European MELCOR Users Group Meeting (EMUG) 2012:

Modelling In-Vessel-Retention

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Overview

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- Critical heat flux (CHF)
  - Experimental results
  - CHF correlation in MELCOR
- Model of In Vessel Retention
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- Results
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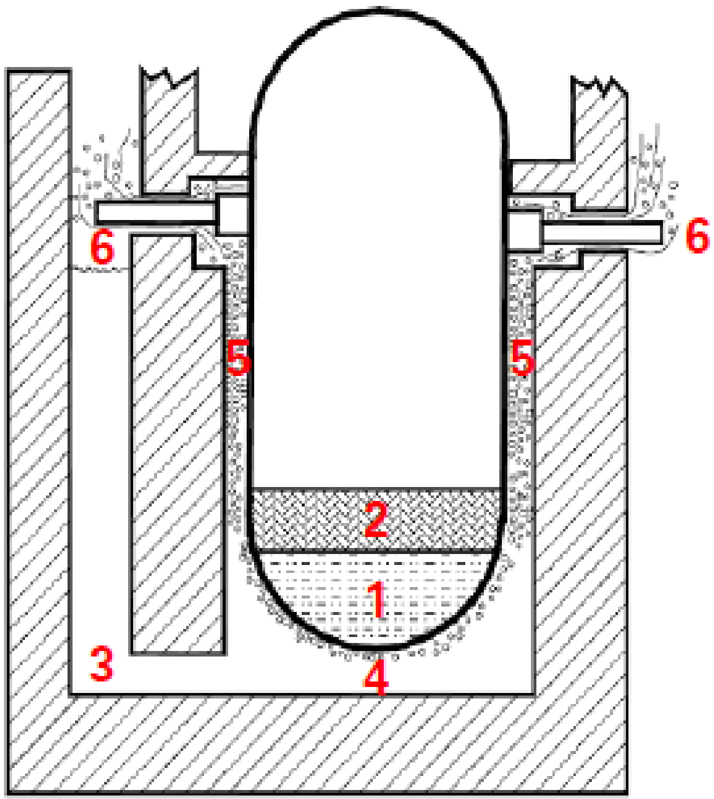
  - Variation – SB-LOCA with lower flow rate
  - Variation – SB-LOCA with increased decay heat
  - Variation – 200 cm^2 LOCA
- Summary

Introduction

In-vessel melt retention (IVMR) concept



Principle:

1: oxidic melt layer,
2: metallic melt layer,
3: channel for cooling water,
4: reactor pit,
5: rising two-phase mixture,
6: separation of liquid phase and steam at the elevation of the primary coolant lines

Source: Westinghouse Electric Company, AP1000 European Design Control Document, Chapter 39, Pittsburgh, 2009

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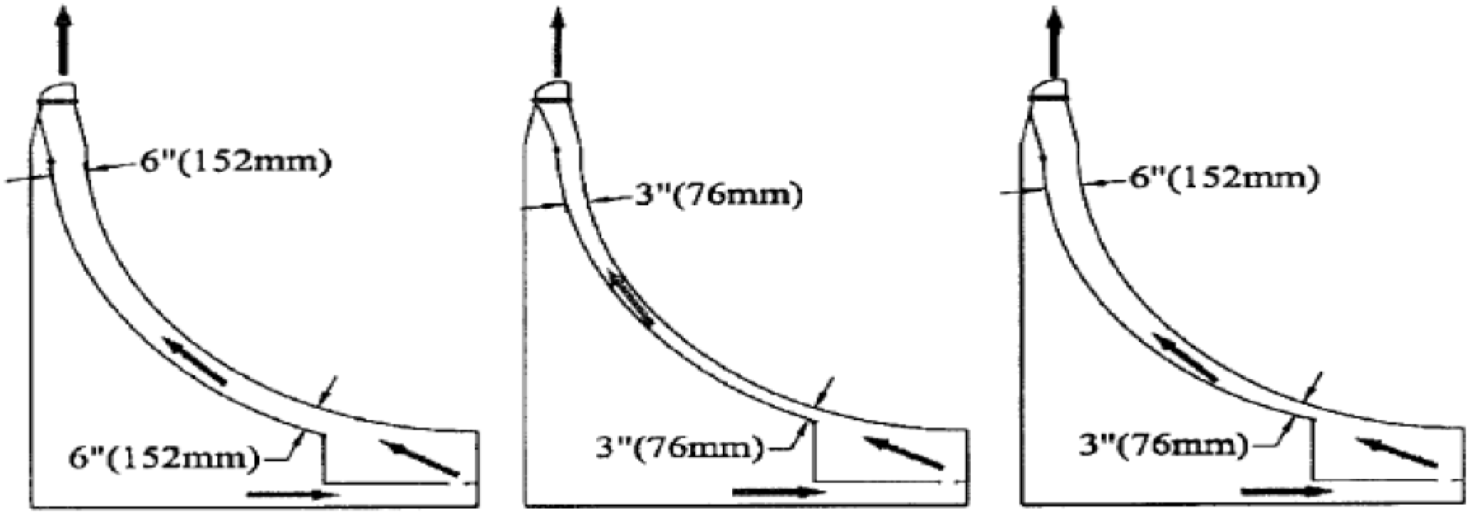
Critical heat flux (CHF) - Experimental results

- Determination of Critical Heat Flux (CHF) for AP600 (ULPU-III, -IV) and AP1000 (ULPU-V) geometries
- ULPU-III: simple flow duct (consists of inclined metal sheet)
- ULPU-IV: improved flow duct (constant flow channel width)
- ULPU-V: improved flow duct + optimized flow cross section
- Results: CHF in dependence of surface inclination of RPV



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Critical heat flux (CHF) - CHF correlation in MELCOR (1)

Calculation of the critical heat flux in MELCOR

$$q_{CHF}(\theta) = (A + B * \theta^{C}) * \rho_G^{0,5} * h_V * [g * \sigma * (\rho_F - \rho_G)]^{0,25} * \frac{kW}{m^2}$$

	A	B	C
Default values MELCOR	0,034	0,0037	0,656
Values (experiment ULPU V)	0,069	0,0067	0,656

ULPU boundery conditions:

- 5 K subcooled water
- pressure of 1.7 bar (abs.)

Θ: surface angle (0 = horizontal)

σ: surface tension gas- fluid

ρ_G, ρ_F: density gas, fluid

h_V: evaporation enthalpy

g: gravity acceleration

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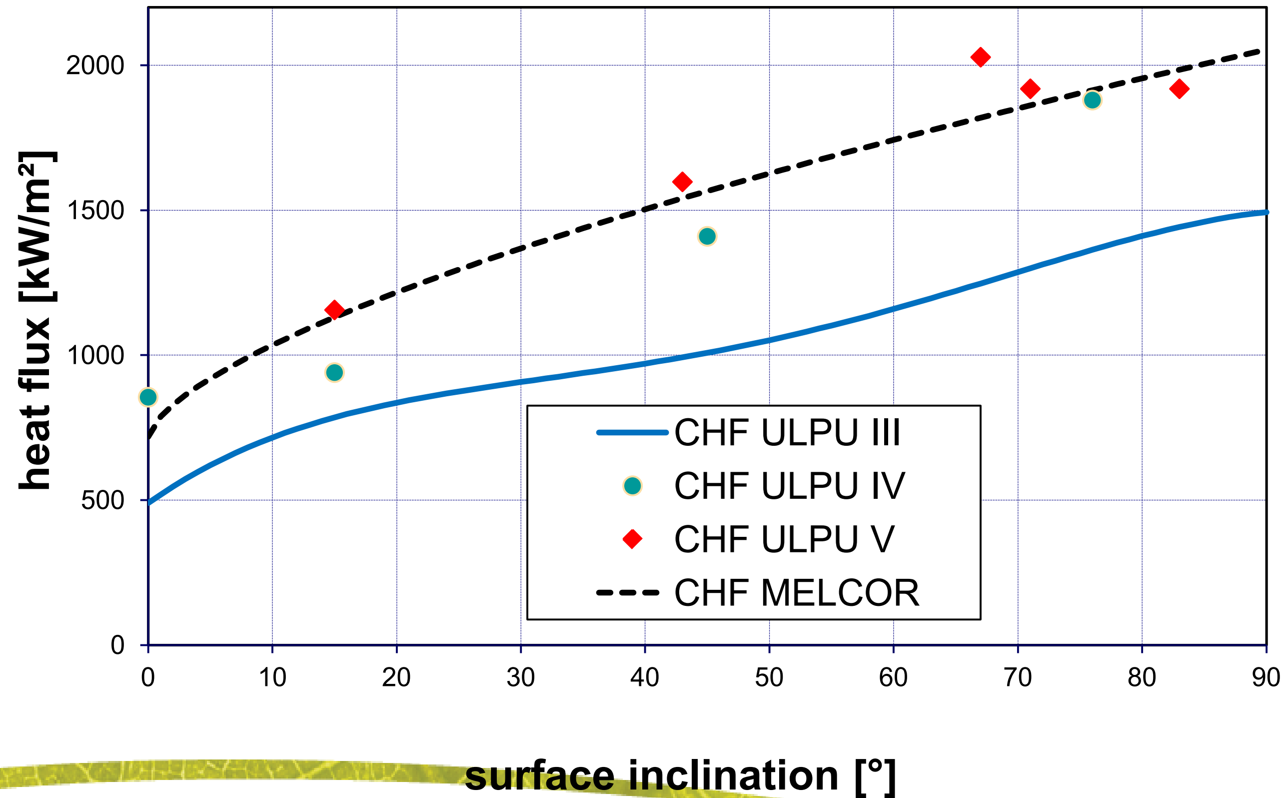
Critical heat flux (CHF) - CHF correlation in MELCOR (2)

- Modified MELCOR correlation for CHF for the boundary conditions of the ULPU experiments



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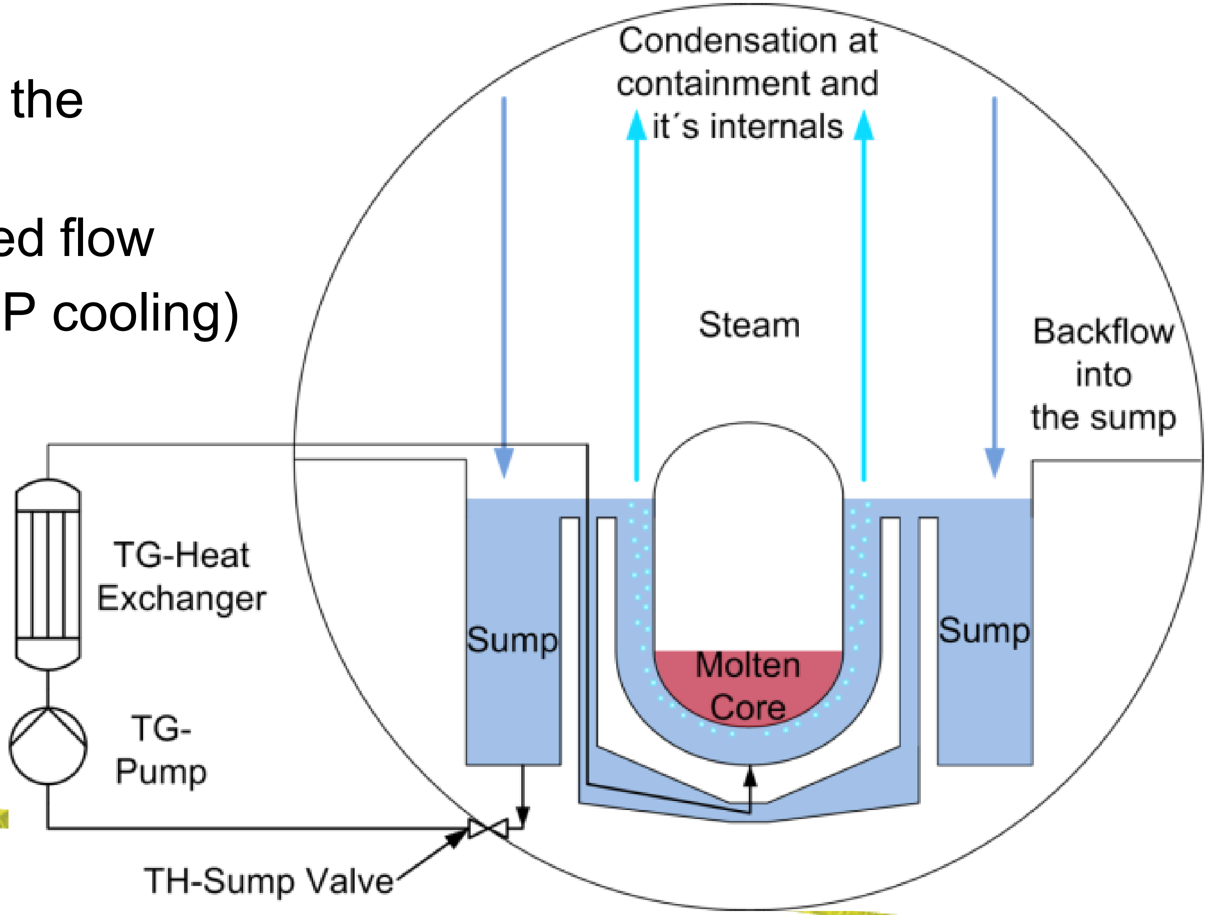
Model of In Vessel Retention (1)

The concept of the IVMR was validated using MELCOR 1.8.6 model of German PWR (~ 3700 MW)

Base Case:

- Adapted to simulate the IVMR-system
- Installation of a forced flow
- Heat exchanger (SFP cooling)
- Modified correlation for CHF



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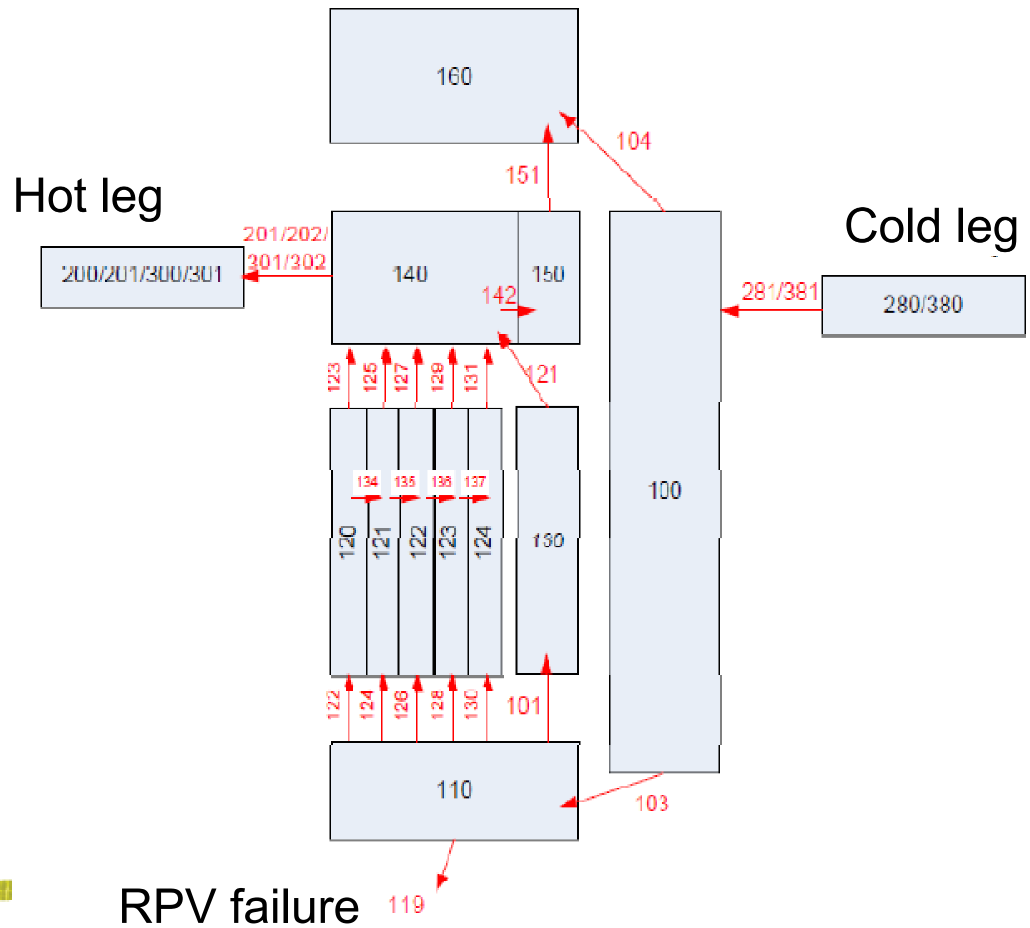
Model of In Vessel Retention (2)



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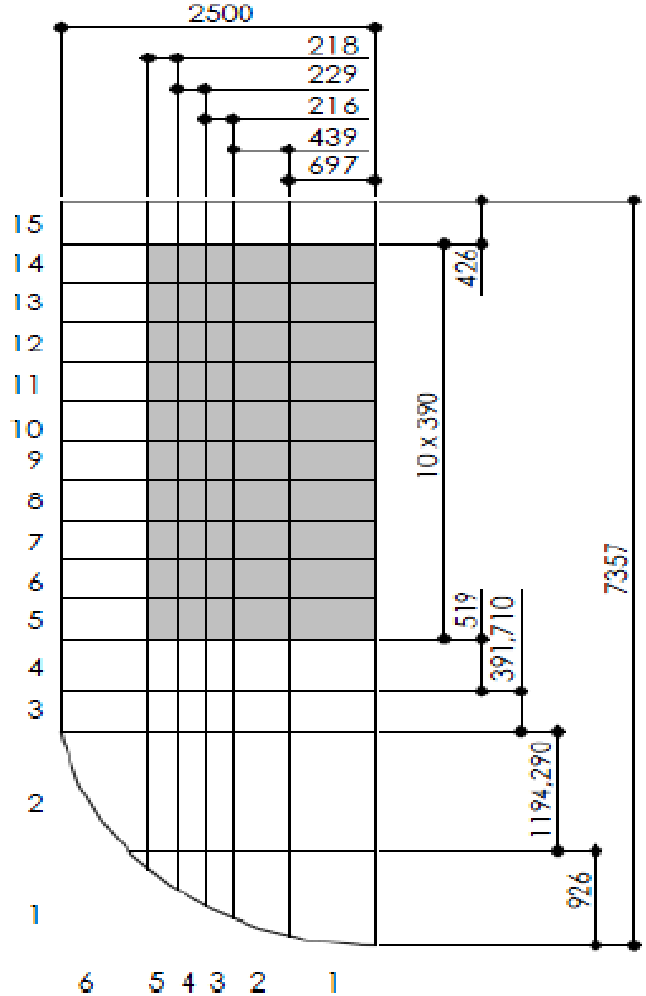
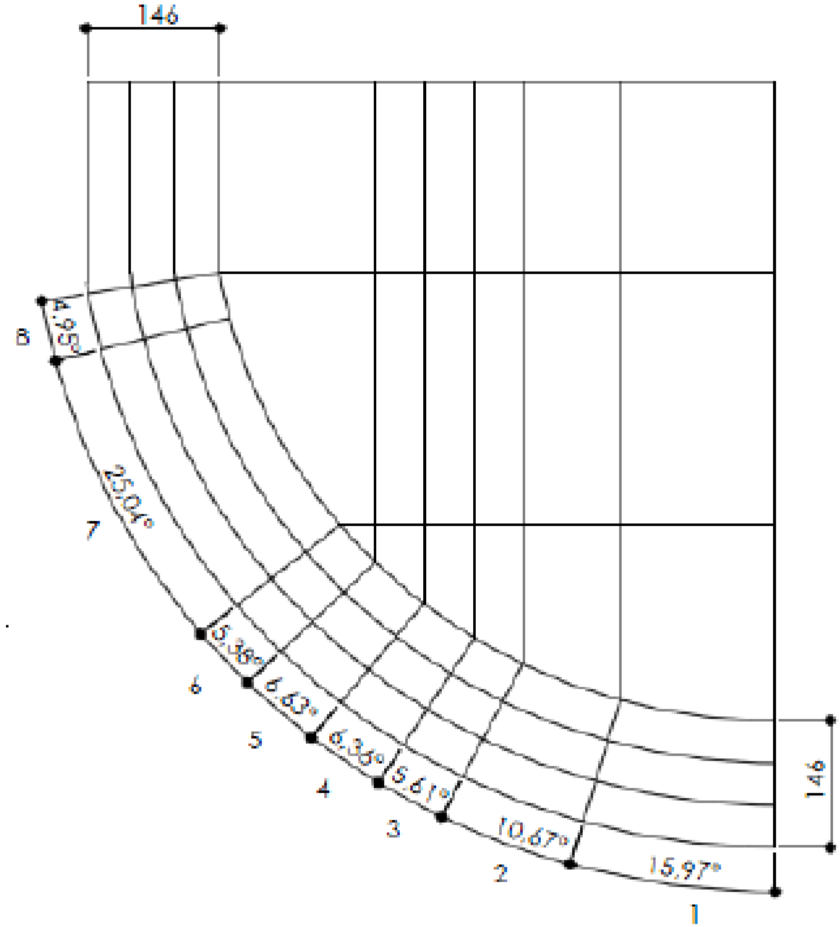
Model of In Vessel Retention (3)





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Model of In Vessel Retention (4)

For the failure of the RPV in the simulations the following criteria were used. The lower plenum fails if

- the sum of the relative thermal expansion and the plastic deformation due to creep in any layer exceeds 18 % or
- a pressure increase to 200 bar in the RPV occurs (caused by the falling of core debris into a water pool in the lower plenum) or
- when the outside of the lower plenum reaches a temperature greater than or equal to the melting temperature of the material. (This is always the case when the local CHF is exceeded).

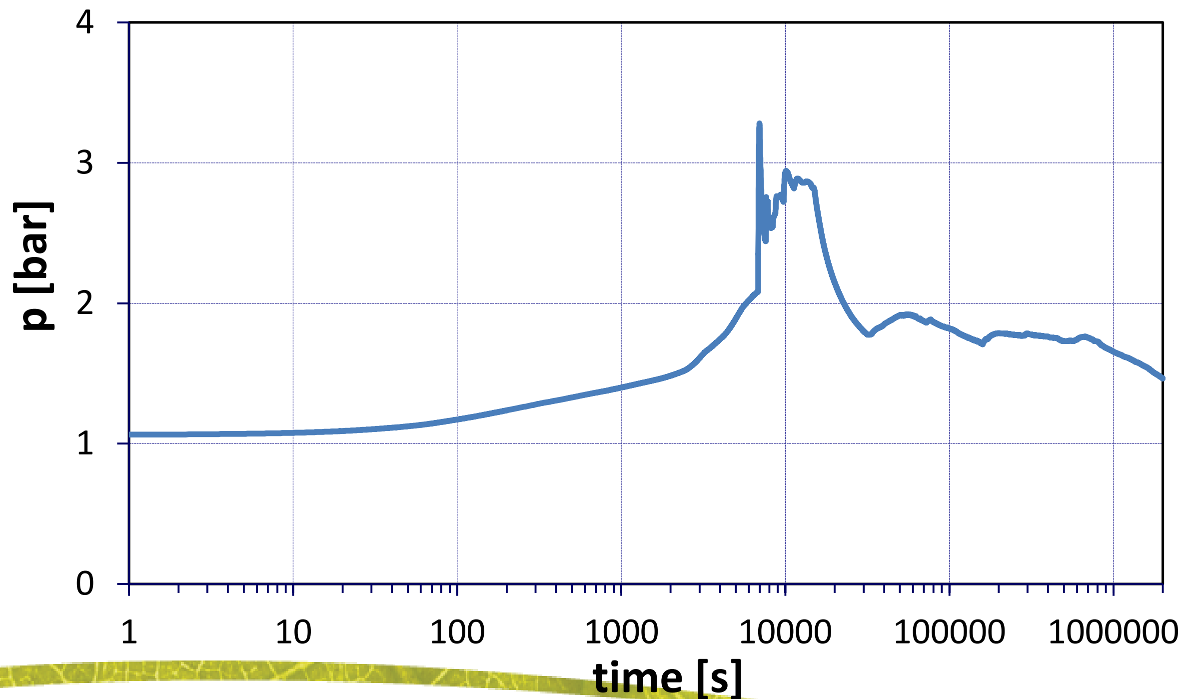
Boundary conditions

- Base case: Small break loss of coolent accident (SB-LOCA)
  - 10 cm^2 leak
  - with depressurization of primary side,
  - flow rate 38.4 kg/s
  - water temperatur after heat exchanger 38 °C
  - IVMR system is activated if the core outlet temperature is 750 K
- Variations:
  - Reduced flow rate
  - Increased decay heat
  - 200 cm^2 LOCA
  - no depressurization of primary side
  - LB-LOCA (2A-break)

Results: Containment pressure

- 750 K criteria for activation of IMVR is reached at 6820 s
- Containment pressure < 3.2 bar

→ No filtered containment venting is necessary



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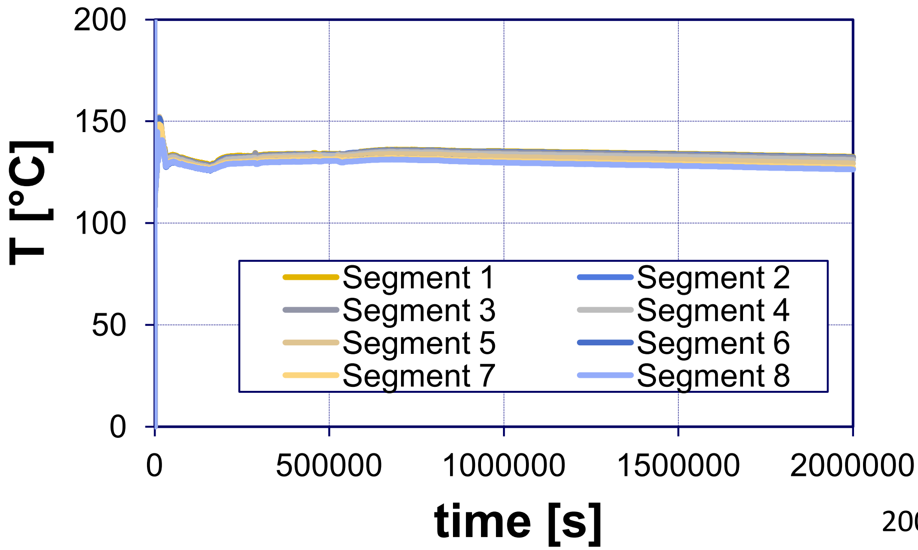
Results: Base case - Temperature on the outside and inside of the RPV

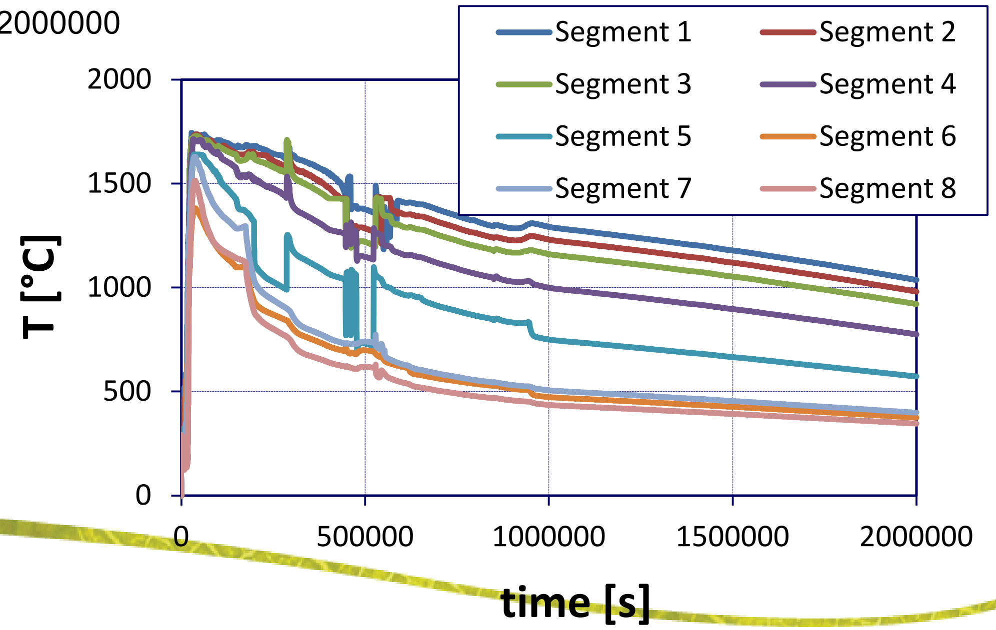


← Outside RPV temperature

- not much spread between curves

Inside RPV temperature →

- for all segments except segment 6 melt temperature of plating is reached



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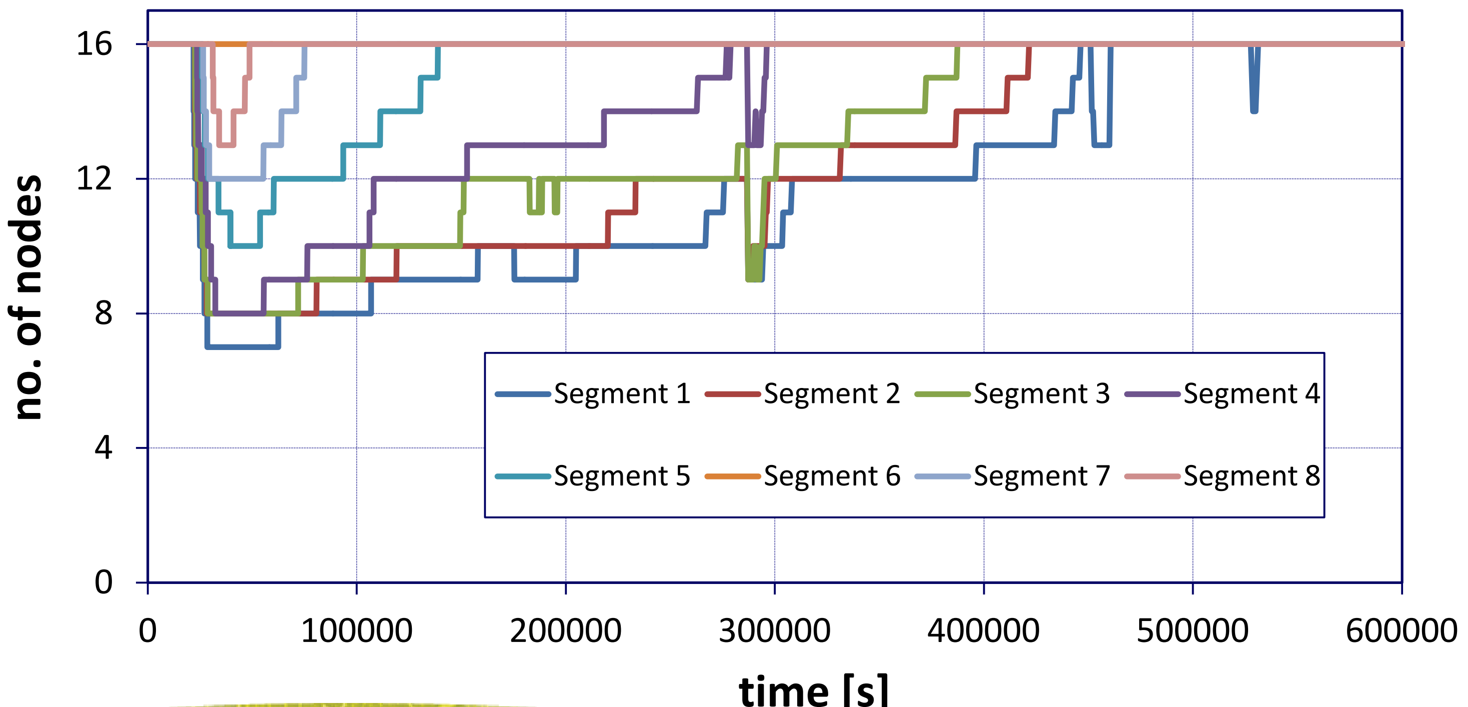
Results: Base case - Nubers of layers of the PRV wall below melt temperatur

- Minimum 7 RPV layers below melting temperature
- About 55 mm remaining wall thickness

→ The structural integrity of the RPV is threatened at no time



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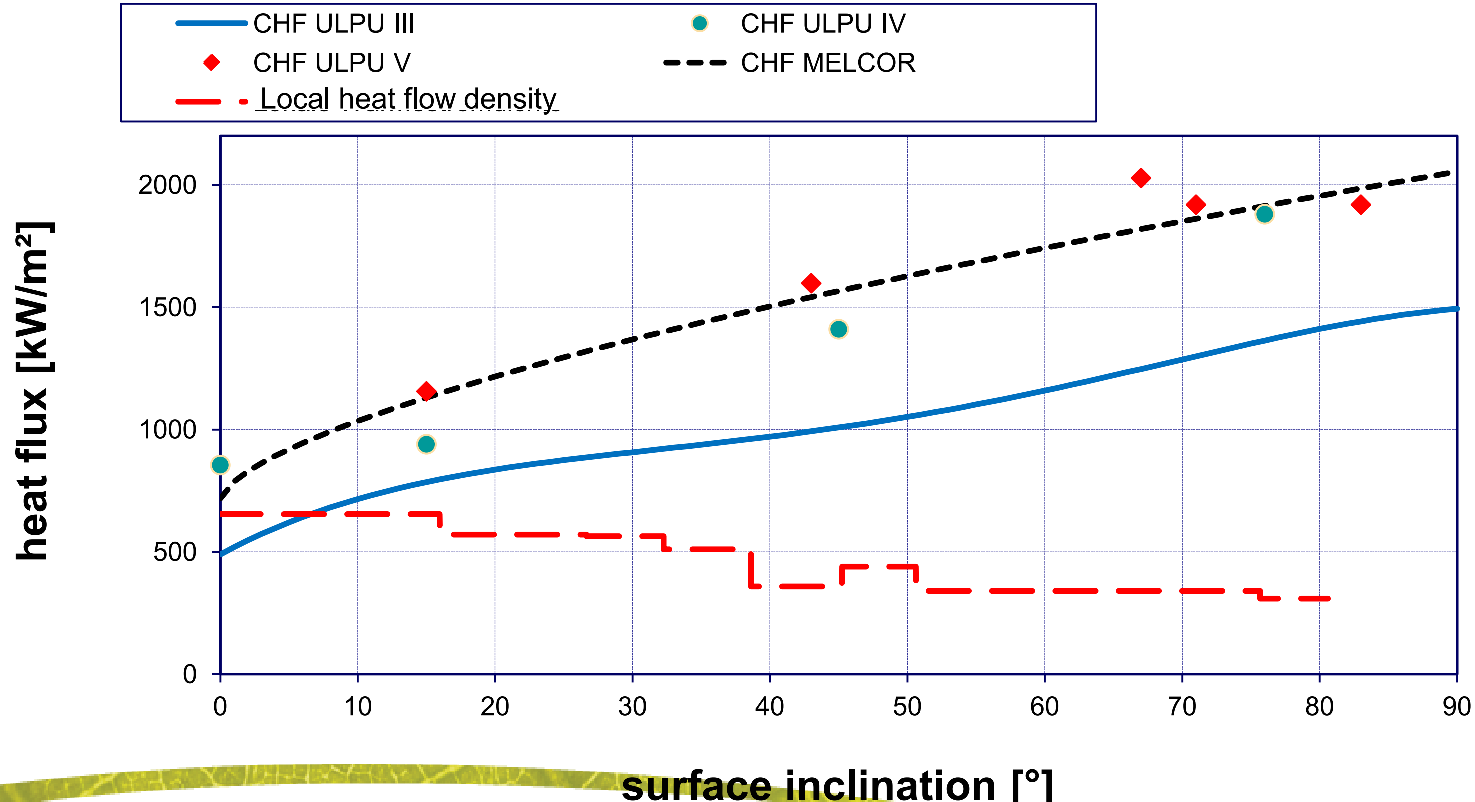
Results: Base Case – experimental CHF compared to calculated maximum heat flux

- Maximum values calculated by MELCOR are always below the CHF values

→ No RPV failure was observed by MELCOR

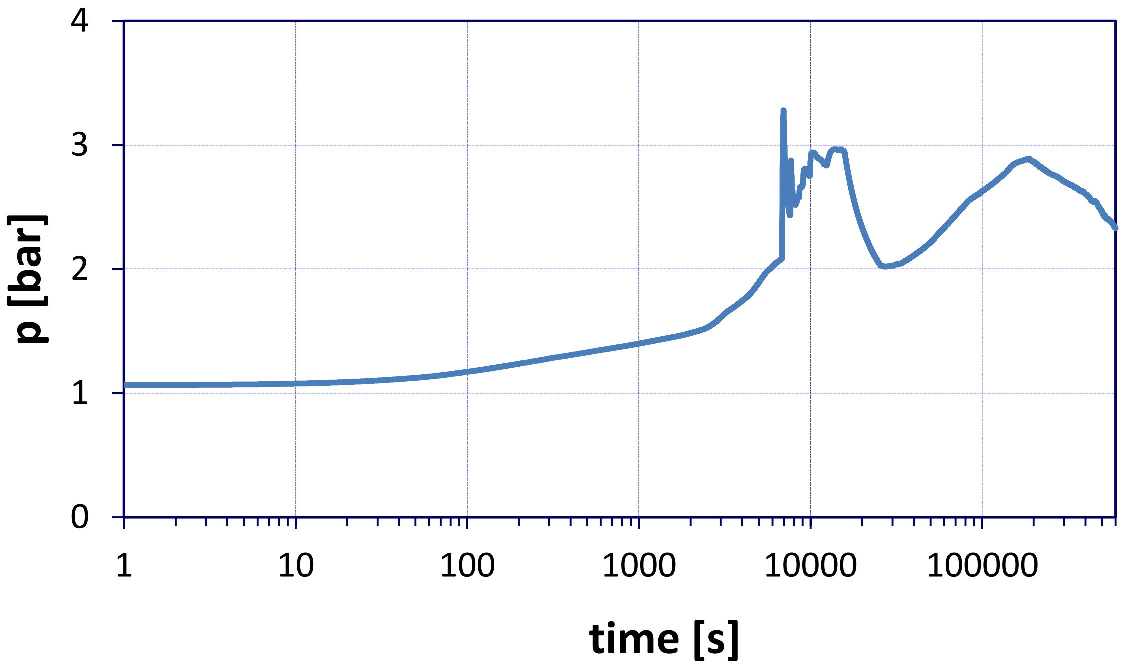


Results:Variation – SB-LOCA with lower flow rate

- The flow rate was reduced to 50 % of the base case (19.2 kg/s)

→ Additional local pressure maximum value of 2.9 bar in containment

→ No venting is necessary



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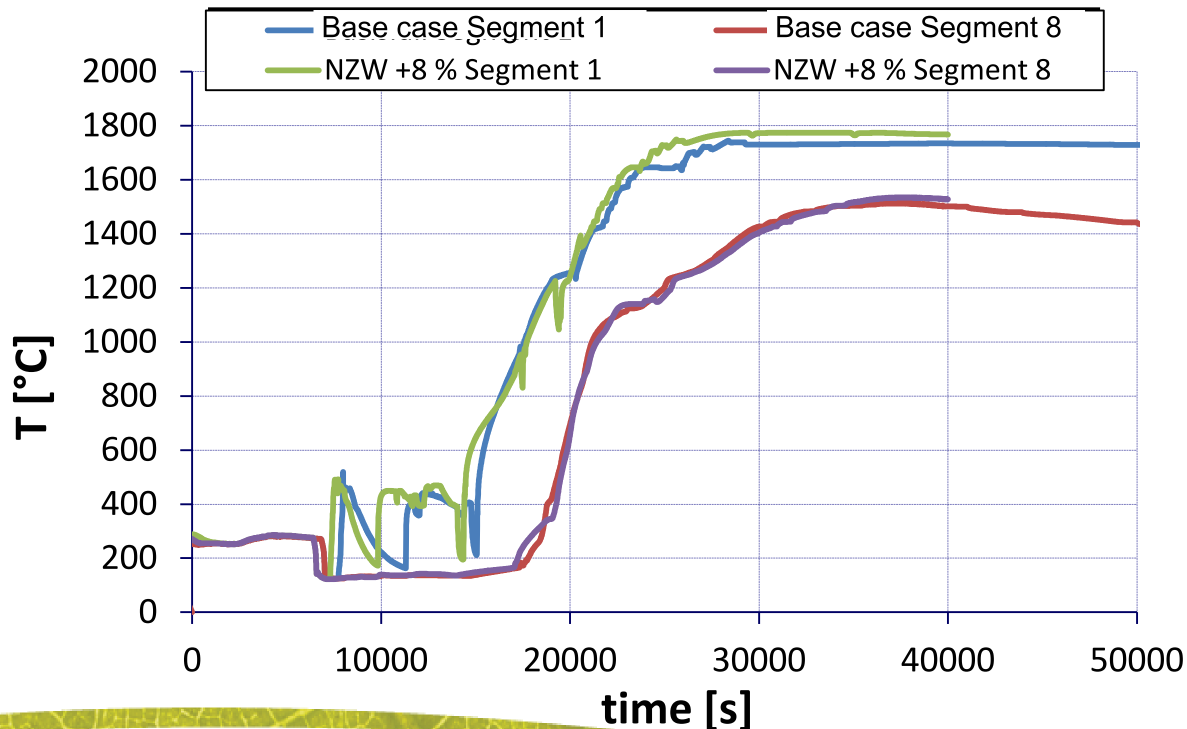
Results:Variation – SB-LOCA with increased decay heat

- Increased decay heat by 8 % compared to base case.

→ Negligible effect on the RPV wall temperature

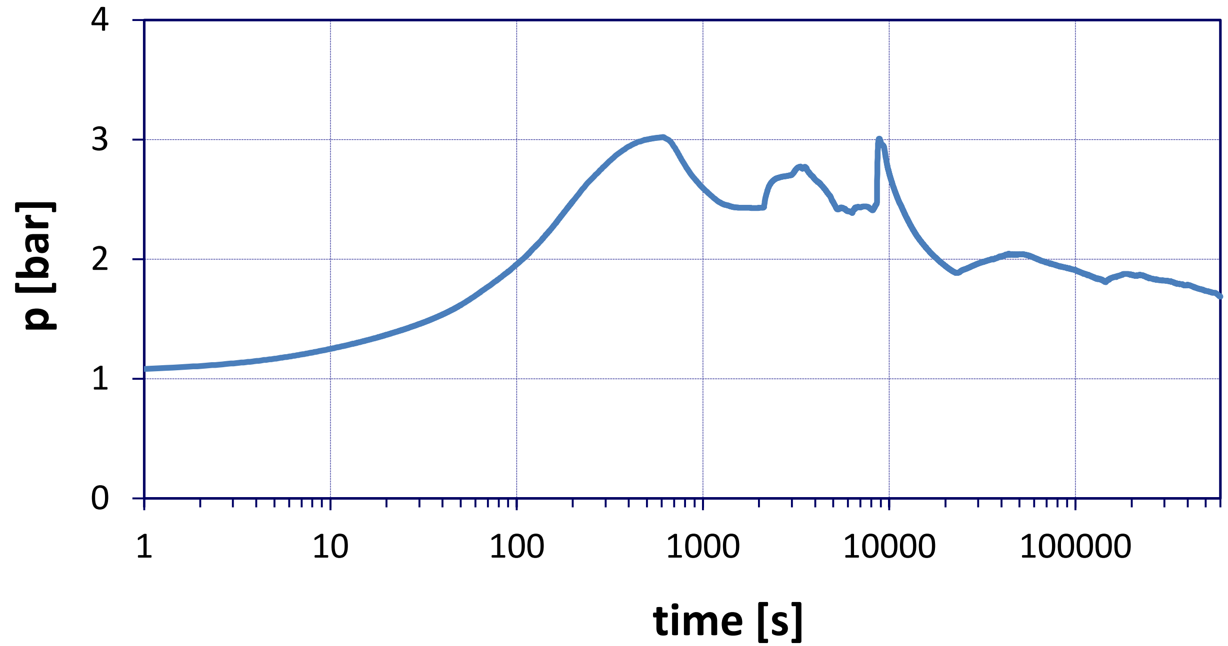
→ Still margin in the design



Results:Variation – 200 cm² LOCA (1)

- Pressure history in the containment
- Faster accident sequence

→ No RPV failure is calculated and no containment venting is required



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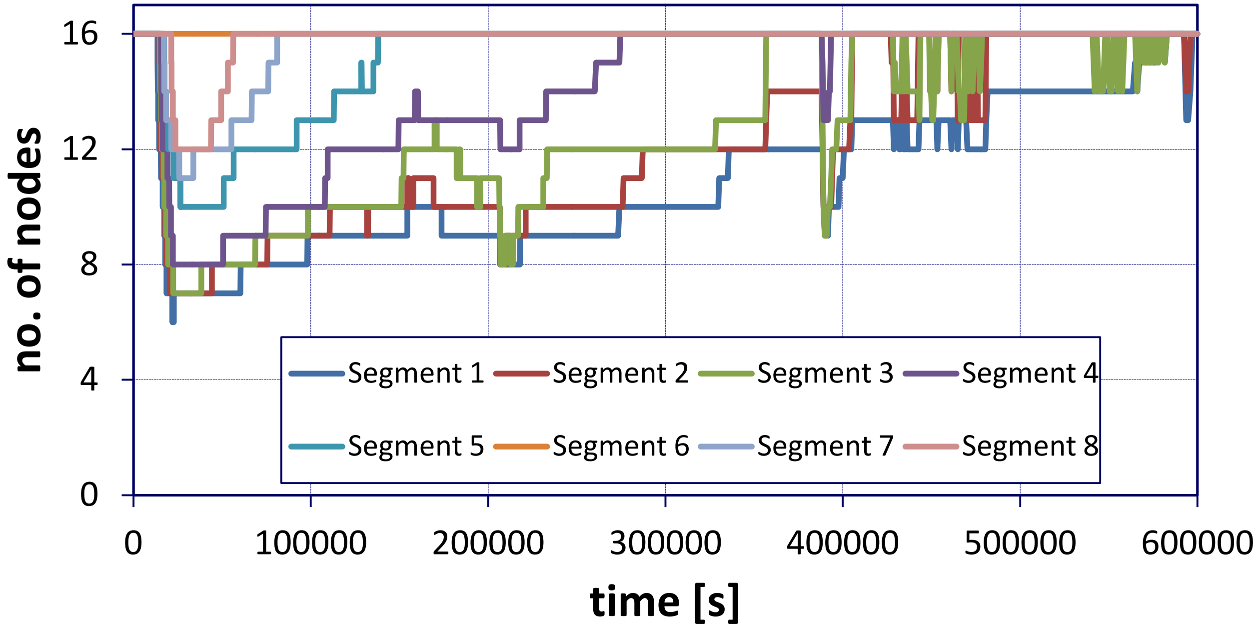
Results: Variation – 200 cm² LOCA (2)

- Number of layers of the RPV wall with a temperature below melt temperature over time, for each segmental ring

→ Minimum 6 RPV layers below melting temperature, equalling 40.55 mm



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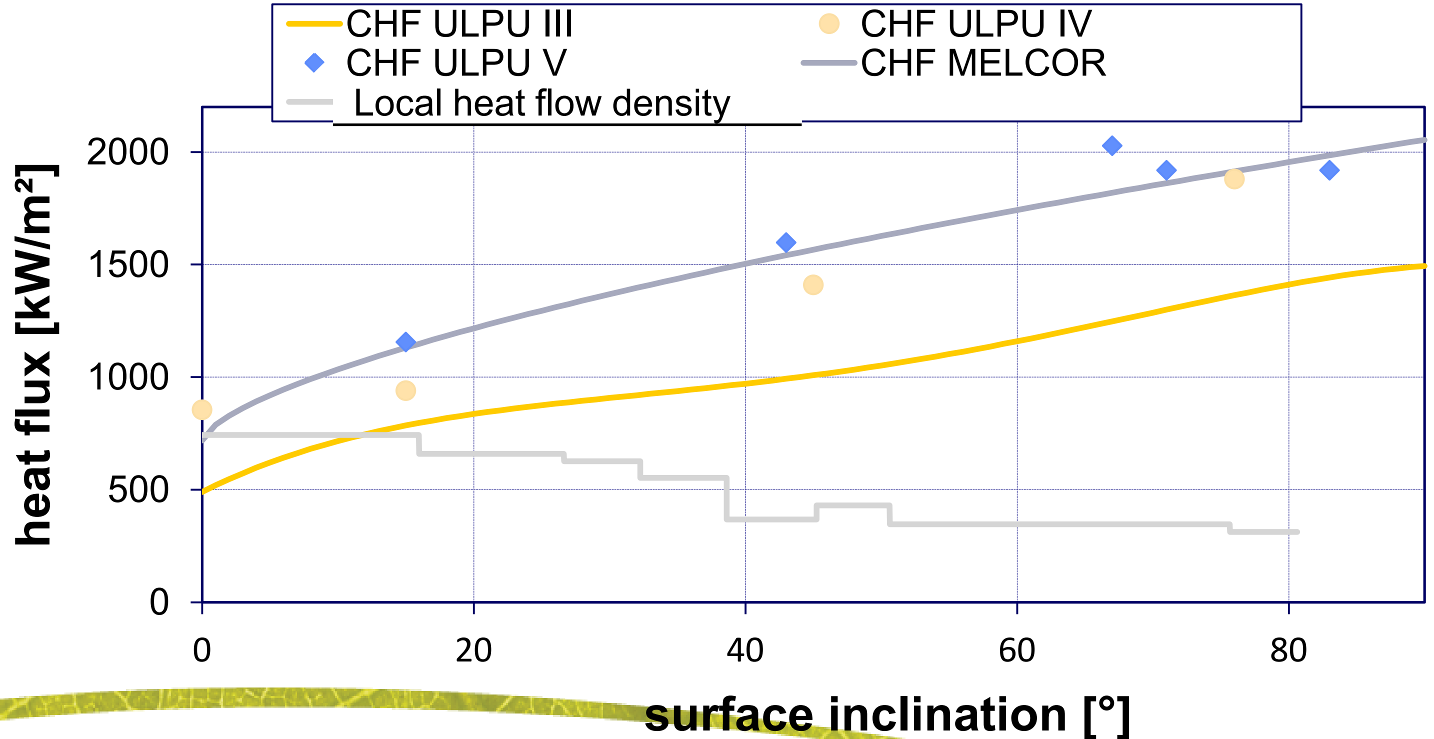
Results: Variation – 200 cm² LOCA (3)

- Comparison of calculated maximum local heat flux on the outside of the RPV to the CHF of the ULPU experiments

→ No RPV failure is calculated



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Summary

- The feasibility of retrofitting IVMR in large PWRs has been analysed based on the ULPU experiments.
- A MELCOR model of a German PWR was modified to model an IVMR based on
  - gravity driven flow from the spend fuel pool and
  - pump driven injections to the RPV cavity.
- The CHF correlations of MELCOR has been modified to reflect the results of the ULPU experiments.
- MELCOR simulations of several severe accident scenarios has been perfomed. In all simulations the melt could successfully be retained in the RPV.
- No venting of containment was necessary.
- Further investigations must be performed using a detailed thermo hydraulic model

→ **„Take home“ message:** The simulations showed the usefullness and feasibility of such a retrofit.

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