MELCOR Application to Plant Accident Analyses at PSI

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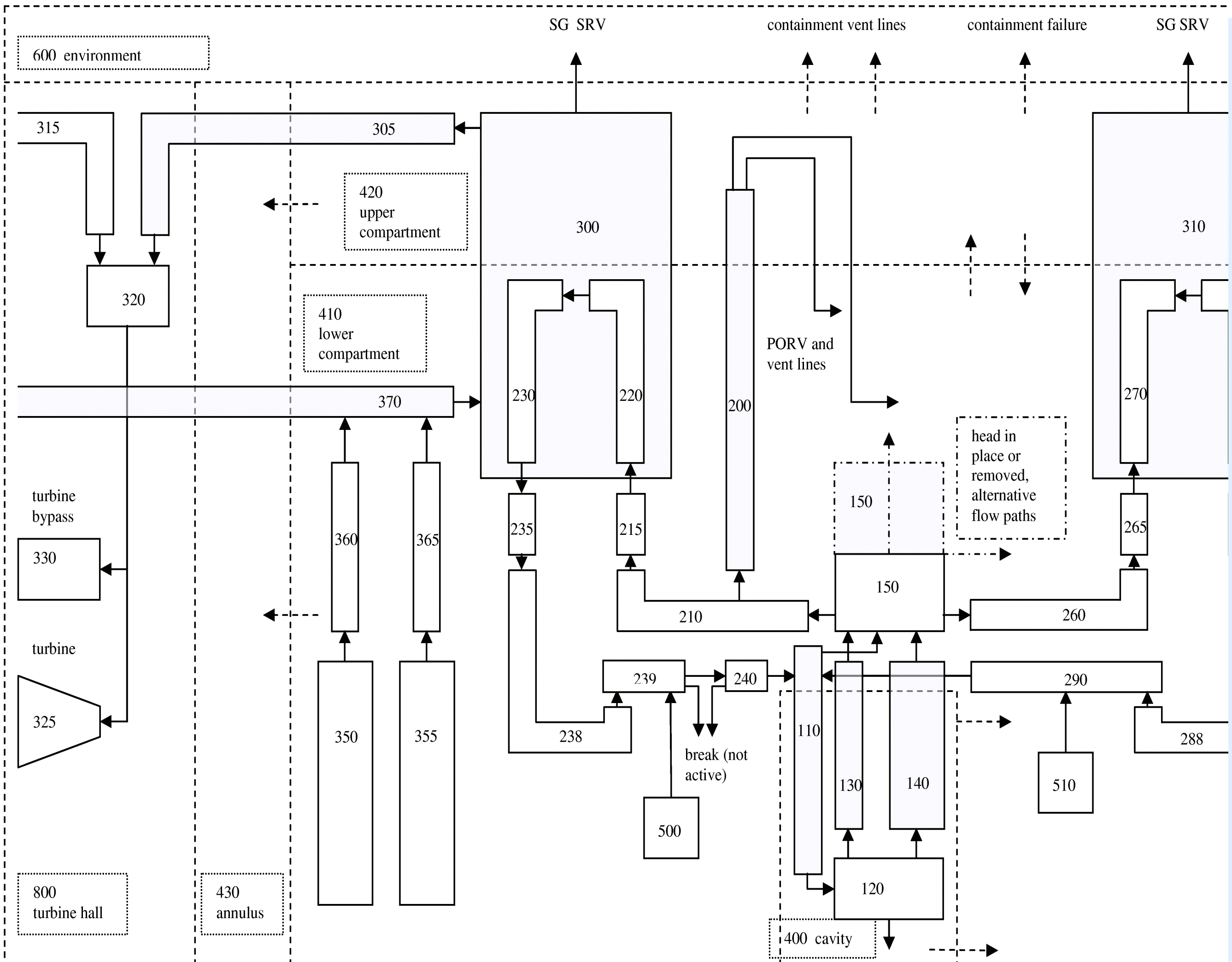
Outline

- Introduction to recent MELCOR applications at PSI
- Loss of RHR accidents during mid-loop operation
- LOCAs during hot shutdown operation
- LOCAs during full power operation
- Sensitivity study to the primary side nodalization
- Conclusions

Introduction to recent MELCOR applications at PSI

- Beznau power plant:
  - Two loop Westinghouse PWR
  - 1130MW core thermal power
  - Safety injection pumps: JSI 1-A, B,C,D
- Loss of RHR during mid-loop operation (22h after reactor trip)
  - Initial conditions with core power at 0.57%FP, low primary pressure
- LOCAs during hot shutdown operation (4h after reactor trip)
  - Initial conditions with core power at 0.92%FP, intermediate primary pressure
- LOCAs during full power operation
  - Initial conditions with core power at 100%FP, high primary pressure
- This talk focuses on effect of safety injection time, injection rate and steam generator reflux condensation on core recovery

MELCOR nodalization for 2-loop Westinghouse PWR



Loss of RHR during mid-loop operation

- Objective
  - Determine latest injection time to recover the core without damage
- Assumptions
  - Upper head in place and bolts detensioned
  - No accumulator available
  - One injection pump available for recovery
    - with limited flow rate (3.5kg/s for base case, 3.0kg/s for sensitivity study)
    - delayed some time after core uncovery (2840s for the reference case, 2640s and 3040s for sensitivity studies)

Comparison of event sequences

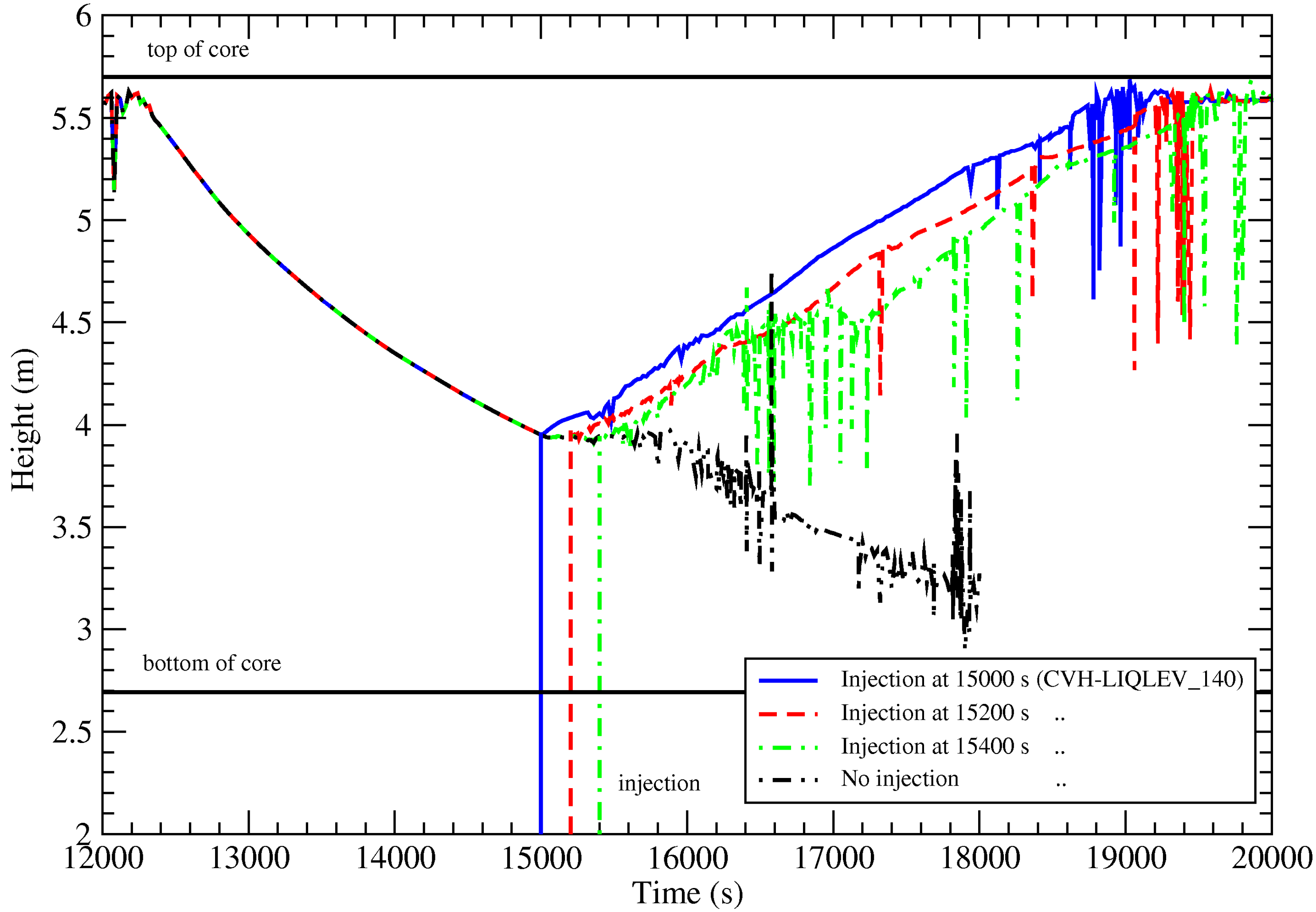
Parameter (unit)	Injection time (s)		
	15000	**15200**	**15400**
Start of core uncovery (s)	12360	12360	12360
Start of injection, t_i (s)	+ 2640	+ 2840	+ 3040
Level in core at t_i (m)	1.26	1.25	1.25
Max. core temperature at t_i (K)	992	1100	1185
Start of oxidation (s)	++ 35	-- 165	-- 365
Peak core temperature (K)	1185	1240	2369
Time to final quench (s)	++ 3920	++ 4010	++ 3040*
Mass of H_2 generated (kg)	2	3	20

+ relative to start of core uncovery

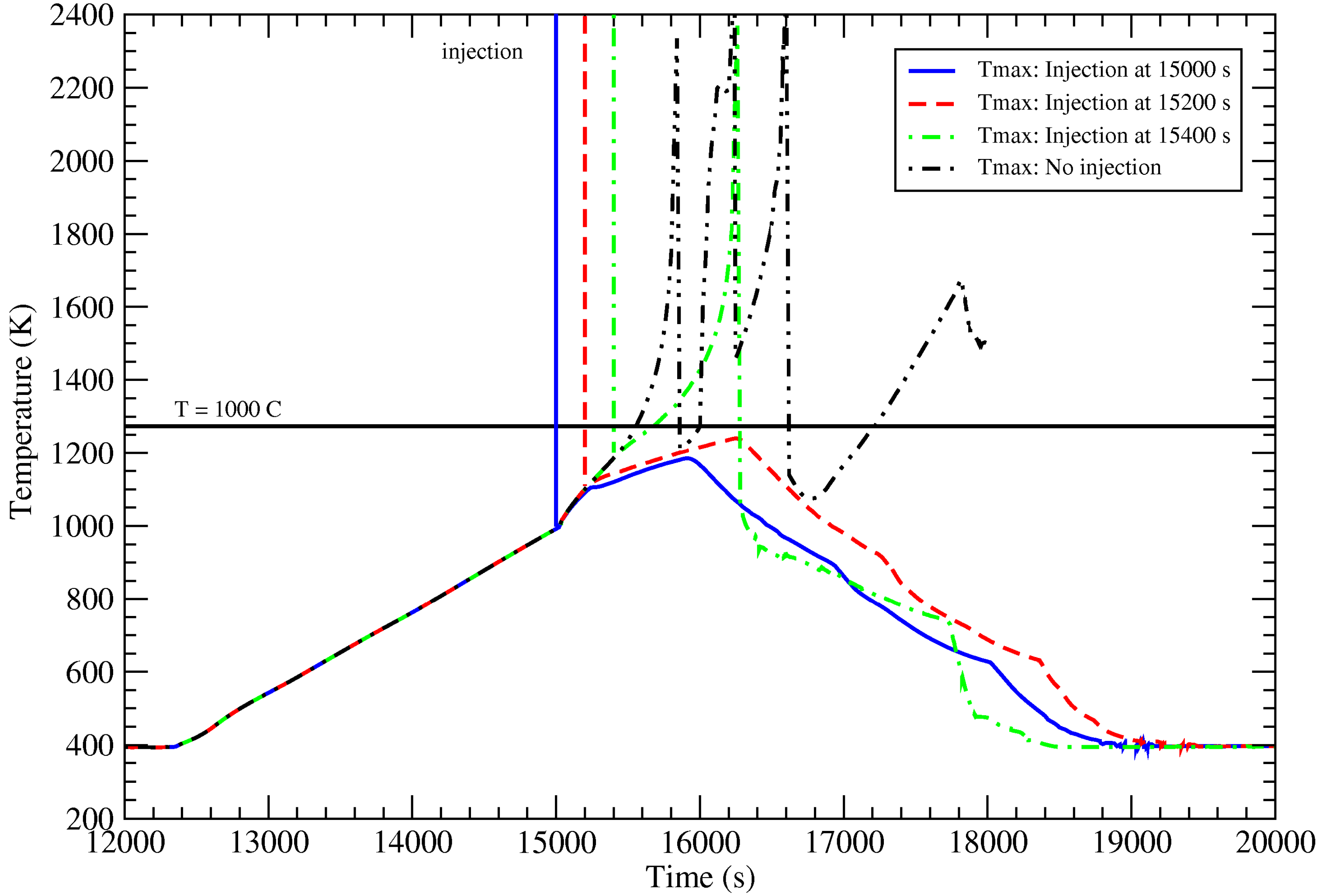
-- / ++ relative to start of injection

* for intact rods

Comparison of core liquid levels



Comparison of maximum fuel rod temperatures



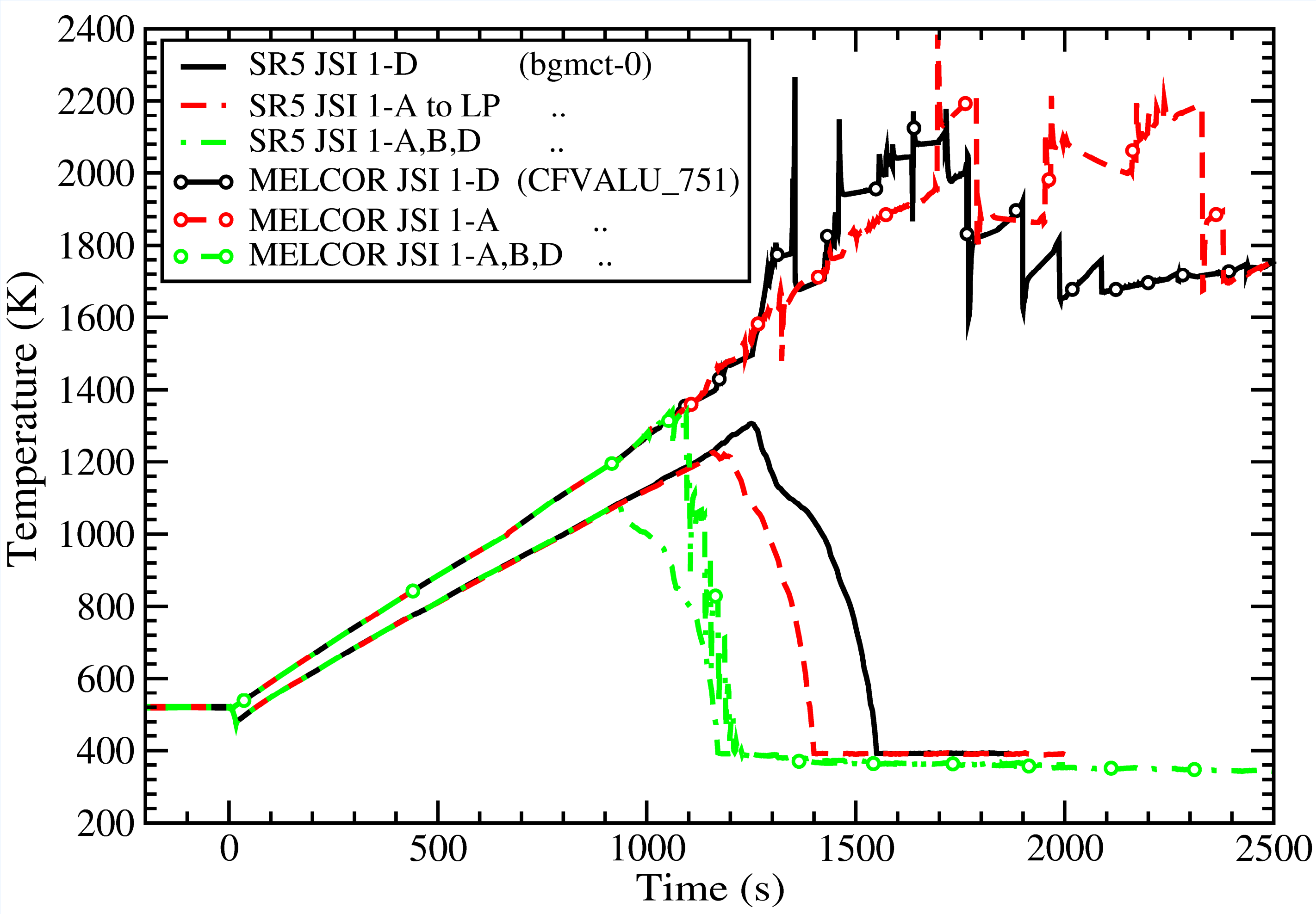
Loss of RHR during mid-loop operation

- Summary
  - Core can be recovered with just 3.5 kg/s injected (one charging pump) before oxidation excursion
    - Insensitive to injection rate as low as 3.0kg/s
  - Injection can be delayed until core is about 50% uncovered
    - corresponds to max. core temperature of about 1000 K in reference case
    - high likelihood of oxidation excursion if injection is delayed further
  - Details appear in Accident Management following Loss of Residual Heat Removal during Mid-Loop Operation in a Westinghouse Two-Loop PWR (J. Birchley, T.Haste, M.Richner, Nuclear Engineering and Design)

LOCAs during shutdown operation

- Objective
  - Examine the margin against core damage when actuation of safety injection is delayed
- Large break LOCA
  - No accumulator available
  - Base case assuming 30s delay for JSI 1-D safety injection shows core recovery without core damage
  - Three sensitivity cases assuming 930s delay to study safety margin against safety injection availability
    - Case I: Full injection rate with only JSI 1-D
    - Case II: Full injection rate with only JSI 1-A
    - Case III: Full injection rates with JSI 1-A, B and D

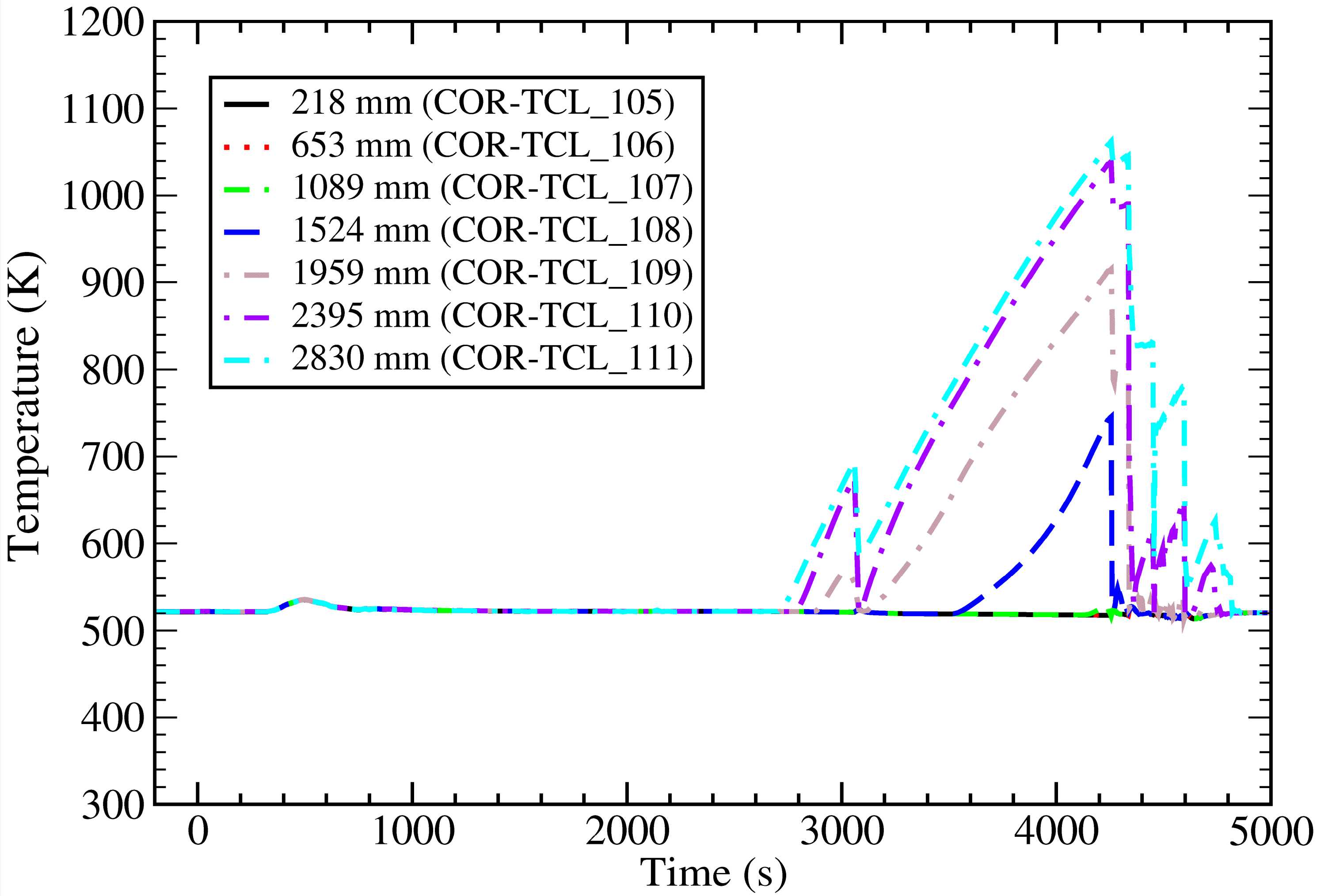
Comparison of cladding temperatures (Effect of JSI availability and injection point)



LOCAs during shutdown operation

- Small break LOCA (3cm)
  - No accumulator available
  - Full injection of only one pump (JSI 1-D) at 1500s after core uncovery
  - Secondary side at constant pressure (37bar)

Cladding temperatures in central ring



LOCAs during shutdown operation

- Summary
  - Large break LOCA
    - MELCOR calculations indicated that with 930s delay, one pump alone might not be sufficient, as the temperatures at the start of core refilling are already high enough for clad oxidation to start
    - If all three JSI pumps available after 930s delay, MELCOR shows that the injection taken may be sufficient to refill the core
  - Intermediate break LOCA (20cm)
    - Recovery shown for injection of one pump alone (JSI 1-D) delayed by 930s
  - Small break LOCA (3cm)
    - Recovery shown for injection of one pump alone (JSI 1-D) even actuated at 1500s after core uncovery
  - More details presented in MELCOR AND SCDAP ANALYSES OF LOSS-OF-COOLANT ACCIDENTS DURING COOLDOWN IN A WESTINGHOUSE 2-LOOP PWR (J. Birchley, T.Haste, M.Richner, NENE 2007 Conference)

LOCAs during full power operation

- Objective
  - Examine effect of SG reflux condensation on core recovery
  - Help the detailed analysis for the success criteria of the recirculation safety injection system once the injection rate is limited by sump clogging
- Assumptions
  - SGs depressurized at 50K/h, AFW available
  - Accumulators available
  - Before switching to sump recirculation
    - Full injection rates available for safety injection pumps JSI 1-A,B,D
  - When switching to sump recirculation
    - One recirculation injection pump available
    - Actuated when core is about 50% uncovered
    - With limited injection rates varying from 0.0 to 10.0kg/s

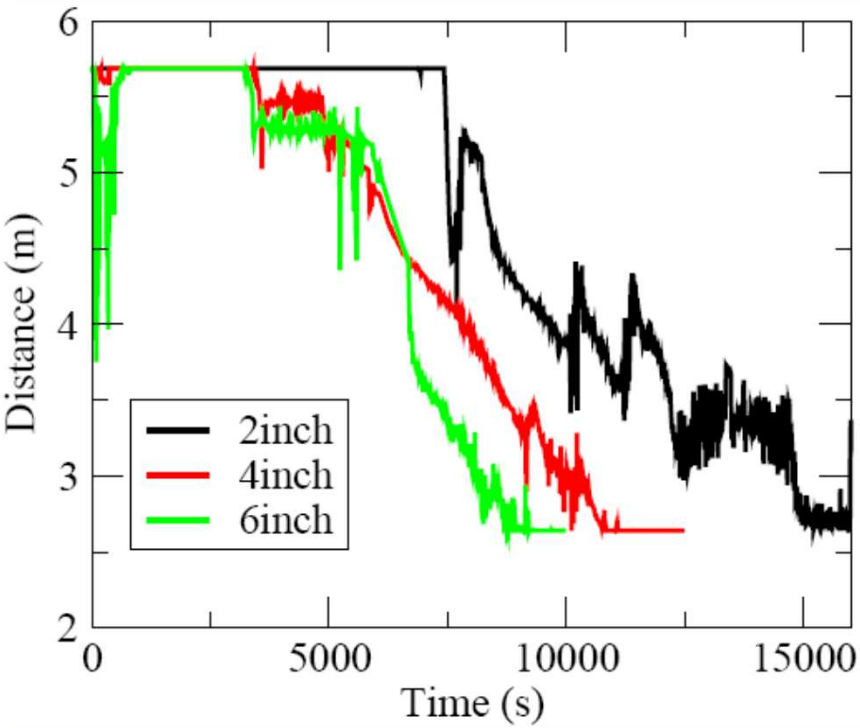
MELCOR cases

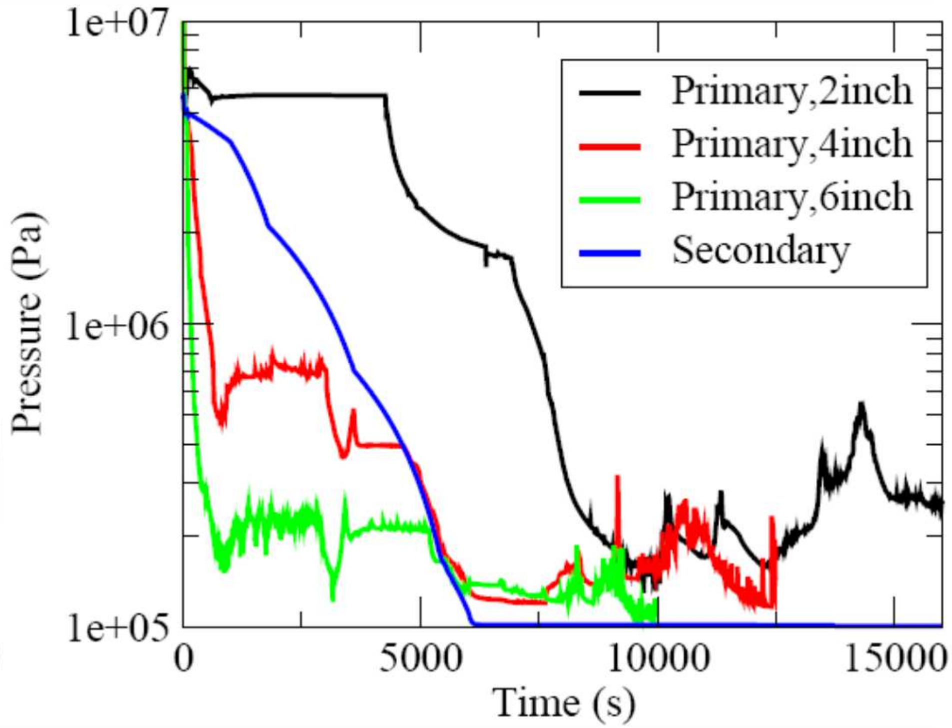
Case Nr.	Break size			Recirculation injection pump availability and flow rate				SG reflux condensation	
	2in	4in	6in	No	10.0kg/s	8.0kg/s	3.0kg/s	Yes	No
Nr.1	x			x				-	
Nr.2		x		x					
Nr.3			x	x					
Nr.4	x				x			x	
Nr.5	x				x				x
Nr.6	x					x		x	
Nr.7	x					x			x
Nr.8	x						x	x	
Nr.9	x						x		x

Cases 1-3: No recirculation injection pump available

Comparison of core water levels

Comparison of pressures



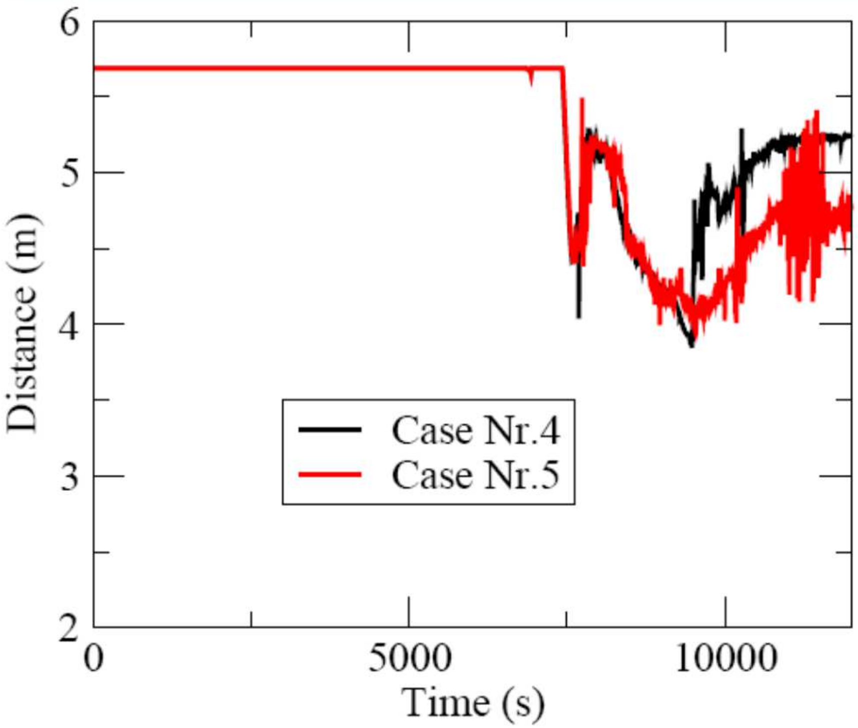


Cases 1-3: No recirculation injection pump available

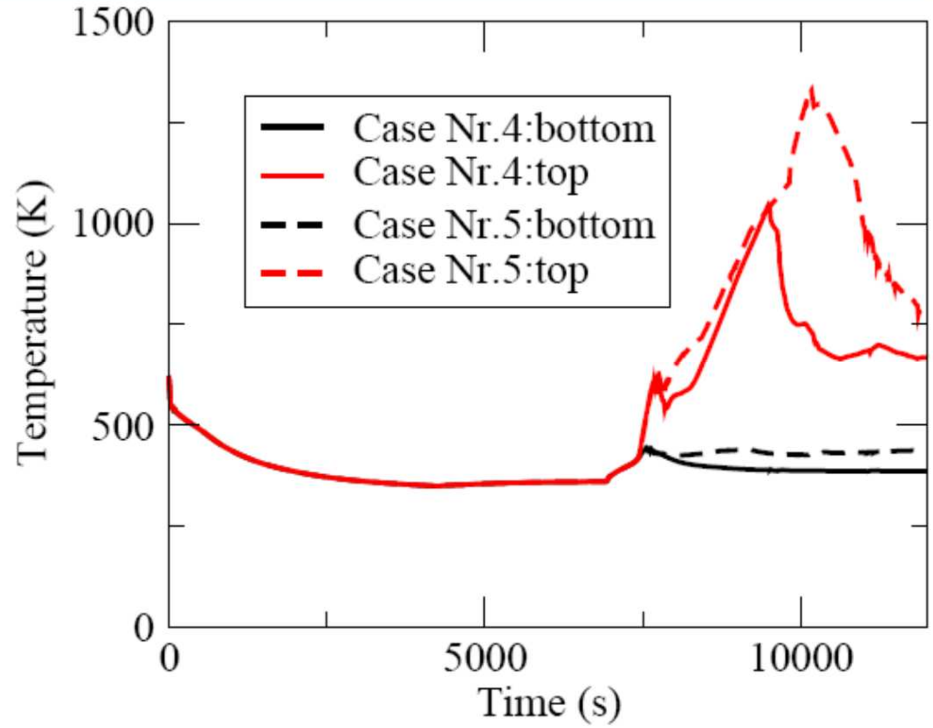
- Summary
  - No core recovery if no recirculation injection pump available
  - SG heat sink established before core uncovery for the 2inch case with a 50K/h depressurization rate
  - SG heat sink may also be established for larger break size LOCAs with a greater depressurization rate
  - SG reflux condensation is more effective for smaller break size LOCAs
  - Next, the 2inch break LOCA analyses in Cases 4 to 9 study the effect of reflux condensation availability combined with limited recirculation injection rates on core recovery

Cases 4,5: Effect of SG reflux condensation with the recirculation injection rate limited to 10.0kg/s

Comparison of core water levels



Comparison of cladding temperatures

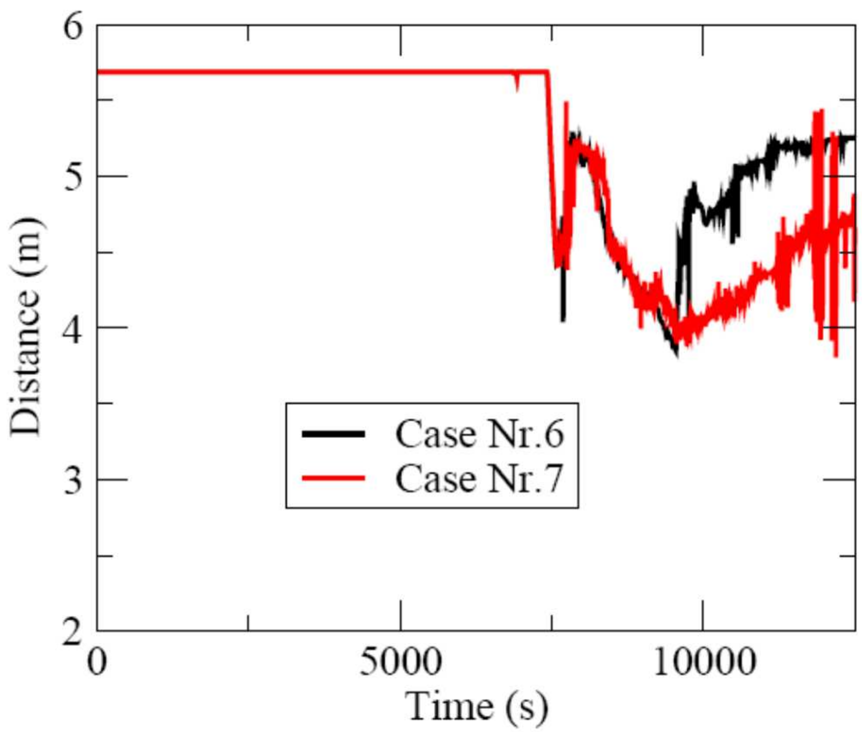


Cases 4,5: Effect of SG reflux condensation with the recirculation injection rate limited to 10.0kg/s

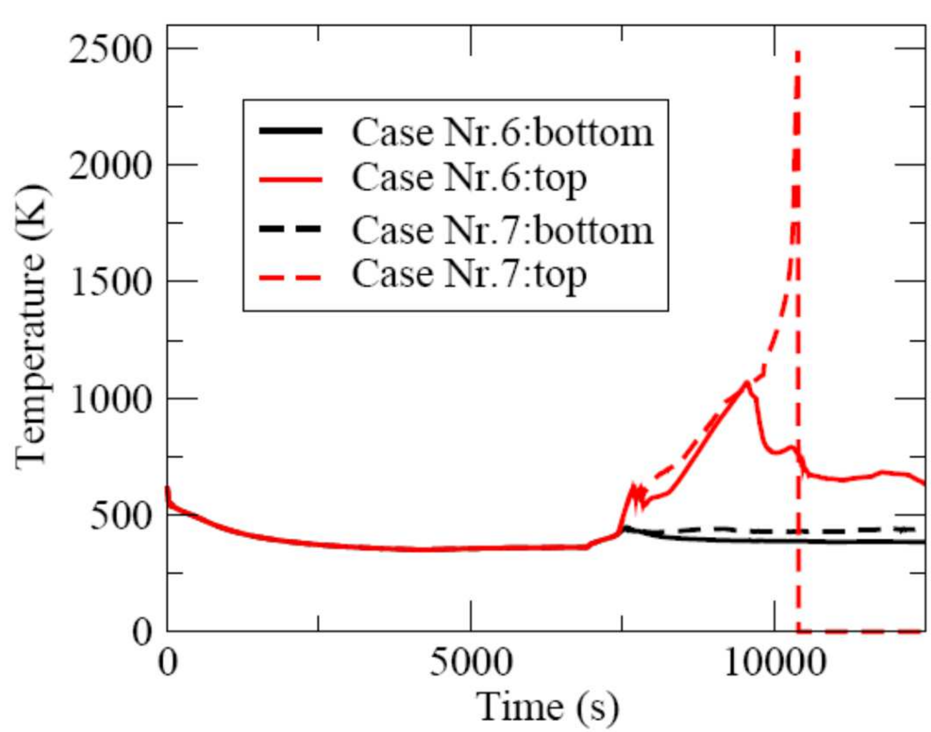
- Summary for Cases 4 and 5
  - With SG reflux condensation taking place, core can be cooled immediately after recirculation injection
  - Without SG reflux condensation, core cannot be cooled so effectively as to avoid cladding failure (>900C)

Cases 6,7: Effect of SG reflux condensation with the recirculation injection rate limited to 8.0kg/s

Comparison of core water levels

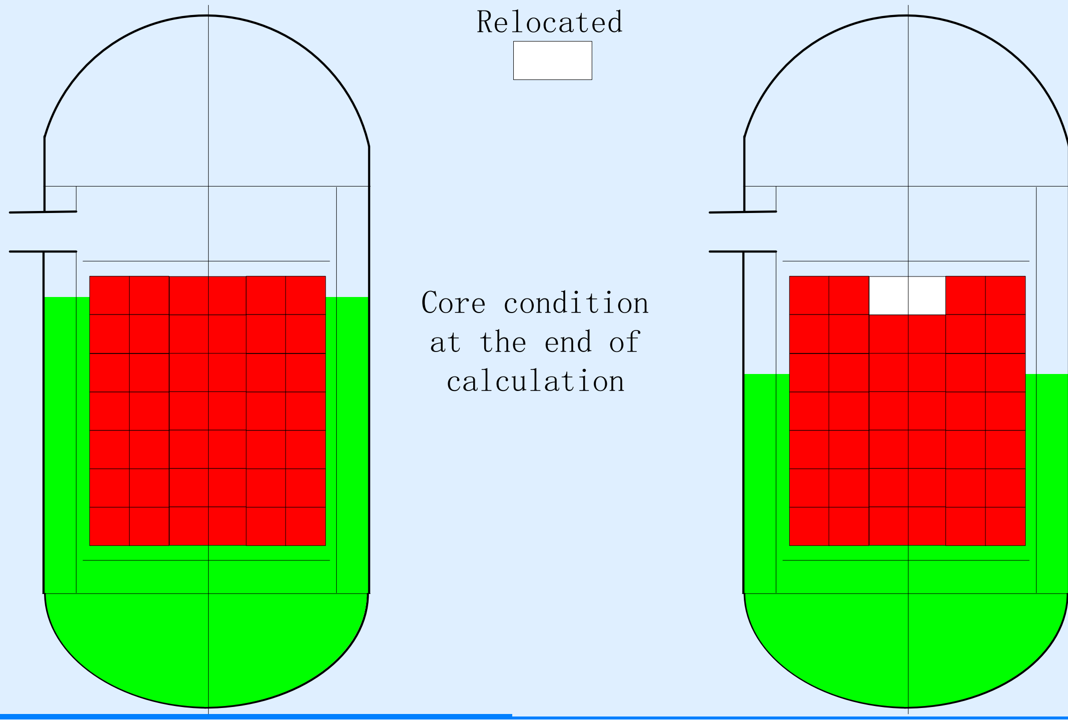


Comparison of cladding temperatures



Cases 6,7: Effect of SG reflux condensation with the recirculation injection rate limited to 8.0kg/s

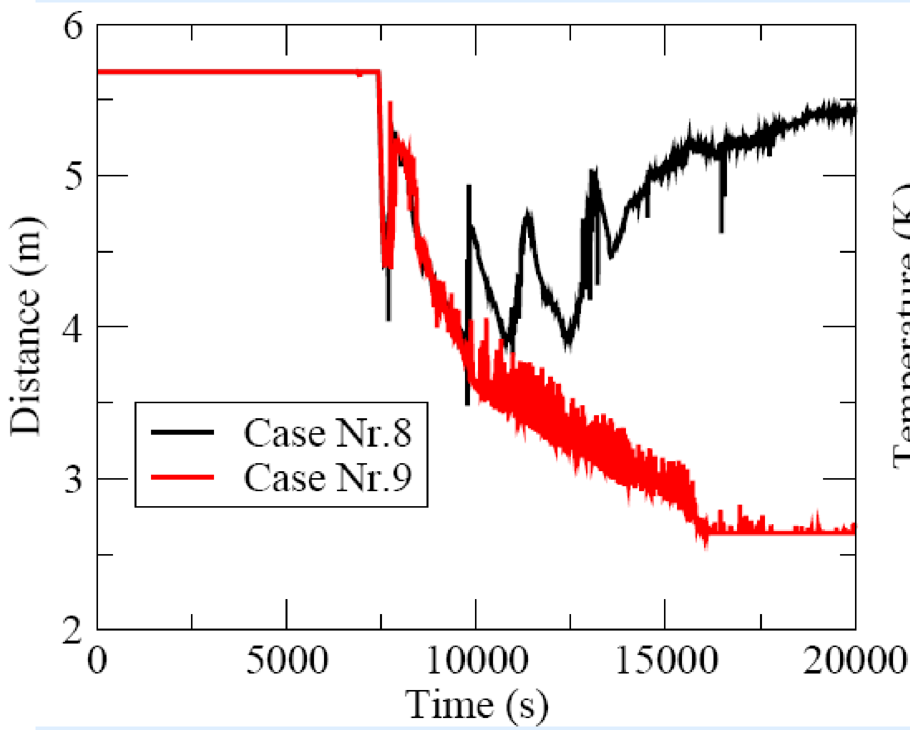
- With reflux condensation:
  - core can be recovered without any cladding failure
- Without reflux condensation:
  - core is damaged and relocated

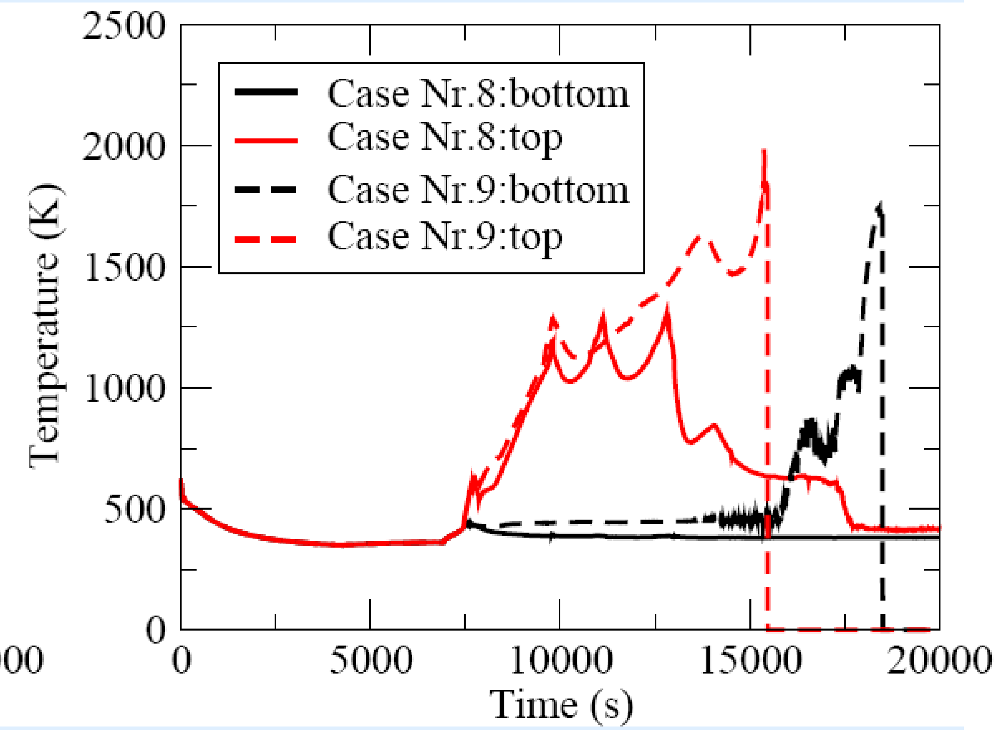


Cases 8,9: Effect of SG reflux condensation with the recirculation injection rate limited to 3.0kg/s

Comparison of core water levels

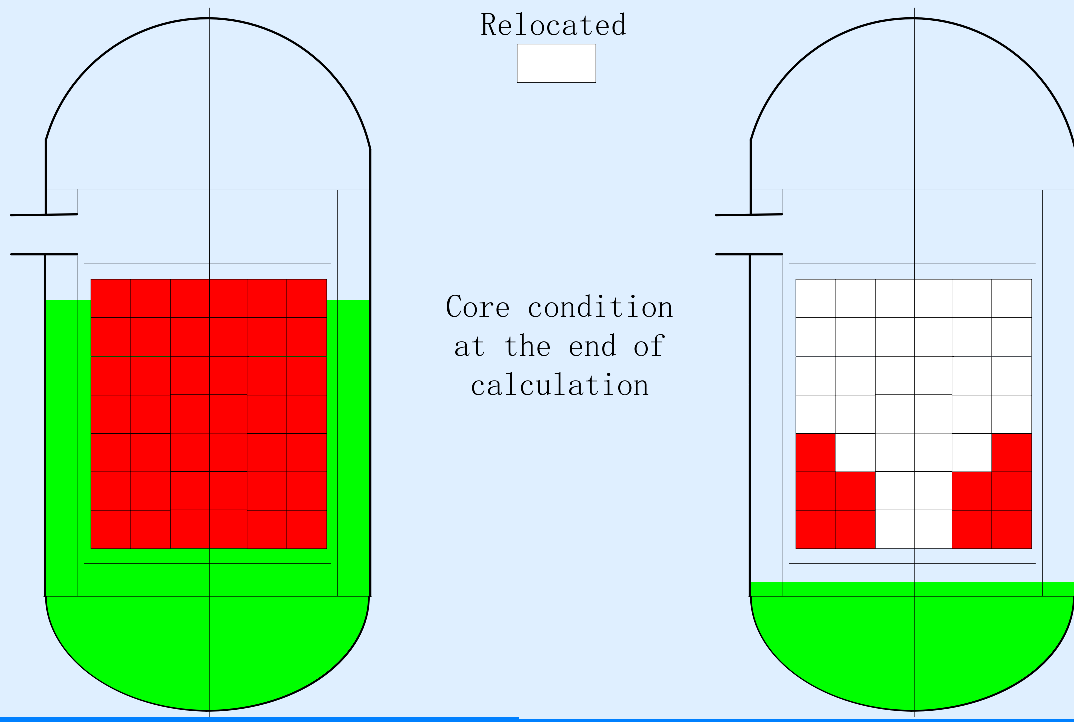
Comparison of cladding temperatures



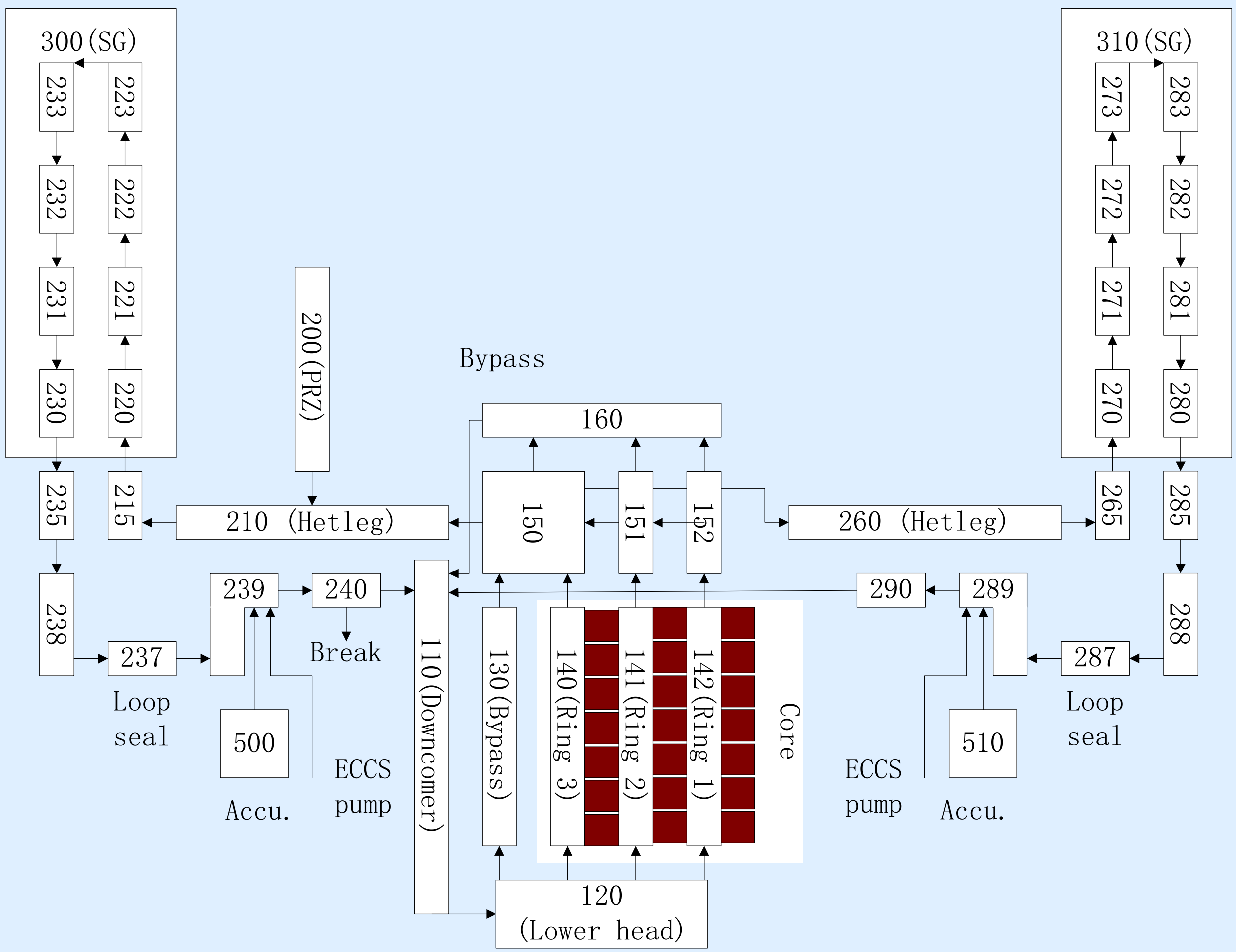


Cases 8,9: Effect of SG reflux condensation with the recirculation injection rate limited to 3.0kg/s

- With reflux condensation:
  - core can be recovered with PCT<1204C
- Without reflux condensation:
  - core is relocated to the lower head



Sensitivity study to the primary side nodalization

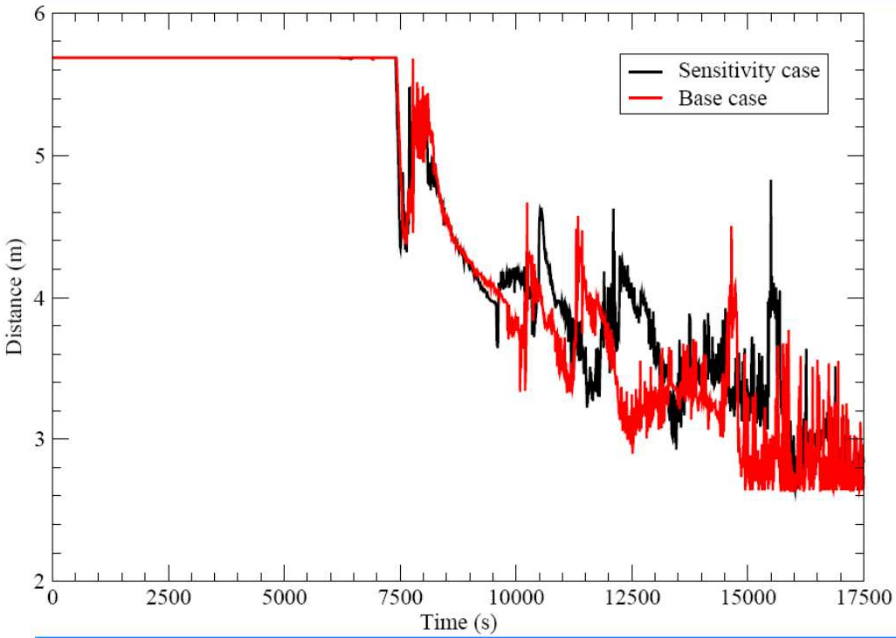


Sensitivity study to the SG and upper plenum nodalization

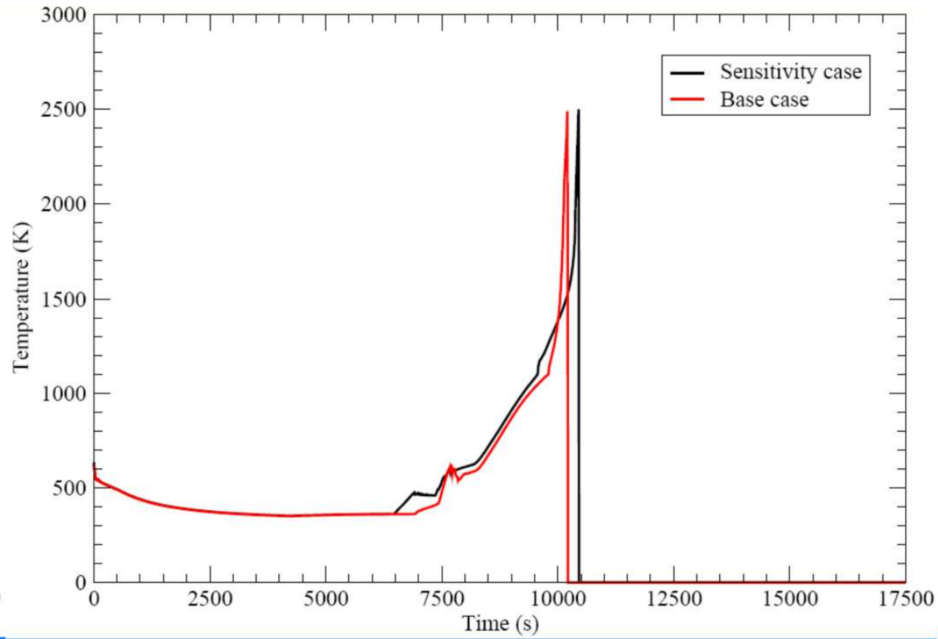
Base case: 2-node SG, 1-node upper plenum

Sensitivity case: 8-node SG, 4-node upper plenum

Comparison of core water levels



Comparison of cladding temperatures

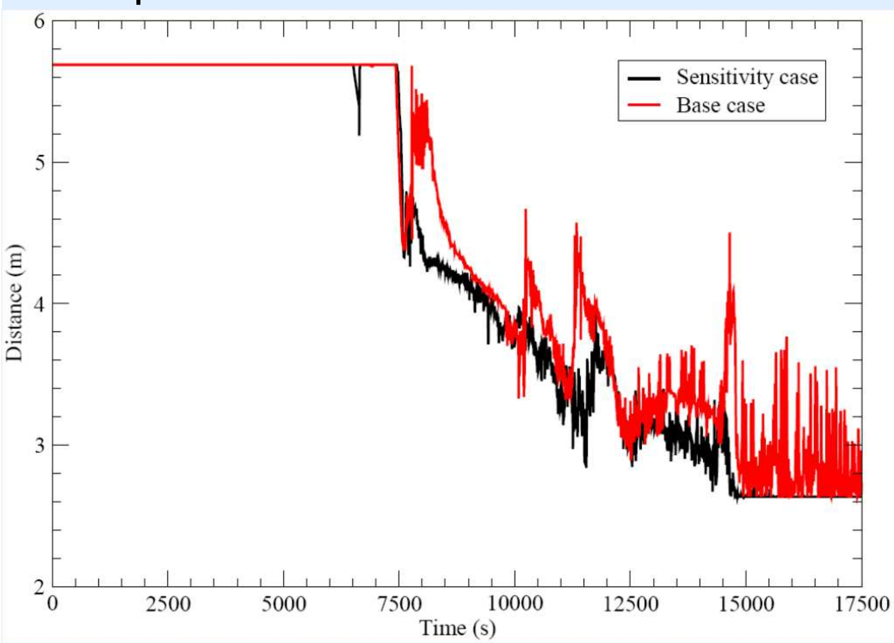


Sensitivity study to the core nodalization

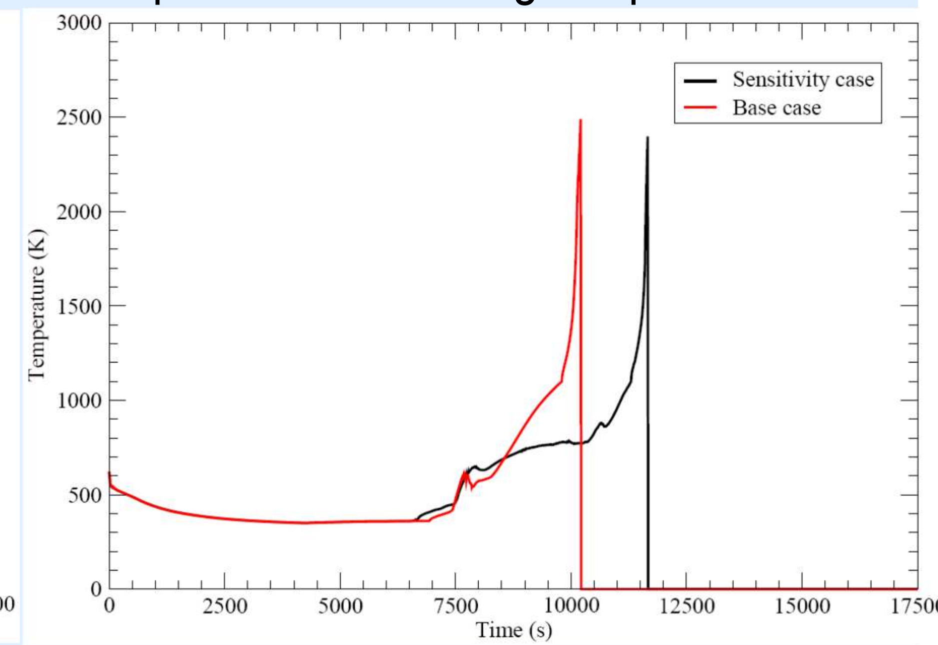
Base case: 2-node SG, 1-node upper plenum, 3-node core

Sensitivity case: 8-node SG, 4-node upper plenum, 9-node core

Comparison of core water levels



Comparison of cladding temperatures



LOCAs during full power operation

- Summary
  - SG heat sink can be established by depressurization for small break LOCAs
  - SG reflux condensation significantly aids core recovery
  - When SG reflux condensation taking place, the recirculation injection system is successful to avoid core damage with injection rates as low as about 3.0kg/s
  - Without SG reflux condensation, the recirculation injection system alone is not successful to avoid core damage with injection rates as high as about 10.0kg/s
  - MELCOR simulation of reflux condensation insensitive to the nodalization
  - Uncertainties may exist for modeling reflux condensation, especially in the presence of noncondensable gases

Conclusions

- MELCOR has been successfully applied to various plant accident analyses at PSI
- MELCOR was used to demonstrate the safety margin against availability of safety injections, injection delay times and limited injection rates
- MELCOR predicted significant SG reflux condensation rates, which ensures core recovery even with limited recirculation injection rates
- Comparison to SCDAP/RELAP5 indicated a degree of conservatism for MELCOR
- MELCOR user experience on condensation heat transfer with SG tubes
  - MELCOR sometimes reminds that SG heat structure is deactivated with such a message: ‘HSOFF: HEAT STRUCTURE BEING DEACTIVATED’
  - MELCOR sometimes reports ‘TEMPERATURE CONVERGENCE FAILURE’ when condensation taking place