Sensitivity study of CVH nodal scheme to MELCOR simulations in a PWR of Westinghouse designs.

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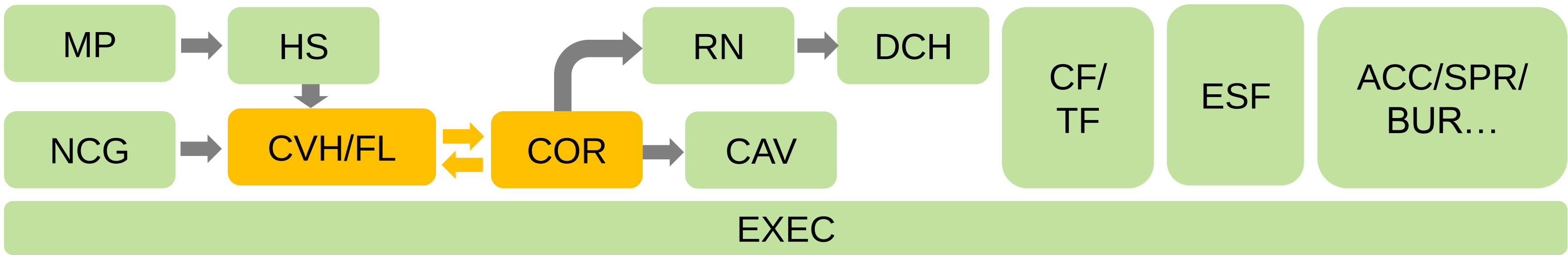
Background

- Develop a MELCOR model of PWR for SAMG V&V.
- Preliminary works involve the sensitivity study of MELCOR nodalization, mainly CVH and COR nodalization
- Various COR nodalization and CVH nodal schemes of core are concerned in the modelling.



Outline

- MELCOR model
  I. Model description
- Simulation
  I. Refined CVH nodes
  II. Steady state simulation
  III. Simulation matrix
- Result analysis
  I. Core degradation
  II. Hydrogen generation
  III. Fission products

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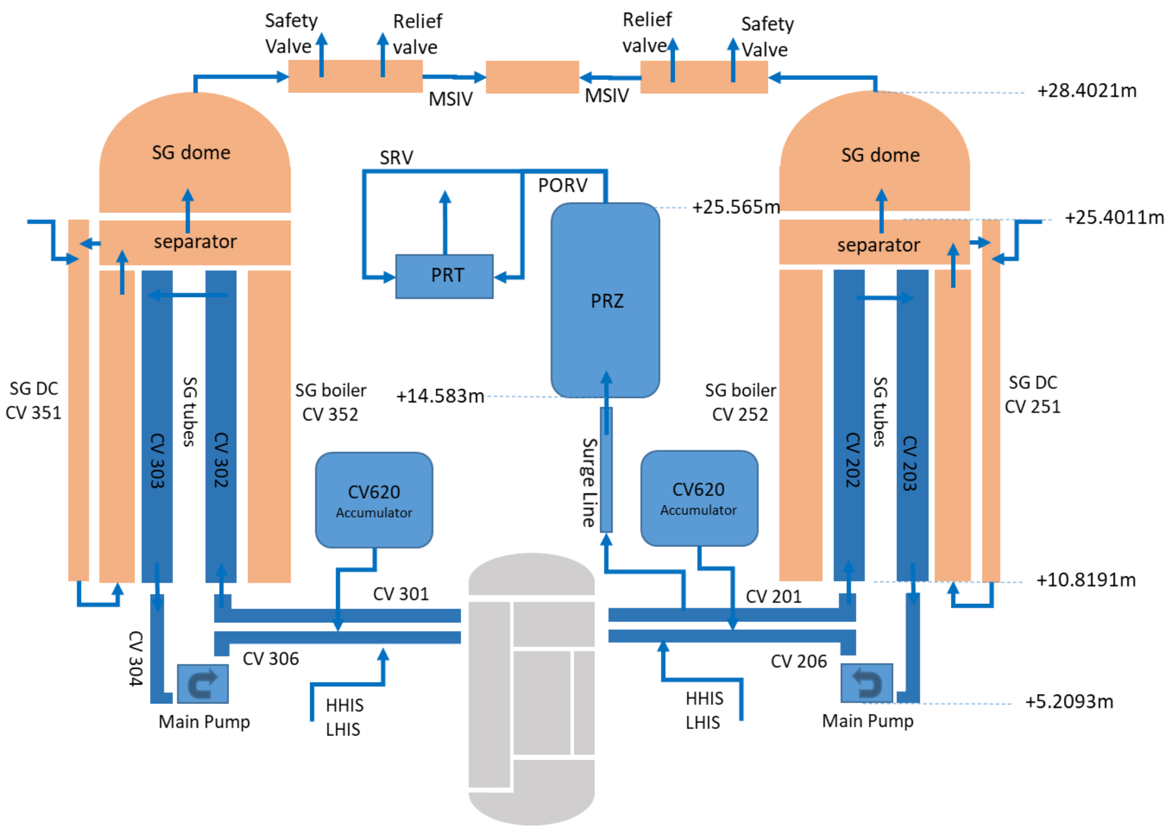
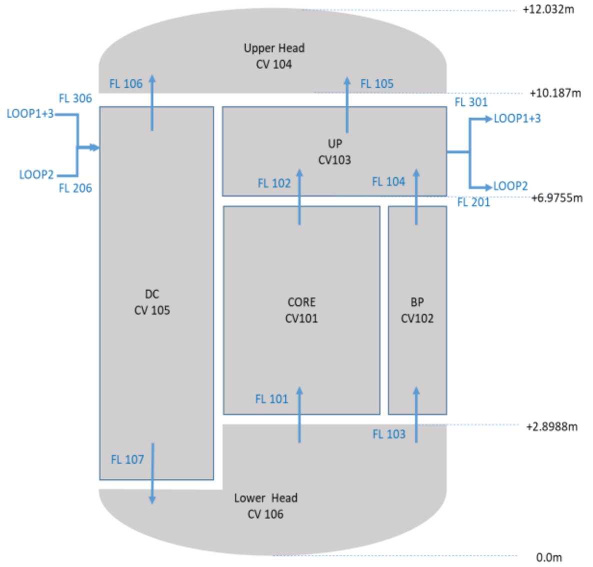
Model description

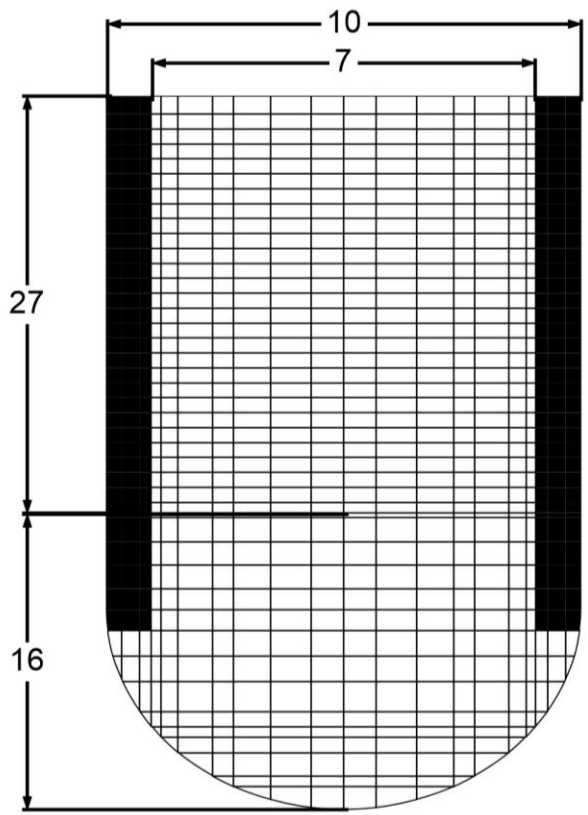
- Nordic PWR with 3 identical loops, with the full capacity of 3152MWt.
- Each loop has hot leg, cold leg, RCP, and a steam generator with 1040MWt capacity.
- Pressurizer connects with the right loop, maintaining the RPV pressure at 15.8 MPa.



Safety systems:
- Safety injection (HHIS, LHIS)
- Accumulators
- Safety relief valves
- PORVs
- Auxiliary feed water systems

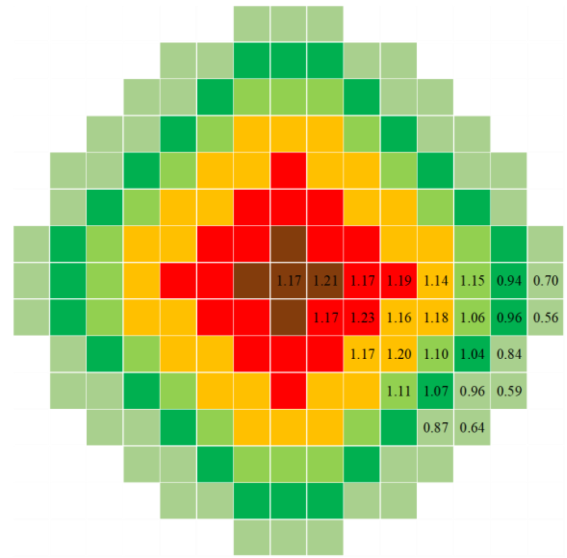


COR nodal scheme

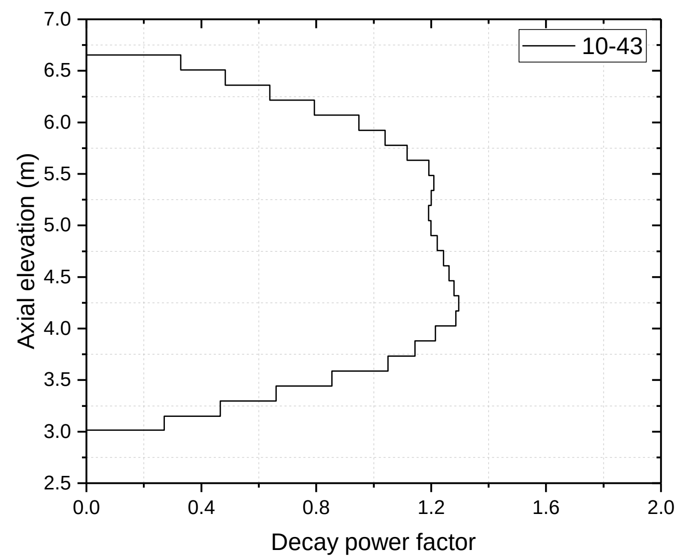


- 43 levels :
  - ✓ 1~16 levels: Lower Head
  - ✓ 17~43 levels: Active Core
- 10 rings (157 assemblies):
  - ✓ Active core: 1~7rings.
  - ✓ Lower head: 1~10rings.

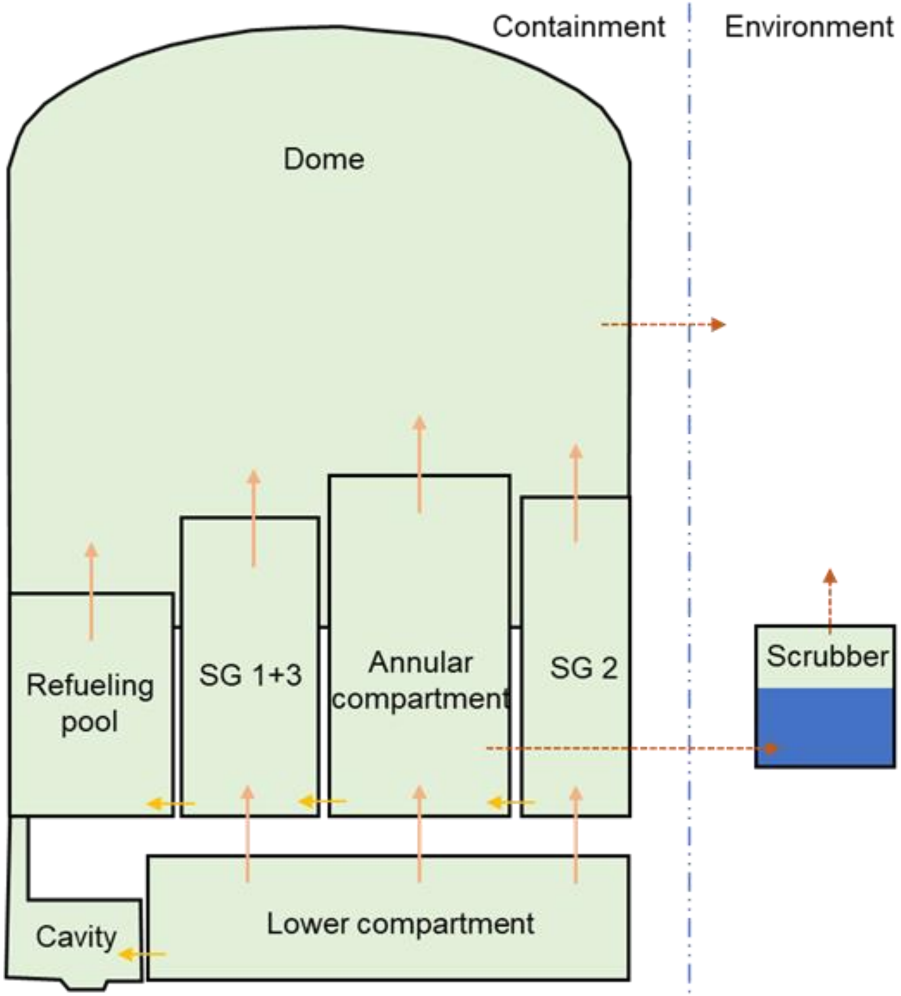
- Radial power distribution



- Axial power factor



Modelling of containment



Containment geometry:

- Inner diameter: 35.4m;
- Total height: ~62m;
- Wall thickness: 1.1m;
- Design pressure: 6.8 bar;
- Gross internal volume: ~50000m3

MVSS:

- Levitation of Scrubber: 10.04m;
- Volume of scrubber: 332 m3;
- Activation criterion: 5.14 bar;

Containment Spray:

- Location: top of containment dome;
- Spray partition coefficients: 5000.0;

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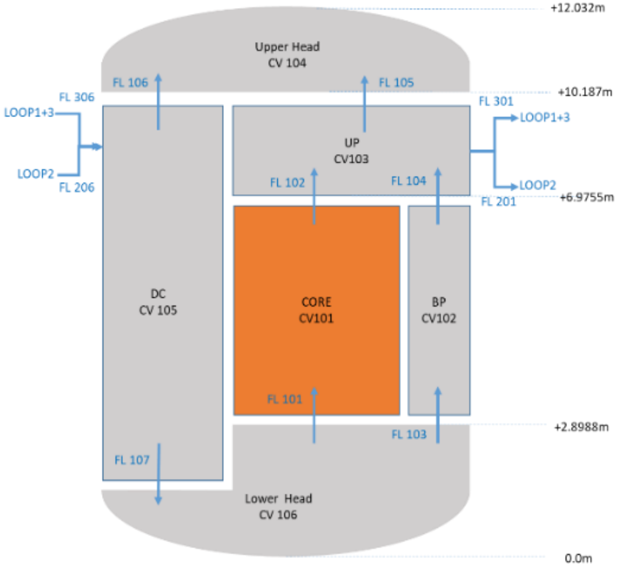
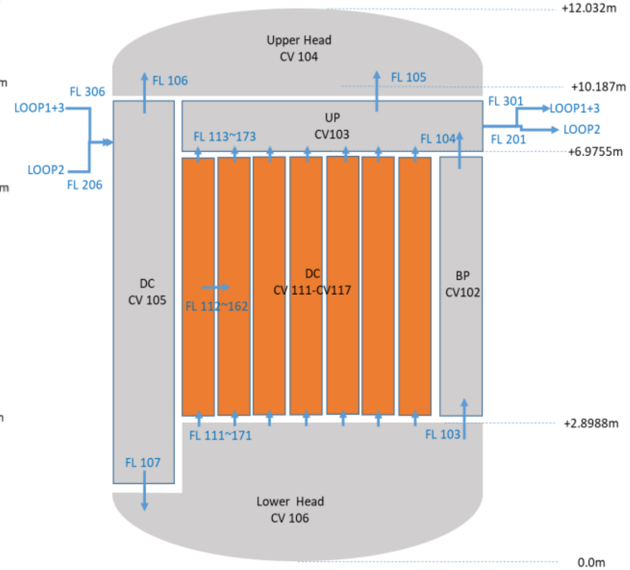
  III. Fission products and in-containment source terms

Refinement of core CVH node

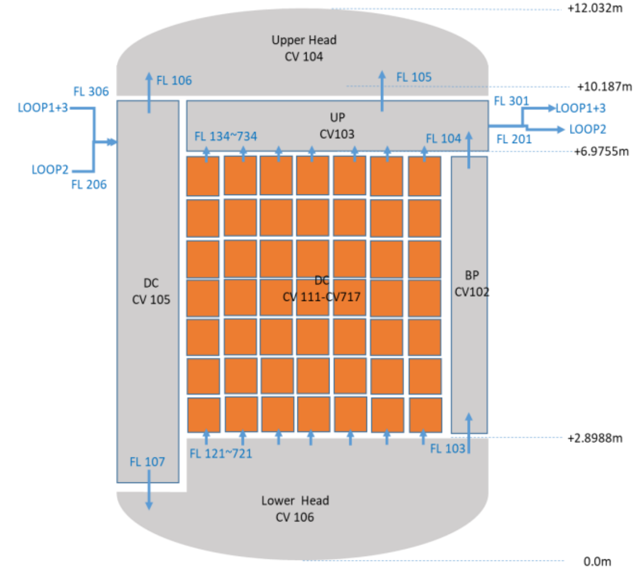
- The general modelling of COR nodalization and CVH nodal scheme for active core are coarse COR mesh and single control volume.
- The sensitivity study of CVH nodal scheme is necessary to develop a stable modelling for further research.



1 Control volume



7 Control volumes



49 Control volumes

- Covers the core support plate and core top plate.
- Contains all COR cells of active core.
- No cross flow to bypass.

- Refine on radial direction.
- Each CV refers to 1 COR ring.
- No cross flow between core and BP.

- Refine along radial and axial direction.
- Each CV contains 4 COR cells.
- Each CV connects with the neighboring CVs.
- No cross flow between core and BP.

Steady-state simulation

Parameters	*1 control volume (reference case)*	*7 control volumes*	*49 control volumes*
Total thermal power (MWt)	**3152**	**3152**	**3152**
RPV pressure (MPa)	**15.87**	**15.87**	**15.87**
Core inlet temperature (K)	**561.29**	**561.31**	**561.30**
Core outlet temperature (K)	**596.35**	**596.36**	**596.35**
Primary flow rate (kg/s) (left loop)	**10591.5**	**10588.7**	**10592.9**
Primary flow rate (kg/s) (right loop)	**5293.6**	**5292.3**	**5292.7**
Secondary side pressure (MPa)	**6.052**	**6.052**	**6.052**
Secondary flow rate (kg/s) (left loop)	**3151.0**	**3150.5**	**3148.4**
Secondary flow rate (kg/s) (right loop)	**1581.9**	**1584.5**	**1584.5**

- The steady-state simulations are performed before the transients in each case.
- To calibrate the refined nodal schemes, the steady-state simulations are performed with full thermal power and full RCP capacity.
- The thermal-hydraulic parameters are compared, and the differences are below 0.5%.

Transient simulation matrix

- **MELCOR version and platform: MELCOR v2.2.9541 on Windows10**
- **Scenario: (1) unmitigated SBO and (2) unmitigated LBLOCA**

  Loss of AC power at 0.0 second, Reactor scrams in 1.0 second.
  RCP and turbine coast down in 60 second.
  Safety injection and AFW are unavailable.
  Passive safety system such as accumulator injection, PARs are available during transients.

	LOCA	***SBO***
Reference case (1 control volume)	LOCA-1CV	SBO-1CV
7 control volumes	LOCA-7CV	SBO-7CV
49 control volumes	LOCA-49CV	SBO-49CV

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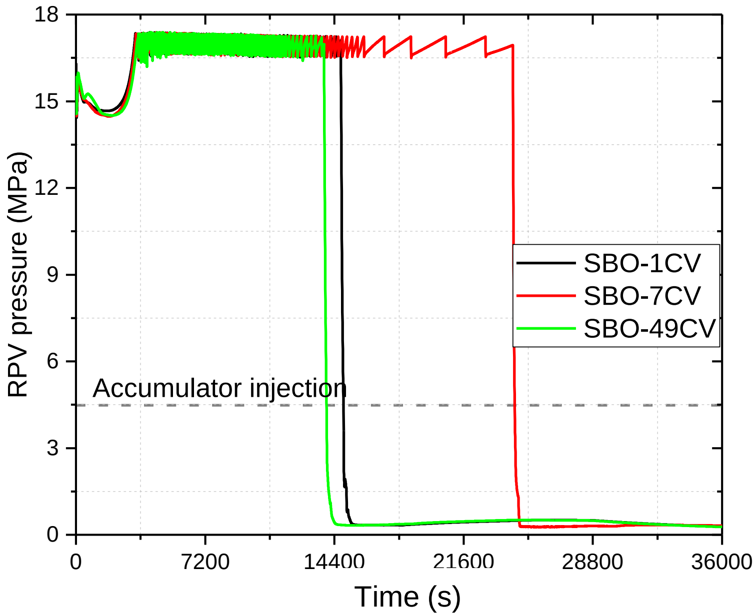
Thermal hydraulic behaviors in RPV (SBO).

- RPV pressure

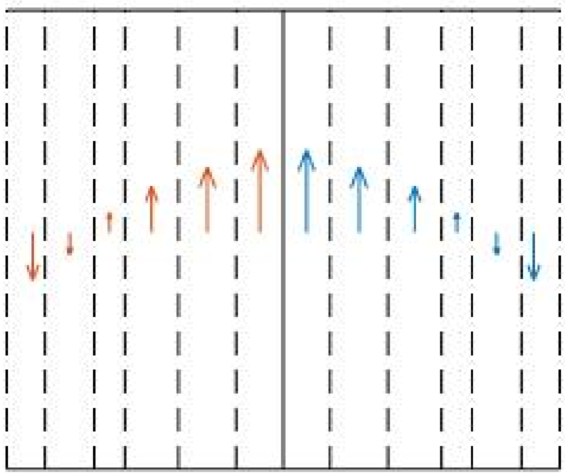


- Timing of events

Events	*Reference (1 Control Volume)*	*7 Control Volumes*	*49 Control Volumes*
Reactor SCRAM	0 s	0	0 s
TAF reached	5962 s	6053 s	5921 s
Cladding failure	7354 s	8797 s	7812 s
BAF reached	7703 s	7855 s	8101 s
RPV boil off	10815 s	15545 s	11975 s
RPV failure	14759 s	30069 s	13822 s
ACC activated	14910 s	24450 s	13965 s
ACC depleted	15095 s	24660 s	14140 s
MVSS activated	25956 s	-	24606 s

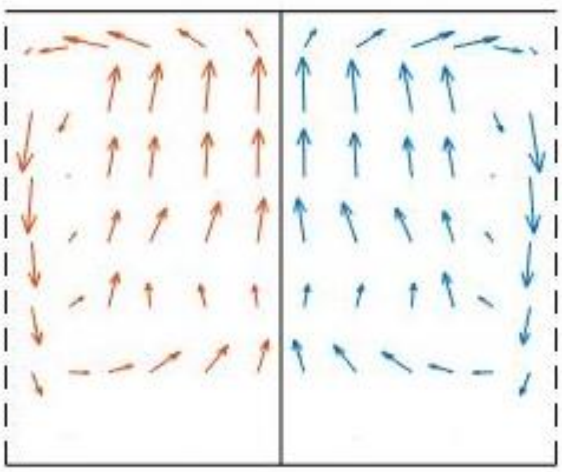
- RPV maintains high pressure until the corium melts through RPV lower head.
- The variations of RPV pressure present little difference between cases in first 3 hours.
- Accumulator injection leads to the spikes of RPV water level.

Flow distribution in active core (SBO).



Area-averaged mass flow rates (kg/m^2s)

LOCA-7CV (BAF reached)



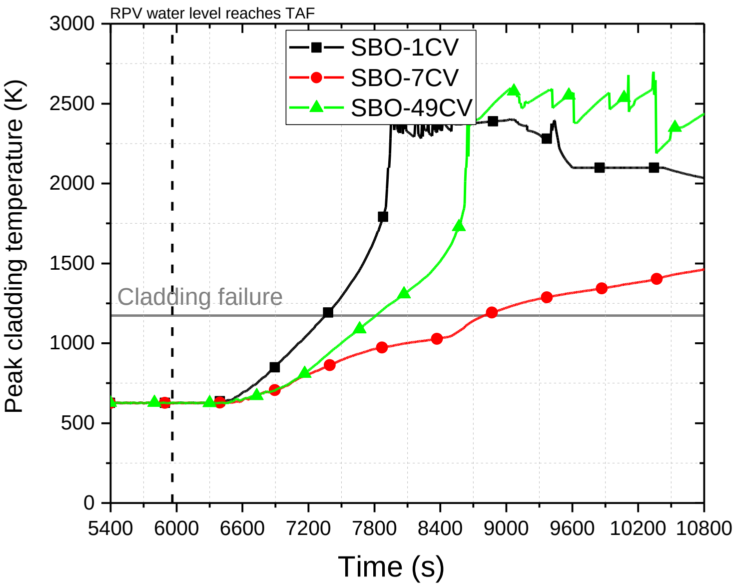
Area-averaged mass flow rates (kg/m^2s)

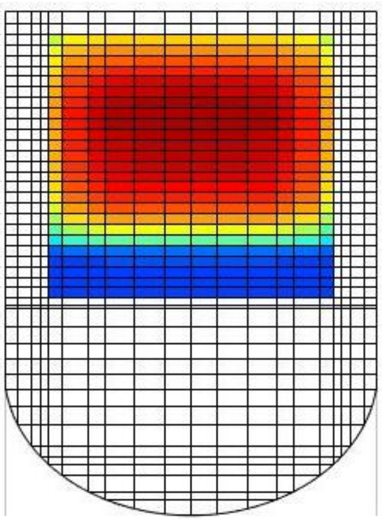
LOCA-49CV (BAF reached)

- In 1CV case, flow distribution in active core is uniform with flow area of core channel.
- In 7CV case, the intermediate rings present higher flow rates, the outer rings present the reverse flows.
- In 49CV case, distinct configurations of natural circulation in RPV are presented.

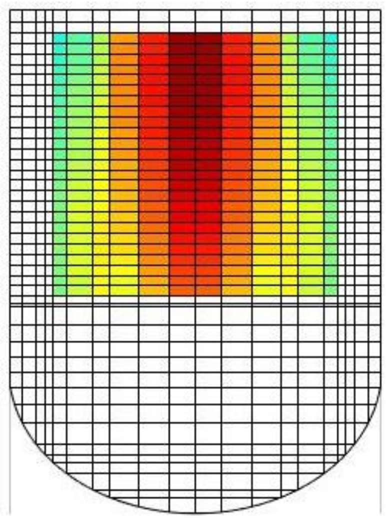
Cladding temperature (SBO).

- Peak cladding temperature

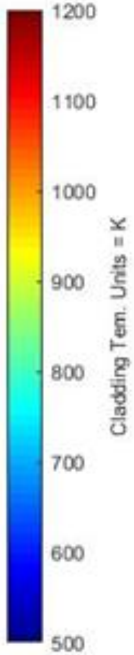


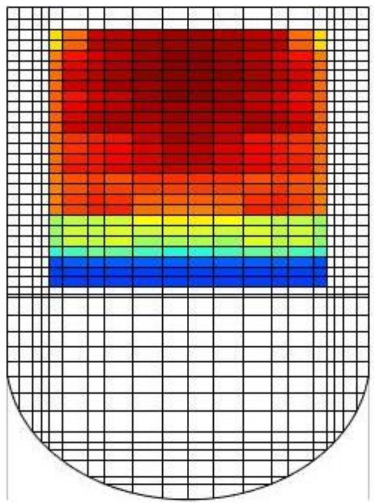


SBO-1CV (reference)



SBO-7CV

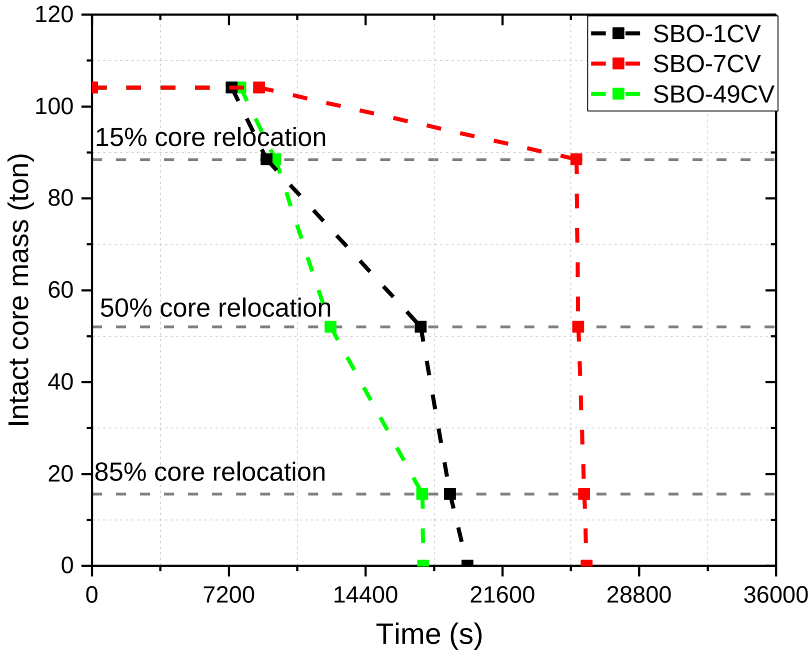




SBO-49CV

- The variations of cladding temperature perform differently with LOCAs.
- The 7CV case predicts the slower increasing of peak cladding temperature.

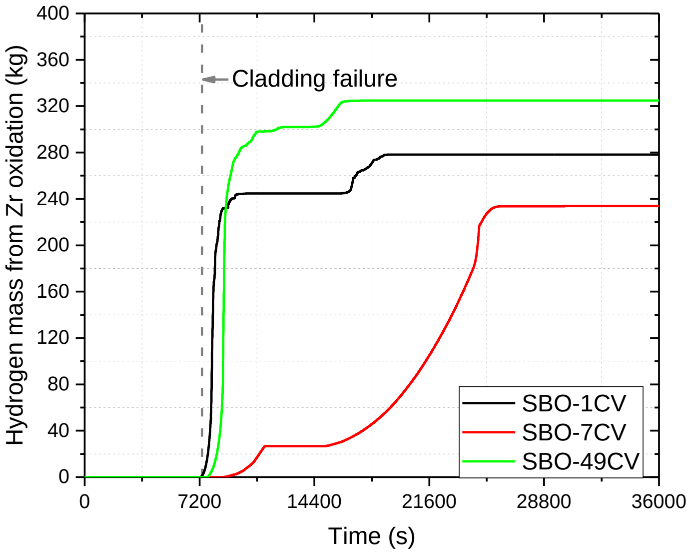
Core damage states (SBO).



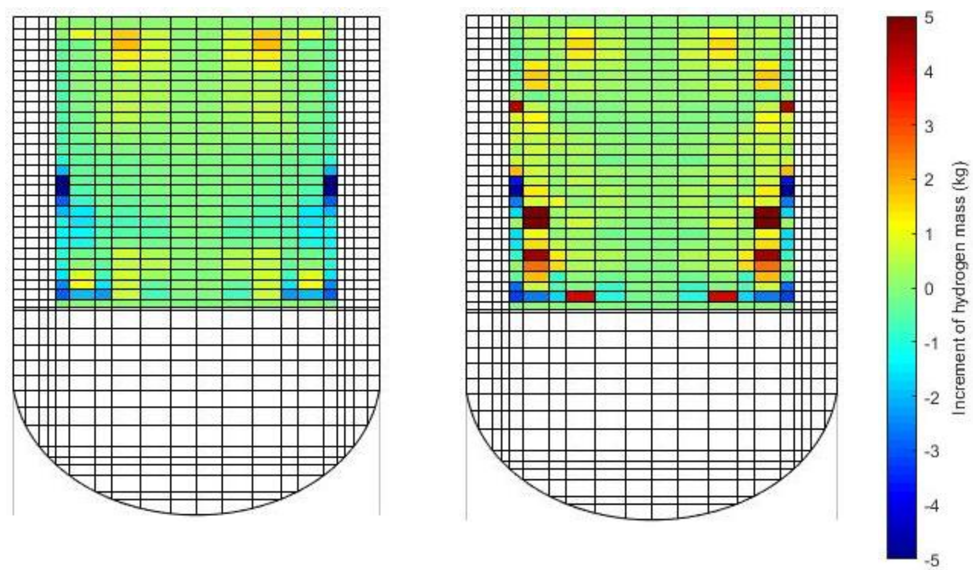
- The 7CV case and 49CV case predict later cladding failure following the slower increasing of cladding temperature.
- In 7CV case, retarded core degradation is predicted.
- In 49CV case, the earlier core degradation is predicted comparing to reference case.

Hydrogen generation (SBO).

- Cumulative hydrogen generation (kg)



- Increments of hydrogen mass in COR cell (kg)



LOCA-7CV LOCA-49CV

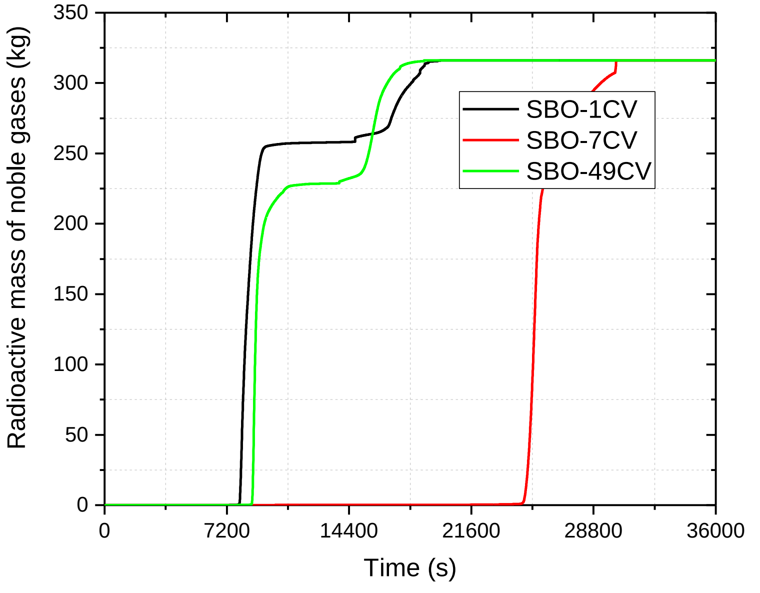
- More hydrogen production in SBO-49CV case.
- The natural circulation in SBO-7CV case results in the lower cladding temperature, leading to the reduction of hydrogen generation in the COR cell of outer rings.
- Steam supply by cross flows leads to more hydrogen generation in SBO-49CV case.

The Increments of hydrogen mass are calculated from the final difference of hydrogen mass generated by cladding oxidation in each COR cell.

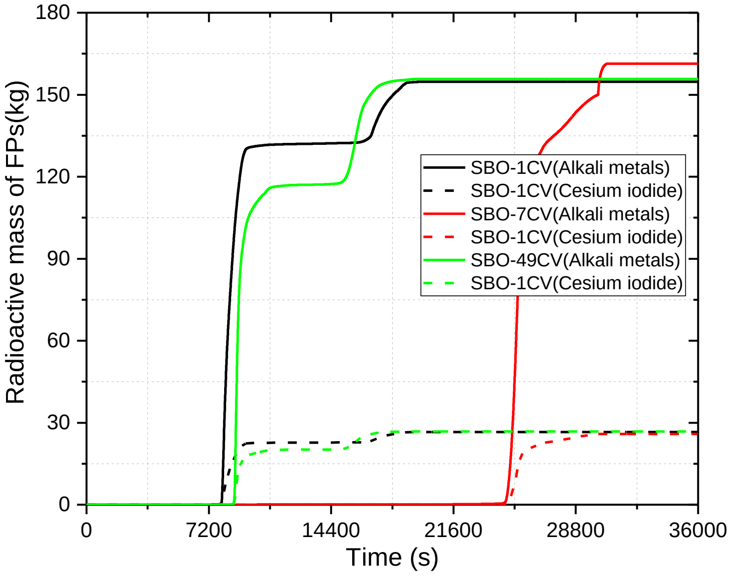
Warm color represents the increment of hydrogen production; cold color represents the reduction of hydrogen production.

Fission products released from fuel (SBO).

- Noble gases (XE class)



- Alkali metals (CS class) and Cesium iodide (CSI class)



- Similar with LOCAs, the CVH nodalization presents little effect on the release of radioactive fission products from the active core.
- Almost 99% initial inventories of noble gases and dissoluble fission products are released from fuel.
- The release of fission products is more likely related to core relocation.

Concluding remarks

- The 49 CV nodal scheme in active core tends to predict the earlier cladding failure, faster core relocation, earlier RPV failure and more hydrogen generation from active core. (more conservative for severe accident simulations.)

- The 7CV nodal scheme perform differentially in LOCA and SBO case. In SBO case, the 7CV nodal scheme tend to predict the later core relocation and less hydrogen production. (different in LBLOCA case) ~multiple flow paths between CVs?

- The final released masses of fission products present little relevance to CVH nodal scheme.

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