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MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
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Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Latest Experiences with MELCOR 2.2: An Overview of Applications, Issues and Challenges

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16th European MELCOR User Group, EMUG 2025
Brno University of Technology, Czech Republic, 7th-11th April, 2025

Areas of Work:

Plants applications

1. BWRs: 1F1 Fukushima Analysis
2. iPWRs: SA scenarios assessment

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01

Scenario re-calibration in 1F1

1F1 Fukushima analysis

- **Frame**

  - **OECD/NEA FACE project (2022-2026)**: Fukushima-Daiichi Nuclear Power Station Accident Information, Collection and Evaluation project.

- **Objective**

  - Fukushima-Daichii accident analysis.

- **Tool**

  - MELCOR 2.2

- **Scope**

  - Re-calibration of the possible scenario in Fukushima Daiichi Unit 1

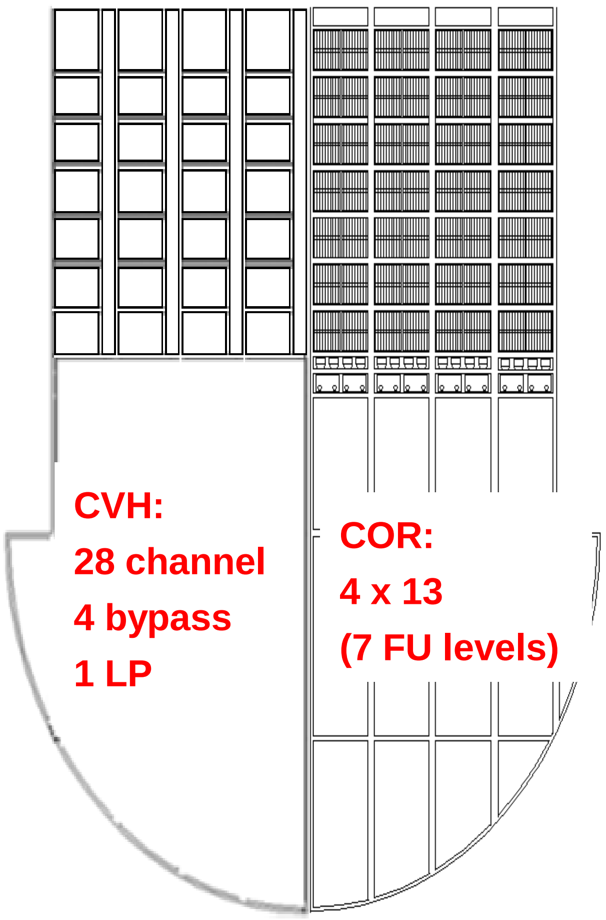
    (i) MELCOR version update (from MELCOR 2.2.9607 to r2024.0.3)

    (ii) Scenario re-calibration

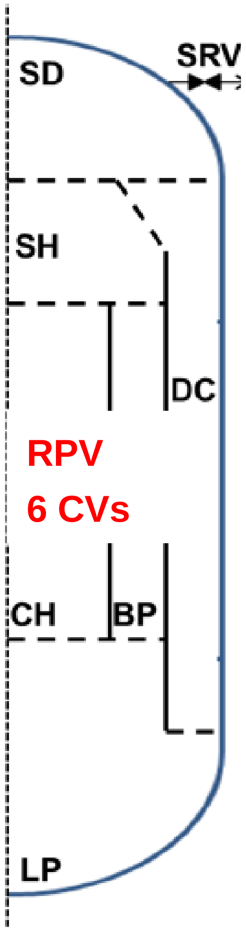
1F1 Fukushima analysis

CODE EM (Evaluation Model)

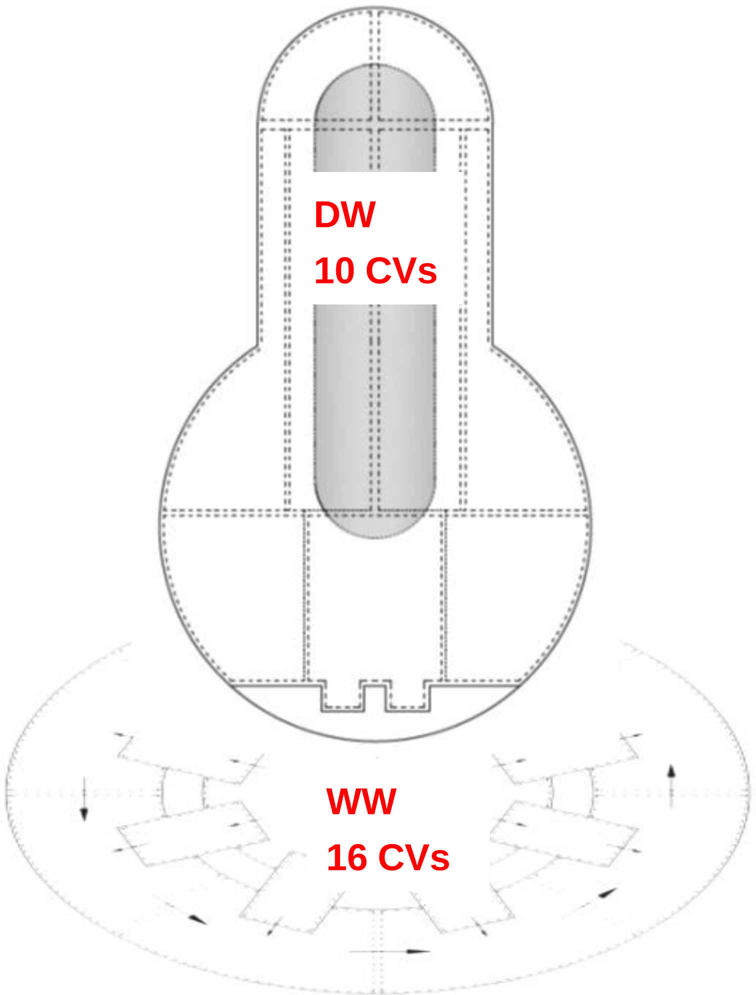
CORE



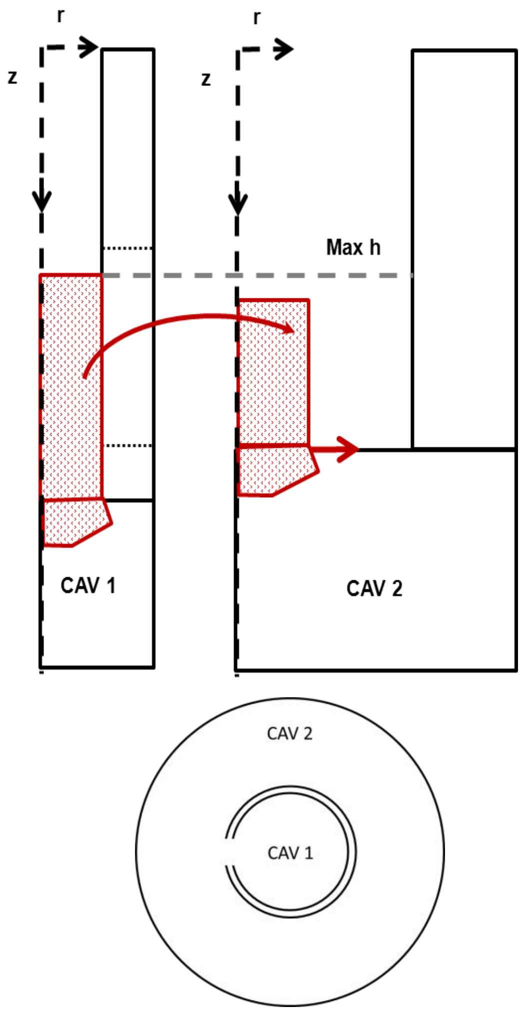
RPV



PCV

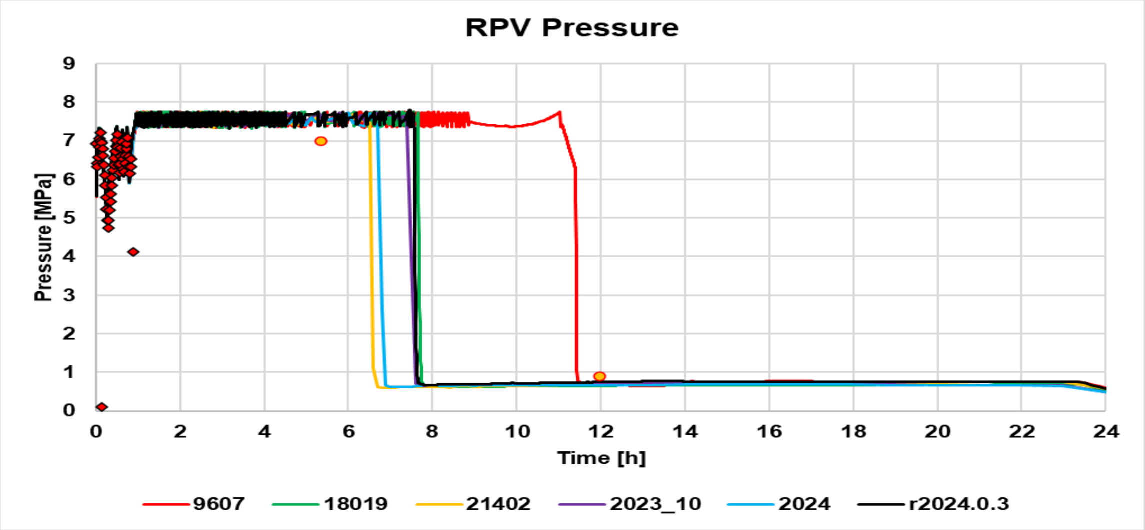


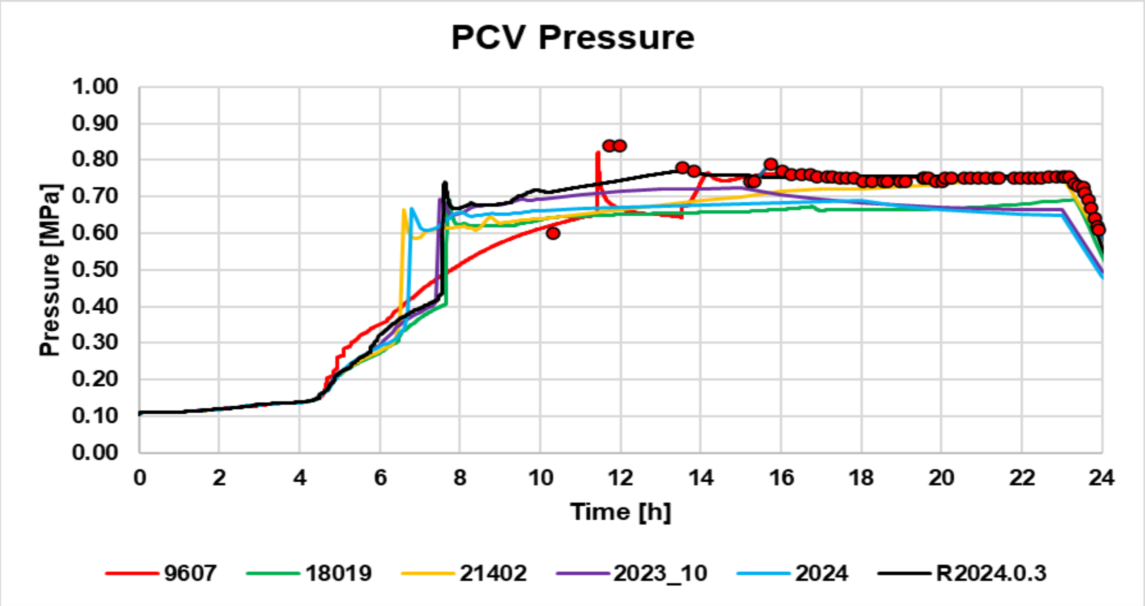
CAVITY



1F1 Fukushima analysis

MELCOR version update





✓ Significant variation in accident progression among MELCOR versions.

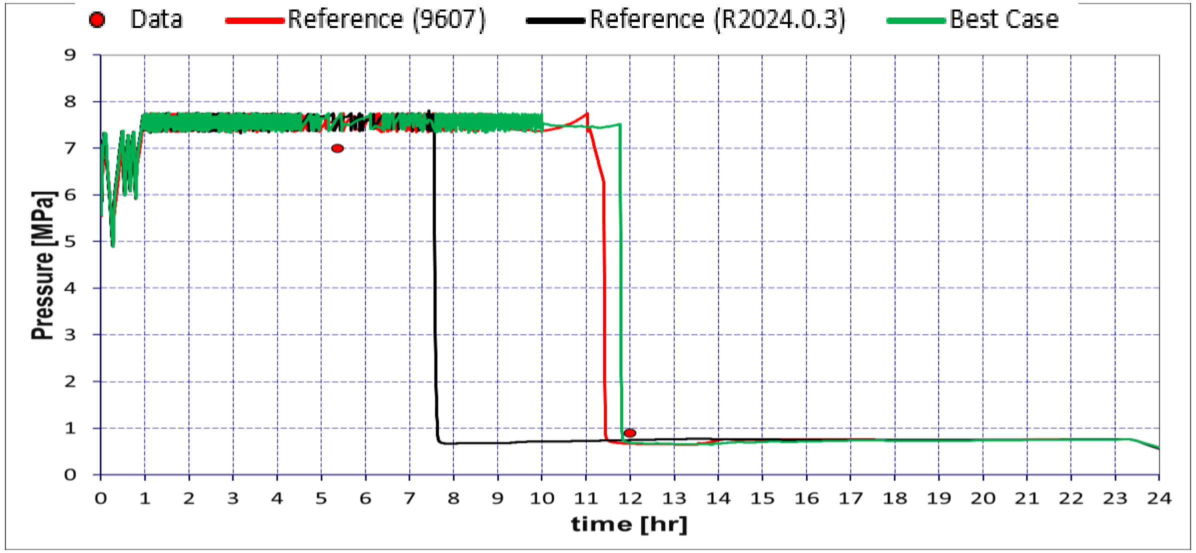
Scenario re-calibration with r2024.0.3 (August 1, 2024)
(Diagnosis based on P_{RPV}, P_{DW})

Hypotheses setting

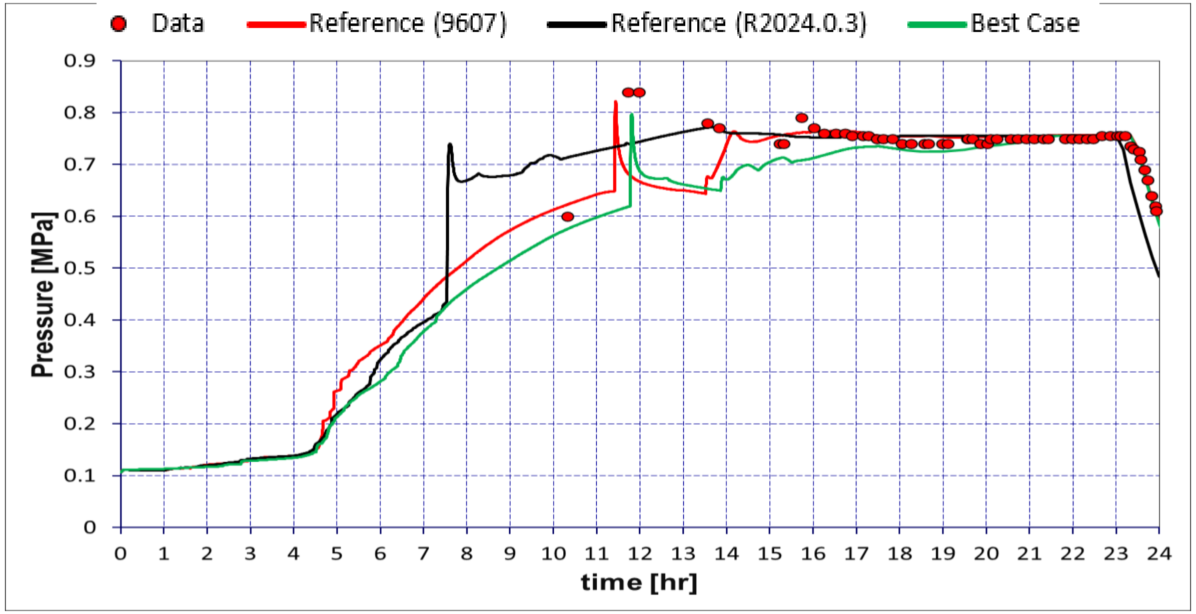
- RCS leakages (GK & LP)
- No water injection before 24 h
- IC effect fitting
- SRVs (4;1 on)
- PCV venting
- Time of calculation = 24h

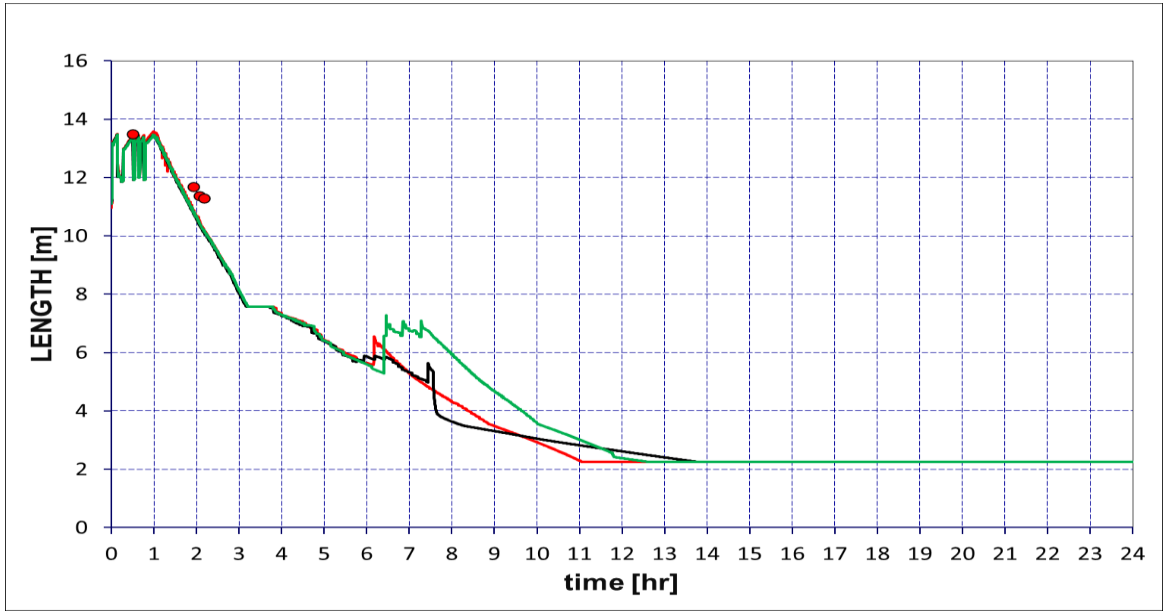
1F1 Fukushima analysis

Scenario re-calibration



- RCS leakages
  - SRV gasket (steam) [10^{-2}m – $3\cdot10^{-2}$m]
  - “Solid” RCS (water) [0 – $5\cdot10^{-3}$ m]
- Thermal setpoints
  - Penetrations failure [1153K – 1673K]
- Materials interactions
  - Eutectics formation
  - Ad-hoc materials interaction





Overview

- Main On-going work – Consolidation stage:
  - Diagnosis based on P_{RPV}, P_{DW}
  - Postulated RCS leakages as an effective tool to guide the core degradation pattern
- Future work:
  - Eutectic model fitting (delay in the liquefaction time)
  - Running time extension to 10 d
  - Explore other possible scenarios

02

SA scenarios assessment in a generic iPWR

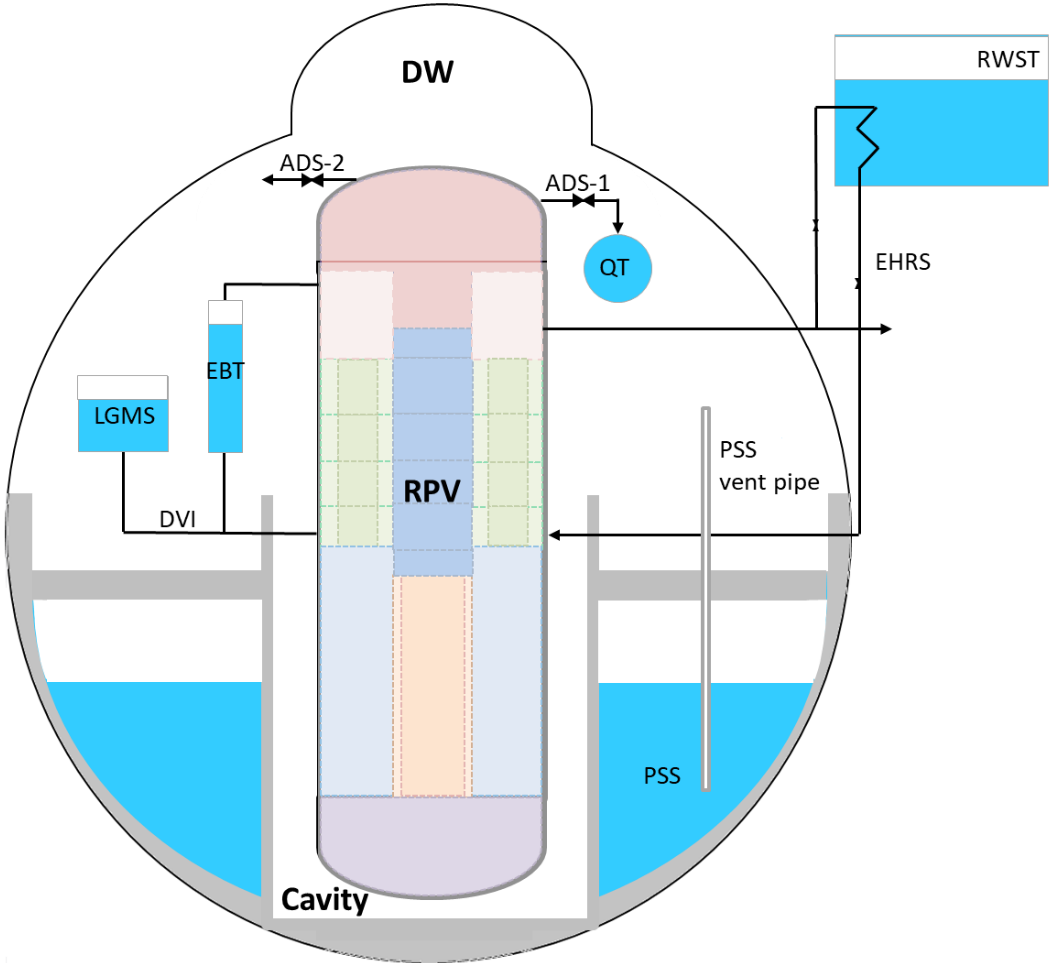
iPWRs

- **Frame**
  - The HORIZON 2020 **SASPAM-SA project**: aims to investigate the **applicability and transfer of knowledge and know-how** accumulated on the **operating large-LWR to the iPWRs.**

    Coordinated by **ENEA** – 23 partners from 13 European countries
- **Objective**
  - Evaluation of the code capabilities for a generic iPWR SA sequences.
  - Explore the potential impact of different SSs availability on the accident progression.
- **Tool**
  - MELCOR 2.2_18019 (SNL, UNRC).
  - Original input from UNIROMA/ENEA.
- **Scope**
  - D2 (300 MWe, dry spherical containment, several passive SSs).
  - Small LOCA (r = 2.14 cm) in one Direct Vessel Injection (DVI) line.

iPWRs

Plant Overview



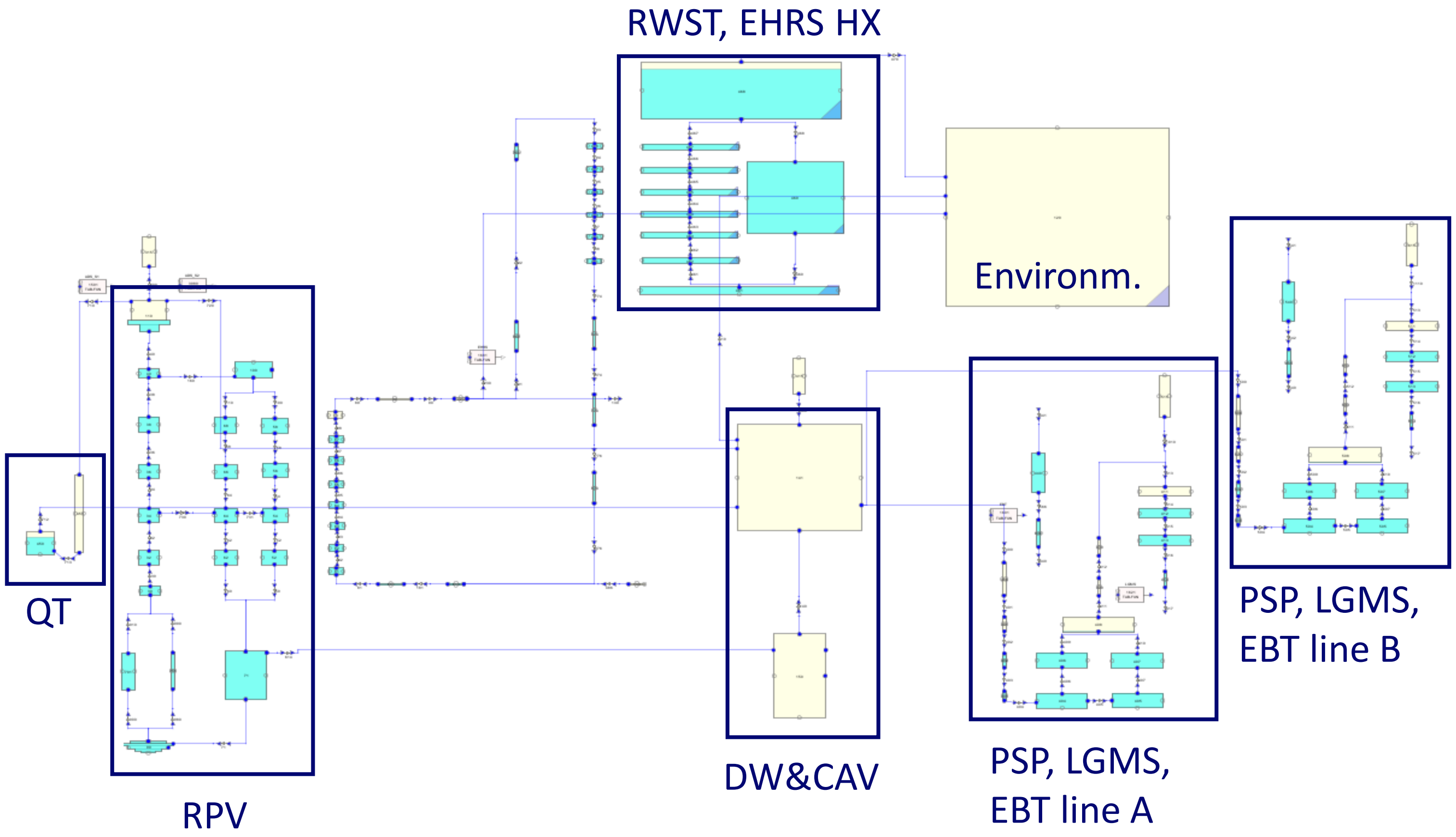
- LWSMR
- 300 MWe iPWR design
- 17x17 XL fuel assembly W design
- Cylindrical RPV (6 m diameter x 21 m height)
- Spherical dry containment (25 m diameter)

- SPSs: LGMS, PSP, ADS, EHRS, EBT

SS	# Units	Actuation condition	Function	Connections (From/To)
EHRS	2	High DW P/Low PRZ P/Low PRZ level	Decay heat removal	Secondary coolant system/RWST
EBT	2	Low PRZ P	High pressure safety injection	Upper plenum/EBT tank EBT tank/DC
ADS st-1	3	Low PRZ P	Primary automatic depressurization	PRZ/QT
ADS st-2	2	Low LGMS tank mass	RPV pressure relief	PRZ/DW
LGMS	2	Low RPV/DW differential P	Low pressure safety injection	LGMS tank/DC

iPWRs

CODE EM (Evaluation Model)



RPV: 20 CVs
Core: 6 radial rings, 16 axial nodes
SSs: EHRS, PSS, LGMS, EBT, ADS
Containment: 1 CV
NPP: 97 CVs, 112 FLs, 121 HSs, 206 CFs
No propriety data used

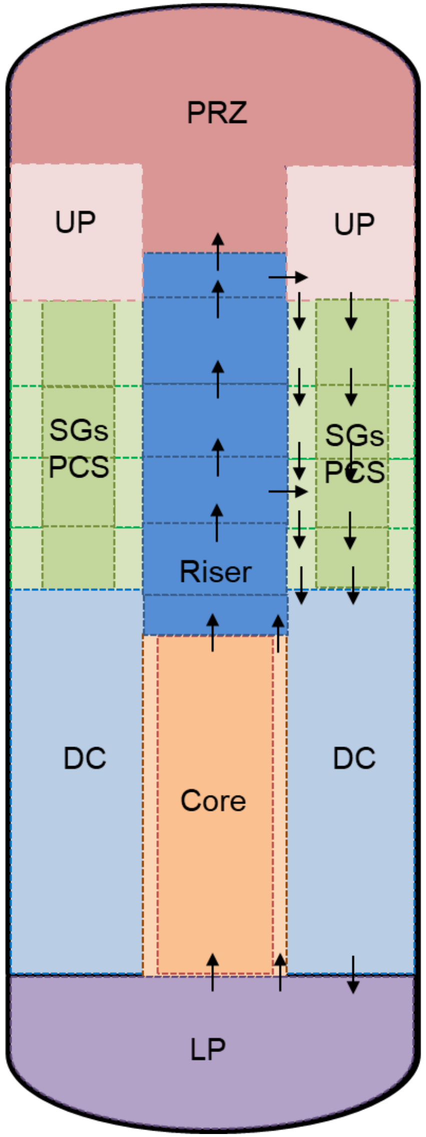
MELCOR 2.2.18019

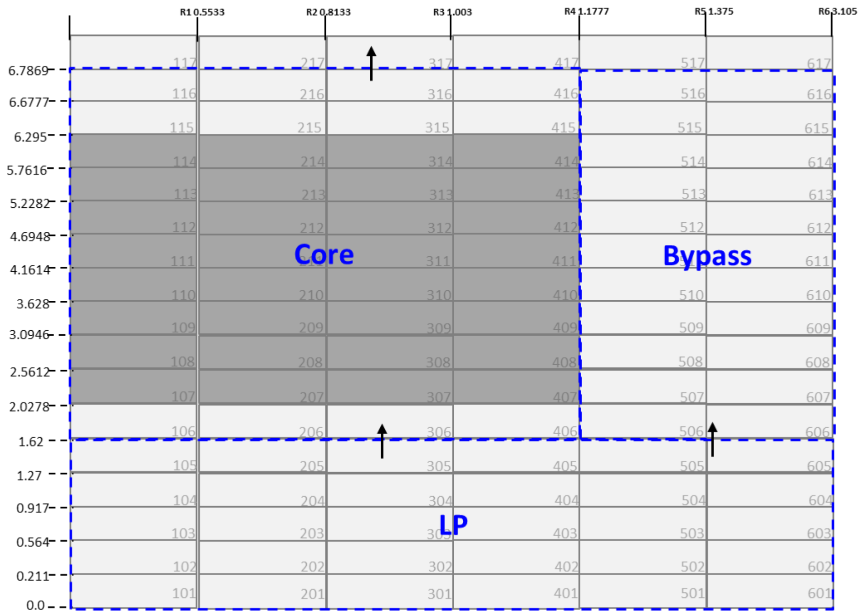
Scenario (DBA)

- Small LOCA in DVI line
- D2
- Steady state analysis carried out

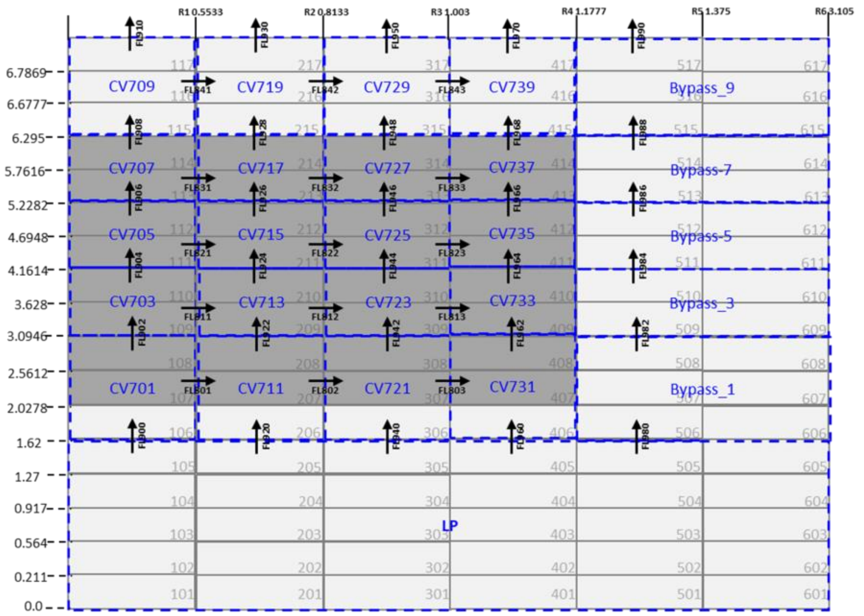
iPWRs

CODE EM – Core nodalization refinement





Coarse nodalization

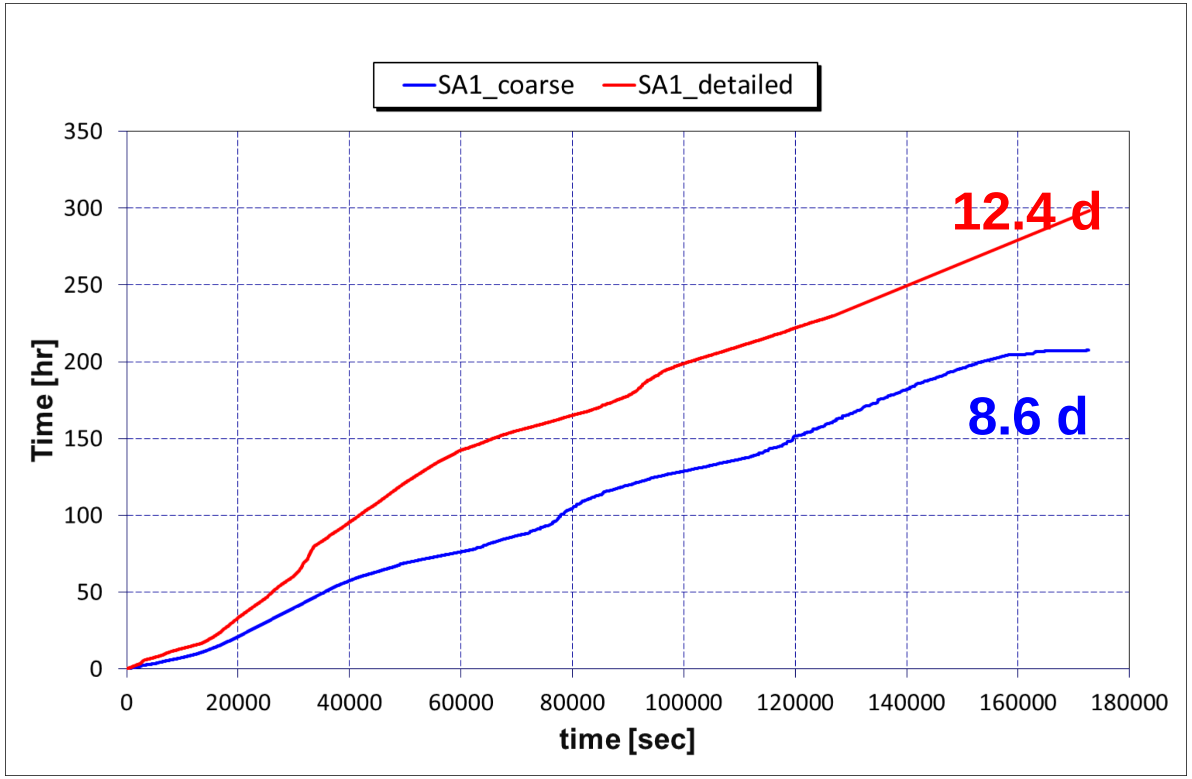


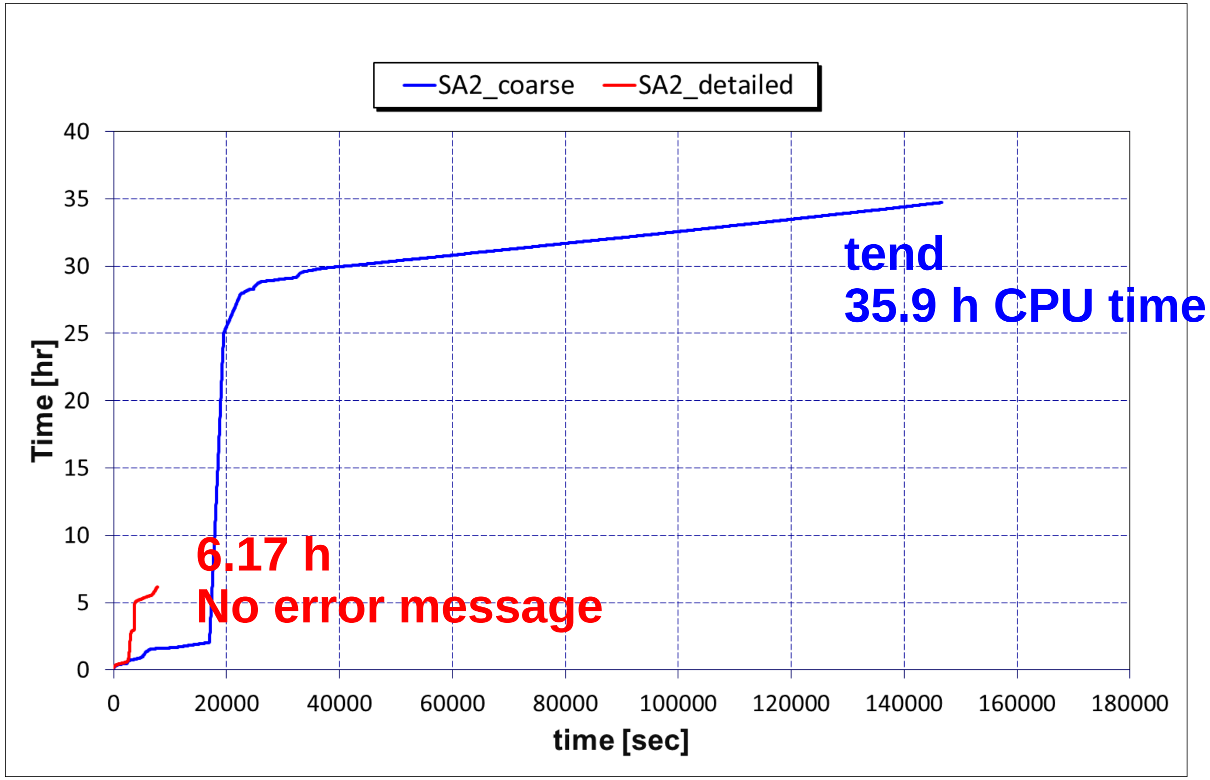
Detailed nodalization
(based on SOARCA best practices)

Vessel Vol.	# CVs (coarse/detailed)	# FLs (coarse/detailed)
Core	1/20	1/35
Bypass	1/5	1/5
LP	1/1	1/5

iPWRs

CODE EM – Core nodalization refinement



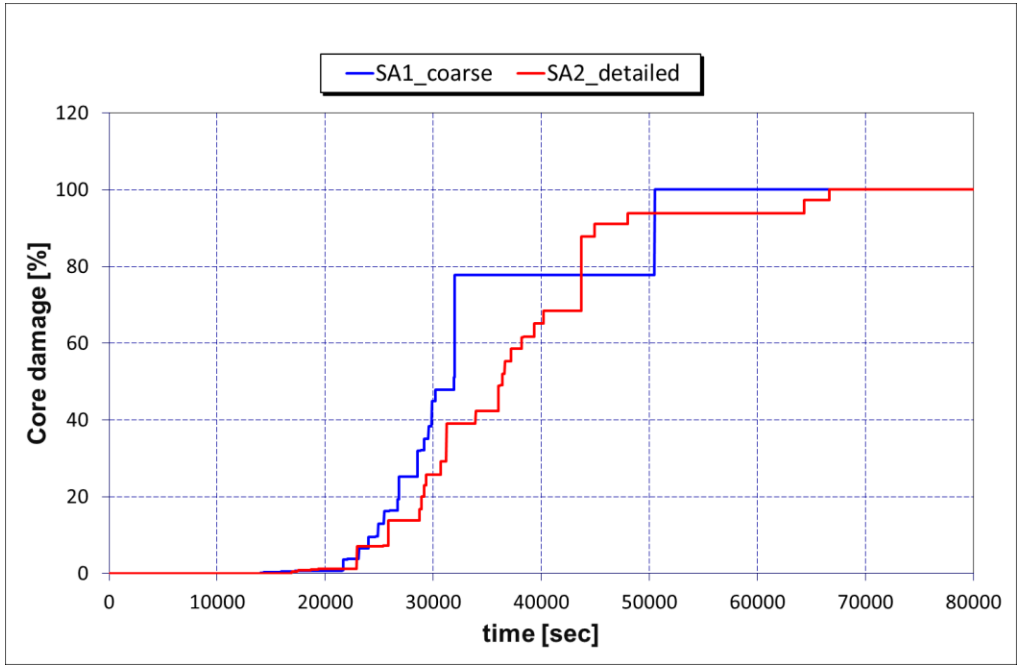


- Both calculations finish successfully(tend = $1.728 \cdot 10^5$ s)
- CPU time x 1.5 when detailed nodalization is used

- Both calculations fail (tend = $1.728 \cdot 10^5$ s)

iPWRs

CODE EM – Core nodalization refinement



- Core damage slow down (10000 s in 65 %)

Minor changes:

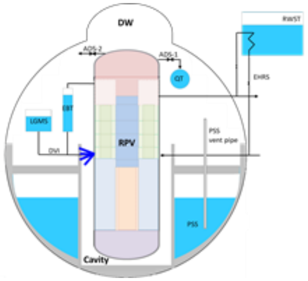
- Containment failure delay (aprox. 1000 s) in the detailed calculation.
- H_2 production decrease ~ 12 % (detailed model)

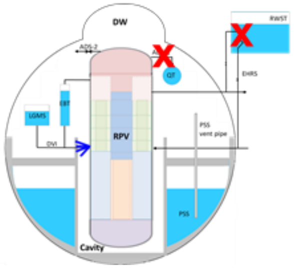
Back to previous core modeling

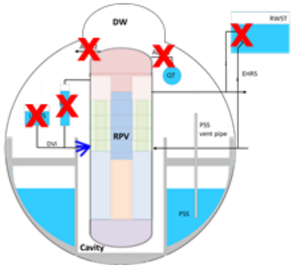
iPWRs

Scenarios

SSs	DBA	SA1	SA2
ADS_st1	✓	X	X
ADS_st2	✓	✓	X
EBT	✓	✓	X
LGMS	✓	✓	X
EHRS	✓	X	X







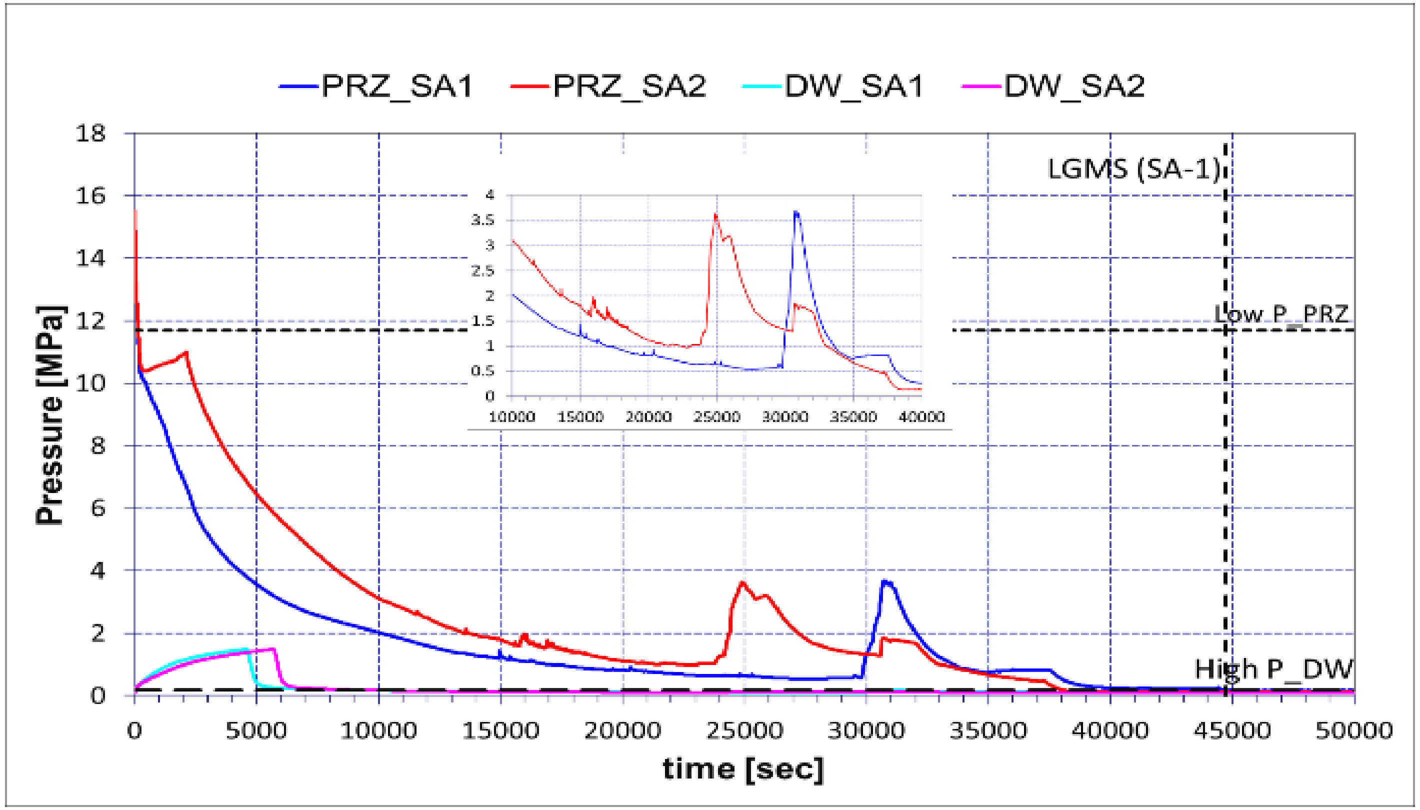
iPWRs

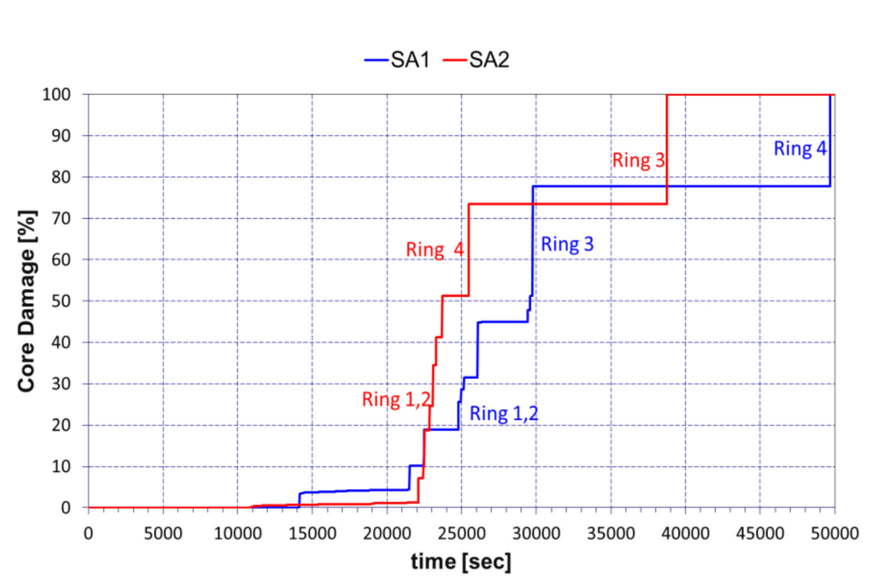
Main results

Event time (s)	DBA	SA1	SA2
Start of the transient	0	0	0
Scram time	28	28	28
Actuation of the EHRS	38	-	-
Actuation of EBT	112	153	-
Actuation of ADS-1	128	-	-
Begin of core uncovery*	186	610	1690
Containment failure	-	4630	5730
Begin of core degradation	-	13450	10270
H_2 production onset	-	12290	9070
Complete core uncovery**	-	23970	18680
Actuation of LGMS (s)	1770	44720	-
Actuation of ADS-2 (s)	11090	-	-
Time of vessel failure (s)	-	-	-

* Swell water level TAF reached

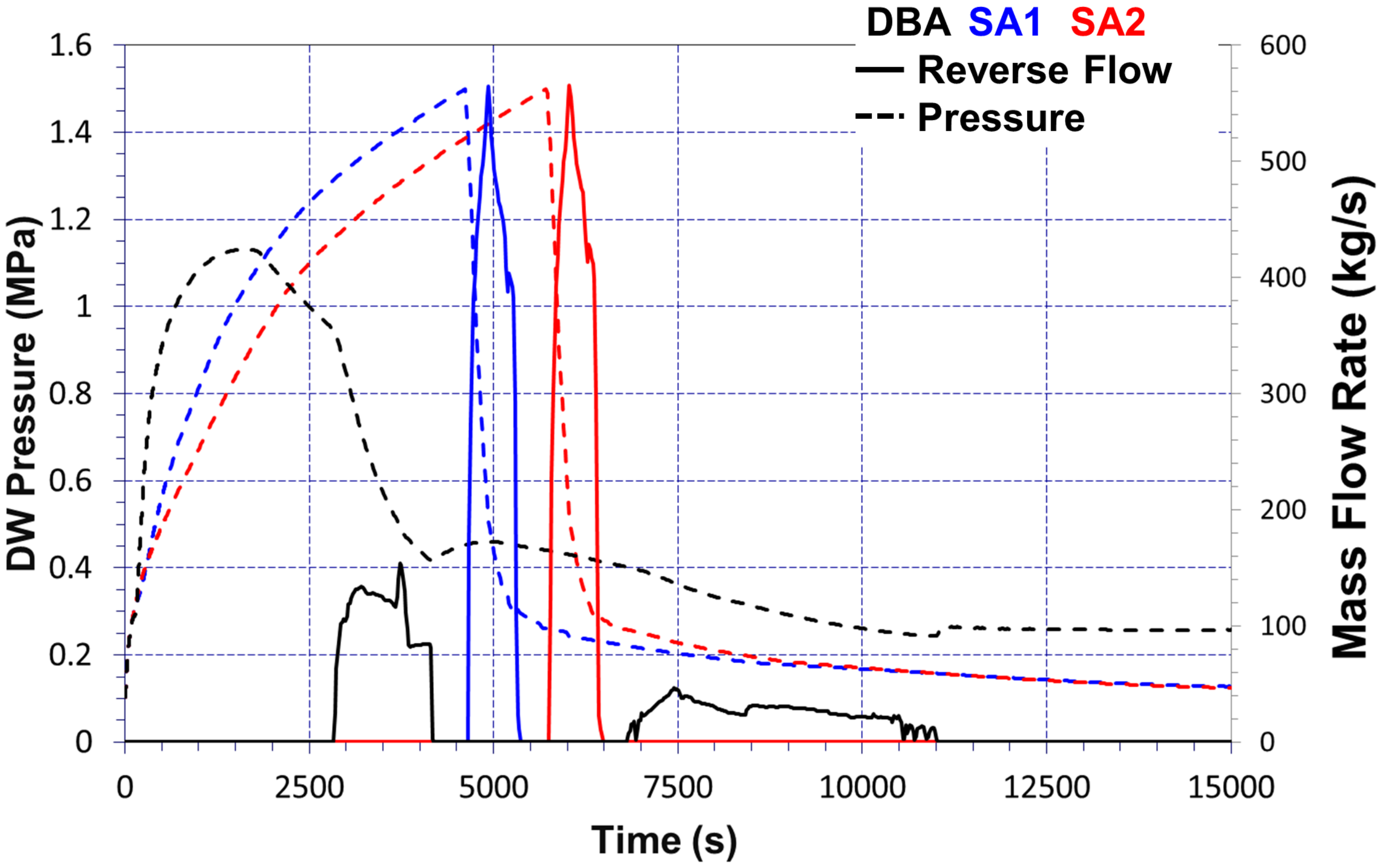
** Swell water level BAF reached





iPWRs

Main results

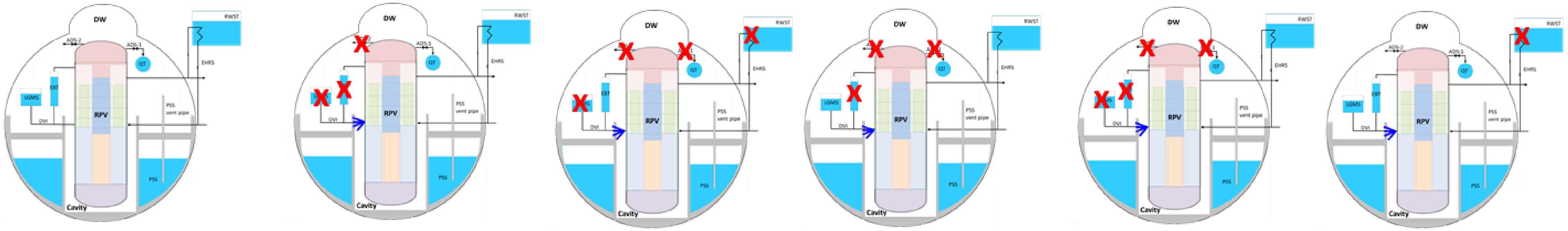


- Water reverse flow from the PSS to the DW.
- Attention to FPs redistribution.

iPWRs

Scenarios: SSs assessment

SSs	DBA	ADS_st1	EBT	LGMS	EHRS	ALL-EHRS
ADS_st1	✓	✓	X	X	X	✓
ADS_st2	✓	X	X	X	X	✓
EBT	✓	X	✓	X	X	✓
LGMS	✓	X	X	✓	X	✓
EHRS	✓	X	X	X	✓	X



CPU TIME (h)	32	27	84	16	15	88

Conclusions/Remarks

- Passive SS performance as designed prevent any core damage in case of a small double-guillotine break in the DVI line.
  - Containment pressure was kept far from losing its integrity.
- SA scenarios might be possible if EHRS is not available.
  - The combined operation of all passive SSs except for EHRS is predicted not to be able to prevent core melting.
- Containment failure is unexpectedly estimated at early times.
  - This should be further explored to check its sensitivity to the scenario modelling.
- RPV integrity preservation, as predicted, should be confirmed with additional studies.
- Flow reversal by depressurization of the containment.
  - Particular attention should be paid in all regards: timing, intensity, consequences on FPs redistribution.
  - This should be proved not to be scenario model sensitive.

Conclusions/Remarks

- In addition
  - H_2 risk (AMHYCO project).
  - Uncertainty quantification
    - Optimization of a BE case.
    - UQ of ex-vessel phase (in collaboration with UNIPI).
    - IUQ for SAs (in collaboration with UNIPI).
- Looking ahead
  - WC-ATFs.
  - Non-WC.

Our highest appreciation goes to:

SNL colleagues for an exceptional work & USNRC for their continuous support to it
CSN for making MELCOR accessible through its bilateral agreement with USNRC

Thank you for your attention!

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