Italian National Agency for New Technologies, Energy and Sustainable Economic Development

EMUG

Analysis of DBA and different BDBA scenarios in a generic iPWR-type SMR

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Introduction

- Light Water SMRs (**LW-SMRs**) are currently one of the technology options of major interest for short-term nuclear reactor deployment. In this regard, integral Pressurized Water Reactor (**iPWR**) using **passive safety systems** present several features aimed at improving the **inherent safety** of the plant.

- However, even if a plant is designed with advanced inherent safety features, some scenarios that could lead to severe accidents (**SA**) must be postulated and studied deterministically, in order to demonstrate the actual safety of the reactor.

- Therefore, it is necessary to analyze the capabilities of computational tools, such as severe accident simulation codes (e.g. **MELCOR**), to predict the behavior of SMR reactors in Design Basis Accident (**DBA**) and Beyond DBA (**BDBA**) transients.

Introduction

- Aim of the activity:

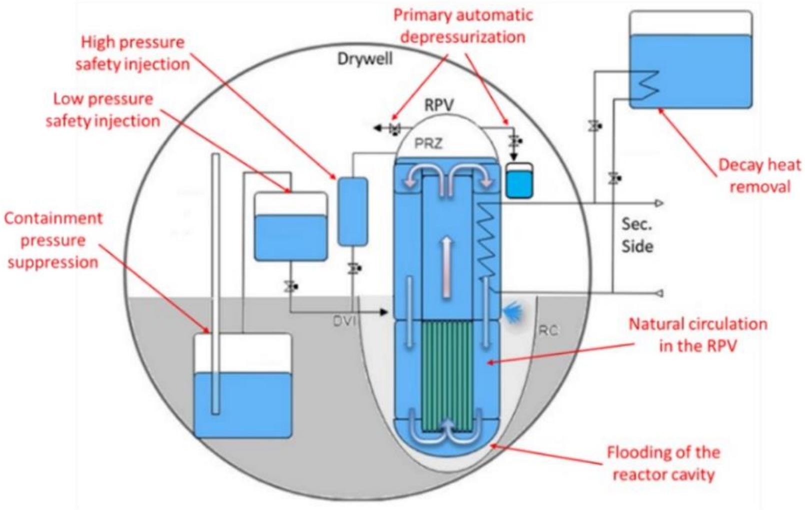
Evaluate **MELCOR's capabilities** in simulating the primary phenomena occouring in a generic 300 MWe **iPWR**-type reactor during DBA and BDBA conditions (where passive systems are postulated to fail due to valve failures), using key parameters (e.g. core and cavity levels, hydrogen generation) to assess the impact of passive safety systems failures on the transient evolution and identify the scenario with the most severe core degradation.

The present activity has been conducted in the framework of the Horizon Euratom **SASPAM-SA project**. The project is coordinated by ENEA and 23 organization from 14 countries are involved.

Funded by the European Union

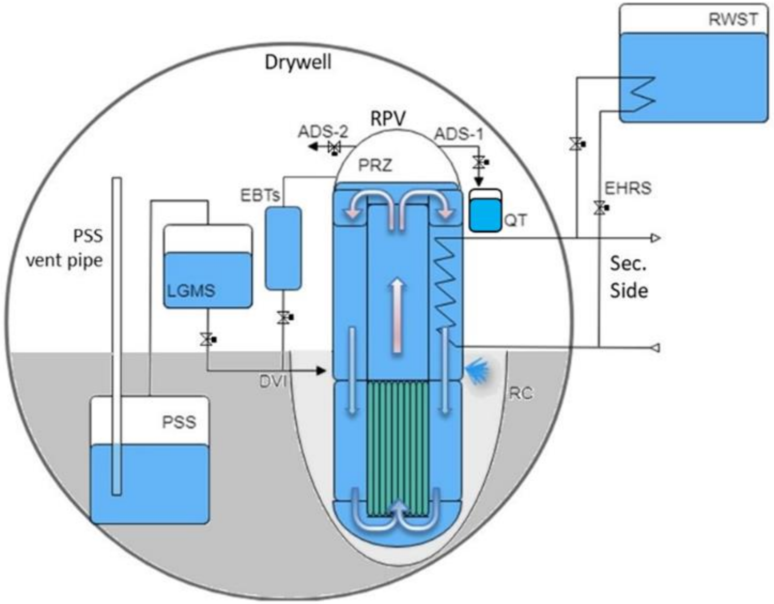
Design-2

- The **iPWR Design-2** is characterized by the use of several passive systems, by a dry containment and a power of about 300 MWe:
  - The reactor operates in **forced circulation during normal operation** and employs a passive mitigation strategy in accidental transients;
  - It consists of an **integral RPV**, which contains the core, a compact SGs, the Control Rod Drive Mechanism (CRDM), the primary pumps and the pressurizer included in the upper head;
  - The hot water at the core outlet flows **upward in a circular riser** up to the primary pumps suction. The flow path continues through the annular region of the DC, outside the core, to the LP and then back to the core.
  - **Passive systems** selected are: Emergency Passive Heat Removal System, Automatic Depressurization System, Passive High-pressure safety injection, Passive Low-pressure safety injection, Contaminent pressure suppression, passive flooding of the cavity.



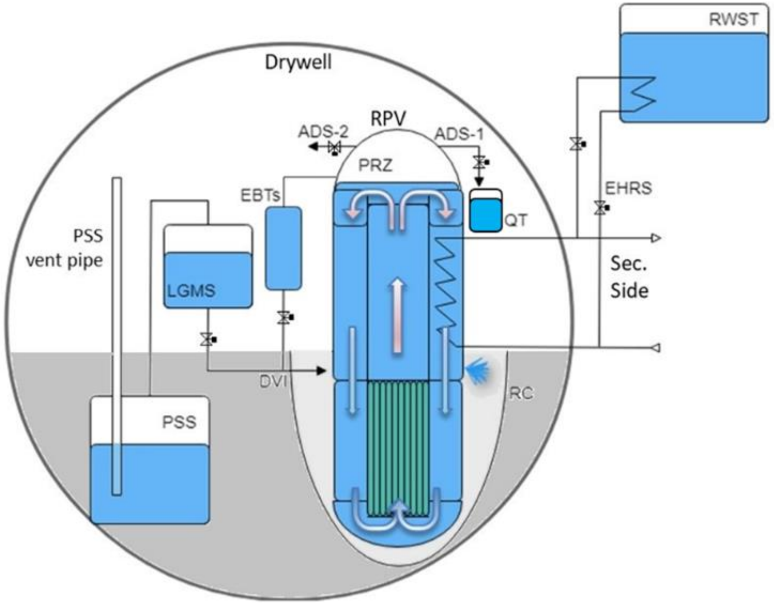
Design-2

- **Desing-2 Passive systems** modelled:
  - **EHRS** - Emergency Heat Removal System: Passive decay heat removal
  - **ADS** - Automatic Depressurization System: ADS Stage-1 and ADS Stage -2
  - **EBTs** - Emergency Boration Tanks: High-pressure safety injection via Direct Vessel Injection (**DVI**) line in the RPV DC;
  - **LGMS** - Long-term Gravity Make-up System: Low-pressure safety injection via DVI line;
  - **PSS** - Pressure Suppression System: Containment pressure suppression
  - **RC** - Reactor Cavity: Passive flooding of the Reactor Cavity



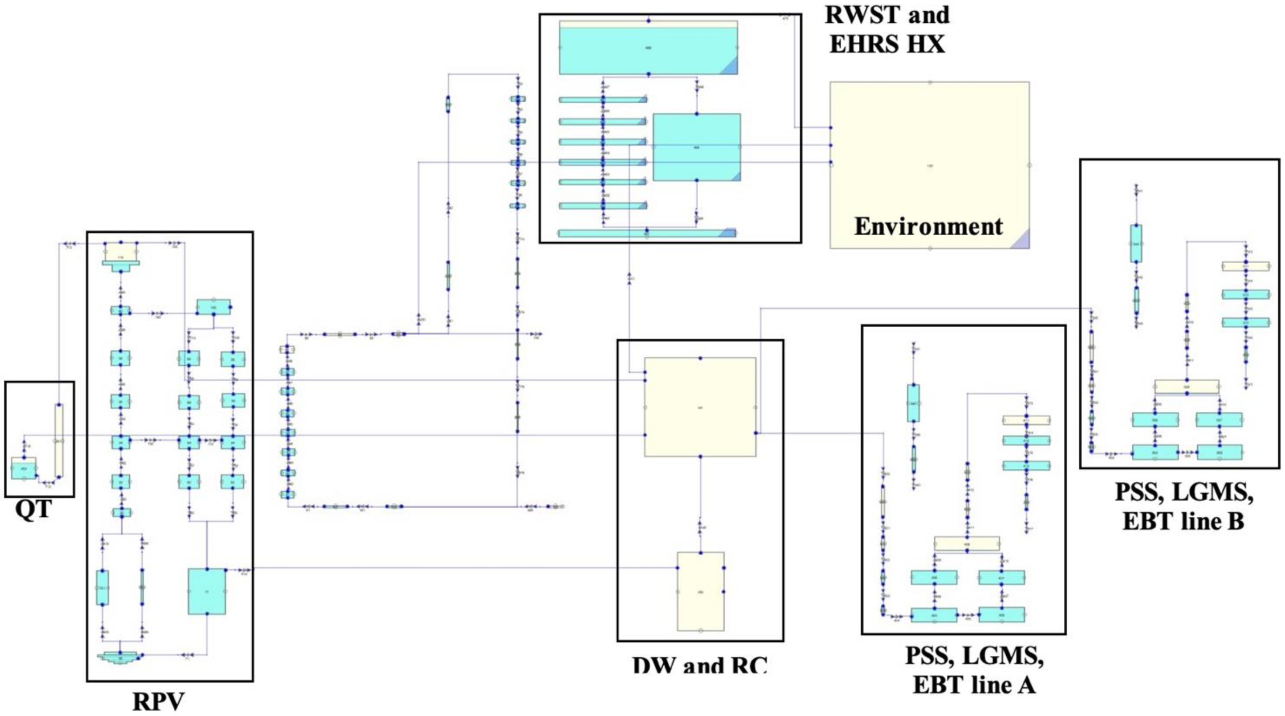
Design-2

- To develop the **MELCOR input-deck** a reference database was needed:
  - Considering the **characteristics of Design-2 reactor** type and the selected passive systems, a **generic** International Reactor Innovative and Secure (**IRIS) SMR type has been considered as reference** for this analysis;
  - During the nodalization development of the generic IRIS design**, no proprietary data have been used**;
  - The **main geometric information** has been determined by **scaling the data available from the SPES-3 facility**, by **engineering evaluation** and **public data available** for the IRIS reactor.



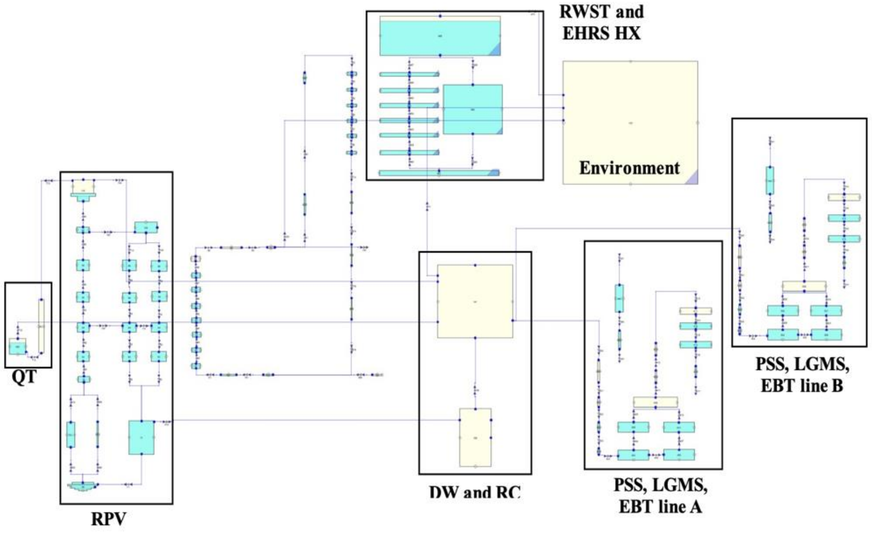
MELCOR Input Deck

- Symbolic Nuclear Analysis Package (**SNAP**) has been used to develop the nodalization and for the post processing of the results using its animation model capabilities.



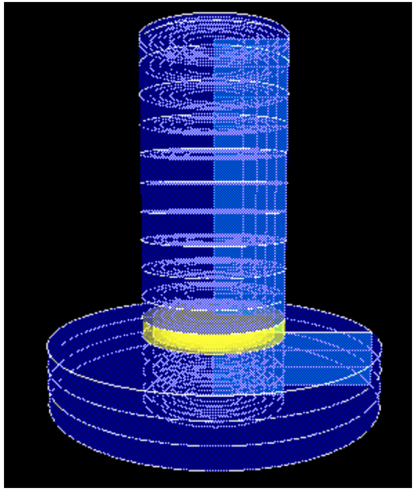
MELCOR Input Deck

- The **two passive system lines** were modelled separately, including the EBT, PSS, PSS vent, and LGMS;
- The **SGs** were represented **as an equivalent unit** with four CVs on the primary side and eight CVs on the secondary side;
- The **containment region** was nodalized with one CV for the **RC**, coupled with the correspondent CAV, and one CV volume for the Drywell (**DW**) region, thermally connected with the environment CVH volume;
- The **reactor core**, the **core bypass,** the **LP** and the **downcomer** has been modelled by a **single hydraulic CV.**

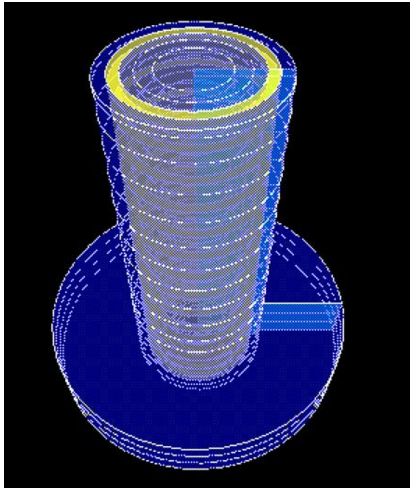


MELCOR Input Deck

- A **2D axisymmetric cylindrical** geometry of the COR package was used to describe the core and lower plenum;
- A **detailed nodalization** was chosen for the COR package compared with that of the CVH;
- In the COR package, the core was modelled as **16 axial levels** and **6 concentric rings.**



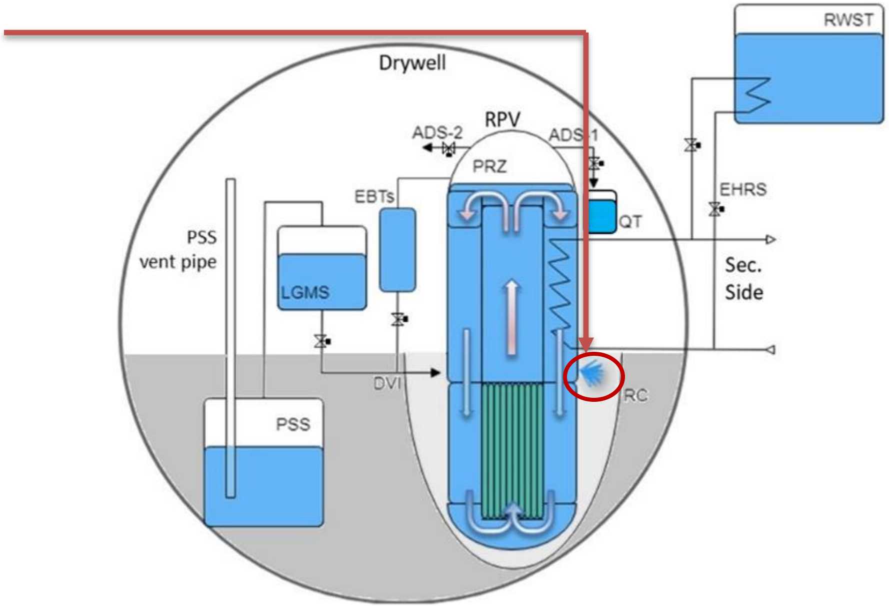
Axial levels



Concentric rings

Scenarios

- After the steady state qualification , the selected **DBA** scenario was the **guillotine break of one DVI line**, considering the availability of all safety systems.
- The study of **BDBA** sequences is critical to confirm the inherent safety of iPWRs, support the licensing process, and mitigate extreme scenarios. After the DBA analyses, **five** separate **scenarios were** analyzed in which the **failure of passive safety systems was assumed, one at a time**:
    - **EBT**
    - **ADS-2**
    - **LGMS**
    - **ADS-1**
    - **EHRS**



DBA

BREAK OF DVI LINE

High Containment Pressure signal
- SCRAM
- Secondary system isolation
- EHRS actuation

Low PRZ level signal
- RCP coastdown
- RI-DC valves opening

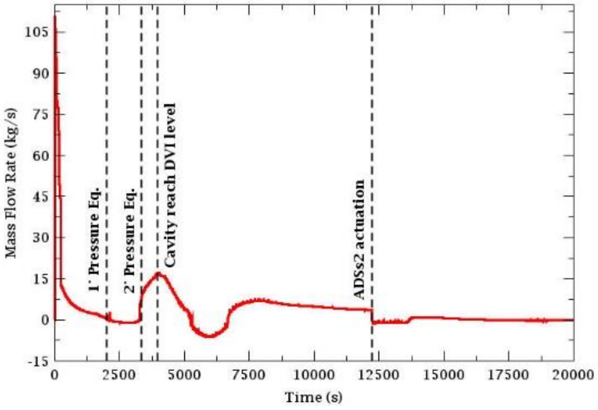
Low PRZ pressure signal
- EBTs actuation
- ADS stage-1 actuation

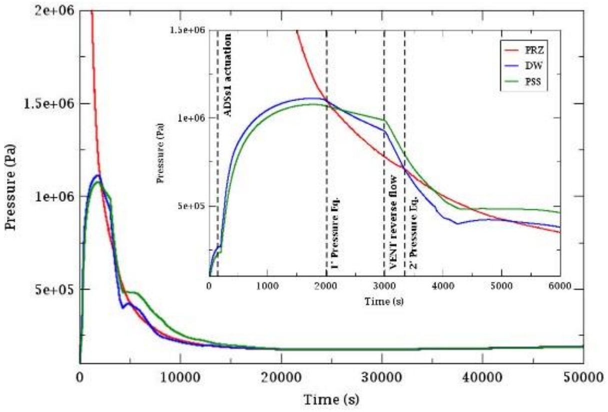
Low DP RPV-Containment signal
- LGMSs actuation

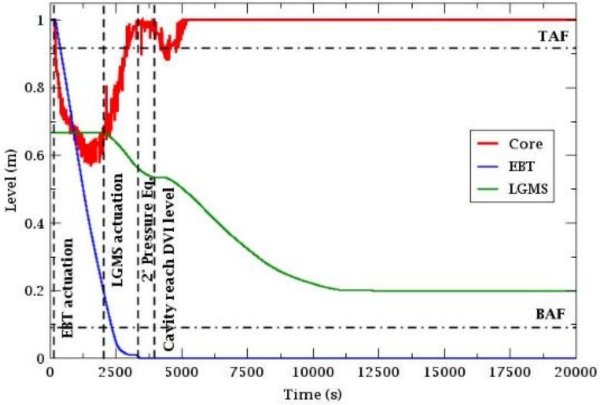
Low LGMS mass signal
- ADS stage-2 actuation

DBA

- Initial phase of the transient







DVI BREAK
RPV pressure decrease
(SOT) 0 s

41 s
High containment pressure

Low PRZ Level
122 s

Low PRZ Pressure
148 s
ADS Stage-1, EBT
Increase Depresurization

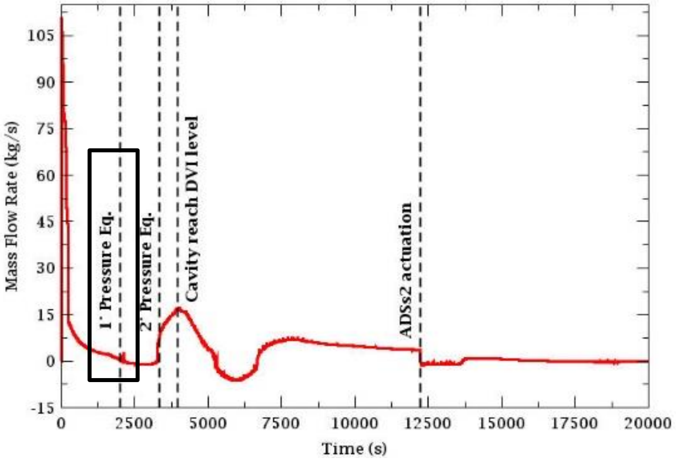
Reached
Saturated Blowdonw
223 s

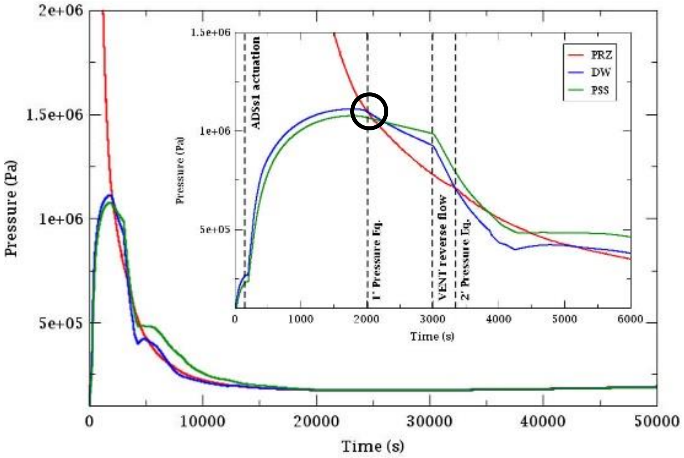
Low DP RPV-Containment
LGMS Activation
1883 s

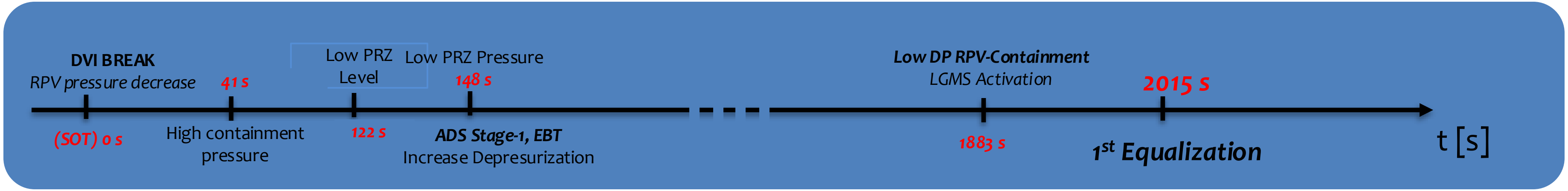
t [s]

DBA

- 1st equalization

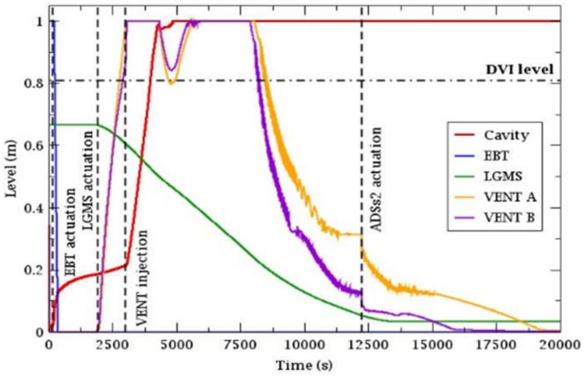


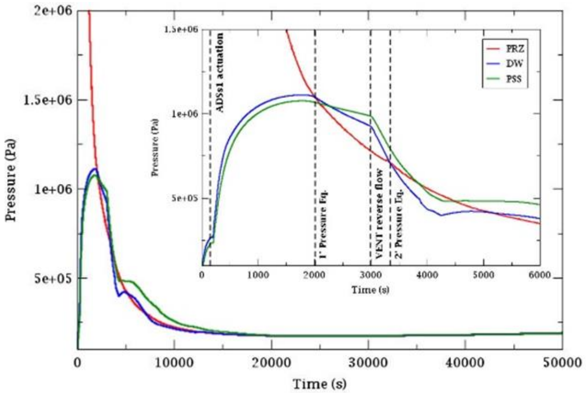


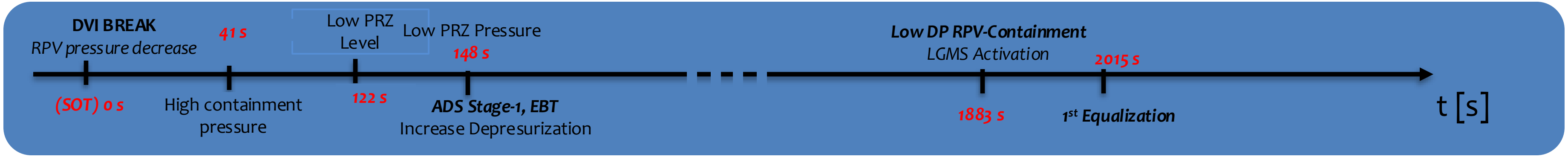


DBA

- **After 1st equalization:**
  - **DW pressure** stay **higher than the PRZ pressure** due to the energy removed from the RPV by the EHRS;
  - **Condensation phenomena in DW exceed suppression** phenomena **in PSS**, causing a **DW-PSS pressure difference**;
- PSS gravity head creates a **driving force pushing PSS water** through the vent **into** DW and consequently into **the RC** sections; **start of the VENT injection 2995s**. -> Resulting in a DW pressure reduction and **second pressure equalization 3346s**.

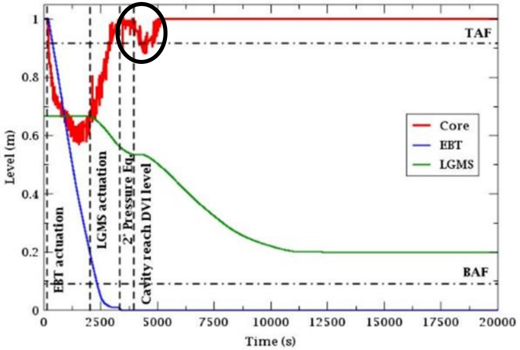


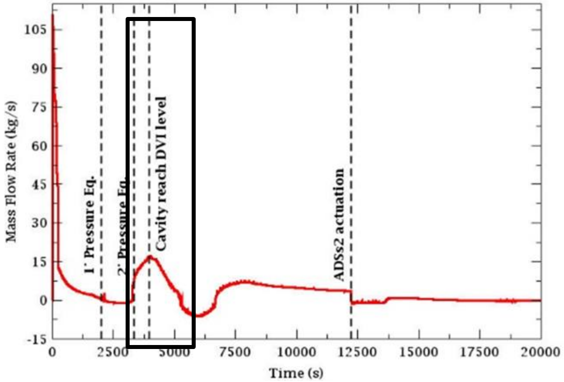


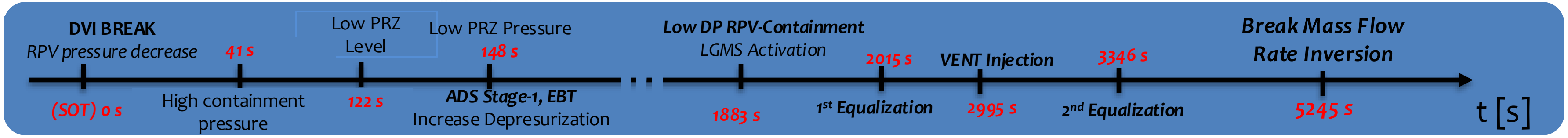


DBA

- **Resumed mass flow rate** from RPV to RC
- **Break Flow Inversion**:
  - The DVI level is reached at 3962s, reducing the break mass flow rate;
  - **Inversion of flow direction from RC to RPV;**
  - Reestablishment of the reactor **core level above the TAF.**

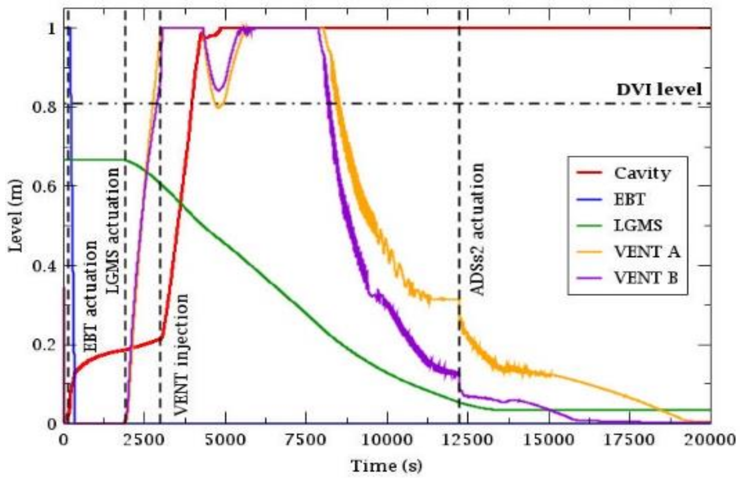


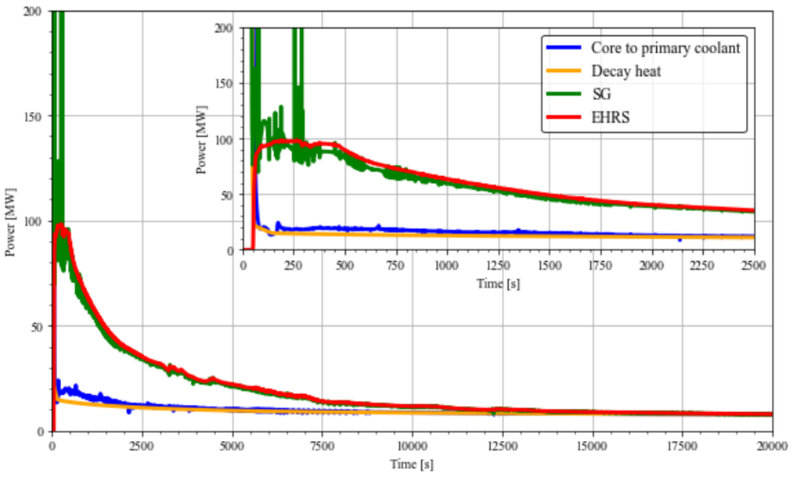


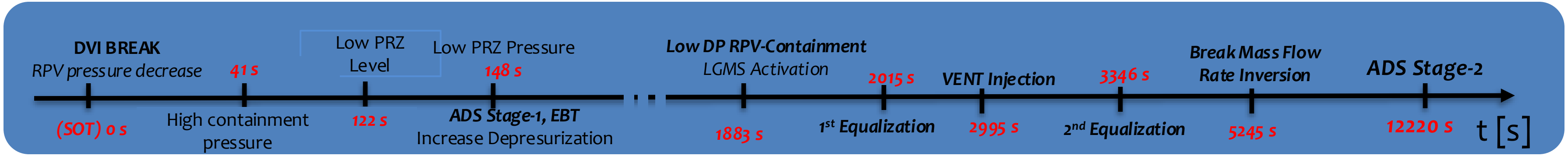


DBA

- Final phase of the transient







BDBA

- No EBT

Slight **delay** in reactor cooling, **depressurization** (RPV side) and **ADS Stage-2 activation**.

- No ADS stage-2

Delay in reaching the **break reverse flow** condition (from RC to RPV), around **15900 s.**

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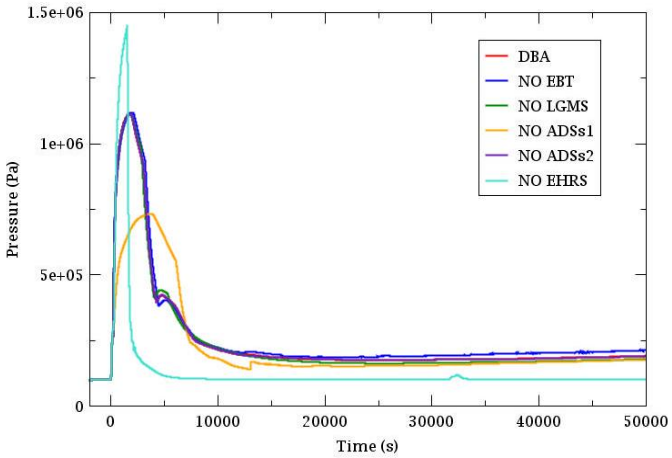
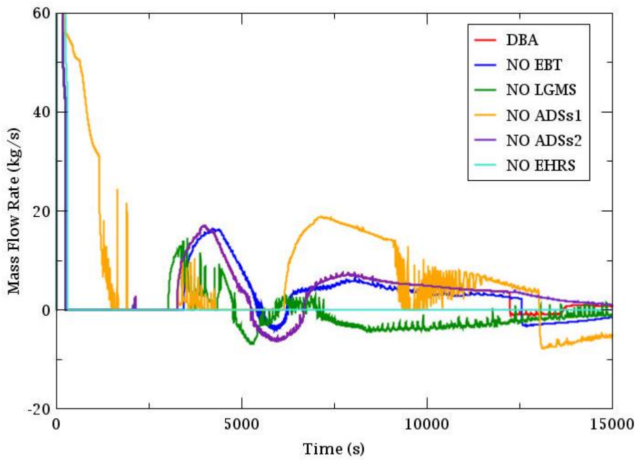
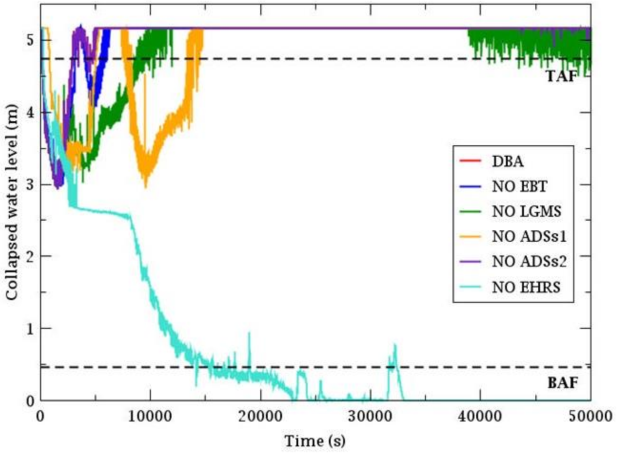
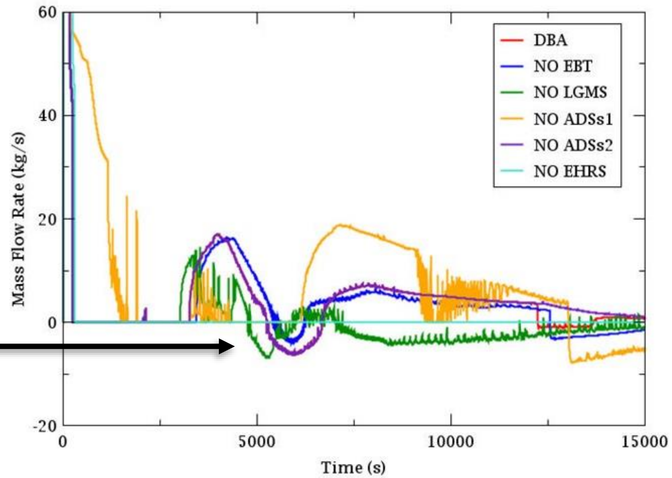




BDBA

- No LGMS
  - **Same pressure evolution until the 1st equalization;**
  - **Higher DW pressure** with respect to the DBA scenario **between 1st and 2nd equalization;**
  - **Anticipated VENT injection → Anticipated 2nd equalization → <u>Anticipated Reverse flow;</u>**
  - Core **level below** the **TAF for longer time, but** there is **no SA.**



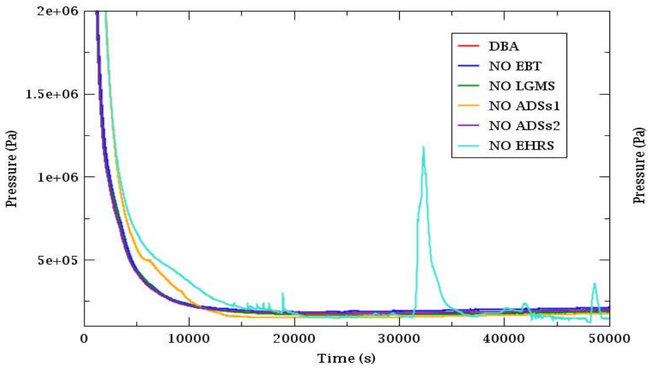


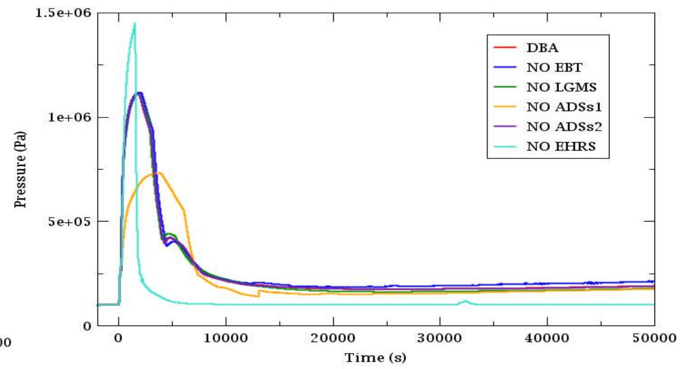
BDBA

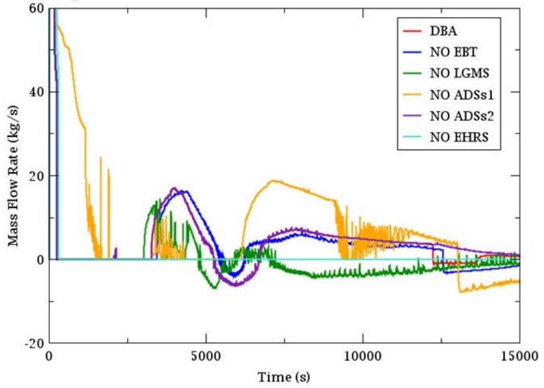
- No ADS stage-1

  Slower Depressurization of the RPV

  - **Higher pressure within the RPV and Lower in the DW**: Slower pressure equalization;
  - **Delay** in the activation of the first **high-pressure containment signal**, also **extended to the subsequent activations** and the attainment of the following signals.
  - Higher break mass water flow rate and **longer subcooled blowdown phase.**





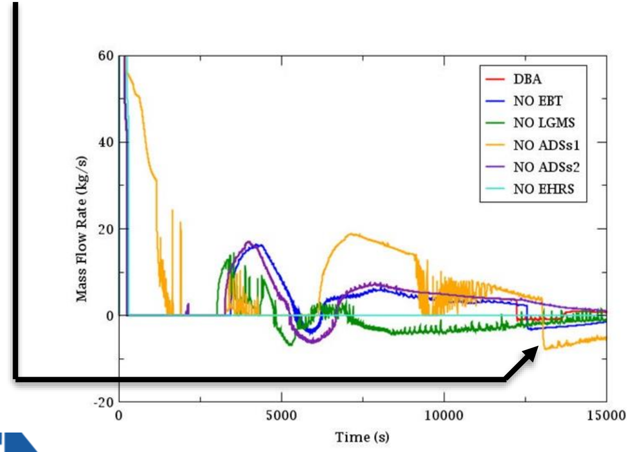


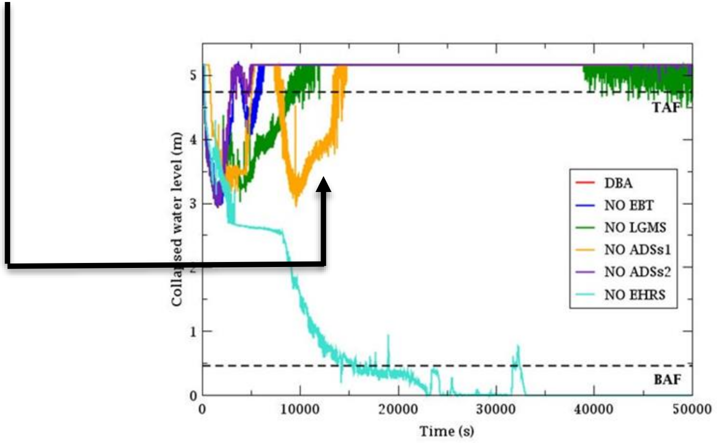
BDBA

- No ADS stage-1

Resumed Flow Dynamics:

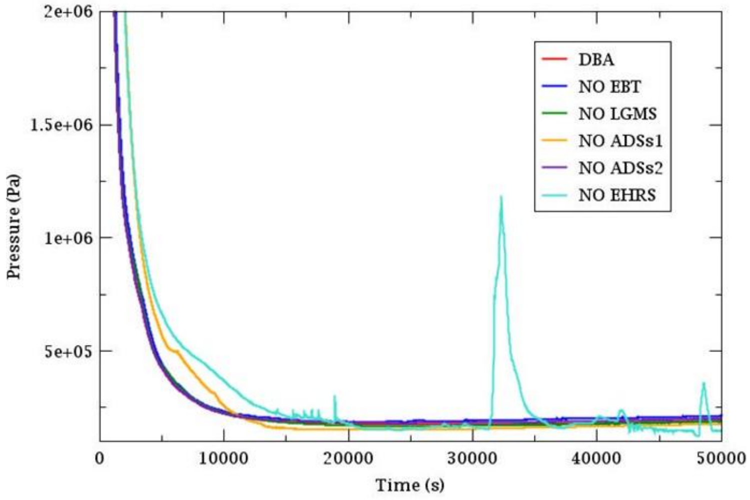
- **Delay in the achievement of DVI** by the water contained in the RC;
- **Greater Pressure difference between RPV and DW** after the VENT injection: **Slow reduction in Resumed Flow Rate** (positive for longer time);
- **Reverse flow begins after the opening of ADS stage-2,** which cancels the pressure difference.

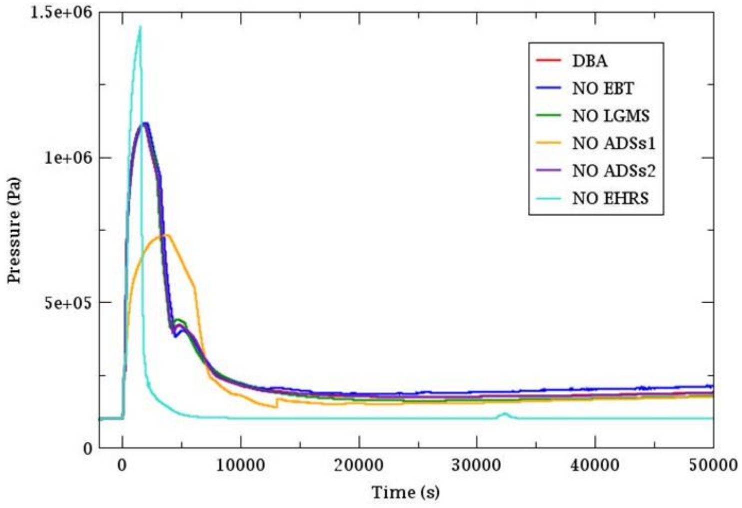




BDBA

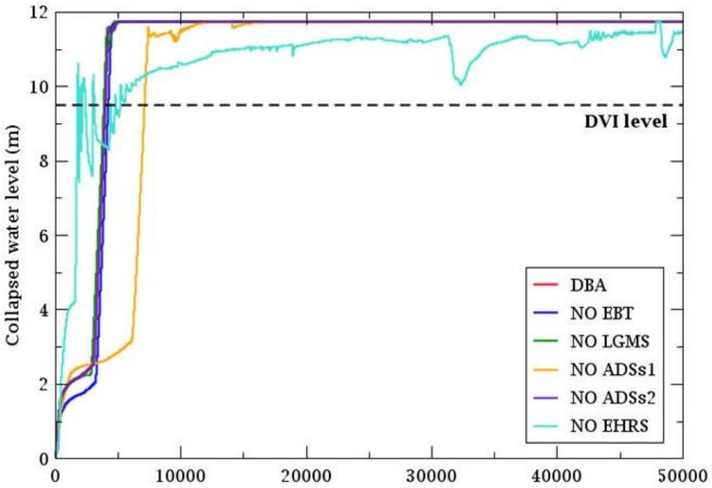
- No EHRS (SA scenario)
  - ADS Stage-1 opening**: Strong pressure increase** in the **DW;**
  - **DW** relief **valve opening to the environment**: Subsequent Pressure Drop;
  - **Delay** in reaching the **LOW ΔP RPV-DW signal** → water loss through the break does not decrease quickly enough to prevent core uncovering in the early stages of the transient.

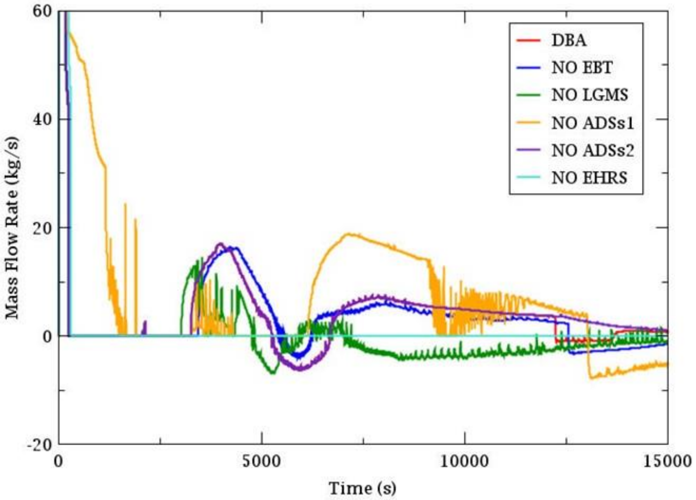




BDBA

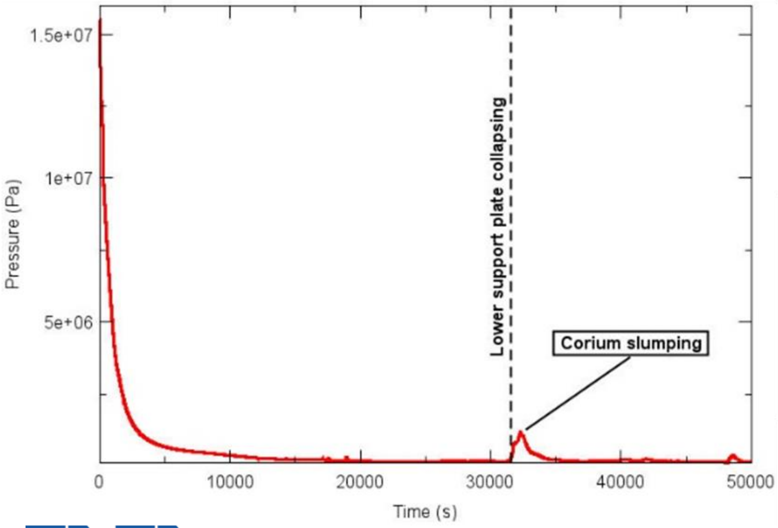
- No EHRS (SA scenario)
  - **Higher RPV pressure** (compared to the safety system lines) → **Failure of the LGMS injection** (Intact Line)
    Slow LGMS injection in RC (broken line);
  - Early VENT injection;
  - **No resumed Flow and Reverse Flow** due to a high **RPV pressure**.

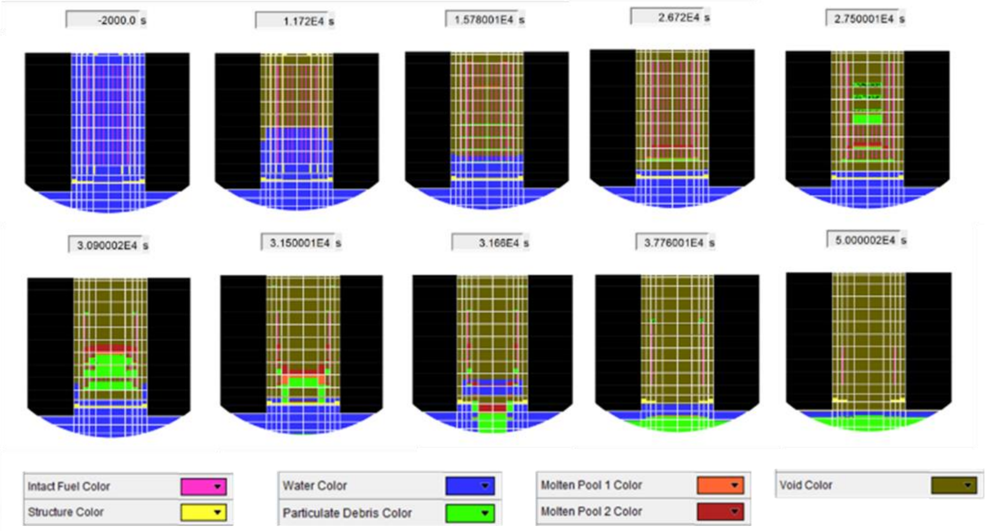




BDBA

- No EHRS (SA scenario)
  - Inability to cool the uncovered core leads to the onset of **degradation phenomena** around 8000 s;
  - The core degradation continues until the lower support plates collapses and corium relocates into the LP;
  - At the end of the scenario, **No LH rupture** occurs.





Conclusions

- The DBA simulation demonstrate **MELCOR**’s capability to **qualitatively predict key thermal-hydraulic phenomena** such as, condensation in the DW, heat exchange in the RWST and SGs, natural circulation and coolant supply;
- **MELCOR accurately simulates the thermal-hydraulic coupling between DW , RPV and Passive Safety Systems;**
- Scenarios with **failed EBT, LGMS, ADS Stage-2** still **show a good margin of safety** due to the correct operation of EHRS and ADS Stage-1;
- The **EHRS failure** is the only one scenario evolving in a **SA;**
- **MELCOR can qualitatively simulate** the main expected **phenomena in LW-SMRs** and predict the impact of passive safety systems on accident sequences;
- **MELCOR is able to predict the impact of the postulated failure of passive systems** on the behavior of the transient scenario.

Acknowledgment/Disclaimer

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ENEA

Thank you for your attention

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