5th Meeting of European MELCOR User Group (EMUG):

Improved In-Vessel-Retention Model

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May 2-3, 2013

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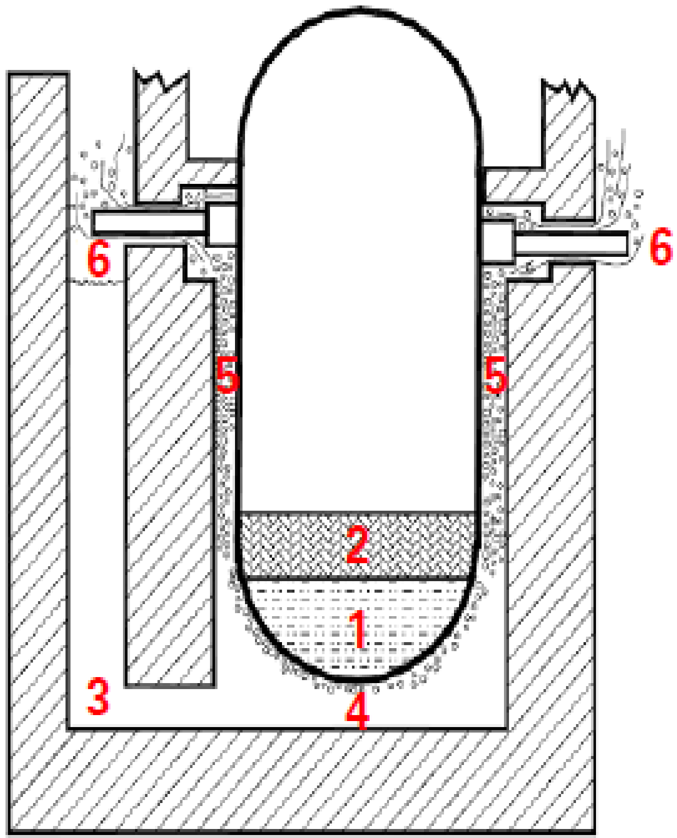
Introduction

- IVR severe accident mitigation measure
- IVR is retrofittable
- A retrofit was realized at the finnish NPP Loviisa (VVER440/213).
- IVR is standard for AP1000/APR1400
- Proof for successfull operation and retrofit for large German PWR is missing.



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

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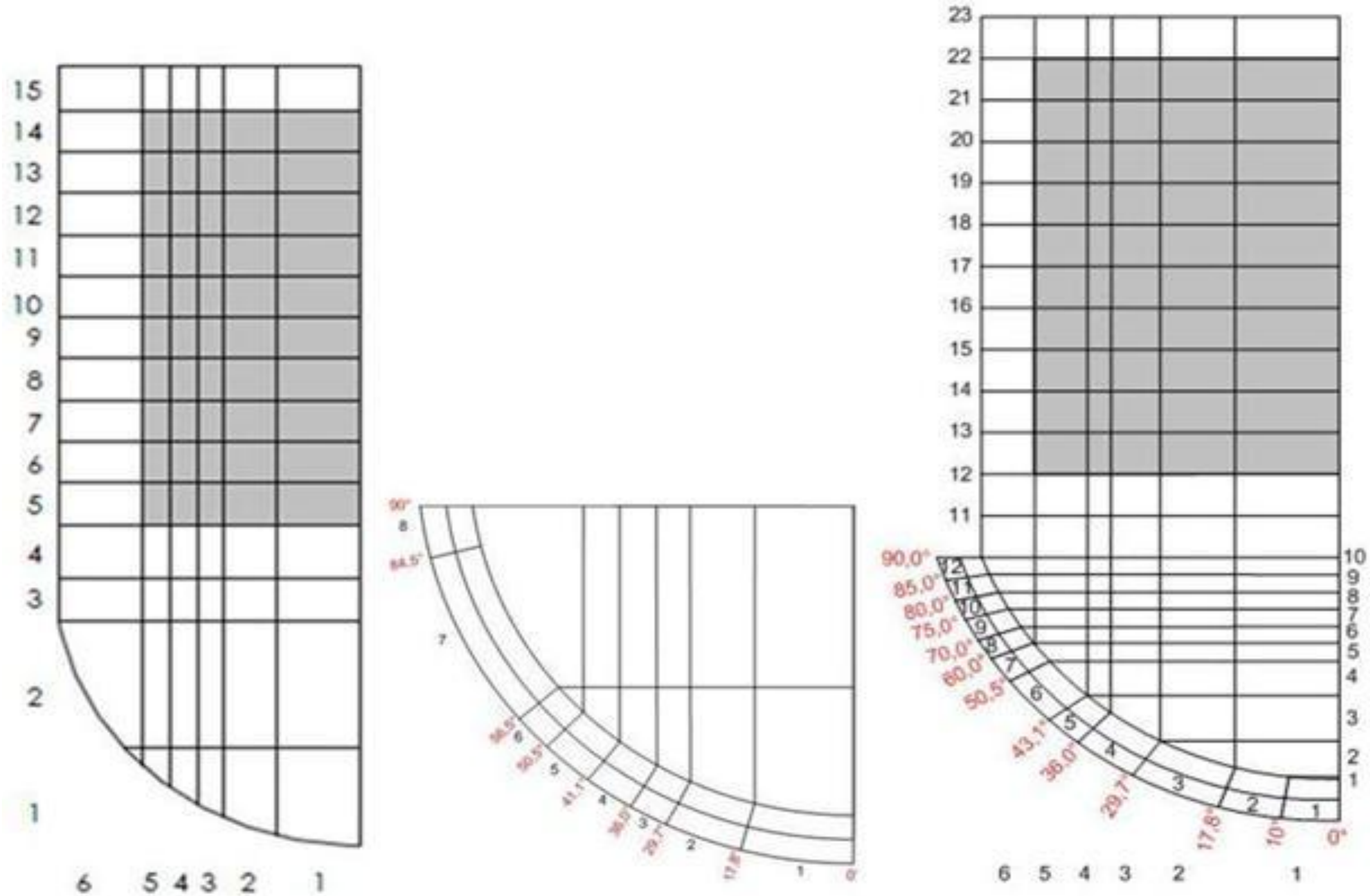
In-Vessel-Retention Model



Scenarios/cases : Boundary conditions (Base case)

- Inital event is a 10cm^2- leak at the hot leg at the pressurizer-loop
- Successful scram, power supply from external net avaliable
- All active feeding systems failed
- Only the primary inventory, accumulator inventory and remaining secondary inventar of the steam generators are avaliable for core cooling
- Depressurization of primary circuit (RPV level) using the „Bleed“-ventiles
- Start of the IVR at T ≥ 922 K (≈ 650 °C) in the hot leg by operator action
- The flooding inventory in the reactor cavity is taken spend fuel pool
- Installation of a forced flow from the containment sump using a heat exchanger (for SFP cooling).

- Used MELCOR 1.8.6 YV (3084) with modified correlation for CHF
- Flow duce with a distance of 152 mm to RPV was assumed.

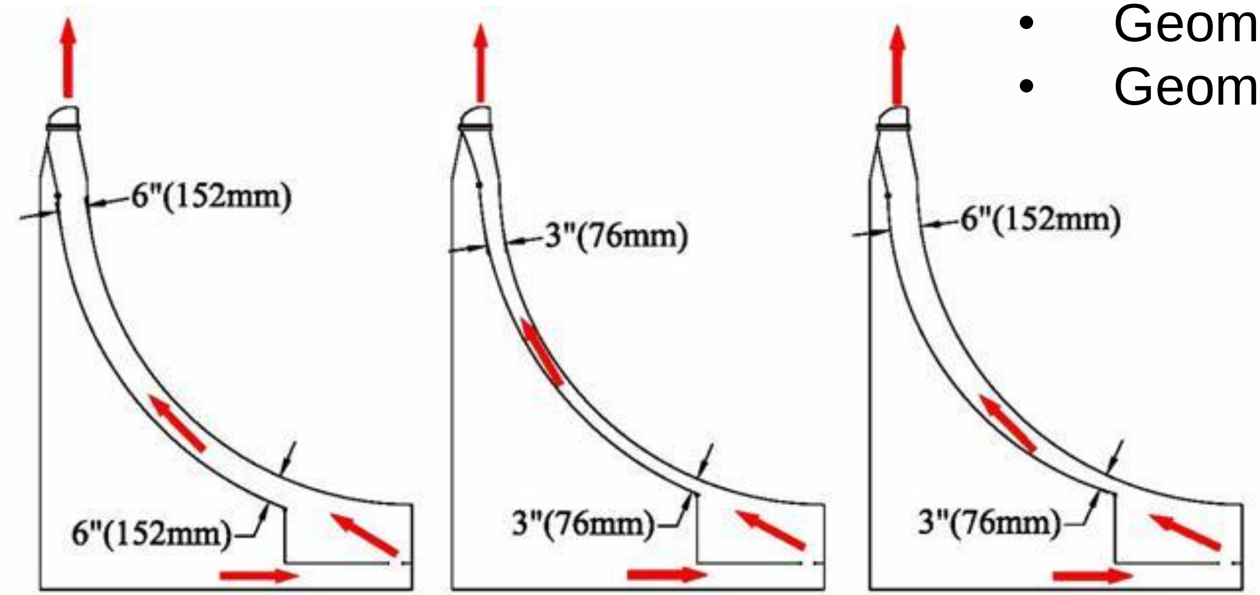
→ **The IVR is successfull if the RPV and the containment stays intakt.**

Scenarios/cases: Parameter variations

- RPV depressuration
- IVR start temperature T_{Start} = 750 K
- Geometry of the flow channel

Combination:

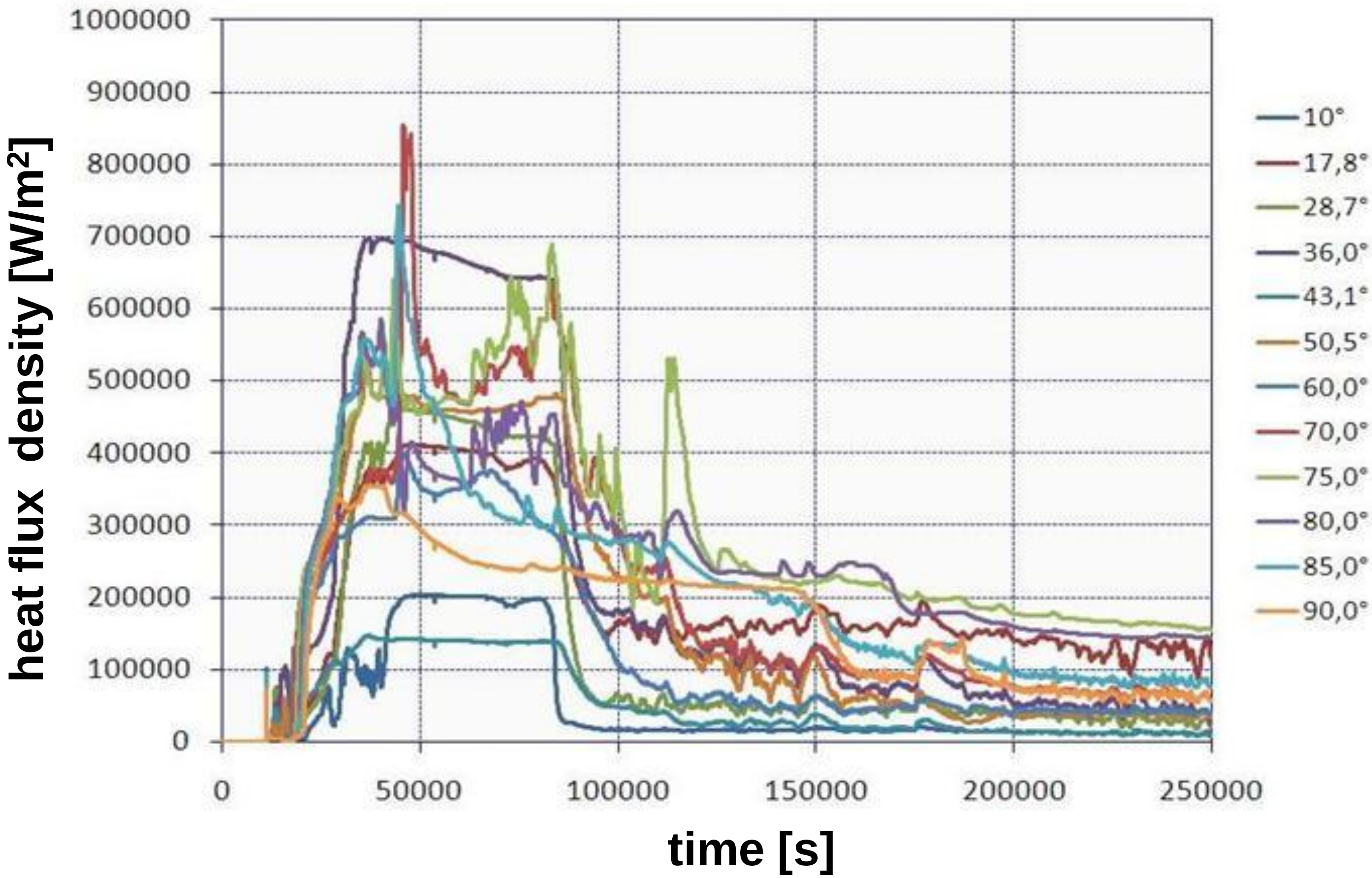
- Geometry B no PDE
- Geometry B with T_{Start} = 750 K



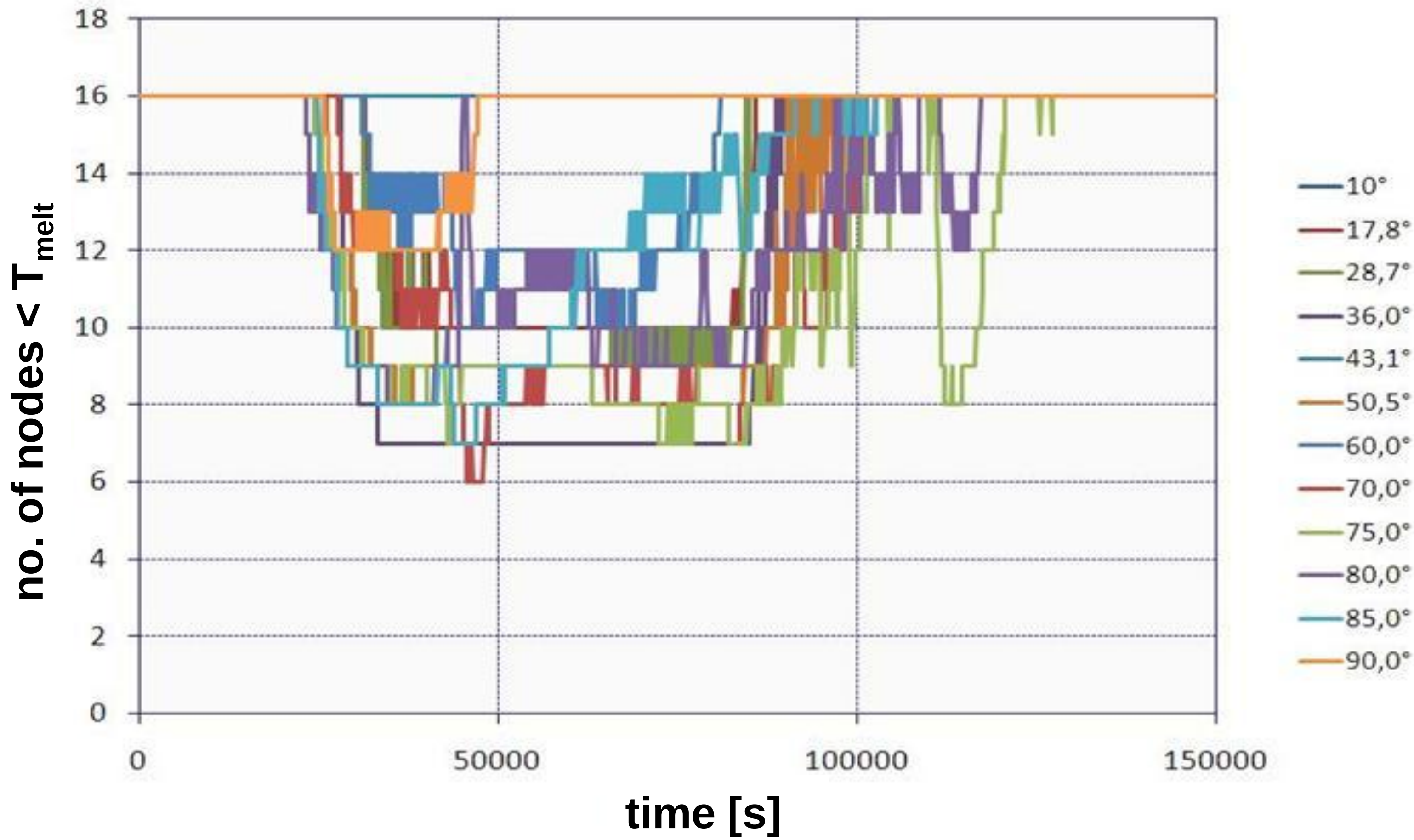
"Geometry A" "Geometry B"

Source:
T.N. Dinh, J.P. Tu, T. Salmassi and T.G. Theofanous
"Limits of coolability in the AP1000-related ULPU-2400 Configuration V facility"
NURETH 10, Seoul, Korea (2003)

Results: Base case (1)



Results: Base case (2)



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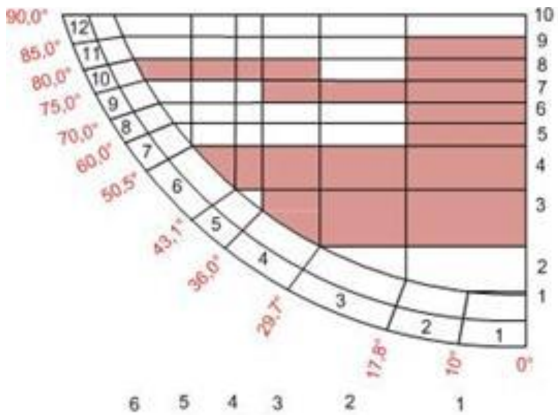
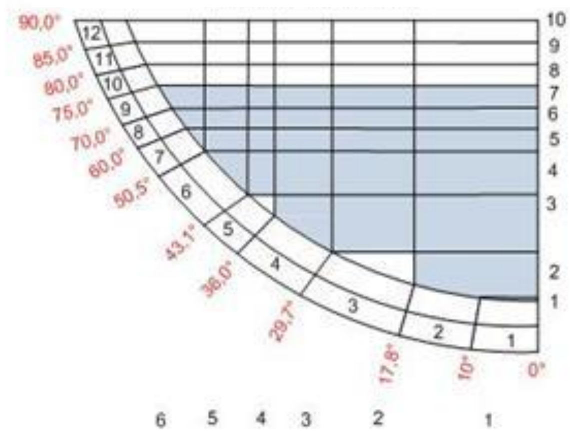
Results: Base case (3)

Cells with temperature differences between oxide and metal molten pool



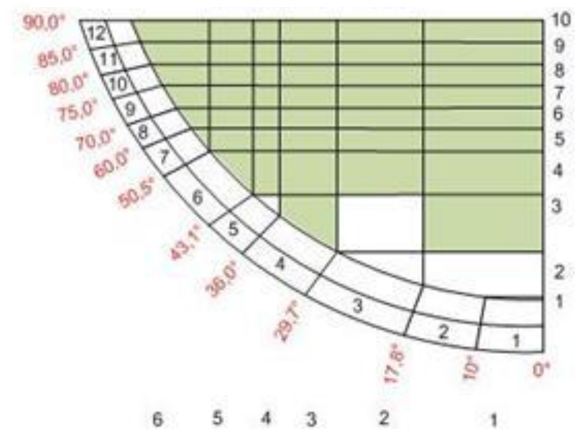
Appearance ~7 – 35 h
Focus on Level 4, 7 and 8

Cells with temperature differences between oxide molten pool and particulate debris



Appearance ~6 h, + 6.5 – 9 h in level 1- 4
Focus on Level 4,
After 12 h in all marked cells, mostly in level 4 - 7

Cells with temperature differences between metal molten pool and particulate debris



Appearance ~ 4 h, ~ 4.75 – 18 h in marked cells
After 30 h in level 7 – 10 mainly in level 8 - 10

Selection criteria: ΔT in cell > 30 K; minmal volume fraction > 5 %

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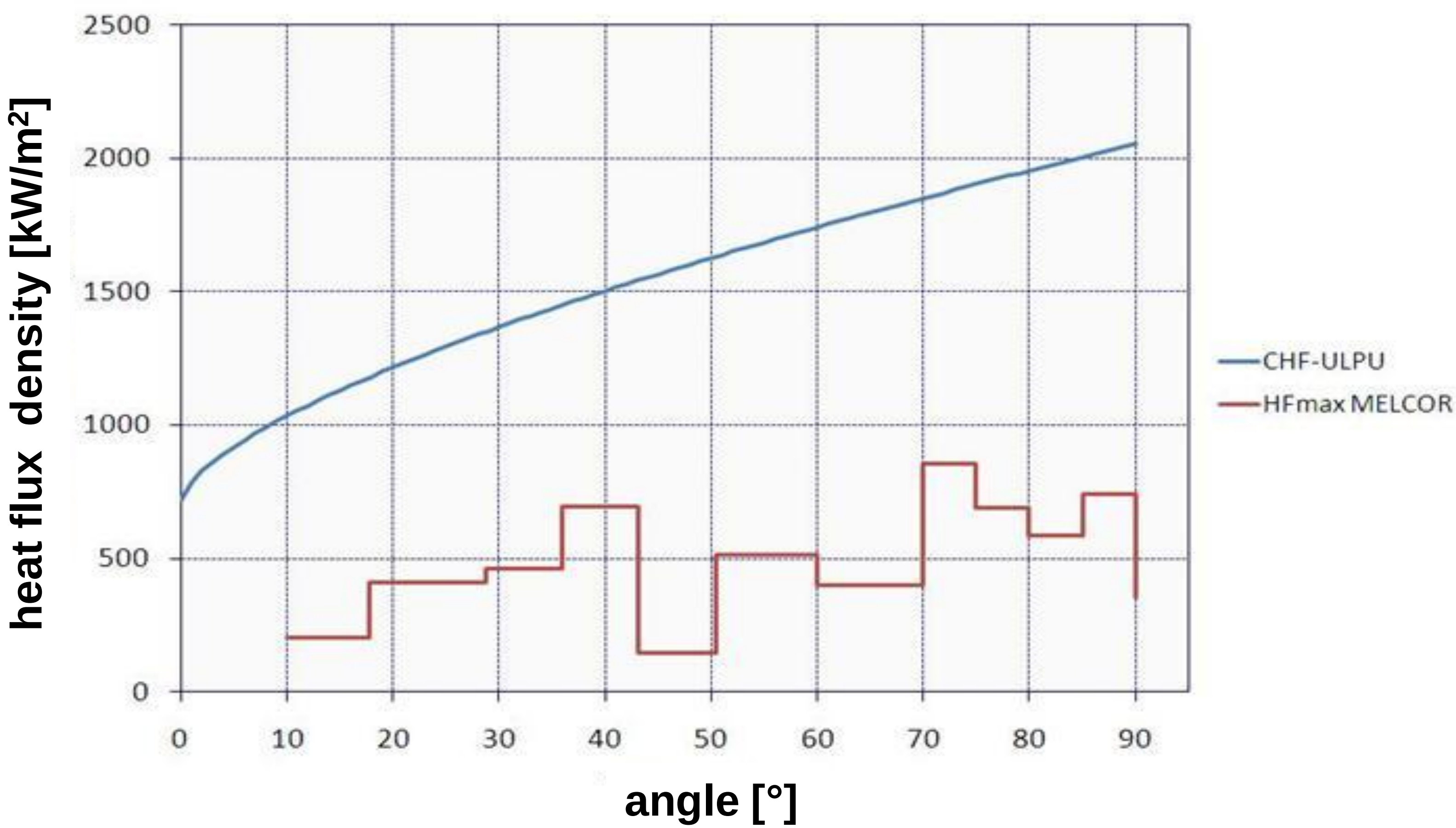
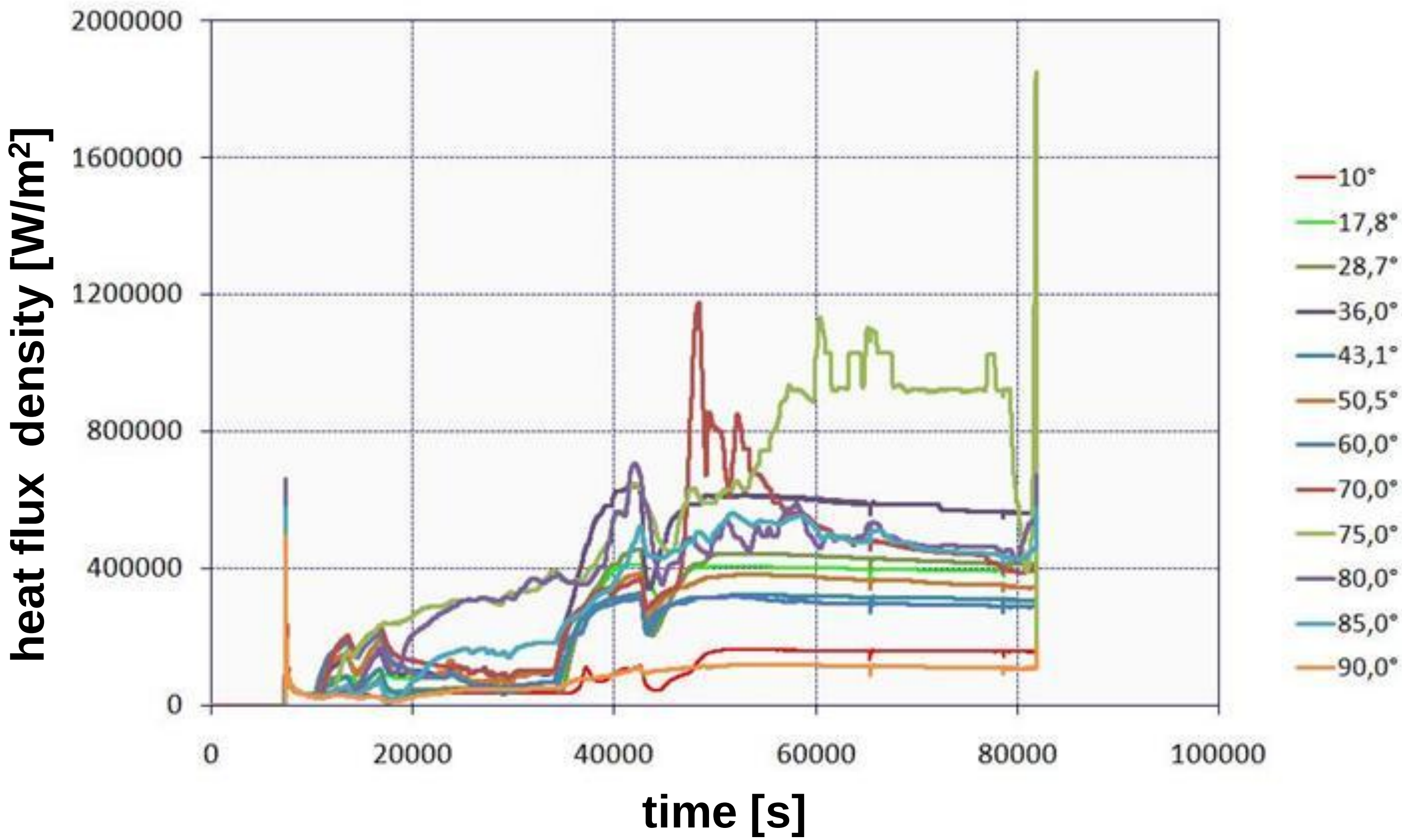
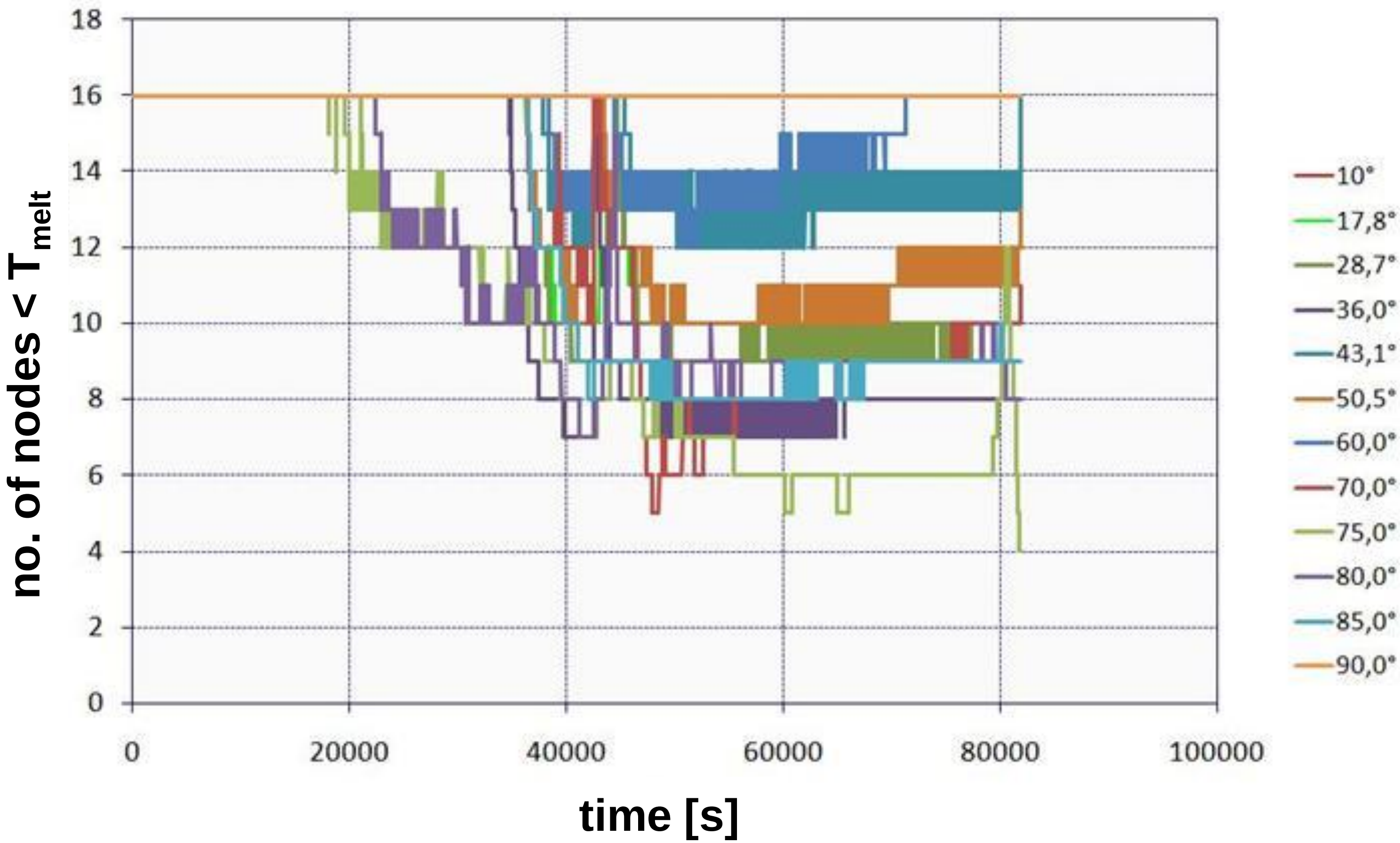
Results: Base case (4)



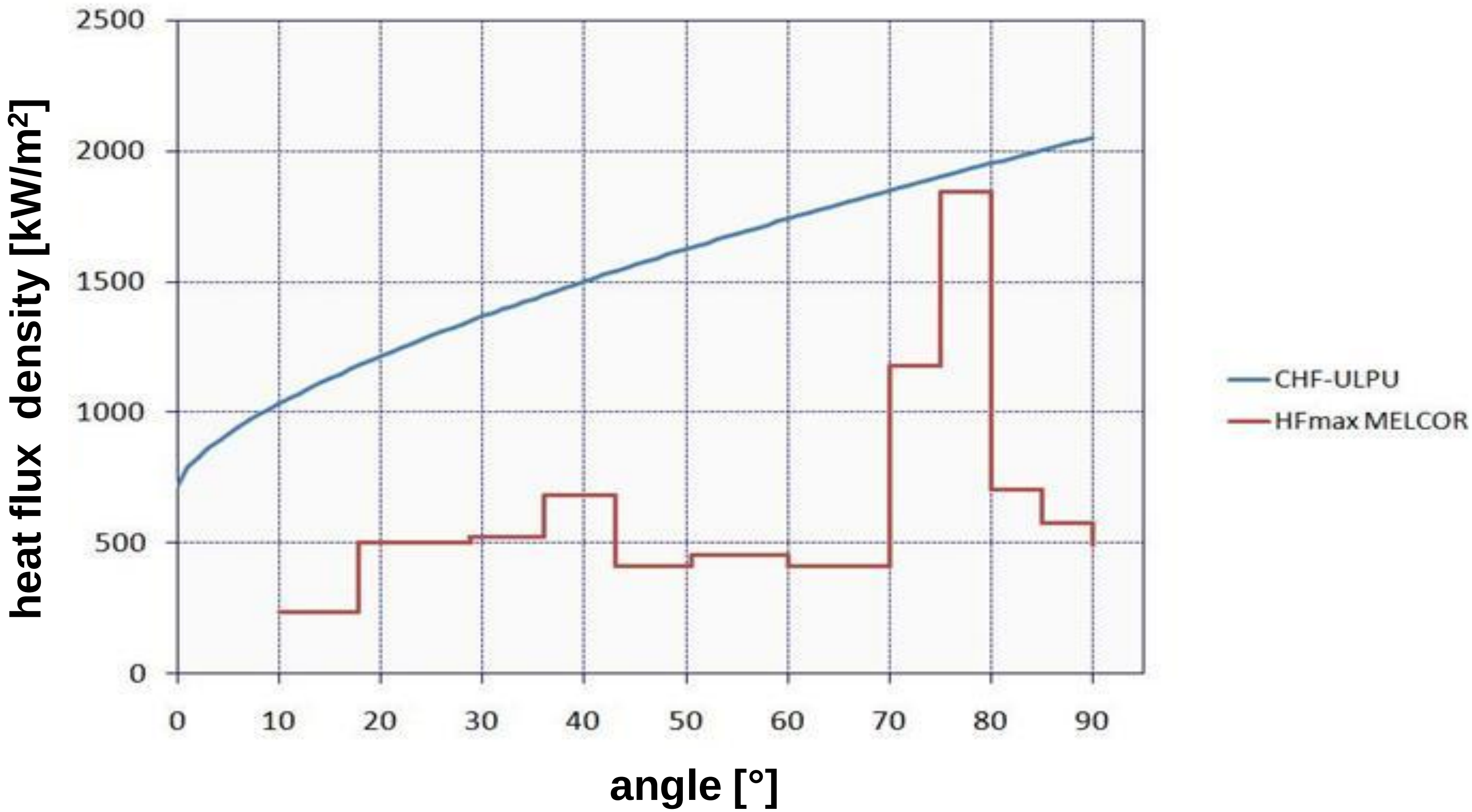
Results: Variation with no RPV depressurization Geometry B (1)



Results: Variation with no RPV depressurization Geometry B (2)



Results: Variation with no RPV depressurization Geometry B (3)



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Results: Overview Results

	RPV-failure	Max. heat flux density [kW/m²]	Position max. heat flow desity [°]	Min. safety factor for CHF [-]	Min. wall thickness RPV [mm]	Max. pressure in containment [bar_{abs}]
Base case	no	855	70	2.08	48.7	2.70
Geometrie B	no	935	70	1.98	38.9	2.79
Base case with no depressurizing	yes[1]	870	70	2.06	48.7	2.38
Base case with start temperatur e 750 K	no	1.193	70	1.55	48,7	2.70
Geometry B with no depressurizing	yes	1.848	75	1.03	29.2	2.17
Geometry B with start Temperature 750 K	no	1.133	70	1.63	38.9	2.78

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Uncertainties in the simulations

Phenomenological uncertainties:

- Water chemistry (influence of boric acid)
- Material properties (for molten conditions are not known e.g. heat conductivity, density)
- Flow conditions between the RPV and the flow duct structure

Uncertainty in the model and numeric:

- Correlations for the simulation of CCFL is simplified in MELCOR
- Melt stratification in the lower plenum
- Software problem: temperature differences for core materials
- Influence of minimal time step on the results

Proposals for code improvments

- „Ghost“ values e.g. mass in core cell 10^{-31} kg

→ There should be a criteria for variables to set low values to zero.

- Software problem

→ The temperature difference between the different core materials (oxide, metal molten pool and particulate debris) should be investigated.

- Influence of minimal time step on the results

→ There should be some guidelines developed (in the „User Guide“) for the selection of the minimal time steps.

- Documentation for current MELCOR-versions are only avaliable as drafts

→ There should be an current final version for the documentation MELCOR 1.8.6 and MELCOR 2.1.

Summary

- The MELCOR simulations have shown that the IVR retrofit could basically successfull for large German PWR.
- The depressurization of the RPV is mandatory as without it the RPV fails despite of the IVR.
- The RPV failure is caused by a combination of high thermal load due to the high heat flux at the RPV outer wall and successive melting of the lower calotte.
- Some proposals for code impovements have been shown.
- Further analysis and simulations are needed to show clear evidence of a succesful IVR for retrofitting ~1300 MW_{el} reactors.