCA	125894	113660	9
BWR/Mark III SBO	97863	87620	10

MELCOR 2.1 Performance Improvement

- Refactoring
- Swapping algorithms
- Loop-based parallelization
- Numerical solvers modernization
- COR and RN1 packages overlap mode

- **Realized for all MELCOR packages**
- **Decrease of total CPU time by 1 – 2 %**

Original version

Copying “Old” = “New” before each time step.
Copying “New” = “Old” if fallback

Version with swapping

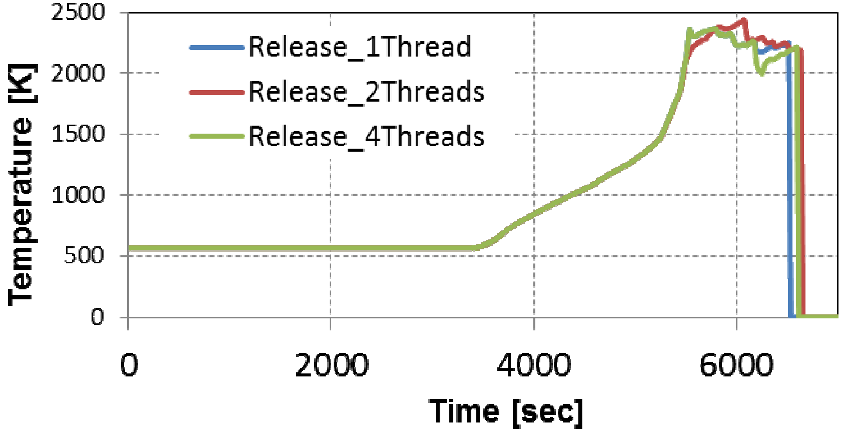
Two pointers pOld and pNew
Two objects Old and New
pOld => Old

pNew => New

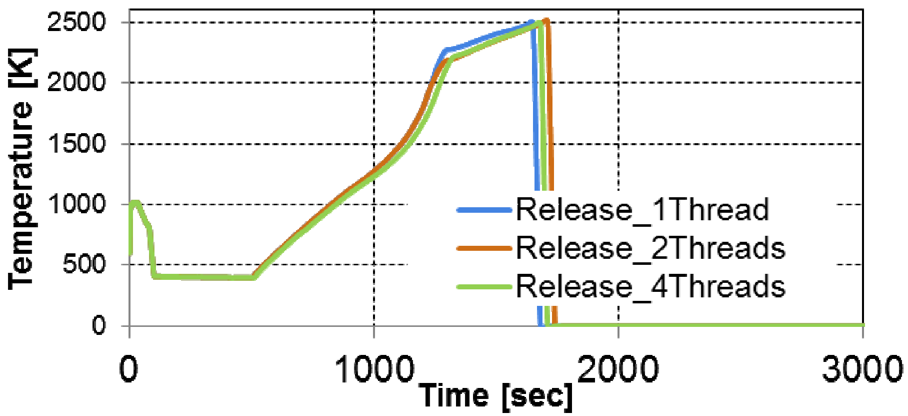
MELCOR 2.1 Performance Improvement

- Refactoring
- Swapping algorithms
- **Loop-based parallelization**
- Numerical solvers modernization
- COR and RN1 packages overlap mode

- **CVH and RN1 packages have been parallelized**
- **Decrease of total CPU time by 5 – 10 %**



Temperature of the cladding for BWR/Mark I SBO test case



Temperature of the cladding for PWR LBLOCA test case

MELCOR 2.1 Performance Improvement

- Refactoring
- Swapping algorithms
- Loop-based parallelization
- **Numerical solvers modernization**
- COR and RN1 packages overlap mode

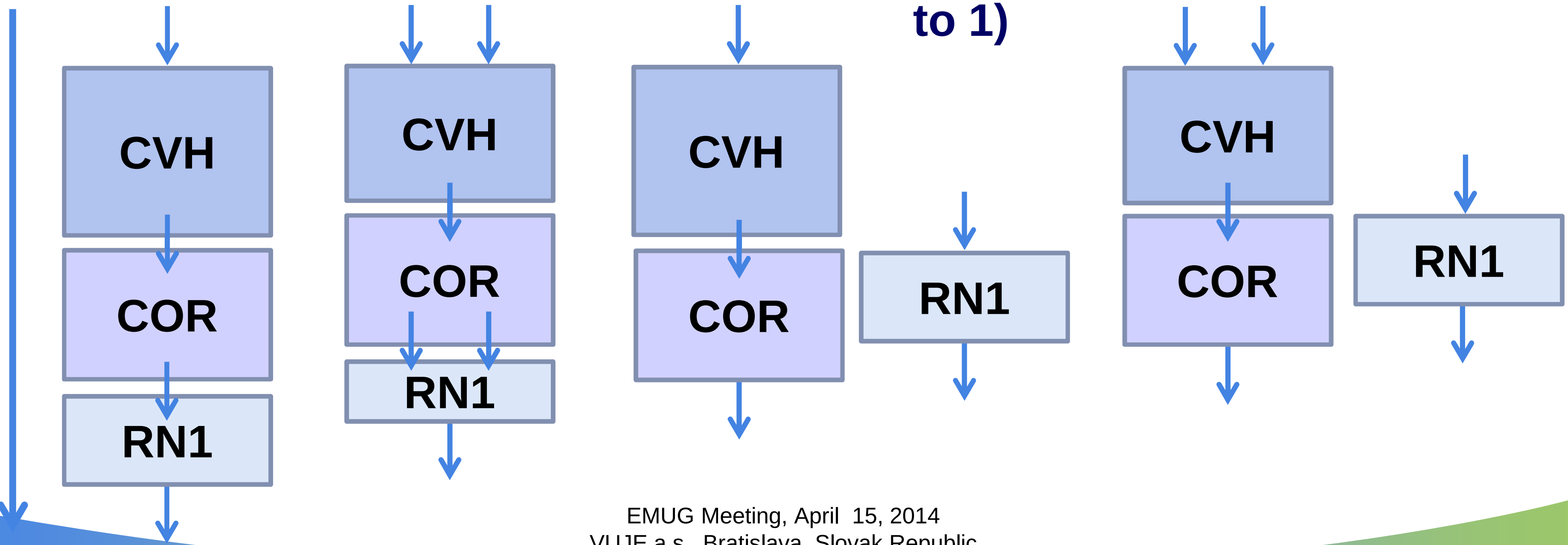
- **Base linear solver BiCG replaced by its modification BiCGSTAB**
- **It has faster and smoother convergence than the original BiCG**
- **Solver speedup about 3 – 4 times**

Test case	BiCG, sec	BiCGSTAB, sec	Speedup
BWR/Mark I SBO	1191,16	348,92	3,41
BWR/Mark III LBLOCA	3776,63	857,19	4,4

MELCOR 2.1 Performance Improvement

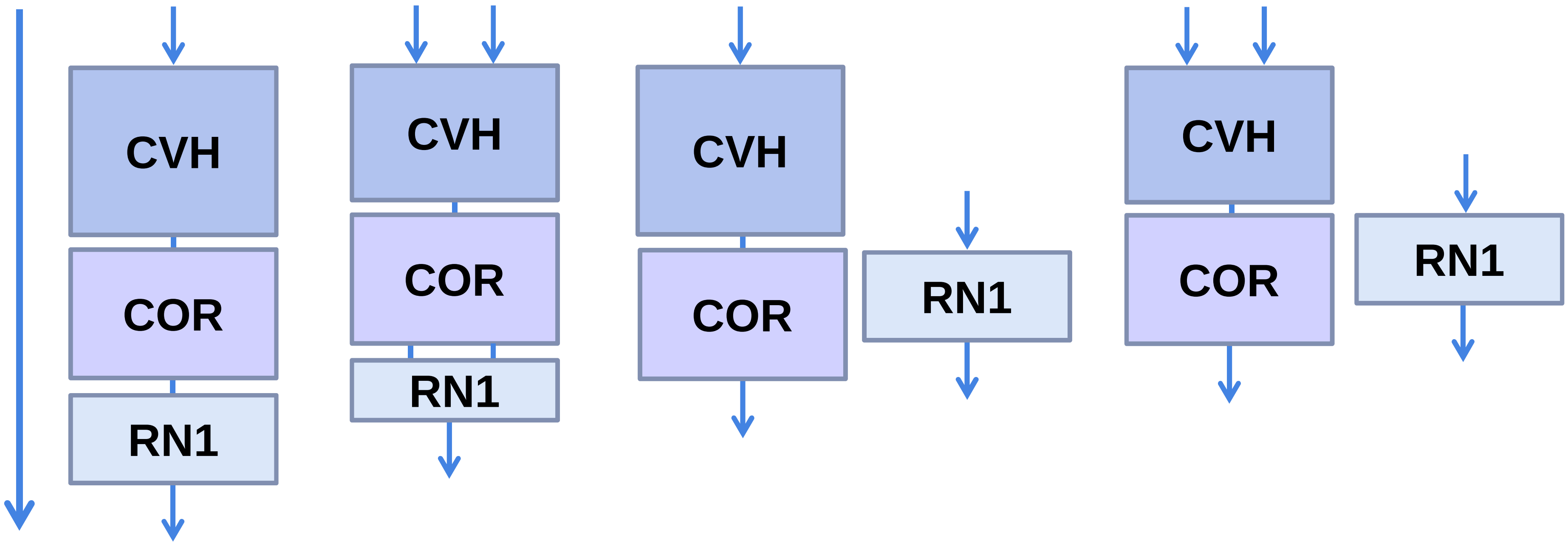
- Refactoring
- Swapping algorithms
- Loop-based parallelization
- Numerical solvers modernization
- COR and RN1 packages overlap mode

- The distribution of COR package is not appropriate for efficient loop-based parallelization
- COR and RN1 packages both took comparable CPU time (generally at a ratio of 3 to 1)

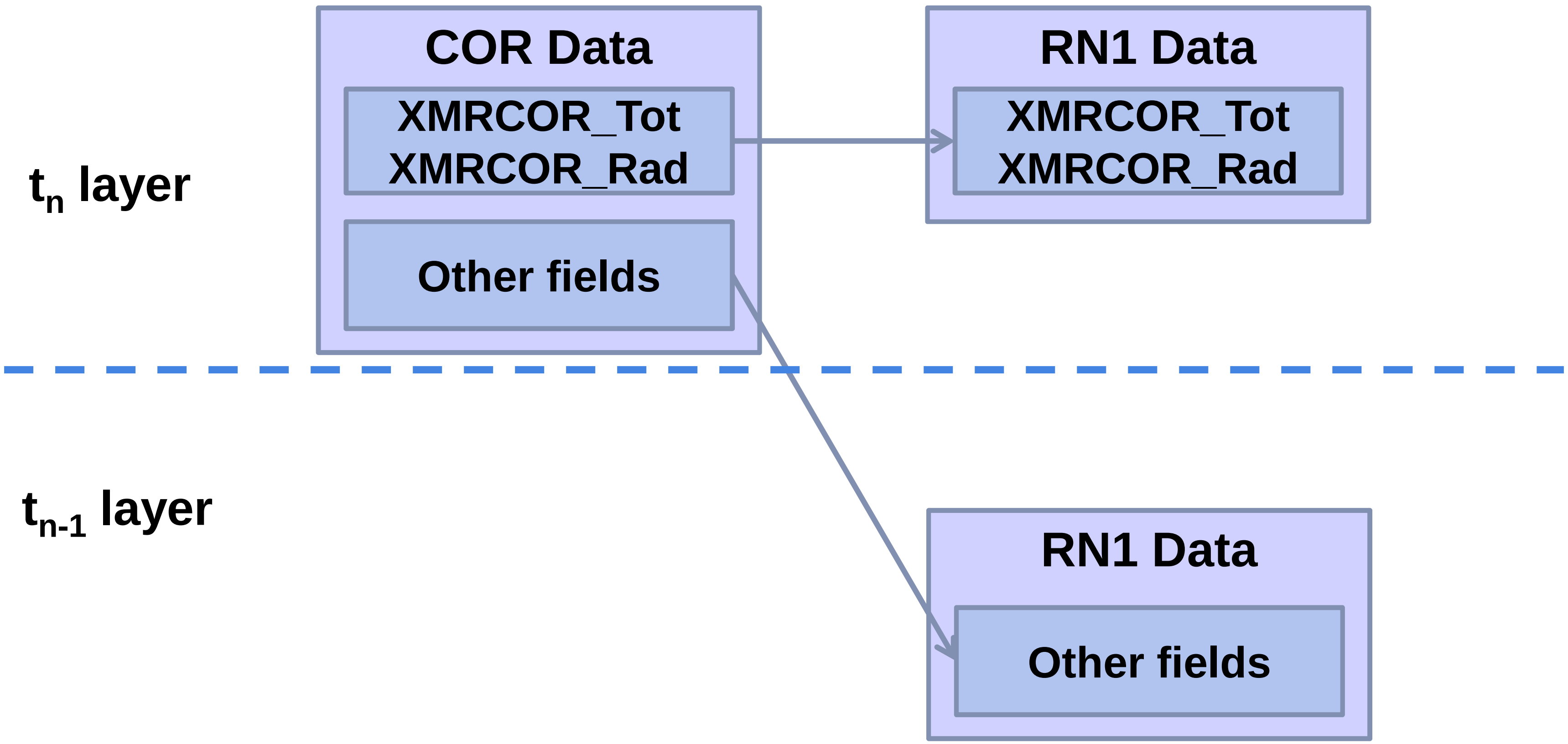


COR and RN1 Overlap

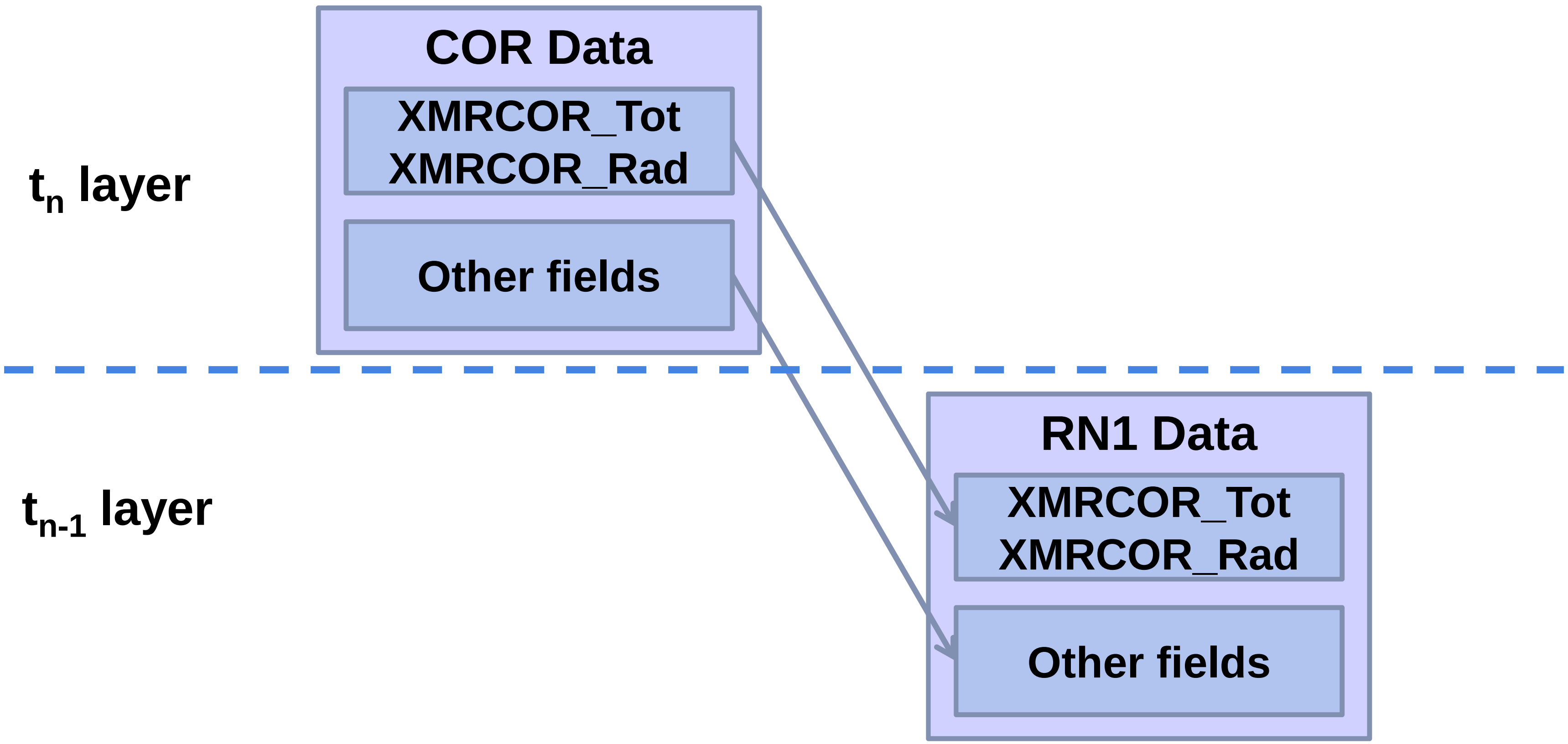
- The distribution of COR package is not appropriate for efficient loop-based parallelization
- COR and RN1 packages both took comparable CPU time (generally at a ratio of 3 to 1)



Changes in the Algorithm



Changes in the Algorithm



Sensitivity Coefficient SC7006

7006 – Criteria for activation and deactivation of overlap mode of RN1 and COR packages

(1) - The flag for used mode

Value	Comment
0	The original mode is used – COR and RN1 take values from the same temporal layer
1	The new COR values used on the next step by RN1 package, but COR and RN1 packages are calculated subsequently
2	The new COR values used on the next step by RN1 package, COR and RN1 packages are calculated simultaneously

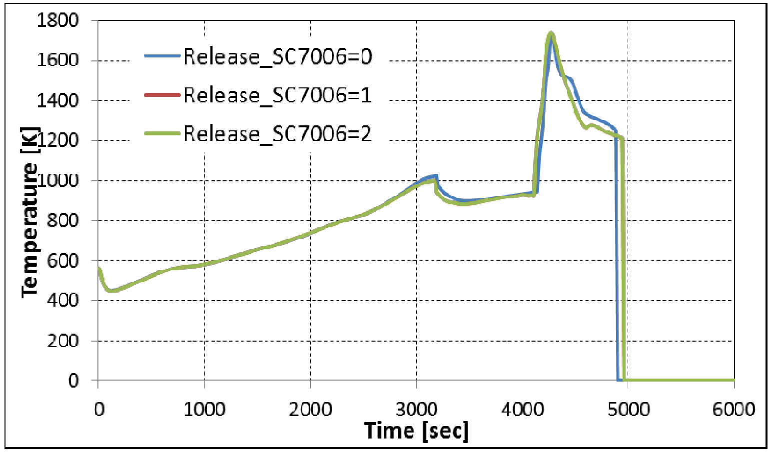
Performance Testing

- Release configuration
- COR and RN1 overlap mode

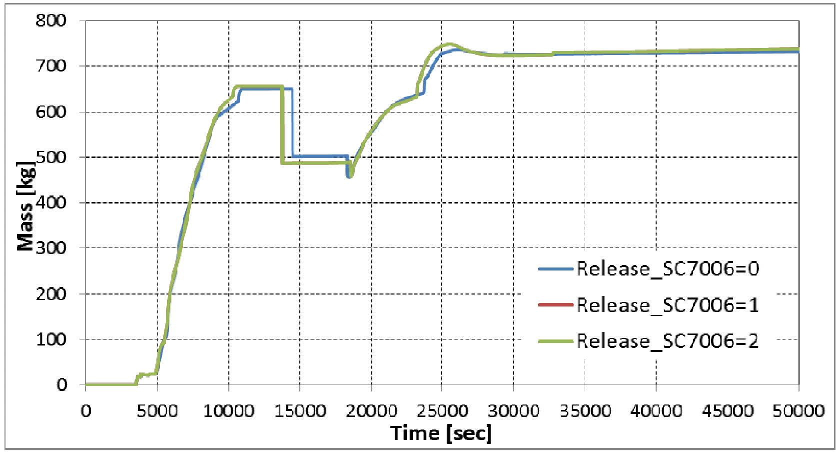
Test case	CPU time, sec/ hours		
	SC = 0	SC = 1	SC = 2
BWR/Mark I SBO	33596.8	31833.89	24597.06
	9.3	8.8	6.8
BWR/Mark III SBO	119830.9	113882.9	98791.5
	33.3	31.6	27.4
BWR/Mark III LBLOCA	121298.6	124093.8	110779.1
	33.7	34.5	30. 8

Calculation Results

- Physical results for base version and version with modified algorithm in RN1 package are of the same quality
- The modified version run in sequential and parallel mode gives identical results for most of the tests



Cladding temperature for the BWR/Mark III LBLOCA test case



Total radioactive mass release for the BWR/Mark III SBO test case

Lower Head Failure Experiments

- Purpose
  - Experimental study of the vessel creep and deformation process
  - Experimental results' utilization to develop and validate analytical models
- Conducted in 1998 in Sandia National Laboratory
  Series of 8 experiments distinguished by
  - Spatial temperature/heat flux distribution
  - Pressure
  - Reactor vessel structure elements and construction features on RPV deformation and failure

Test Matrix of LHF Experiments

Tests	Heat Flux Distribution	Structure Elements	Pressure
LHF-1	Uniform		10 MPa
LHF-2	Center-peaked		10 MPa
LHF-3	Edged-peaked		10 MPa
LHF-4	Uniform	Penetrations	10 MPa
LHF-5	Edge-peaked	Penetrations	10 MPa with transient
LHF-6	Uniform	Weldment	10 MPa
LHF-7	Uniform		5 MPa
LHF-8	Edge-peaked		10 MPa

MELCOR 2.1 Model for Lower Head Failure

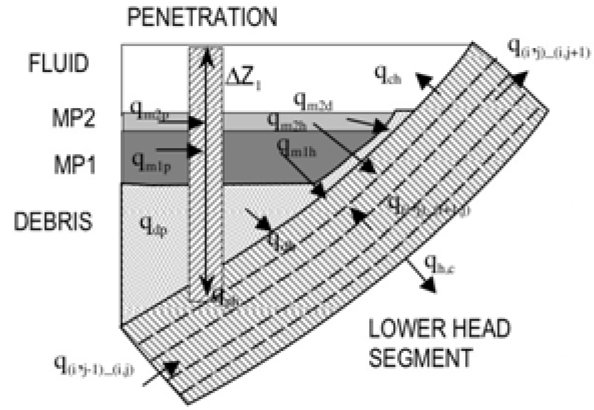
- Creep-rupture failure of a lower head segment occurs, in response to mechanical loading under conditions of material weakening at elevated temperatures
- Creep is calculated based on a Larson-Miller parameter and a life-fraction rule

$$\varepsilon_{pl}(t+\Delta t)=\varepsilon_{pl}(t)+0.18\,\frac{\Delta t}{t_R}$$

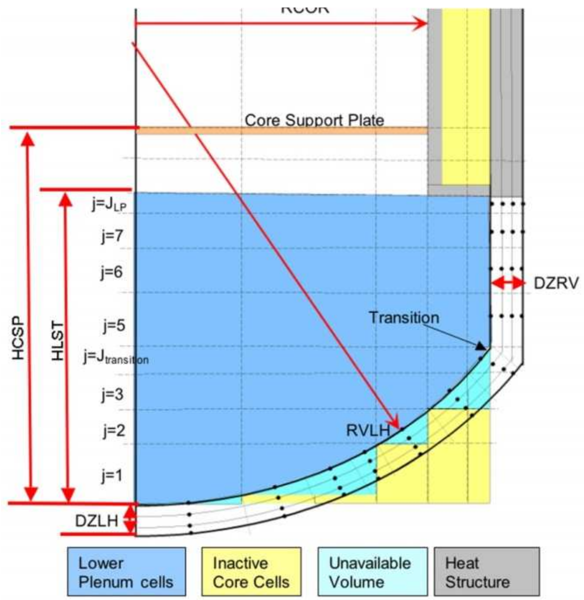
- Zero-dimensional option: effective stress

$$\sigma_e=\frac{(\Delta P+\rho_d g \Delta z_d)R_i^2}{R_o^2-R_i^2}$$

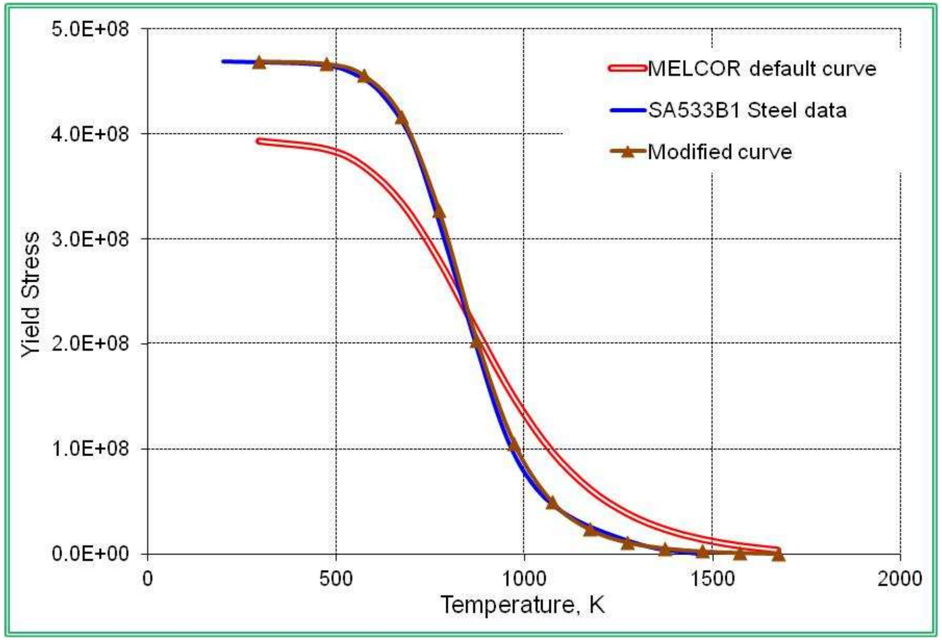
- One-dimensional option: predicts the stress-strain distribution through the lower head, and treats stress redistribution from both thermal strain and material property degradation

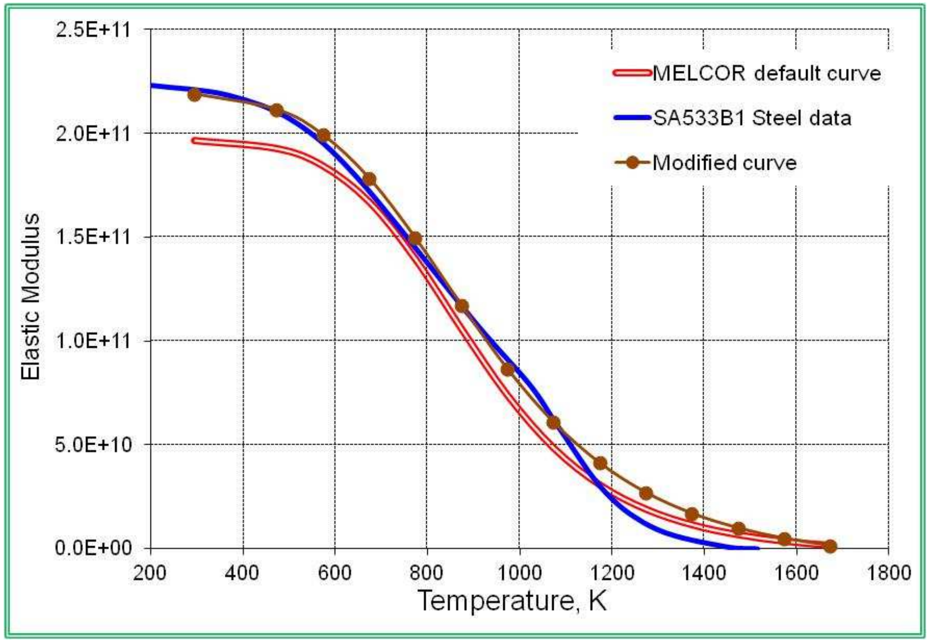


Curved Lower Head



Mechanical Properties of the Vessel Steel



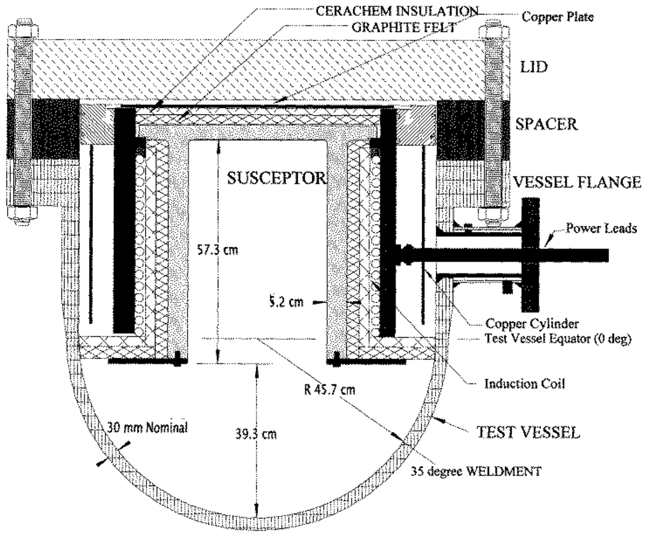


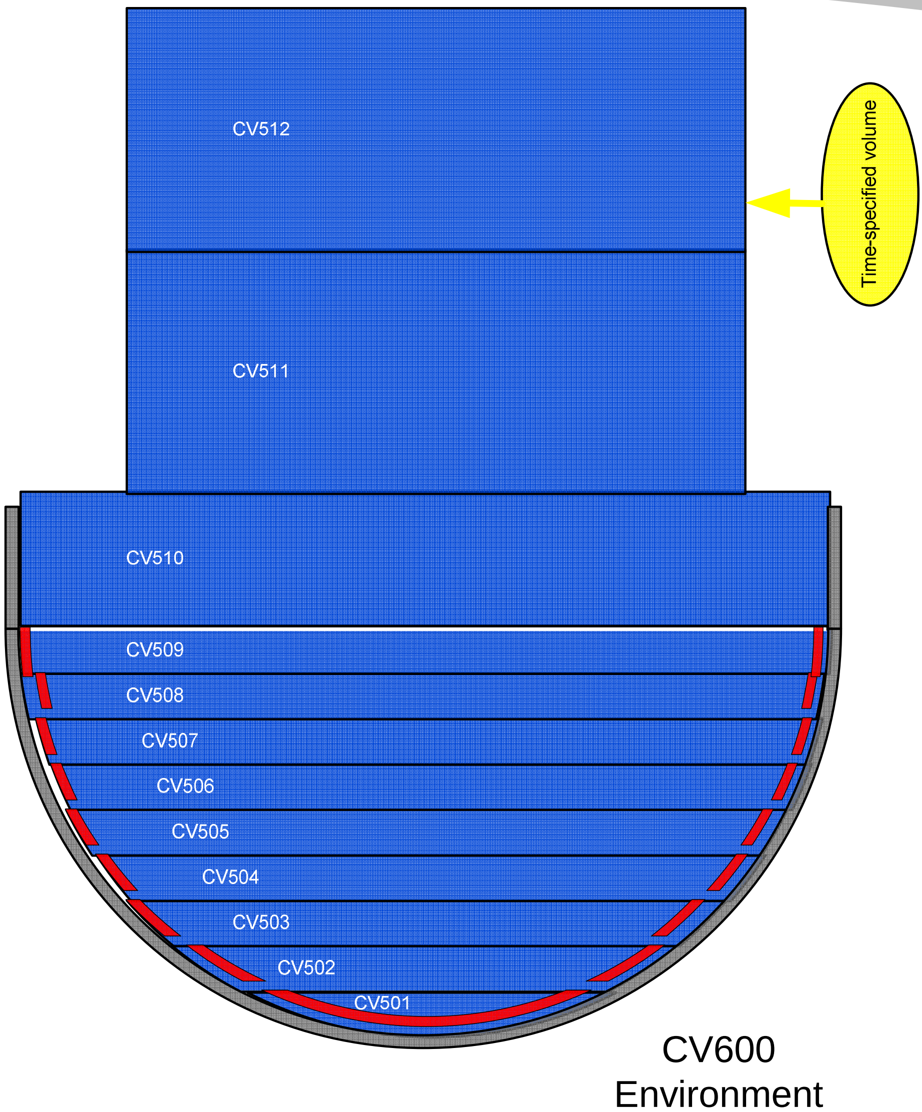
LHF Test Nodalization Scheme

14 Control volumes

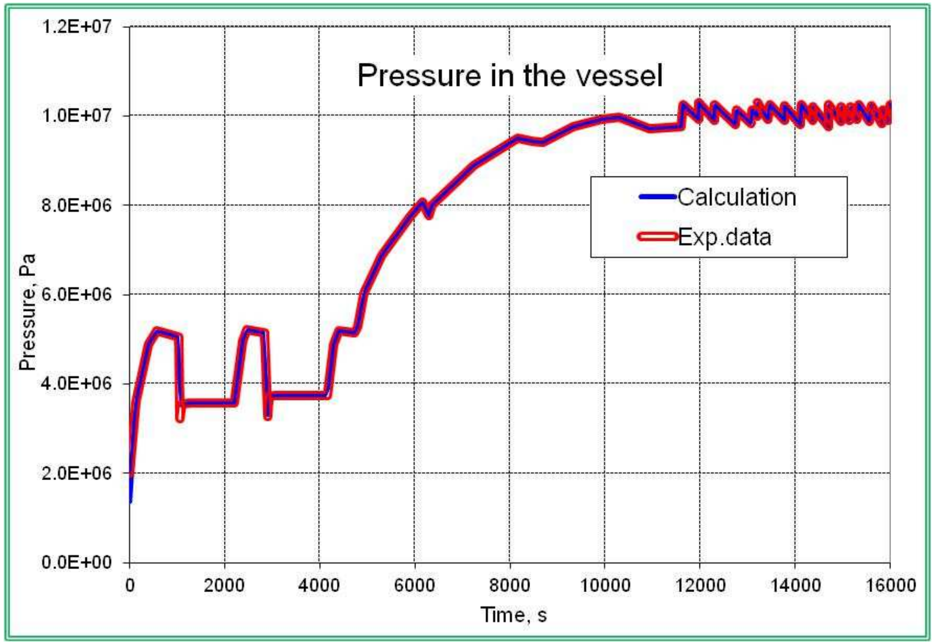
9 Lower Head segments

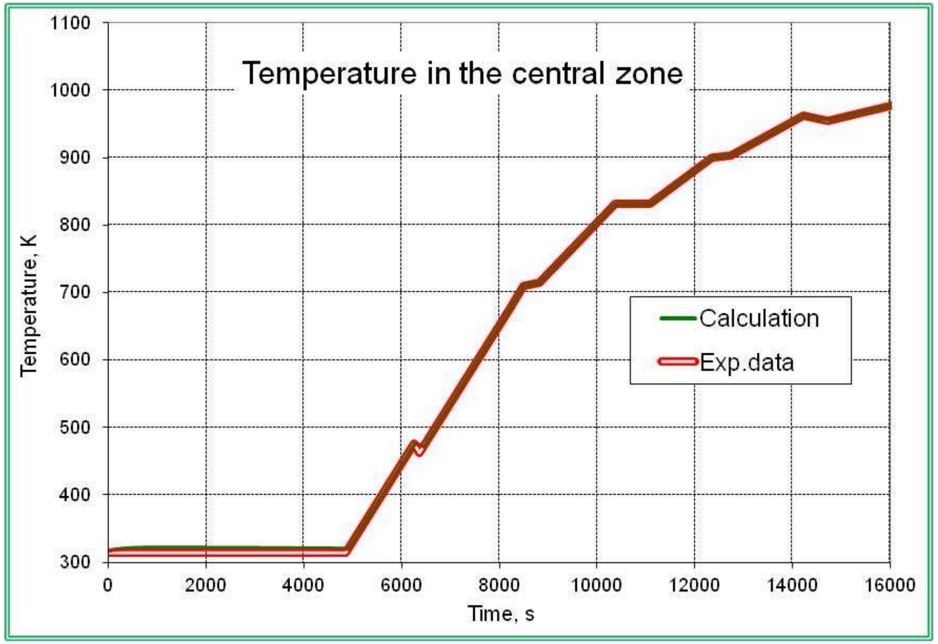
9 heated Support Plates in Lower Head



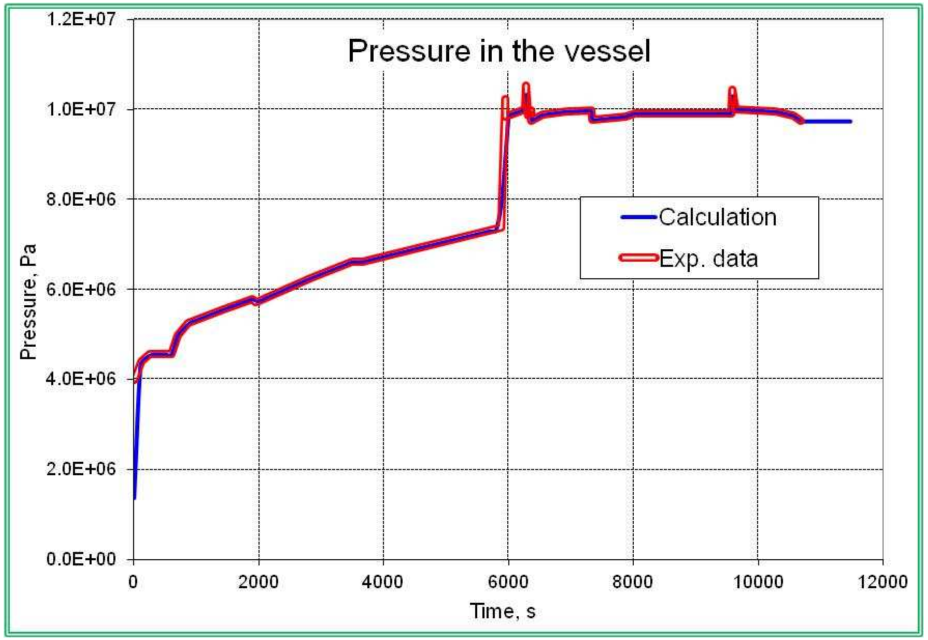


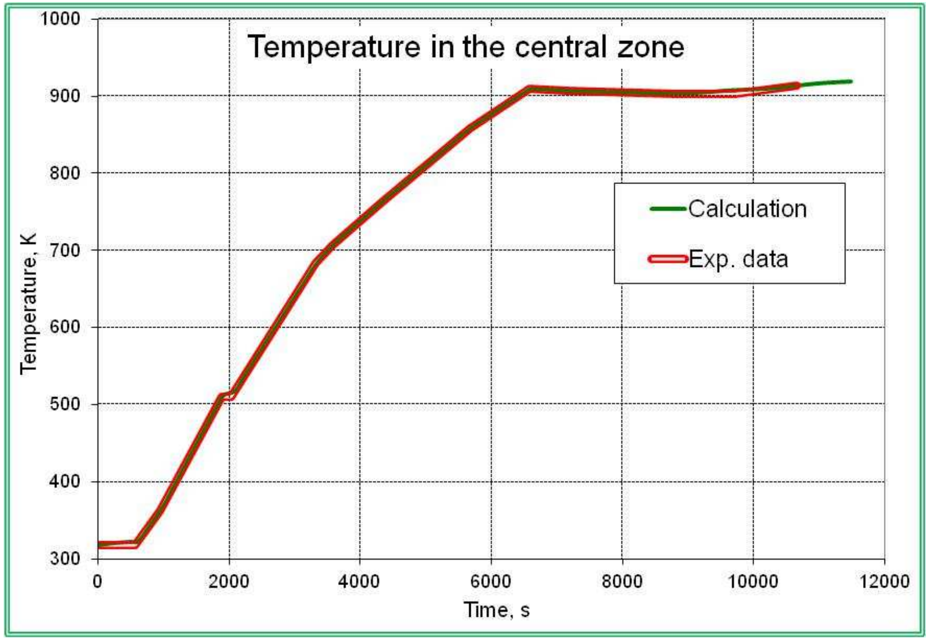
LHF-4 Experiment (Boundary Conditions)



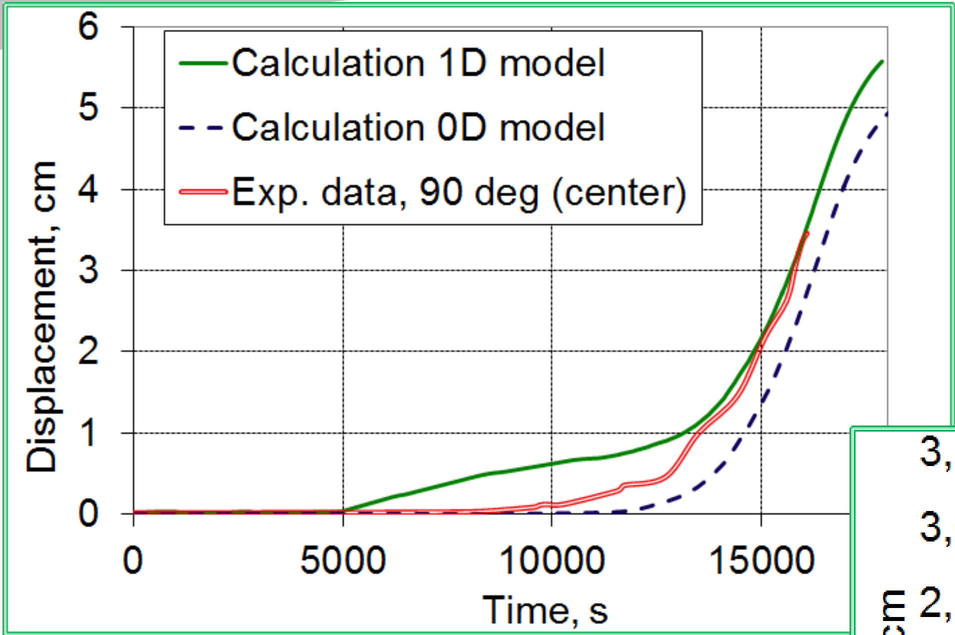


LHF-3 Experiment (Boundary Conditions)



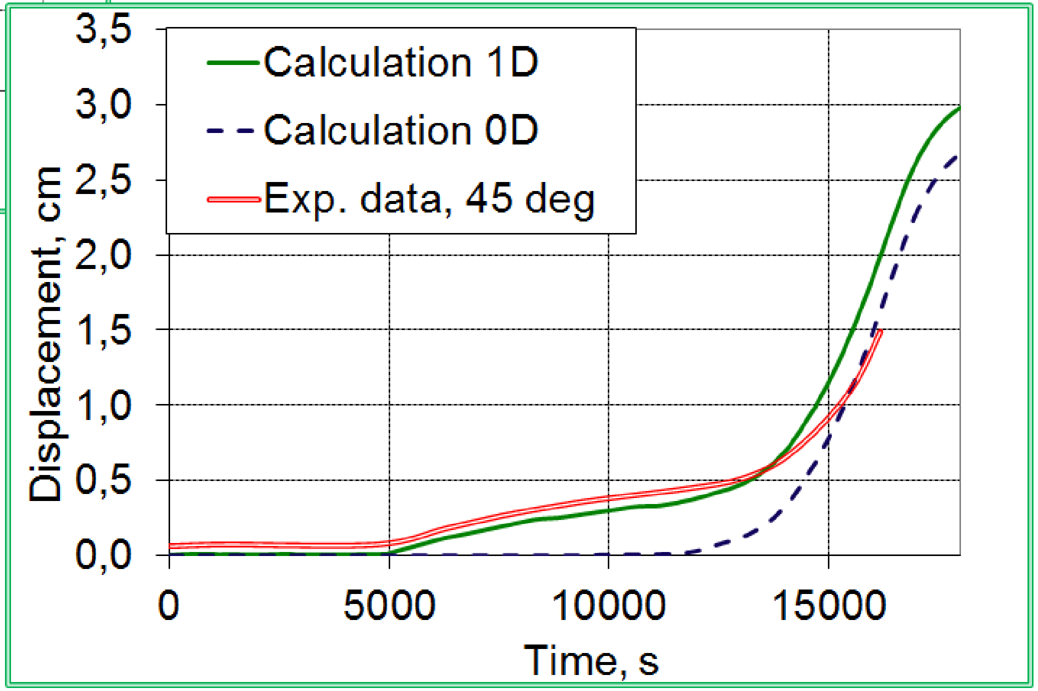


Calculation Results for LHF-4 Experiment

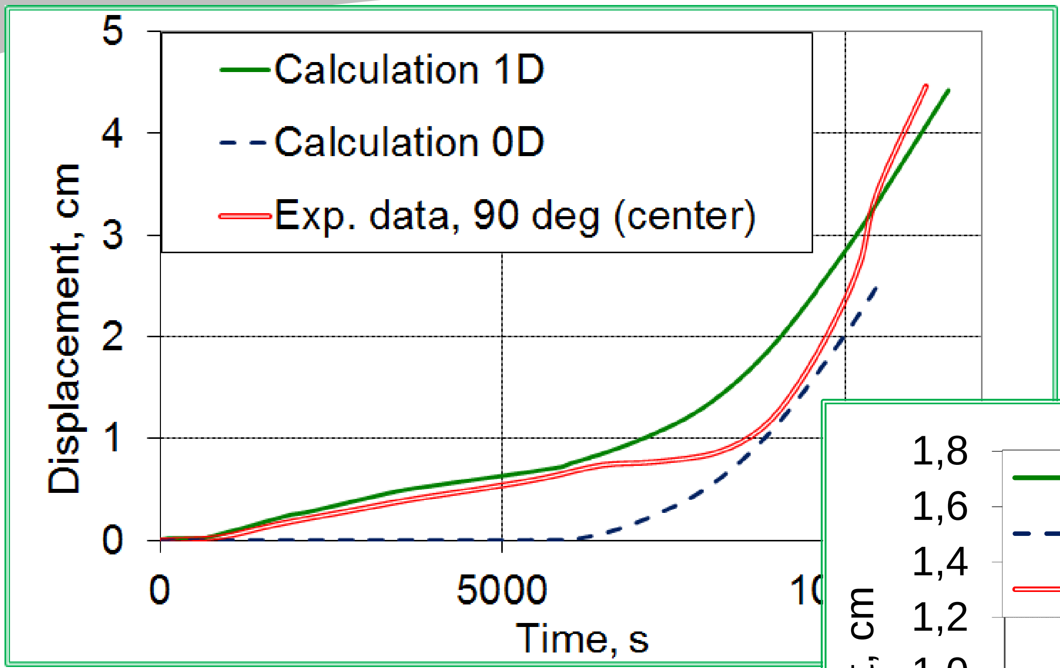


Displacement, 90 degrees

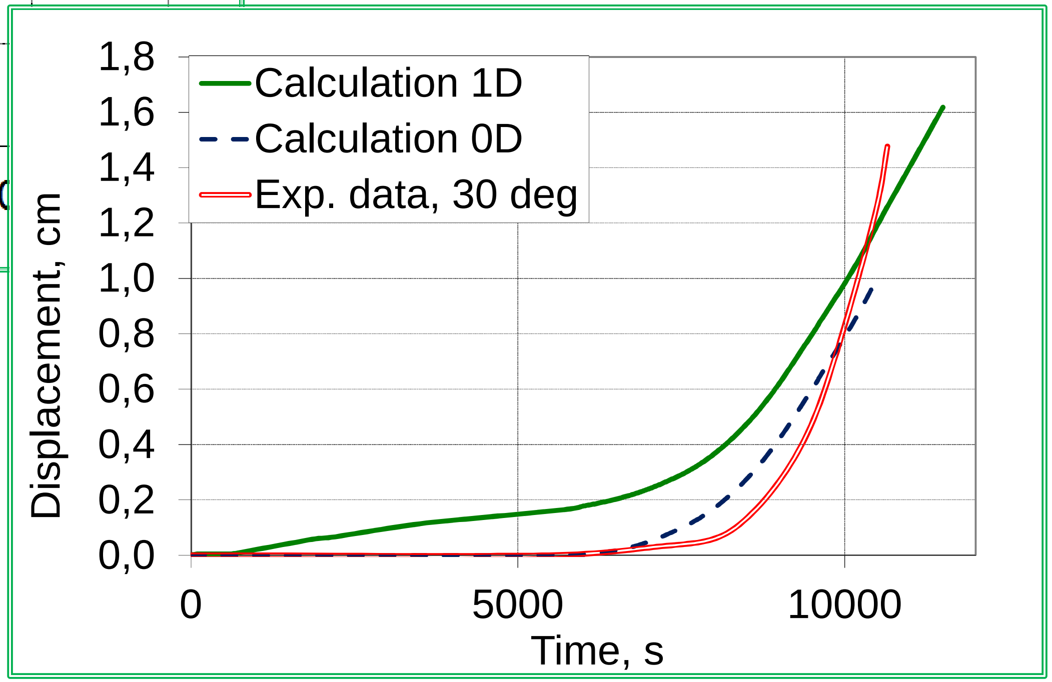
Displacement, 45 degrees



Calculation Results for LHF-3 Experiment

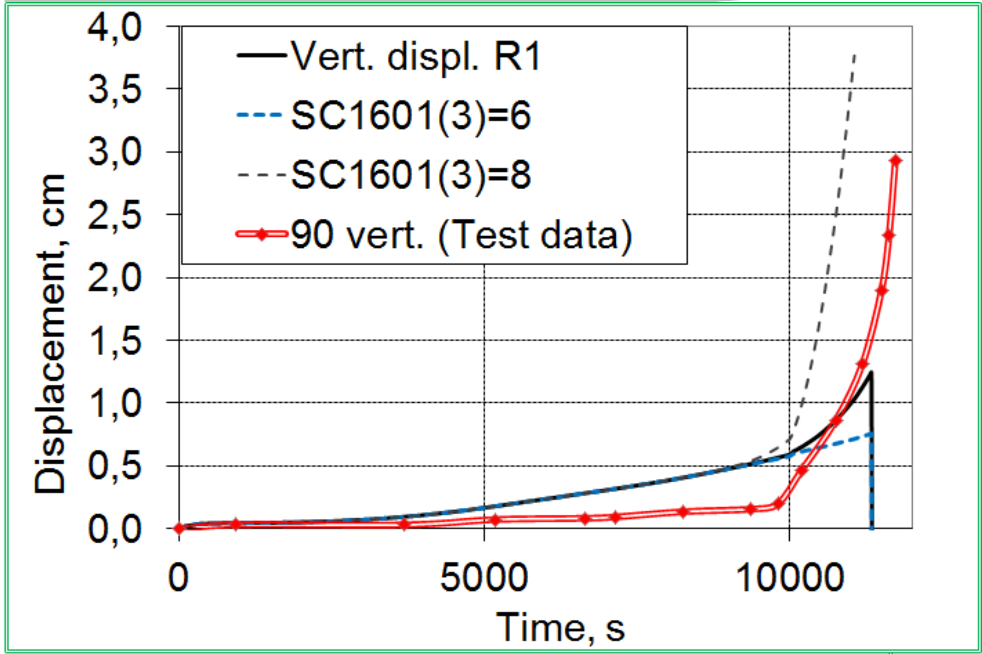


Displacement, 90 degrees



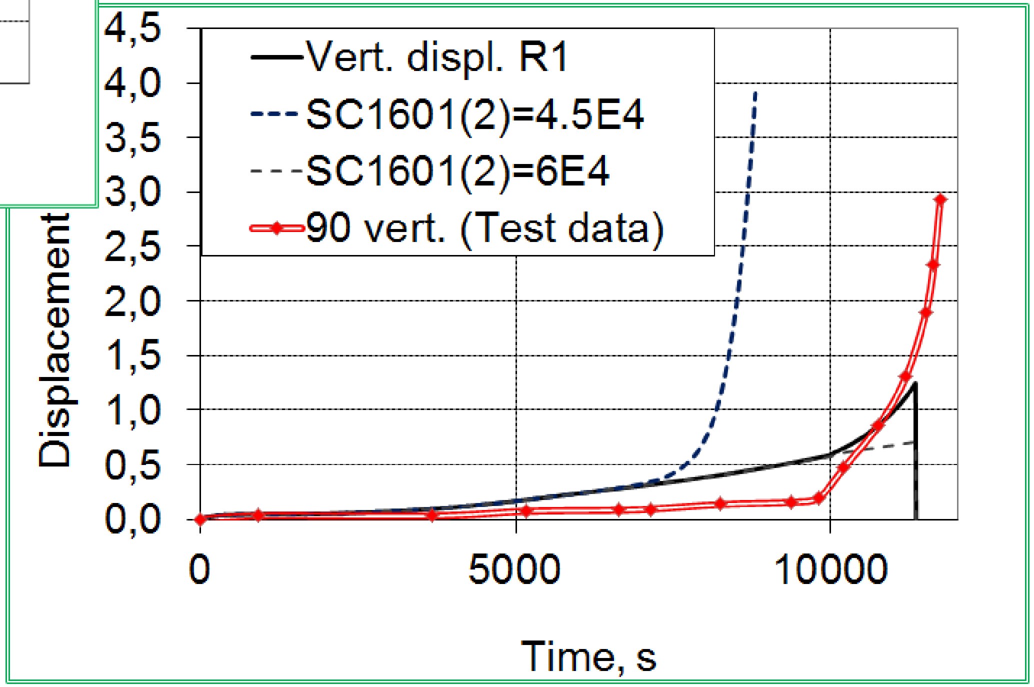
Displacement, 30 degrees

Sensitivity Study for LHF-5 Experiment



Displacement, 90 degrees

Displacement, 90 degrees



Conclusions

- MELCOR 2.1 code activities in IBRAE RAN are presented
  - Code performance improvement
  - Code validation and verification
- Code performance improvement
  - New approach of code performance improvement: COR and RN1 packages overlap - decrease of CPU time by 10-30% for NPP calculations
  - Code refactoring - decrease of CPU time by 10-15% for NPP calculations
- Code verification on LHF experiments
  - Good agreement of MELCOR code calculation results with experimental data for the failure time and the LH pole displacement
  - Using of 1D option to calculate stress-strain distribution through the lower head is recommended
  - Special attention should be paid to set the correct values for material properties
  - MELCOR model underestimates the pole displacement for the experiments with the LH uniform heating