Application of MELCOR 1.8.2 (fusion version) and MELCOR 2.1 on the DEMO Helium Cooled Pebble Bed blanket concept.

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Introduction - Motivation

- Several incidental/accidental conditions can hamper the safety of a fusion reactor, and the Loss of Coolant Accident (LOCA) of the blanket Primary Heat Transfer System (PHTS) is one of the most challenging [1].
- To date, one of the main codes employed for incidental conditions analyses in fusion installations is MELCOR 1.8.x. Although, this version is quite old, and newer version were released (MELCOR 2.1.6342).
- The aim of this work is to stress the positive and negative aspects of M 1.8.2 and M 2.1 through a “version-to-version” comparison employing the same nodalisation.

DEMO & HCPB blanket concept (1/3)

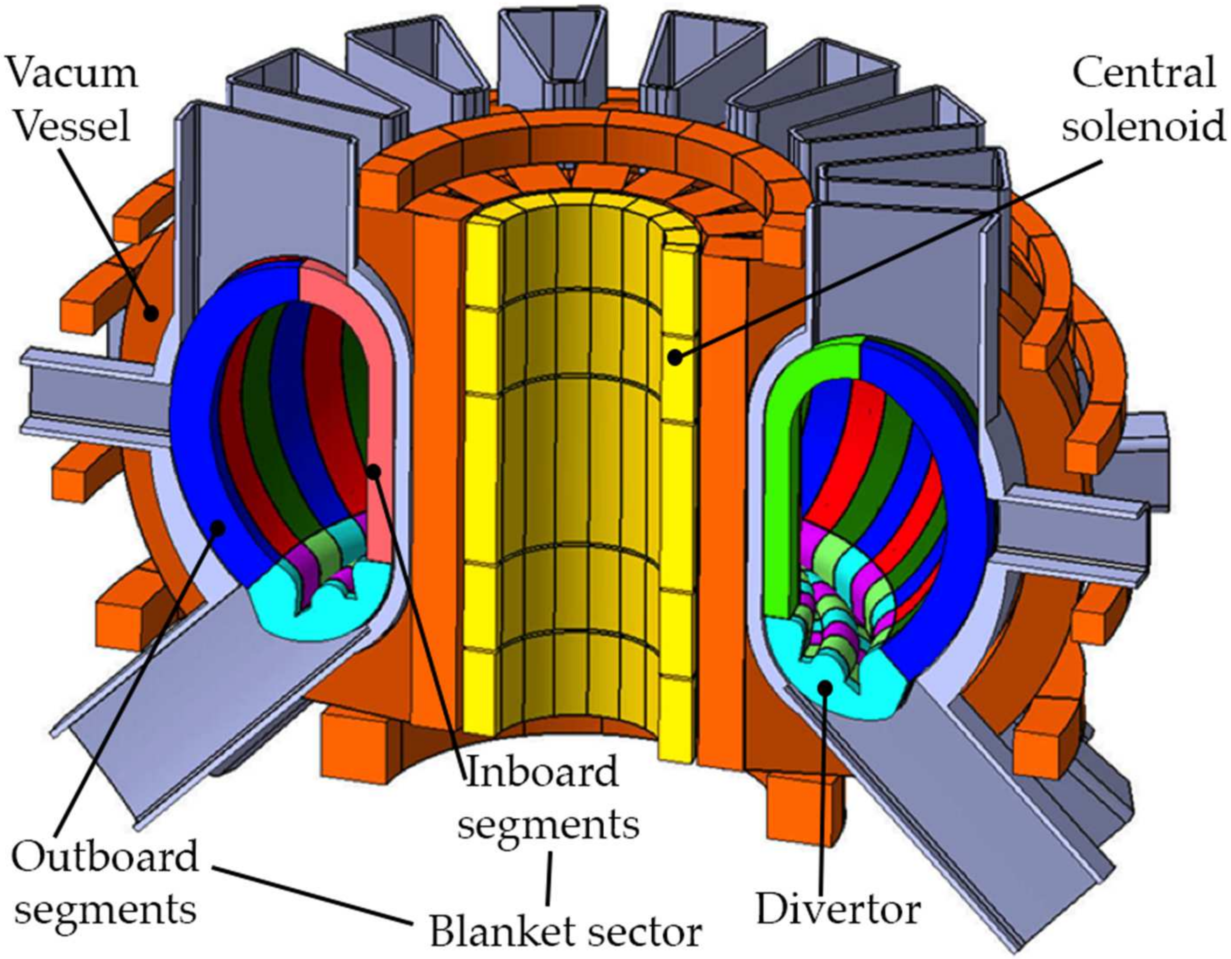
- DEMO represents the prosecution of the scientific and technological challenge of ITER, and it should demonstrate the suitability of the fusion power as a sustainable energy power source.

- To date, several different DEMO concepts exist basing on the various “blanket concept” proposed:

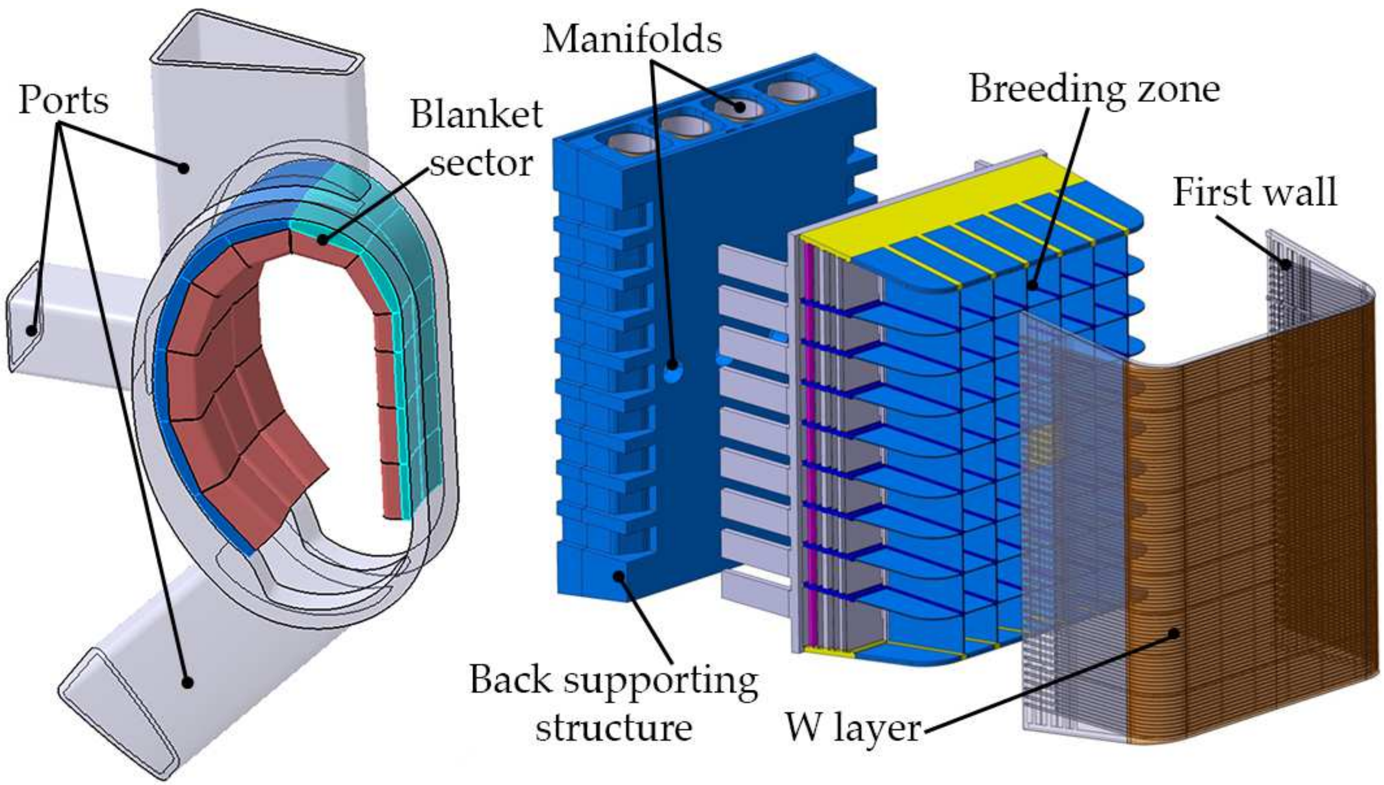
  - HCPB – Helium Cooled Pebble Bed
  - WCLL – Water Cooled Lithium Lead

DEMO & HCPB blanket concept (2/3)

- DEMO is a tokamak machine as ITER;

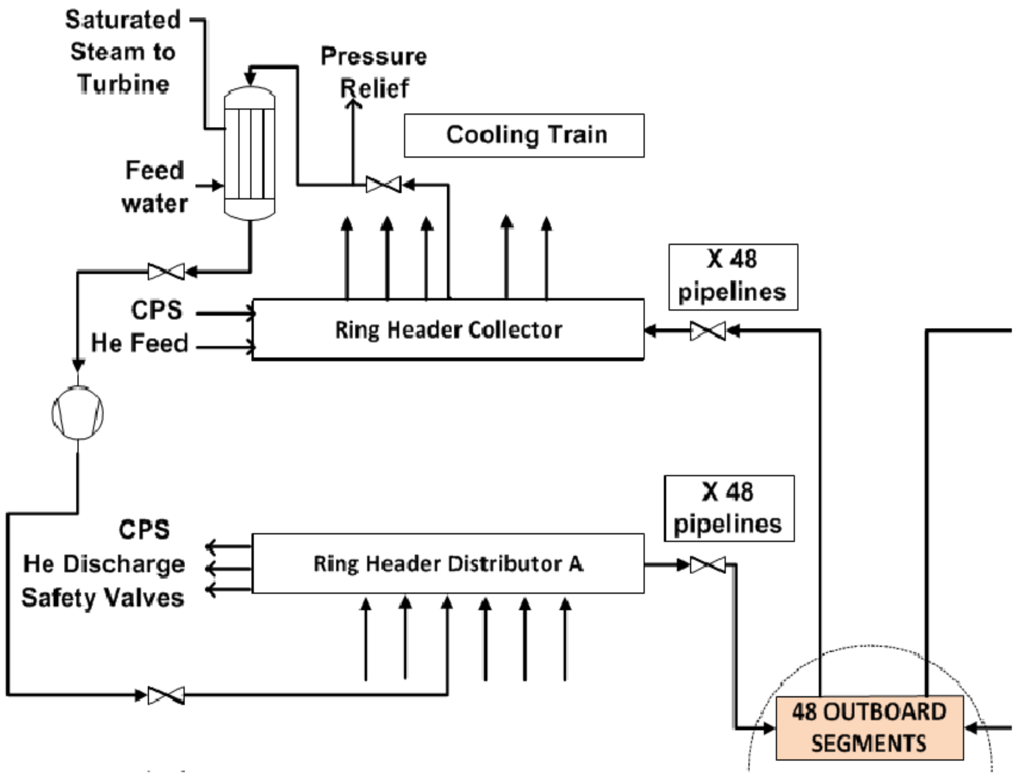


DEMO & HCPB blanket concept (3/3)



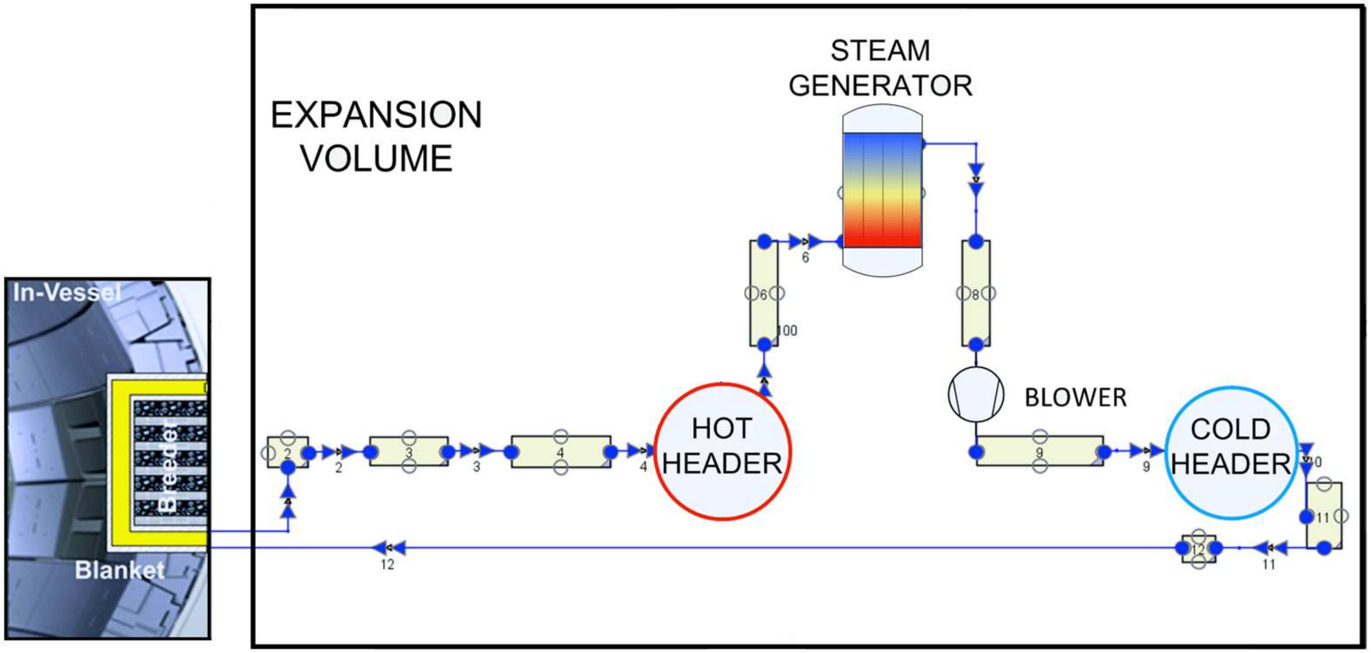
Blanket → 16 sectors → 3 (48) OB segments / 2 (32) IB segments → 6 box rows

PHTS description: Reference design



- Two independent coolant loops for the Out-Board (OB) segments and two for the In-Board (IB) ones. [2]
- He as coolant at 8.0 MPa in the temperature range of 300 – 500 °C. He inventory ~7000 kg each OB coolant loop. [3]
- Each OB loop removes 910.5 MW. [3]
- 6 Cooling trains (CTs) with one helicoidal steam generator each (5 operational and 1 spare). [2]

PHTS modellization: stationary run



- 13 CV (12–PHTS, 1-EV).
- 12 Flow Junction (FJs).
- 2 HSs (blanket and SG).

Characteristics	MELCOR
EV Volume [m^3]	70000.0
Heat transfer area [m^2]	15000.0
Blanket HS temp. [K]	773.15
SG HS temp. [K]	573.15
Total mass flow [kg/s]	875.5

Characteristics	MELCOR
EV Temperature [K]	313.35
Blanket temp. [K]	773.15
SG temp. [K]	573.15
Total pressure drop [MPa]	0.37
Heat flow [W/m^2]	60700.0

Stationary run results (1/2)

Parameter	Reference	1.8.2	2.1	Difference [%]
Blanket Total Pressure [MPa]	-	8.19	8.2	0.1 %
SG Total pressure [MPa]	-	7.82	7.83	0.1 %
Pressure drops [MPa]	0.37	0.37	0.37	0.0 %
Mass Flow rate [kg/s]	875.5	872.8	872.3	< 0.04 %
He mass [kg]	~ 6620.0	6795.4	6795.4	3.0 %
Blanket CV Temp. [K]	773.15	771.39	773.39	~ 0.2 %
Blanket HS Temp. [K]	773.15	773.43	781.61	< 1.1 %
SG CV Temp. [K]	573.15	573.83	573.82	~ 0.1 %
SG HS Temp. [K]	573.15	570.3	570.52	< 0.5 %
HTC Blanket [W/m^{2}K]	-	29686.8	7384.7	75.0 %
HTC SG [W/m^{2}K]	-	17221.8	18421.1	7.0 %

- The results of the stationary run are quite similar, but great differences exist on the inner heat transfer coefficients of the two HSs.

Stationary run results (2/2)

- Differences on the HTC → Due to the different temperature equilibrium among CV and HS.

$$q'' = HTC(T_{HS} - T_{CV})$$

  - M 1.8.2 → To remove 60700.0 W/m^2 with a ΔT of 2.04 K an HTC of 29754.9 W/m^{2}K is needed.
  - M 2.1 → To remove 60700.0 W/m^2 with a ΔT of 8.22 K an HTC of 7384.7 W/m^{2}K is needed.

- No differences changing the default SC from 2.1 to 1.86.

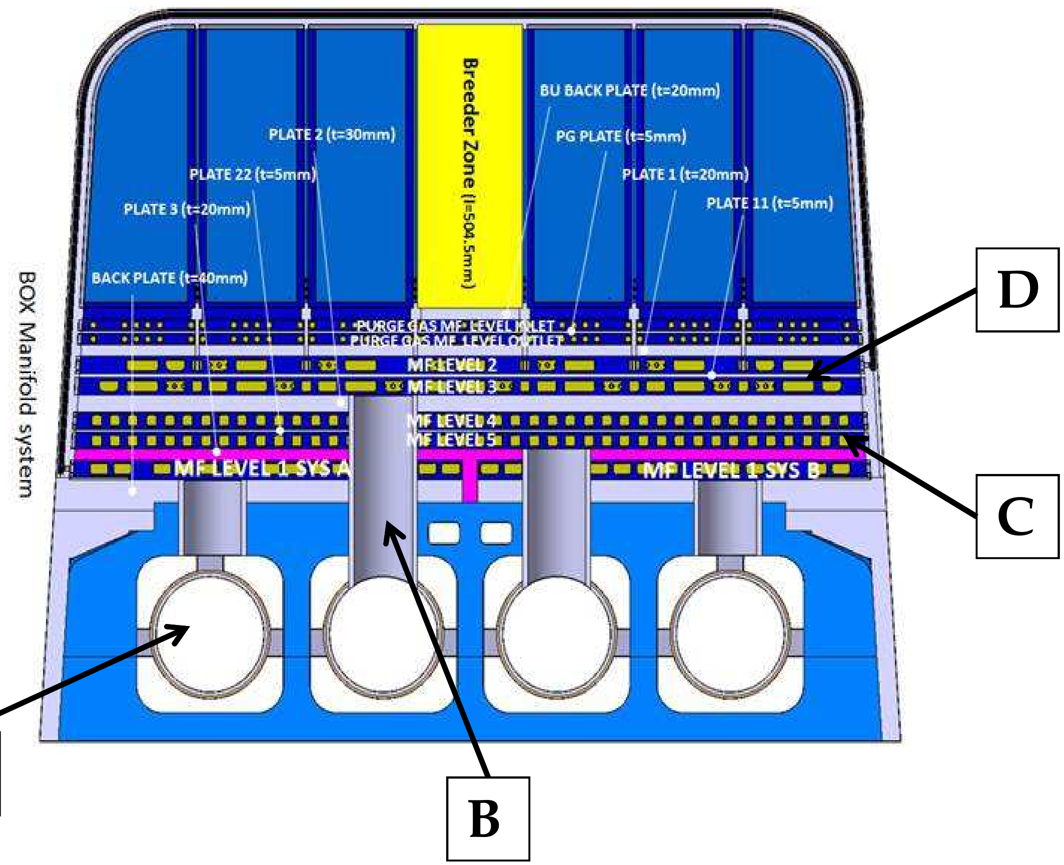
- One difference exists: CPFPL and CPFAL (critical pool fractions) values.
  - In 1.8.2 set both to 0.0;
  - In 2.1 set >0.0 due to numerical error if set to 0.0

- Although, the stationary runs provide exhaustive results. Further analyses with complex nodalisations are required.

In-Vessel LOCA: Approach

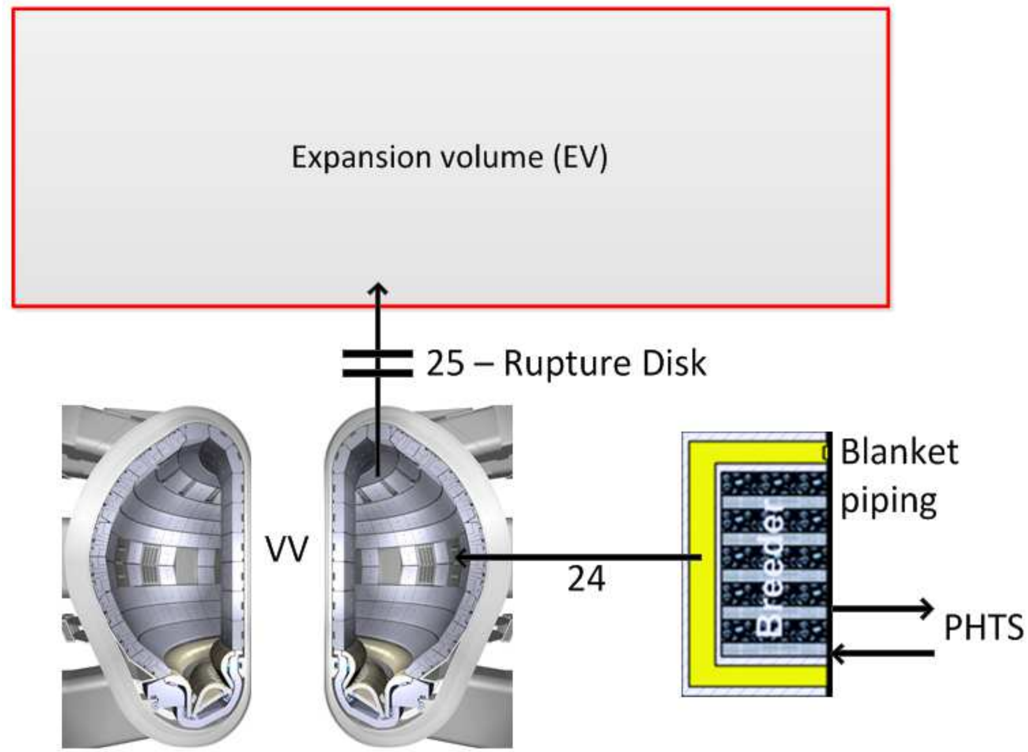
Helium release inside the Vacuum Vessel (VV), and opening of a rupture disk connecting the VV and the Expansion Volume (EV) once reached the imposed set-point.

- Parametric study
  - Different rupture area
    - 0.12 m^2 (max)
    - 1.0E-3 m^2
    - 1.0E-5 m^2



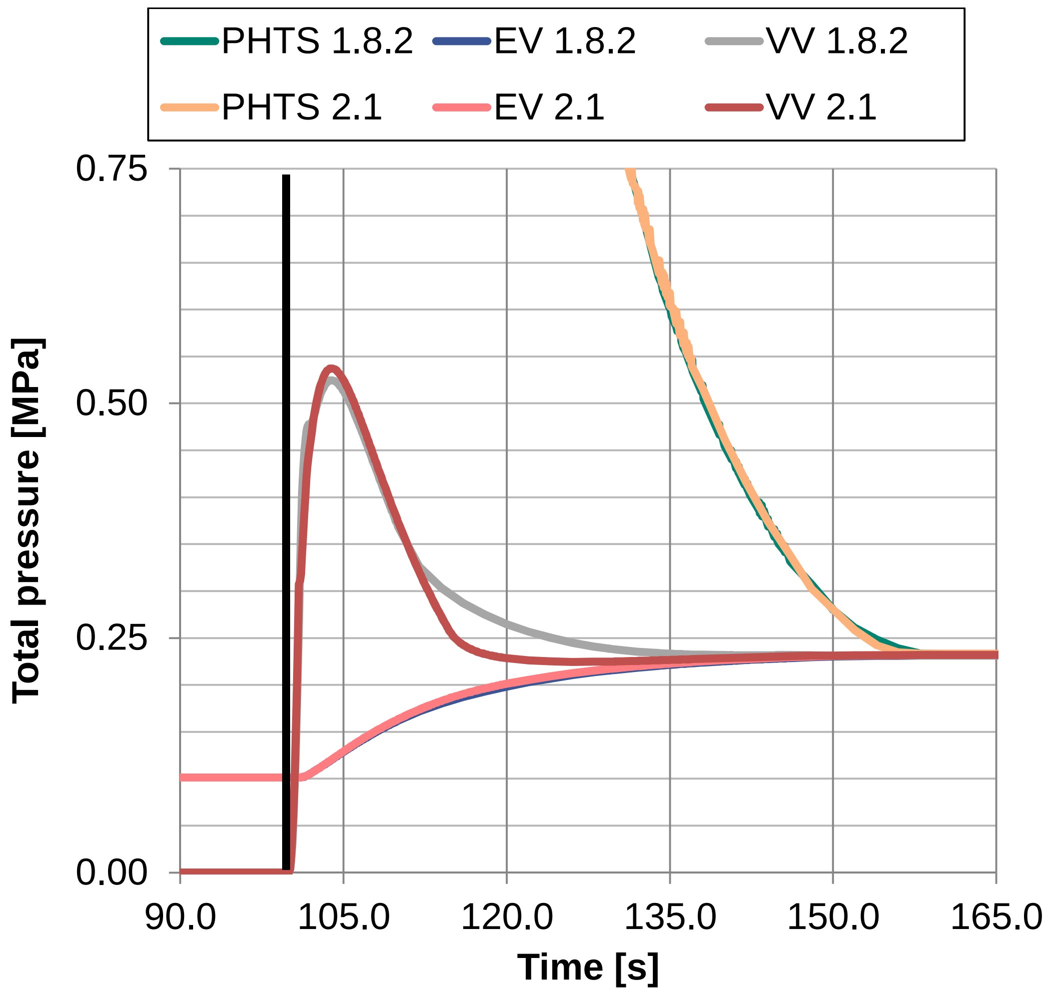
In-Vessel LOCA: modellisation

Parameter	MELCOR
EV Volume [m^3]	70000.0
EV temp. [K]	313.35
VV Pressure [Pa]	210.0
VV Volume [m^3]	1860.0
VV internal Temp. [K]	473.15
W dust mass [kg]	10.0
T mass [kg]	0.2
R. D. area [m^2]	1.0
R. D. set point [MPa]	0.15



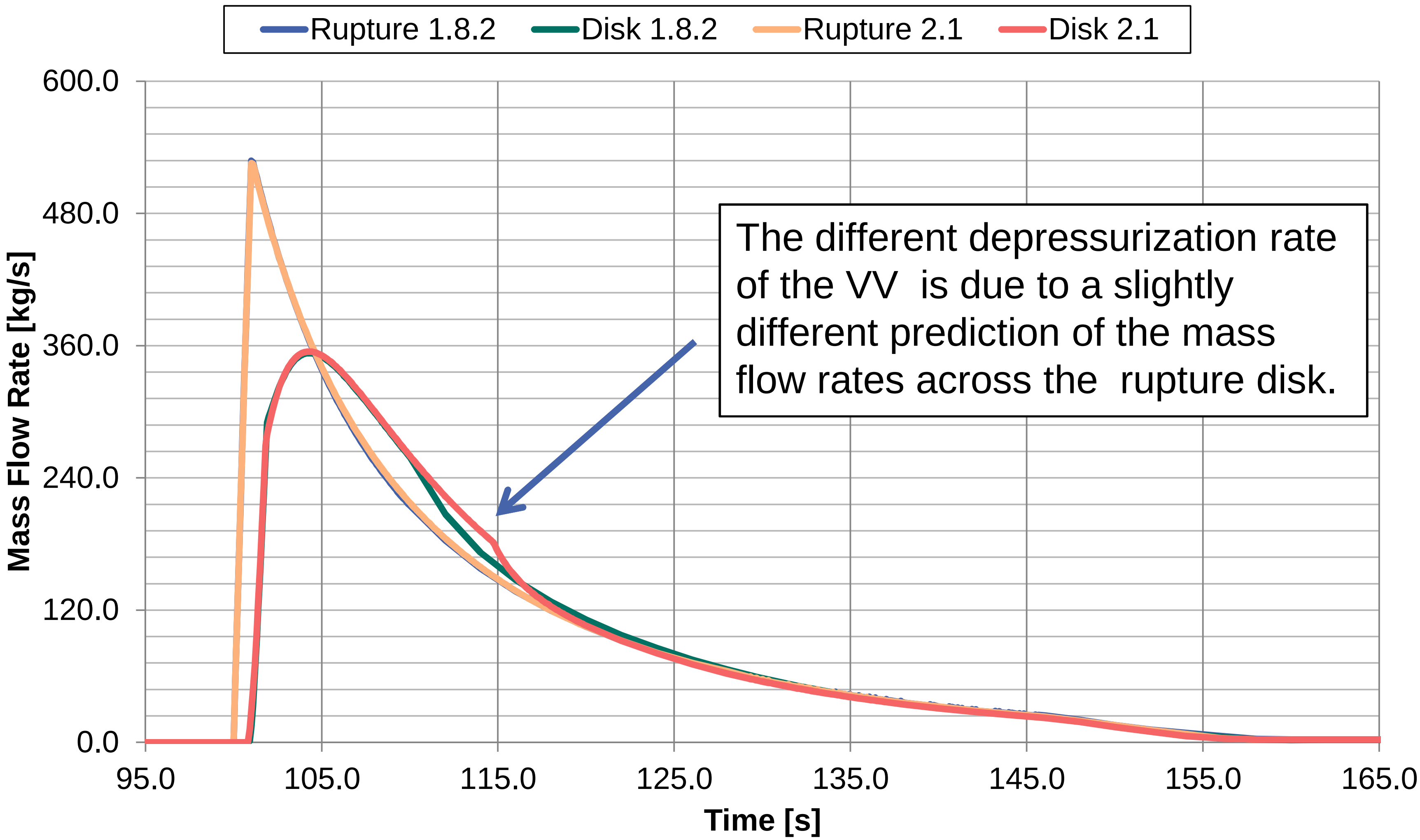
- PHTS as in stationary run.
- VV as a single volume.
- Rupture → Valve connecting PHTS and VV.
- Rupture disk connecting VV and EV.

In-Vessel LOCA: 0.12 m² (1/7)

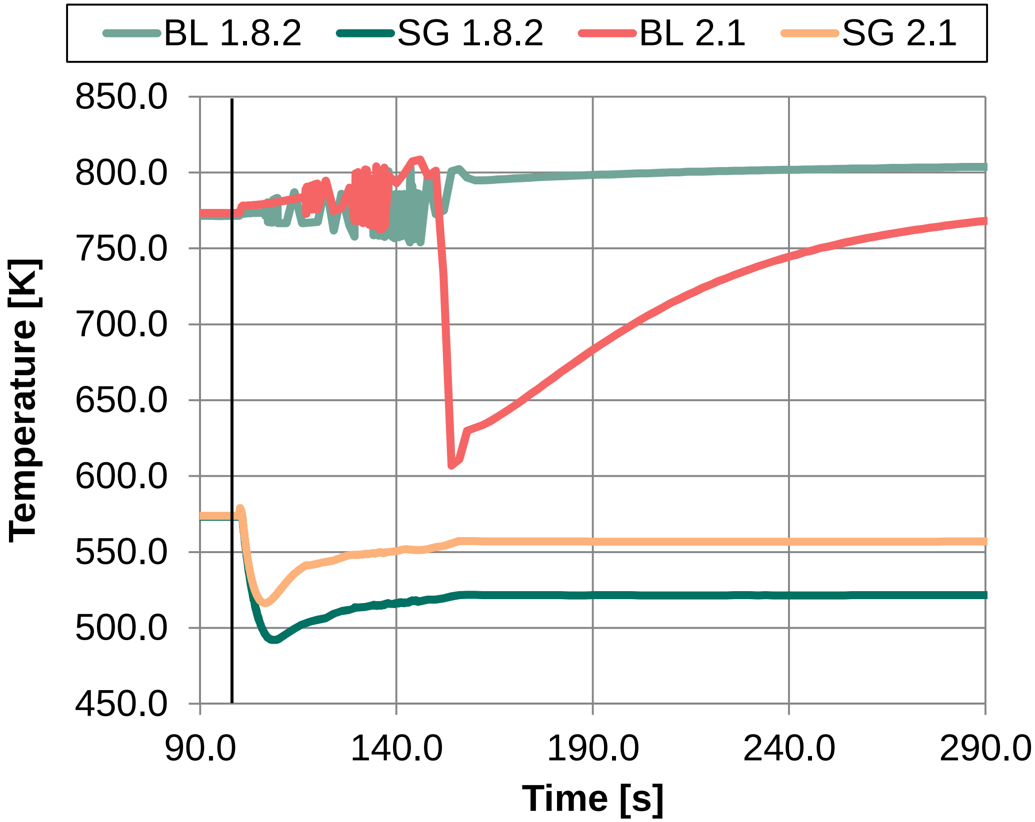


- Similar PHTS depressurization, but numerical instabilities in M 2.1.
- Similar EV depressurization.
- VV depressurization rate different, especially from 114.0 s to 135.0 s.
- The helium ingress inside the VV could cause the W dust mobilisation.

In-Vessel LOCA: 0.12 m² (2/7)

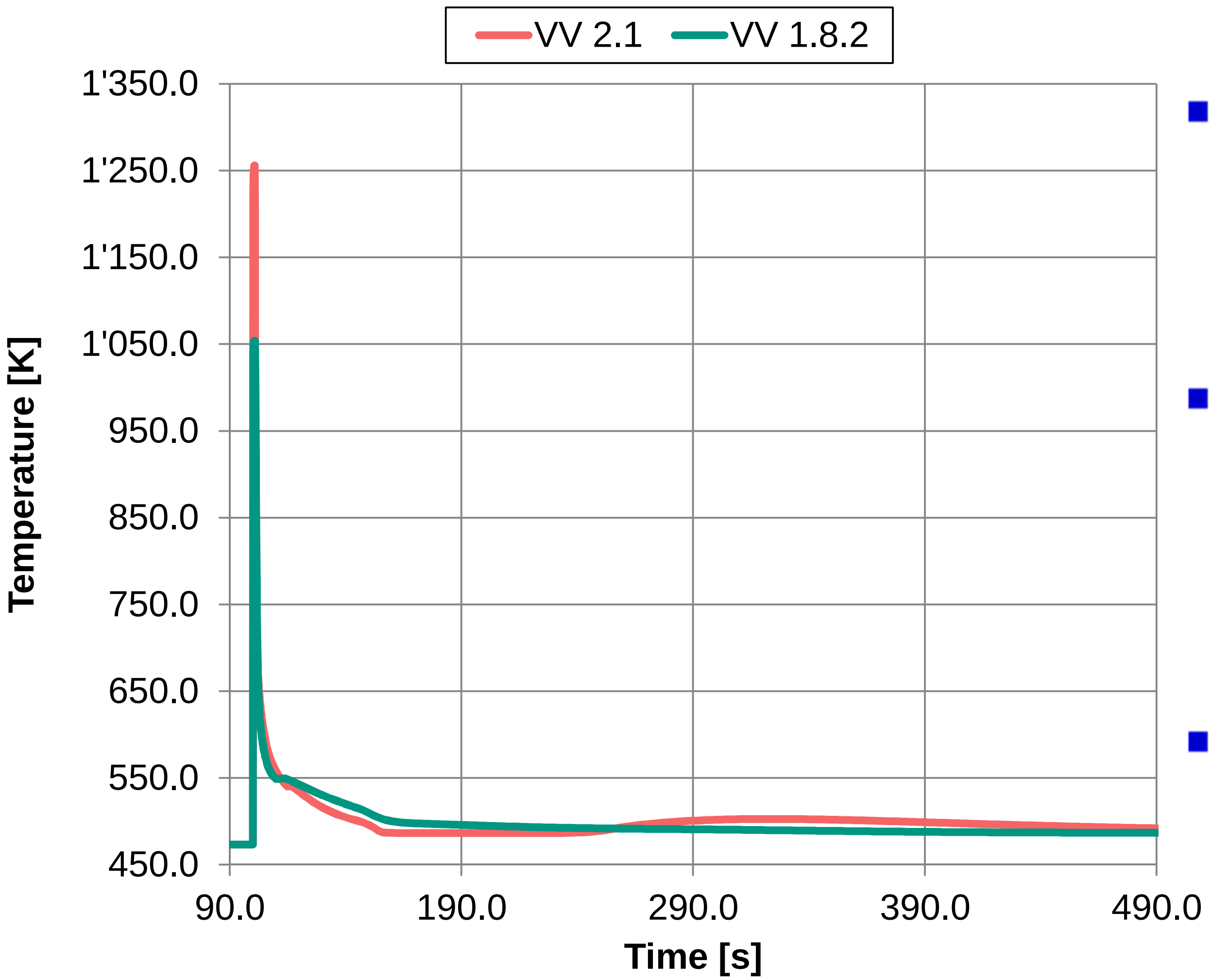


In-Vessel LOCA: 0.12 m² (3/7)



- Two phenomena influence the temperature trends.
  - Helium expansion
  - Unbalanced blanket-SG power.
- Blanket M 2.1 → temperature decrease when the VV and EV reach the same pressure.
- SG → Same trend, but different temperature decrease magnitude (~25 K).

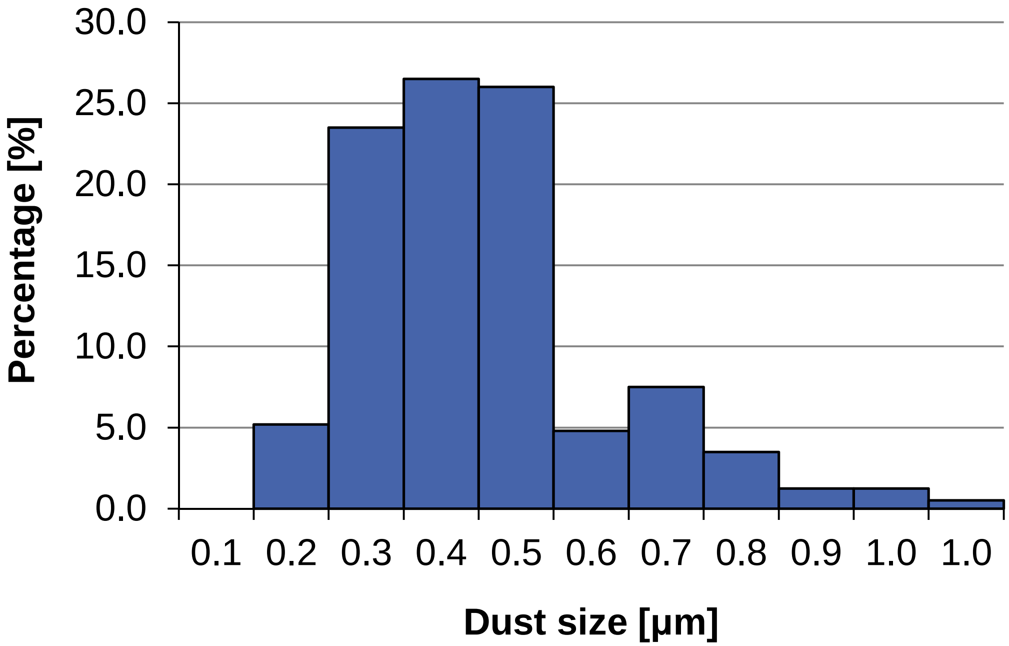
In-Vessel LOCA: 0.12 m² (4/7)



- Max VV temperature:
  - 1255 K – M 2.1
  - 1050 K – M 1.8.2
- Different temperature trends after 110.0 s
  - 150.0 s → M2.1 <15 K
  - 330.0 s → M2.1 >12 K
- No apparent causes for this behaviour (max. pressurization identical).

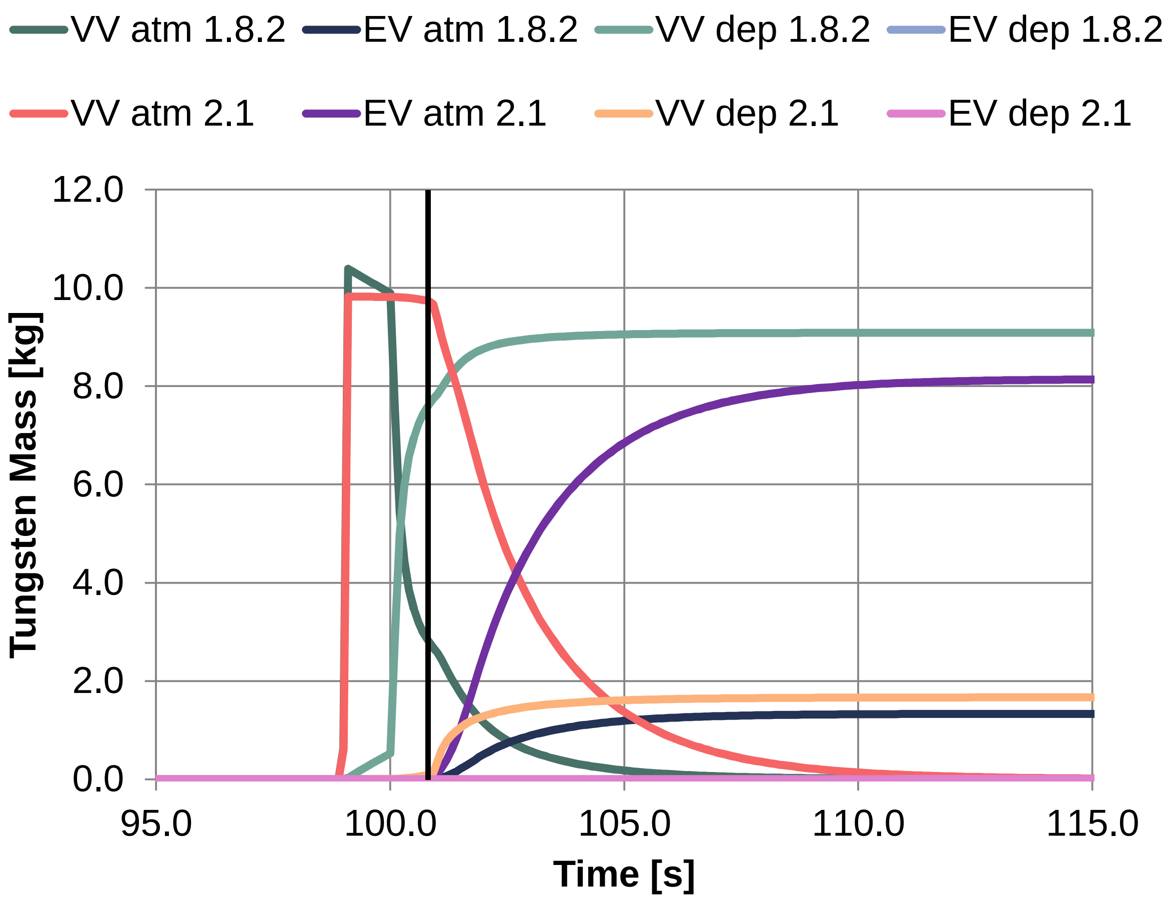
In-Vessel LOCA: 0.12 m² (5/7)

- The fast pressurization of the VV can lead to the W dust resuspension.
- W dust data taken from STARDUST experiment [4].
- M lacks of a resuspension model.



- Two cases investigate:
  - W injected 1 s before the rupture event.
  - W injected during the rupture event.

In-Vessel LOCA: 0.12 m² (6/7)



- M 1.8.2. → Injected mass overestimated (~200g).
- M 1.8.2 → W mass mainly deposited on VV.
- M2.1 → W mass mainly in EV atmosphere.
- M 2.1 results similar to ASTEC ones.
- Further investigation needed.

Conclusions

- Version-to-version comparison among M 1.8.2 (fusion version) and M 2.1.6342 employing the same nodalisation.
- Stationary run: Different blanket HTC value, but reliable and satisfactory results for both versions.
- In-Vessel run: Minor differences, except for the atmospheric temperatures and the W dust behaviour.
- In the future the introduction of fusion specific models of the 1.8.6 version inside the 2.1 version could be an interesting evolution.

Acknowledgments

- The work with MELCOR 1.8.2 has been performed at Karlsruhe Institute of Technology (KIT) at Karlsruhe (D).

- The work with MELCOR 2.1 has been performed at University of Pisa (UNIPI) at Pisa (I).

Thank you for your attention

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References

1. D. N. Dongiovanni, T. Pinna, and D. Carloni, *“RAMI Analysis for DEMO HCPB blanket concept cooling system”*, Proceedings of Symposium of Fusion Technology 2014 (SOFT2014), San Sebastian, Spain, September 29-October 3, 2014.
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4. M. T. Porfiri, N. Forgione, S. Paci and A. Rufoloni, "Dust mobilization experiments in the context of the fusion plants - STARDUST facility," in *Seventh International Symposium on Fusion Nuclear Technology - ISFNT-7 Part B*, 2006.