Gas Coolability of Decayed BWR Fuel in SFP Loss of Coolant Accidents

9TH EUROPEAN MELCOR USER GROUP MEETING (EMUG)

CENTRO DE INVESTIGACIONES ENERGÉTICAS, MEDIO AMBIENTALES Y TECNOLÓGICAS (CIEMAT)
MADRID, APRIL 7, 2017

BKW

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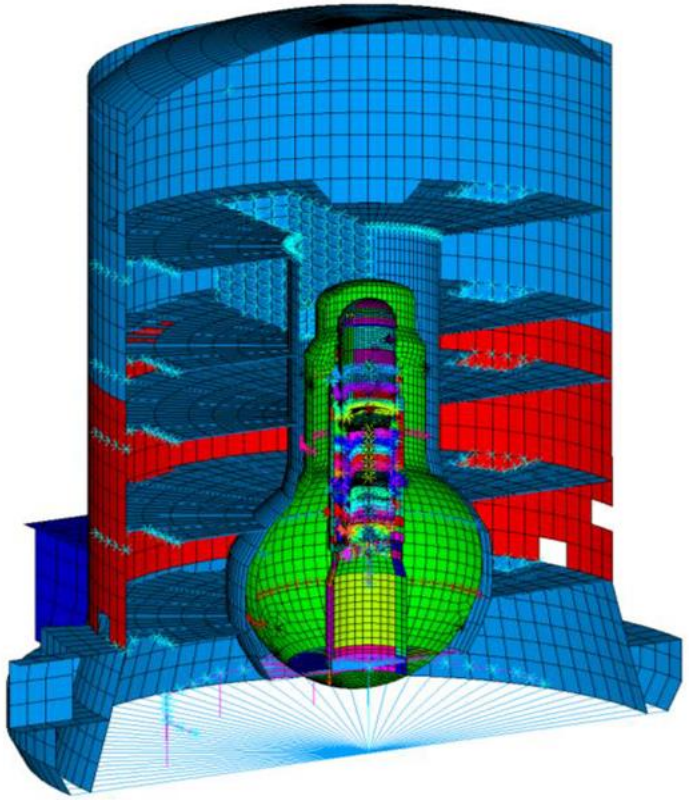
BKW Engineering
Our services at a glance

Safety Analysis and Risk Management

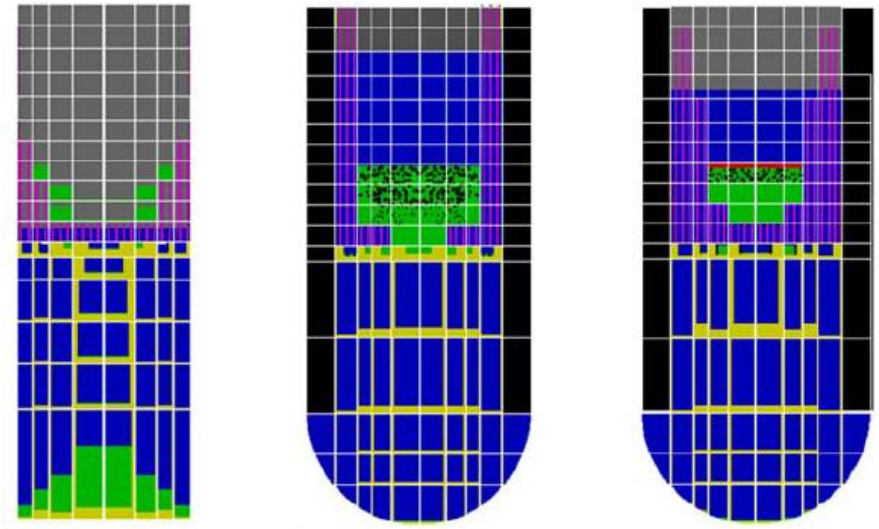
As operator of nuclear power plants for over 40 years, we are experts in safety and thermal hydraulic analysis, structural mechanical calculations and the material ageing phenomenon. Handling technical and economic risks is our strength.

- Safety and system analysis of nuclear facilities
- Power operation, shutdown, decommissioning
- Deterministic safety analyses
- Thermo hydraulic analyses (RELAP, TRACE, ATHLET, MELCOR)
- Radiological safety analysis
- Probabilistic safety analysis
  - Levels 1 and 2
  - Risk of core damage and potential release of radioactive substances
  - Data analysis, component reliability analysis, risk monitoring
  - Human reliability analysis
- Severe Accident Management Guidance (SAMG) development and training
- Licensing support
- Partnership with Paul Scherrer Institute (PSI) for safety analysis services (Link to press release)

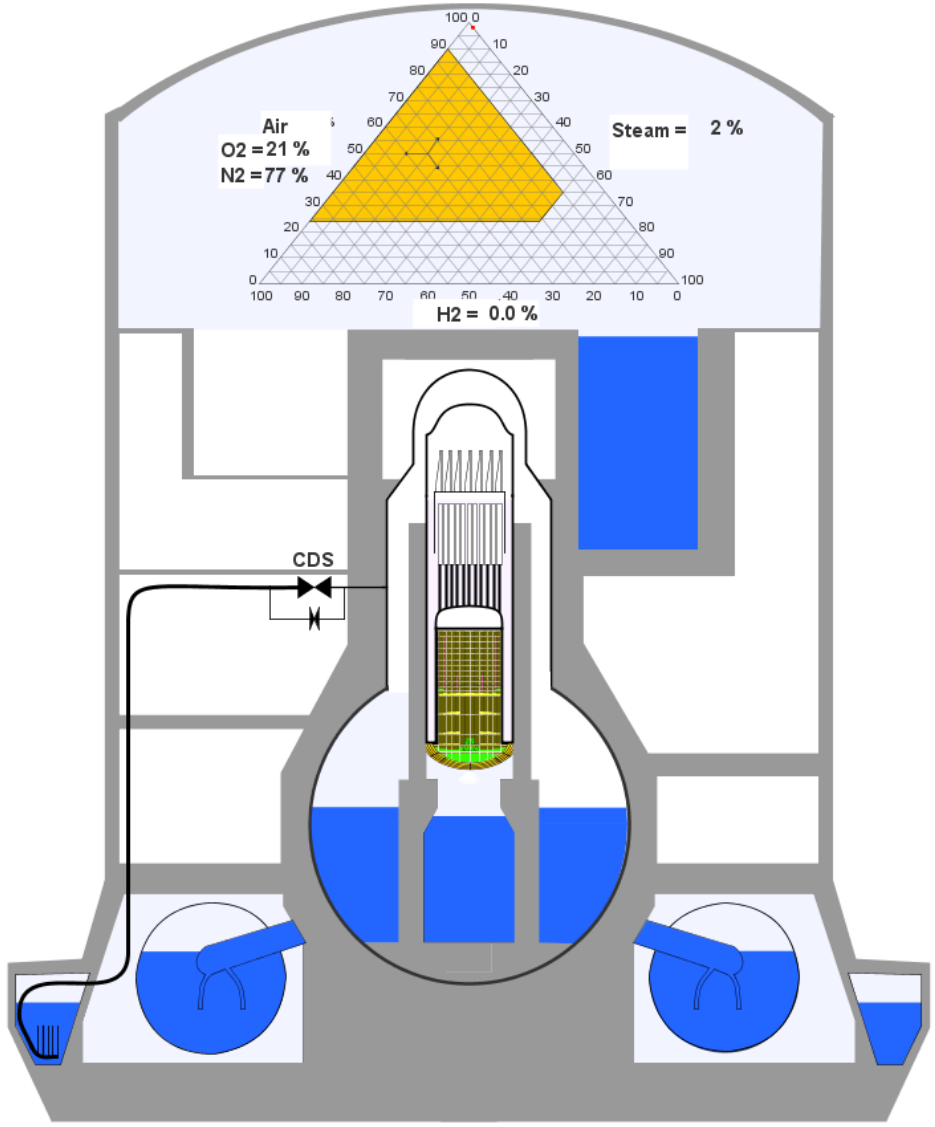


BKW Engineering
Accident Analyses with MELCOR Code

- Reactor and spent fuel pool simulations
  - MELCOR analysis of success criteria for PSA level 1
  - Accident progression and radioactive releases for PSA level 2
  - Accident progression to support SAMG
  - Power operation, low power / shutdown, and decommissioning
- Containment thermal-hydraulics and hydrogen management
- Conversion of plant models to MELCOR version 2

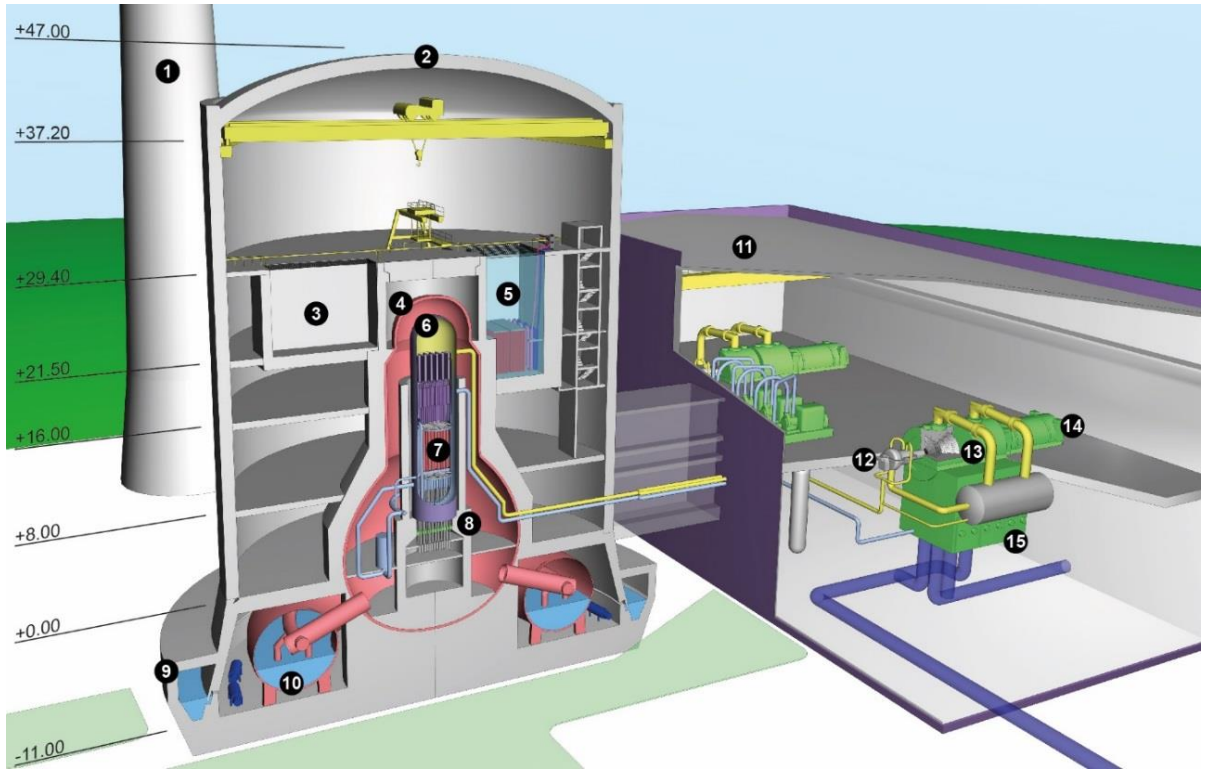


MELCOR 1.8.5 MELCOR 1.8.6 MELCOR 2.1



Decommissioning of BKW Mühleberg Nuclear Power Plant

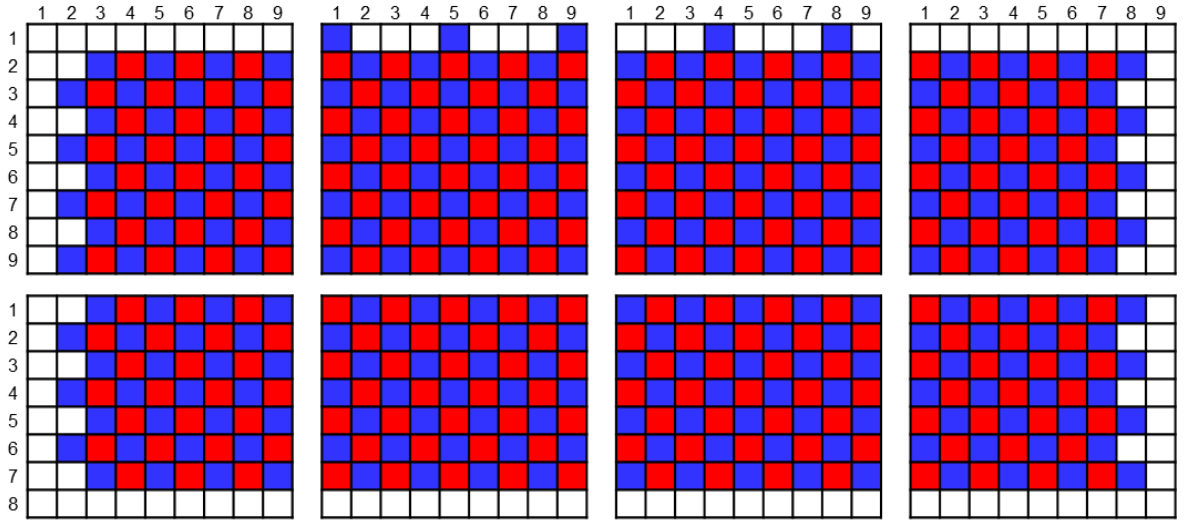
- General Electric BWR 4
- Power: 373 MW el., 1097 MW th.
- 240 fuel assemblies
- Mark 1 containment
- Concrete secondary containment
- Bunkered emergency building
- Commissioning: 1972
- Final shutdown: December 2019
- October 2020:
  - End of operating license
  - Start of first "decommissioning phase"
- DSA and PSA including MELCOR analysis

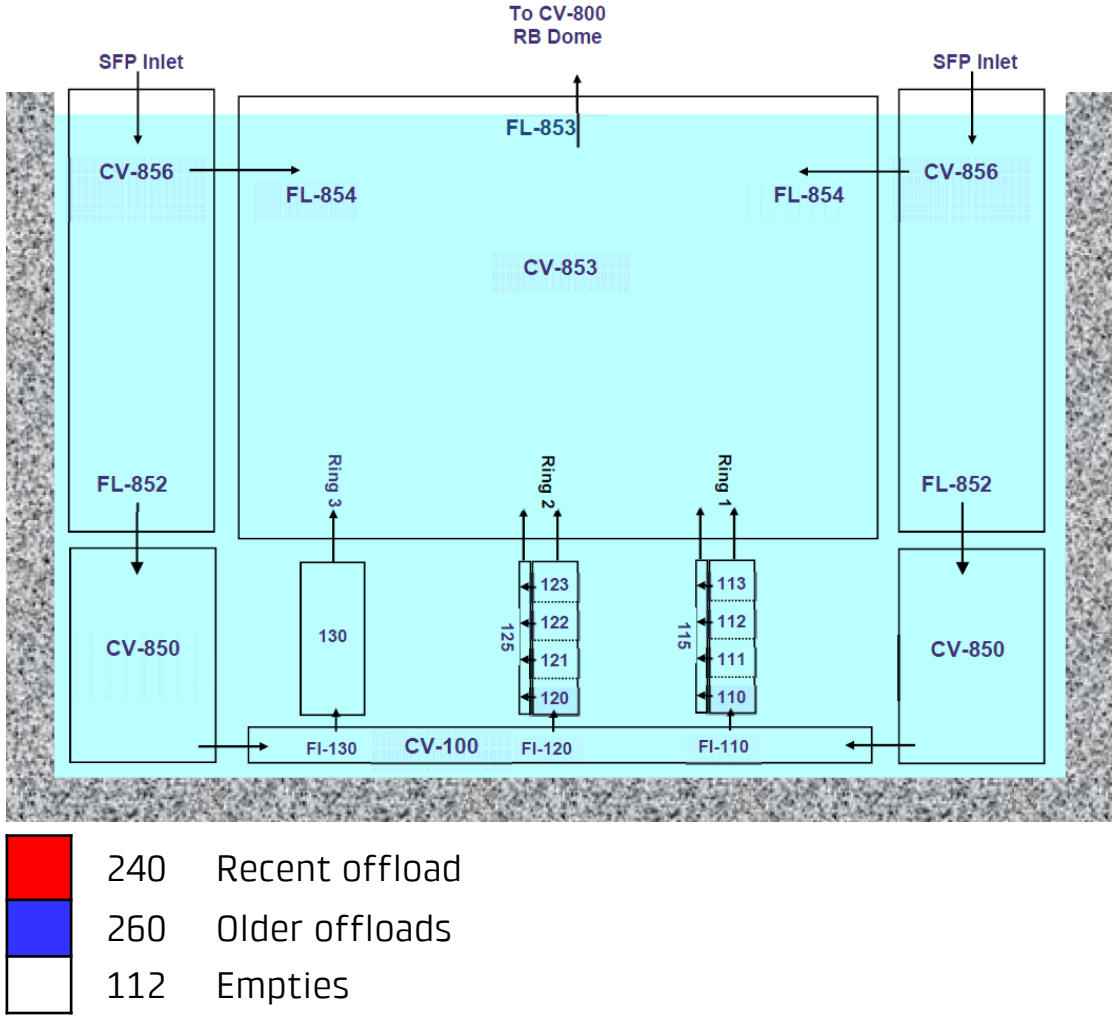


Decommissioning of BKW Mühleberg Nuclear Power Plant

MELCOR analysis

- MELCOR analyses in context of PSA level 2
- Assumed 500 fuel assemblies in SFP
- Assumed minimum 9 months of decay
- Low average decay heat of 1.8 kW / assembly
- MELCOR 1.8.6
- SFP nodalization with 3 rings





240 Recent offload
260 Older offloads
112 Empties

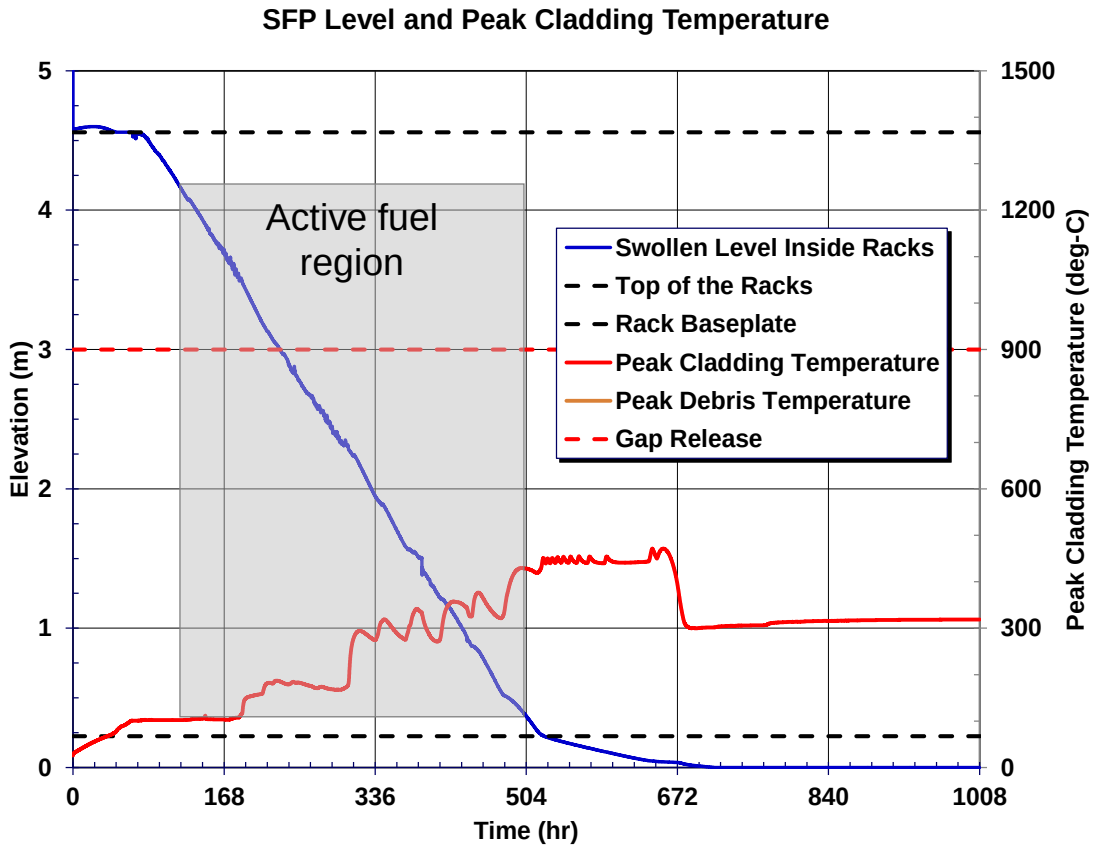
Decommissioning of BKW Mühleberg Nuclear Power Plant

MELCOR analysis

- Plant damage state after severe earthquake
- Failure of SFP dam → initial loss of water to 4.5 m
- Loss of water cooling → boiloff
- 524 h: level drops under the rack base plate
  → gas flow through assemblies
- 672 h: steady gas flow that provides cooling
- Maximum PCT is 470 °C ‹‹ 900 °C

→ **After 9 months of decay no fuel damage due to sufficient gas cooling**

→ **Most of the severe events did not progress to fuel damage**



Decommissioning of BKW Mühleberg Nuclear Power Plant

Criticism of regulator

- Swiss Federal Nuclear Safety Inspectorate (ENSI) questioned gas coolability result
- New findings from PSI show that influence of Nitrogen onto the cladding oxidation are not negligible [1]
- Recent offload was lumped into one single MELCOR ring → average decay heat
- Some assemblies have more important decay heat (peaking)

Study on gas coolability

- Objectives:
  - Demonstrate gas coolability at the beginning of decommissioning
  - Implement current state of the art
  - Assess influence of PSI oxidation model on gas coolability
  - Assess influence of decay heat peaking on gas coolability

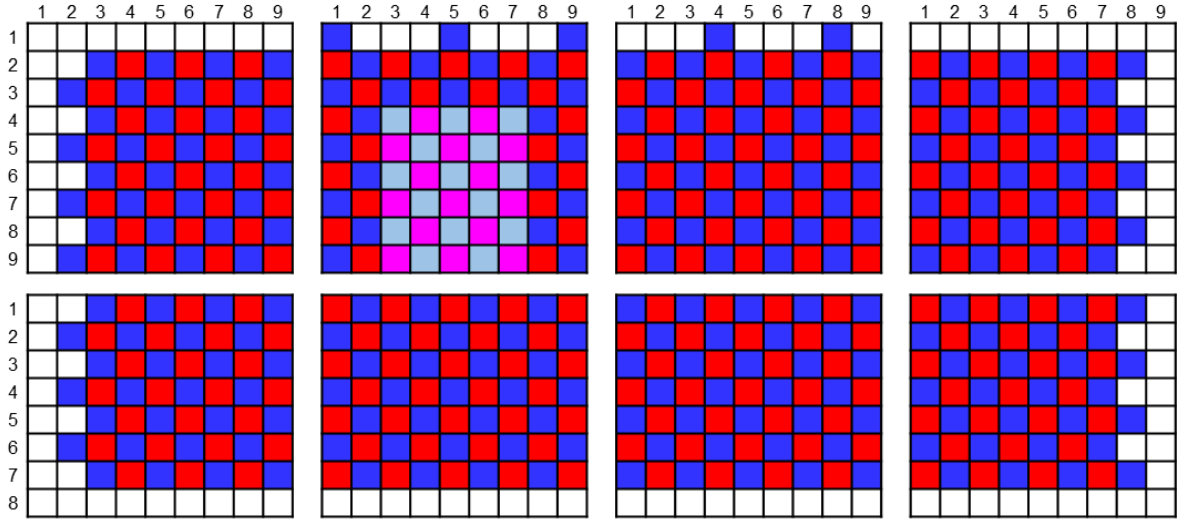
[1] Bernd Jaeckel, Jonathan Birchley, Leticia Fernandez-Moguel, Paul-Scherrer-Institute, Villigen PSI, Switzerland, "Spent Fuel Pool Under Severe Accident Conditions", 22nd International Conference on Nuclear Engineering, Prague, Czech Republic, July 7–11, 2014

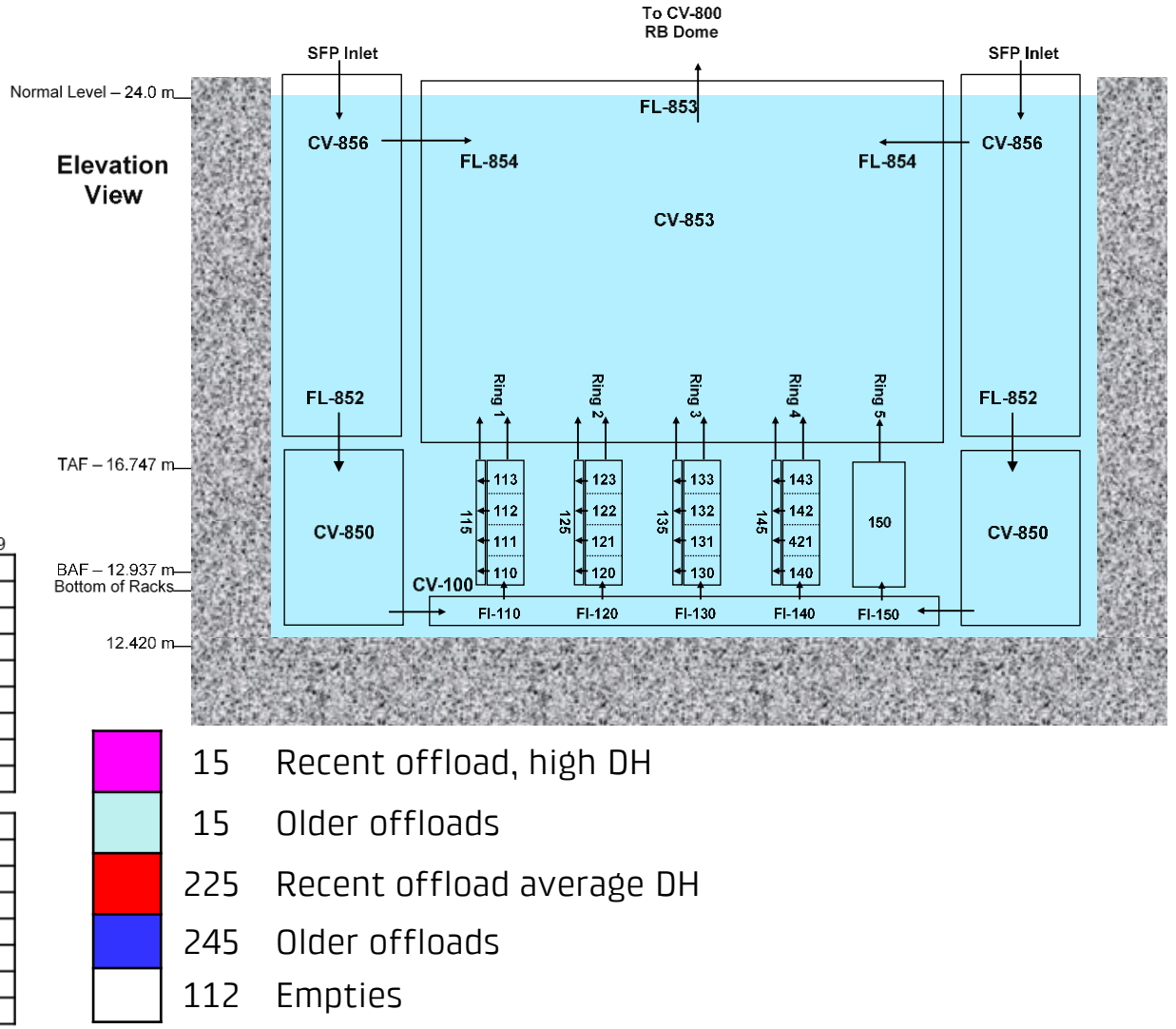
Study on gas coolability
Refinement of SFP model

- Peaking ratio for decay heat (DH):

$$\frac{maximum\ DH\ per\ assembly}{average\ DH\ per\ assembly} = 1.5$$

- Conversion to MELCOR 2.2
- SFP nodalization with 5 rings
- 10x10 GE14C fuel assemblies
- Form loss coeff. k according to GEH
- Laminar friction coefficients S_{lam} according to [1]





15	Recent offload, high DH
15	Older offloads
225	Recent offload average DH
245	Older offloads
112	Empties

[1] N.Todreas and M. Kazimi, "Nuclear System II: Elements of Hydraulic Design," Vol. 2, Taylor and Francis, Massachusetts Institute of Technology (MIT), 2001.

Study on gas coolability
Oxidation modeling

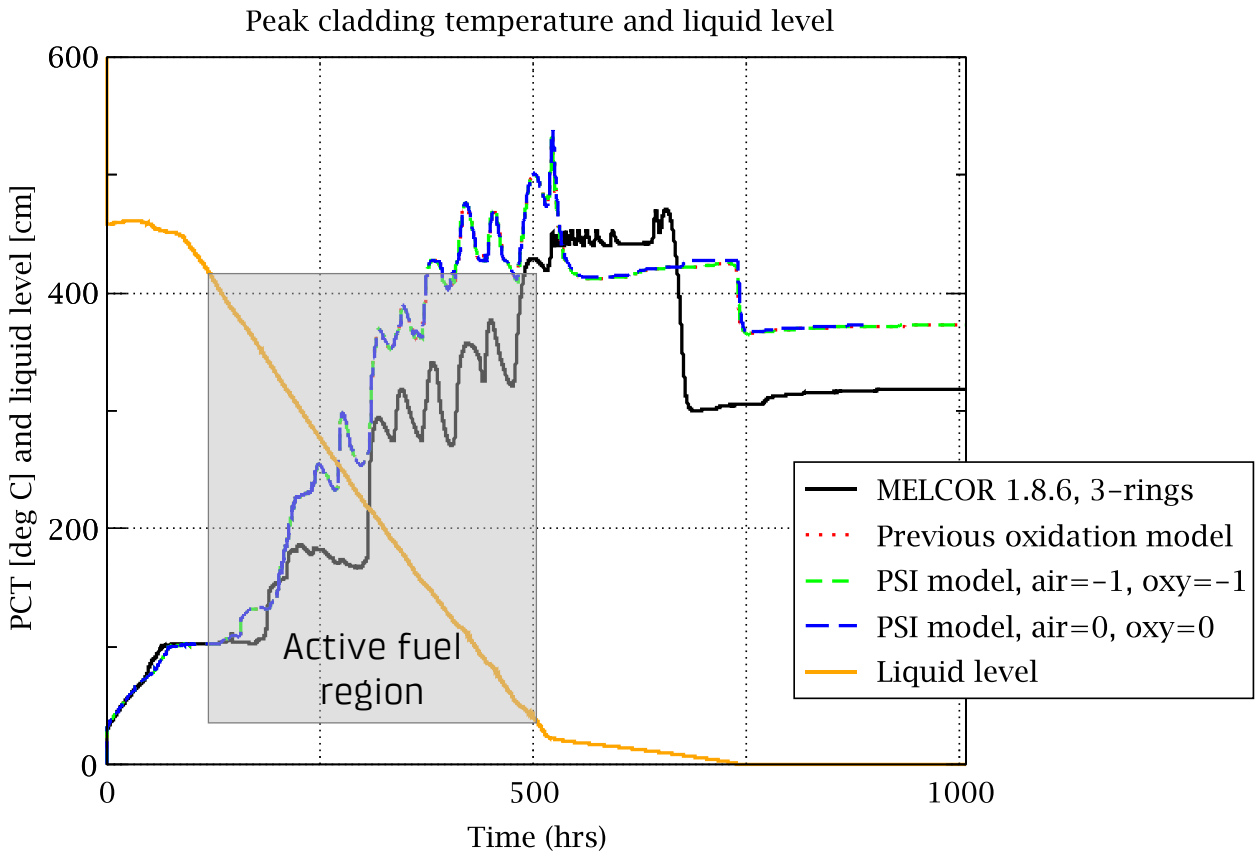
COR_OX input card

MODEL	0	Previous MELCOR oxidation model is used
	1	PSI oxidation model is used
STEAM	0	Catchart-Pawel/Urbanic-Heidrick
	1	Leistikov-Schanz/Prater-Courtright
	.....	
AIR	0	Hofmann-Birchley
	.....	
	-1	Kinetic parameters given by sensitivity cards (SC1001)
OXYGEN	0	Uetsuka-Hofman
	-1	Kinetic parameters given by sensitivity cards (SC1001)
NOBRK	0	Enable in steam and air (recommended)
	1	Enable in air; disable in steam
	2	Disable in both steam and air

COR_OXB input card

IOXB	0	Breakaway model is off.
	1	Breakaway model is on for clad and canister.
	2	Breakaway model is on for all Zircaloy components (not recommended)

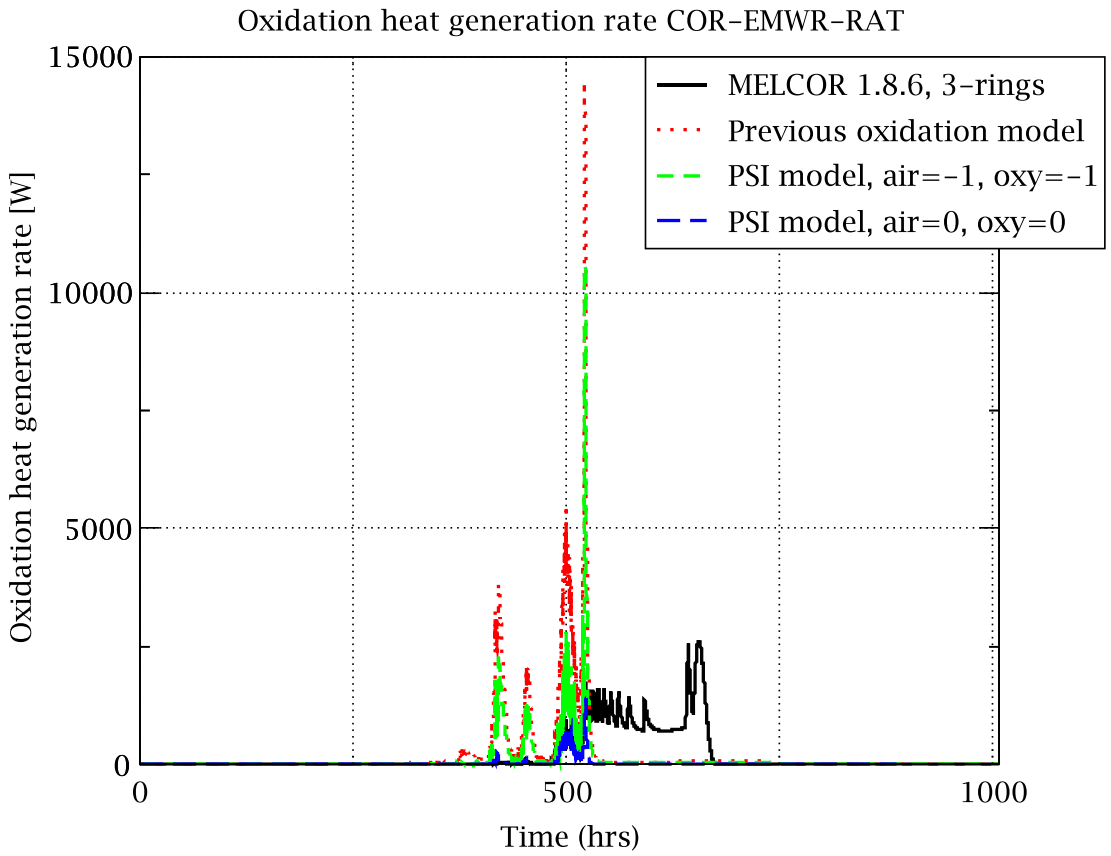
Study on gas coolability
Peak cladding temperature



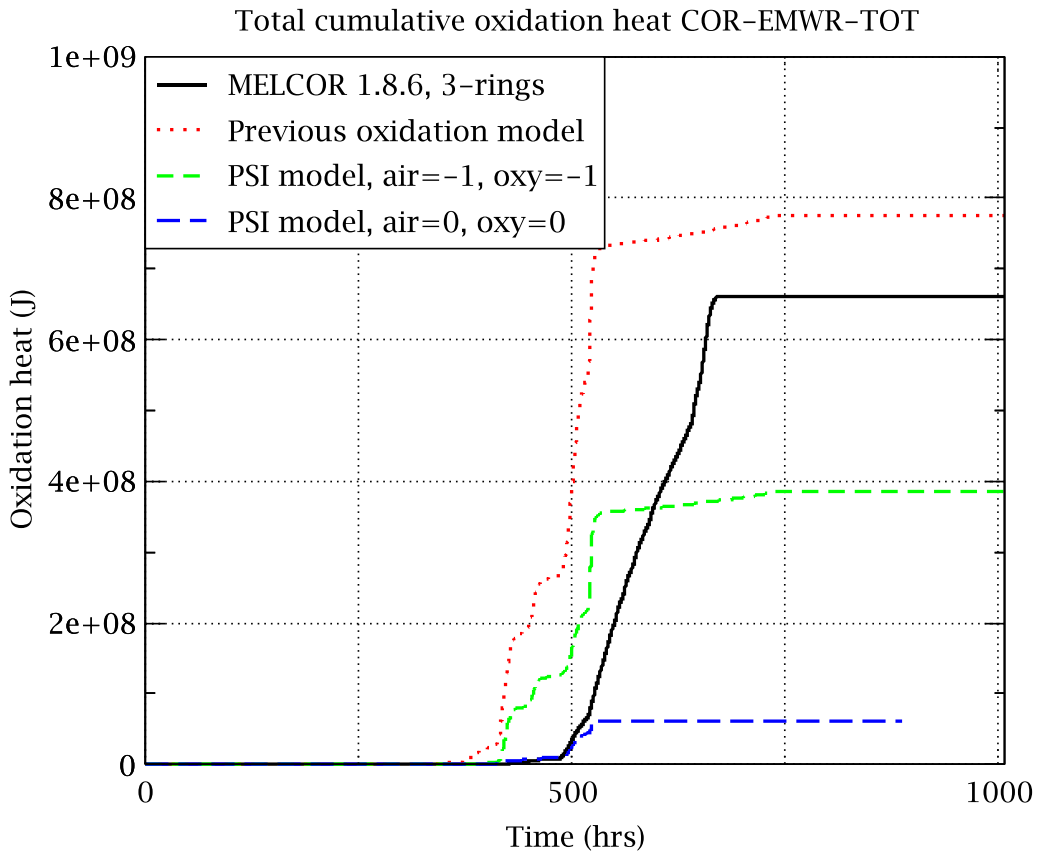
- PCT << 900 °C
- Maximum PCT differs by less than 10 °C in between different oxidation models
- Maximum PCT is 472 °C in 3 ring model
- Maximum PCT is 530 °C in 5 ring model

→ Oxidation models don't have significant influence on the PCT after long decay time.
→ Decay heat peaking affects the PCT
→ **Gas coolability is confirmed**

Study on gas coolability
Oxidation heat



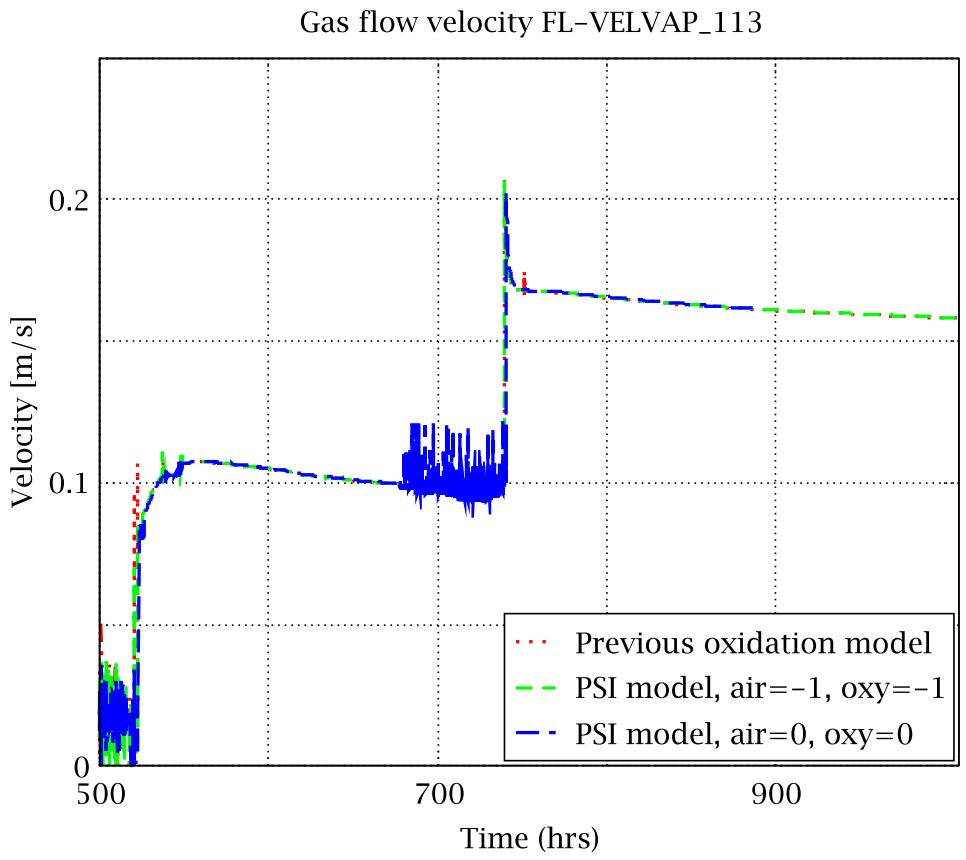
Zirconium fire: 1.E5 W to 1.E7 W



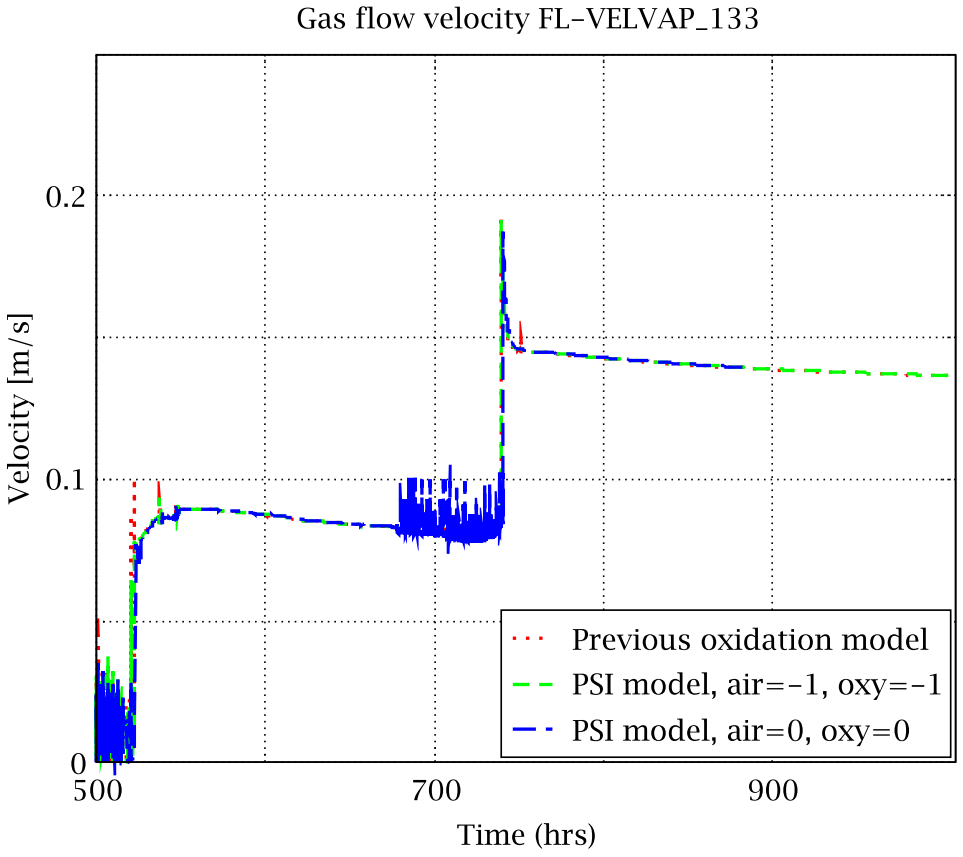
Zirconium fire: 1.E11 J for 500 assemblies

Study on gas coolability
Gas flow through assemblies

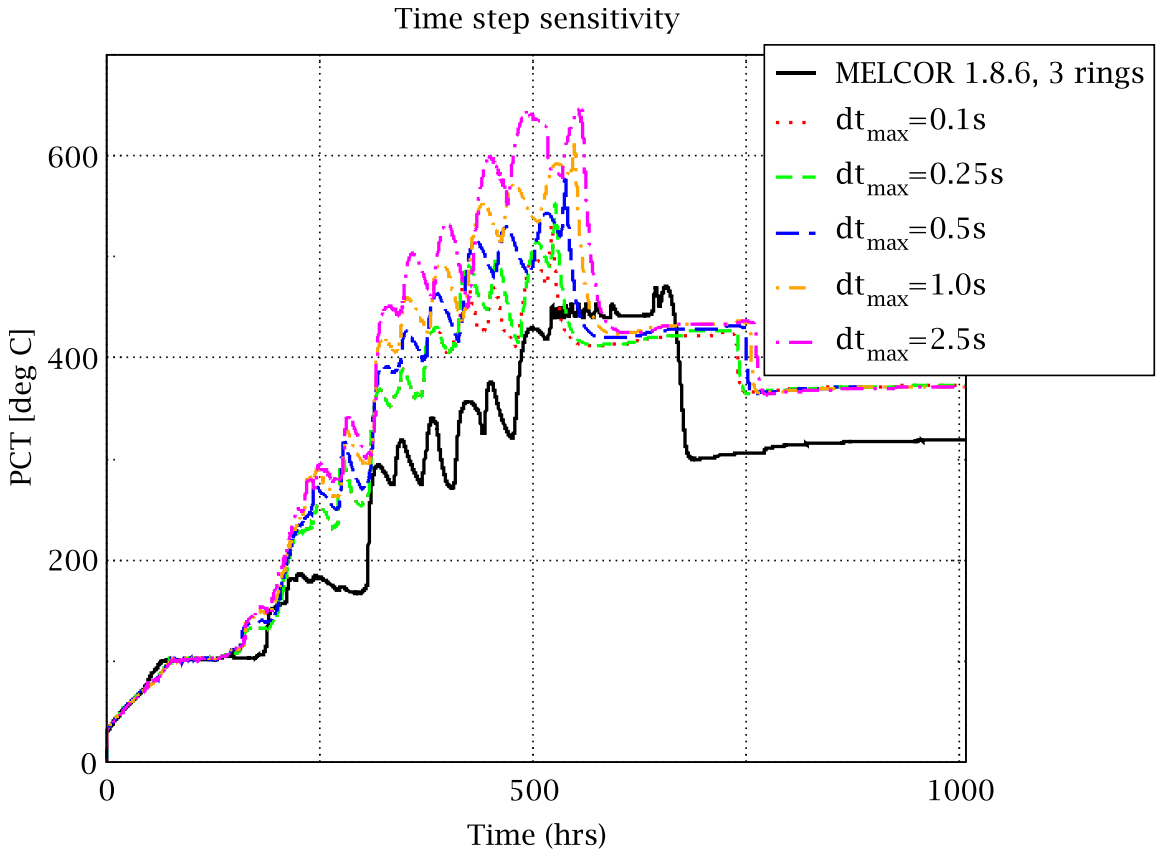
Ring 1



Ring 3



Study on gas coolability
Time step sensitivity



- Time step logic of the Mühleberg SFP model was modified to allow different Δt_{max}
- The lower the Δt_{max} the lower the PCT
- Results converged for lower Δt_{max}

→ Δt_{max} =0.1s and 0.25 s are adequate

Summary and conclusion

Background
- BKW Engineering provides services to both Mühleberg Nuclear Power Plant and external customers
- We use MELCOR for PSA level 1, 2, and SAMG
- MELCOR analysis in the context of a PSA for decommissioning
- Result: Gas coolability → most of the severe events did not progress to fuel damage
- The result was questioned by Swiss Federal Nuclear Safety Inspectorate

Study on gas coolability
- Conversion of the SFP model to MELCOR 2.2
- Sensitivity of the PCT to different oxidation models was studied
- 5 ring nodalization accounted for decay heat peaking

Findings
- Gas coolability in SFP in severe event can be assessed with MELCOR
- Different oxidation models did not affect the low PCT
- Decay heat peaking affected the PCT

→ **Gas coolability at the beginning of decommissioning was confirmed**

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