# Application of MELCOR 1.8.6 for fusion in comparison with the pedigreed MELCOR 1.8.2 for ITER to simulate DEMO HCPB in-box LOCA

***EUROfusion WPSAE project***

Institute for Neutron Physics and Reactor Technology (INR)

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# Outline

- MELCOR 1.8.6 for fusion
- DEMO HCPB blanket concept (2014)
- In-box LOCA
- MELCOR simulation for the selected accidental case
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  - ☐ Simulation results
  - ☐ Impact of time steps
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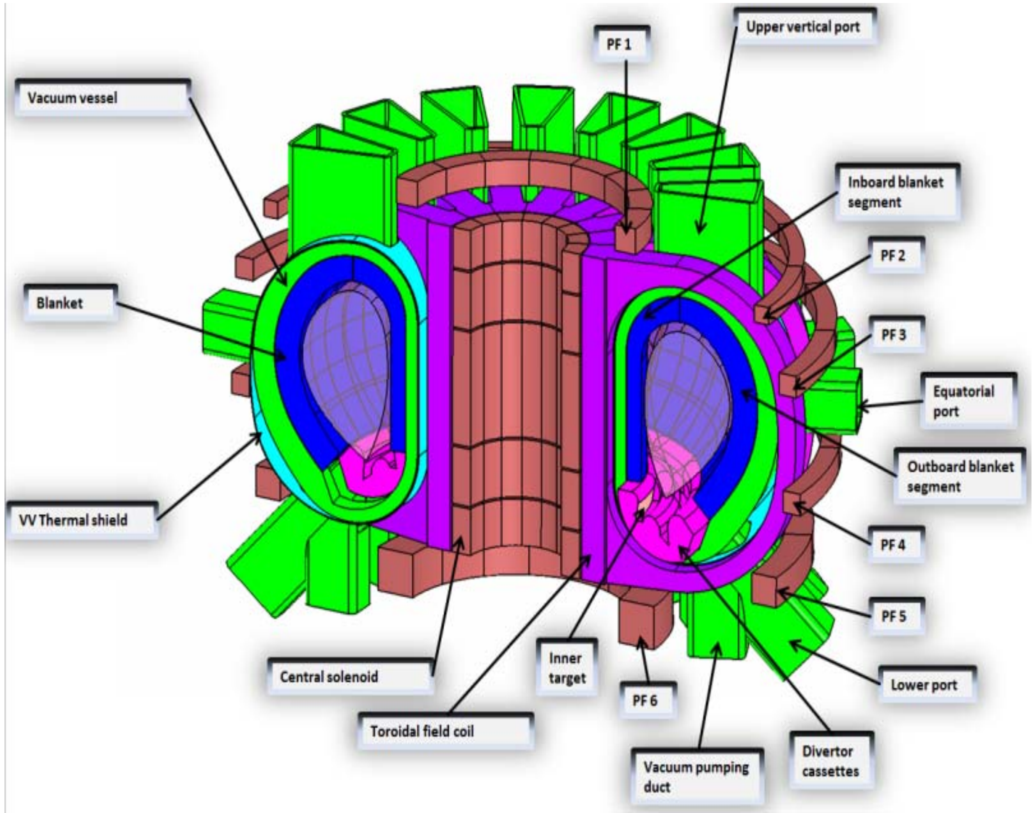
- Conclusion

# MELCOR 1.8.6 for fusion

- ❑ MELCOR for fusion has more than 25 users in US, JA, KO and EU*.
- ❑ V1.8.6 was released in Aug. 2015 by INL (Idaho National Laboratory).
  - ➢ to combine the capabilities of MELCOR 1.8.2 and MELCOR 1.8.5,
  - ➢ to allow for much large models and perform double precision accuracy,
  - ➢ Helium and LiPb as working fluids.
- ❑ Modifications for ITER purposes in the previous versions:
  - ➢ chemical oxidation reactions of steam or air with Be, C and W
  - ➢ EOS (Equation of State) modifications for water freezing & ice layer formation
  - ➢ Aerosol transport module modifications for gas mixtures, turbulent & inertial deposition
  - ➢ the cryogenic He or air as the primary fluid
  - ➢ Flow boiling heat transfer
  - ➢ Enclosure thermal radiation heat transport
  - ➢ HTO transport model

** Merrill B.J.: "MELCOR for Fusion Development", MELCOR workshop at CCFE, 17.12.2015.*

# DEMO HCPB blanket concept (2014)

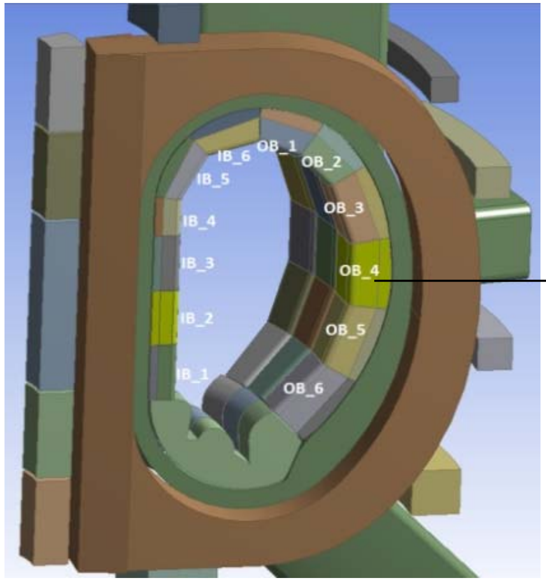


**DEMO design 2014 ***

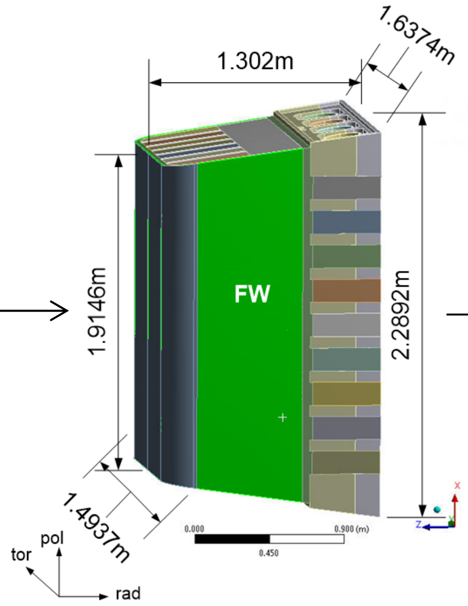
| Parameter | Quantity |
|---|---|
| Plasma power (MW) | 1572 |
| Thermal power including n-multiplication in blanket (MW) | 1972 |
| Plant electricity output capability (MW) | 500 |
| Lifetime neutron damage in steel in the FW (dpa) | 20+50 |
| Major radius, $R_0$ (m) | 9.0 |
| Minor radius, a (m) | 2.25 |
| Plasma current (MA) | 14 |
| Toroidal field, $B_0$ at $R_0$ (T) | 6.8 |
| Elongation, $\kappa_{95}$ | 1.56 |
| Triangularity, $\delta_{95}$ | 0.33 |
| Plasma volume (m³) | 1453 |
| Plasma surface area (m²) | 1084 |
| Auxiliary heating power, $P_{inj}$ (MW) | 50 |
| Auxiliary ramp-up power, $P_{ramp\text{-}up}$ (MW) | >60 |
| Average neutron wall load (MW/m²) | 1.067 |
| Nuclear heating in blanket (MW) | 1380 |
| Power to divertor (MW) | 180 |

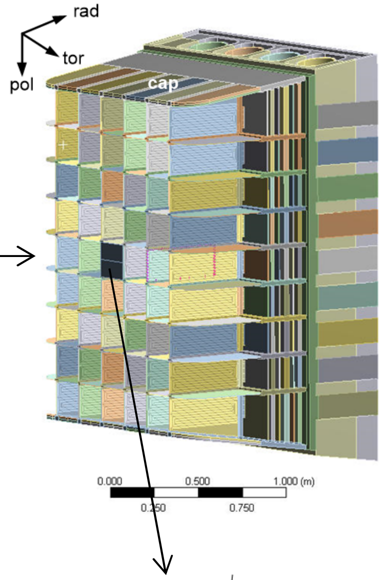
** C. Bachmann: “Plant Description Document”, Version 1.2, EFDA_D_2KVWQZ, 13/6/2014.*

## HCPB blanket sector *



## Equatorial module OB_4

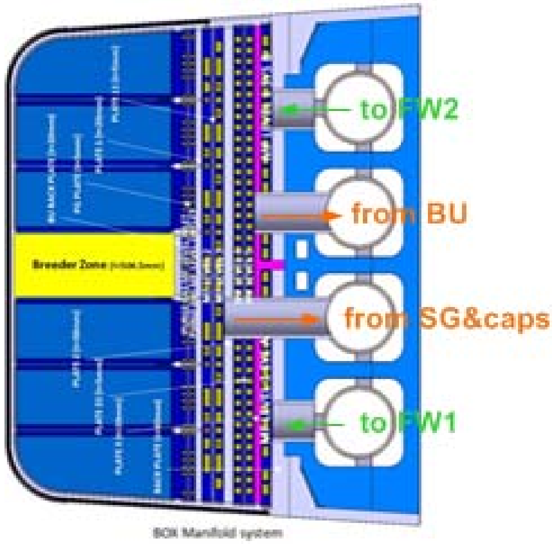


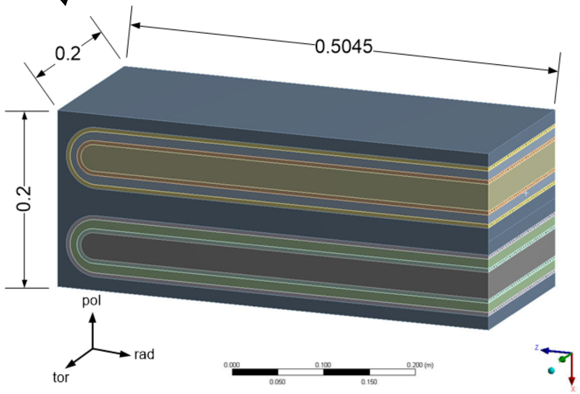


## Stiffening grids (SG)

*Each sector includes 2 IB and 3 OB segments with 6 modules for each segment (30 modules / sector)*

## Manifolds

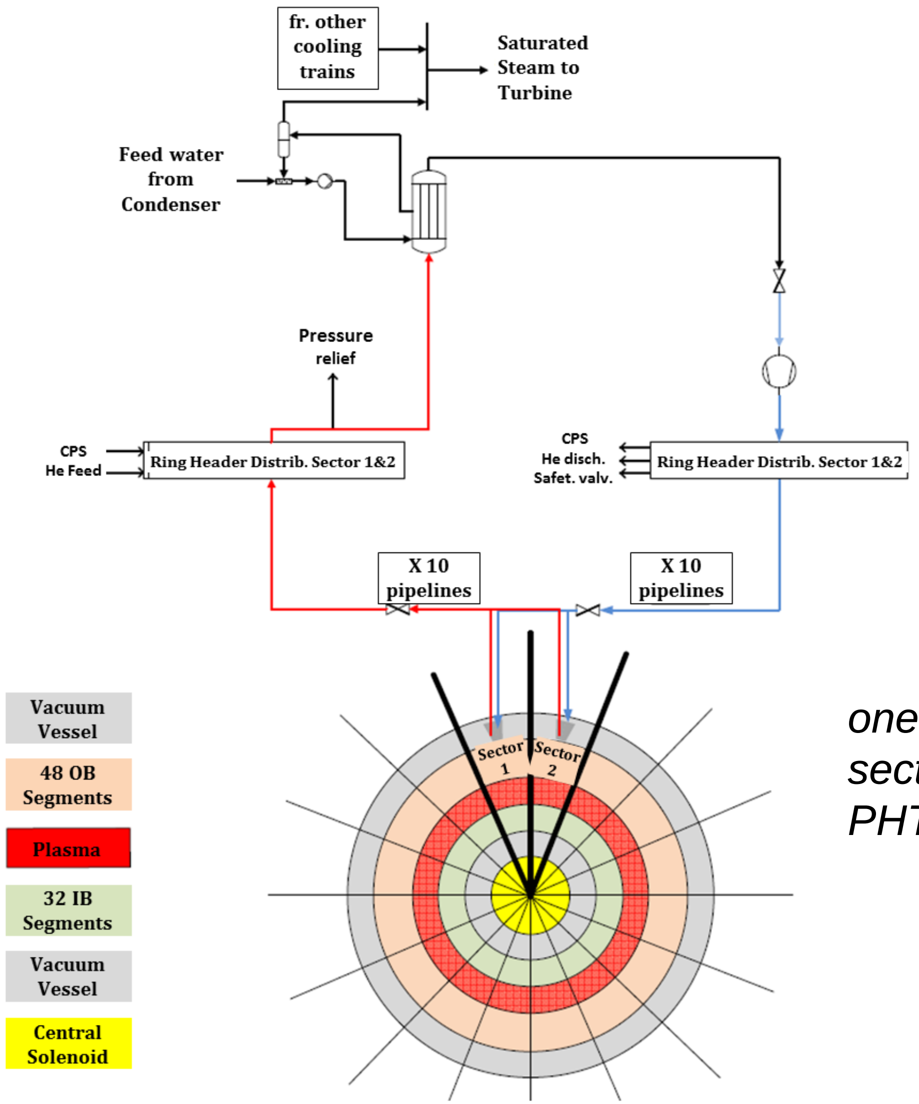




## Breeder unit (BU)

** EUROfusion WPBB (work package breeding blanket)*

# Primary heat transport system (PHTS) *



*one PHTS loop serves 2 sectors. Each sector is supplied by 2 independent PHTS loops for the redundancy.*

** EUROfusion WPBB*

# Main design data

| Parameter | | | value |
|---|---|---|---|
| **Affected module OB4** | Fluid | | He |
| | Surface heat flux on the FW (MW/m²) | front wall | 0.5 |
| | | BU to front wall | 0.06 |
| | | BU to side wall | 0.035 |
| | Neutron power (MW) | | 5.142 |
| | Mass flow rate $\dot{m}$ (kg/s) | | 6.323 |
| | Pressure at inlet (MPa) | | 8.0 |
| | Temperature (°C) | inlet | 300 |
| | | outlet | 500 |
| | Material | W thickness (mm) | 2.0 |
| | | EUROFER to W (mm) | 3.0 |
| | FW | Cross section (mm x mm) | 10 x 15 |
| | | No. of channels | 95 |
| **PHTS1 for 60 modules** | Pressure (MPa) | | 8.0 |
| | Temperature (°C) | | 300 |
| **Vacuum vessel (VV)** | Pressure (MPa) | | 5.0E-04 |
| | Temperature (°C) | | 300 |
| **Expansion volume (EV)** | Pressure (MPa) | | 0.09 |
| | Temperature (°C) | | 20 |

# In-box LOCA

## Possible failures

- Failure of horizontal plate (HP) / vertical plate (VP) in the SG
- Failure of channels in the FW (in-vessel LOCA)
- Failure of cooling plate (CP) in the BU

⬇

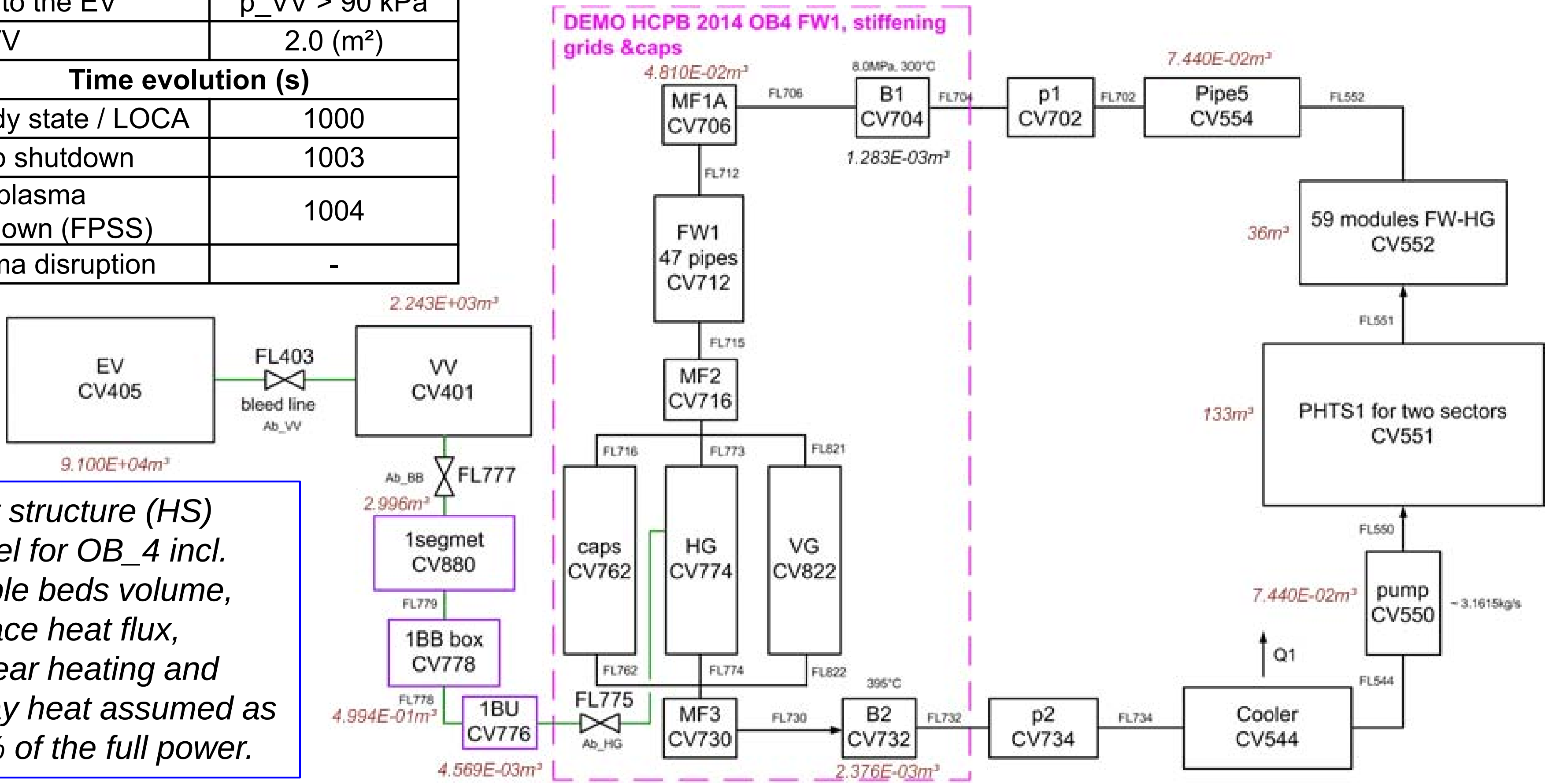
## Three representative accidental cases

- Case I: failure of one HP in the SG with double pipe break, connected to the free volume of the BB, VV and EV.
  - *MELCOR 1.8.6*
  - *MELCOR 1.8.2*
- Case II: failure of ~10% FW channels with double pipe break, connected to the VV and EV.
- Case III: failure of one CP in the BU with double pipe break, connected to the purge gas (PG) system and EV.

# MELCOR simulation for the selected accidental case

| Case I assumptions | |
|---|---|
| Break size Ab_HG | 5.28e-4 (m²) |
| LOCA into volume | 1xBU |
| Volume | 4.56876e-03 (m³) |
| Leak to the VV | p_BB > 1.0 MPa |
| Ab_BB | 0.5 (m²) |
| Leak to the EV | p_VV > 90 kPa |
| Ab_VV | 2.0 (m²) |
| **Time evolution (s)** | |
| Steady state / LOCA | 1000 |
| Pump shutdown | 1003 |
| Fast plasma shutdown (FPSS) | 1004 |
| Plasma disruption | - |

## Loop modelling for case I



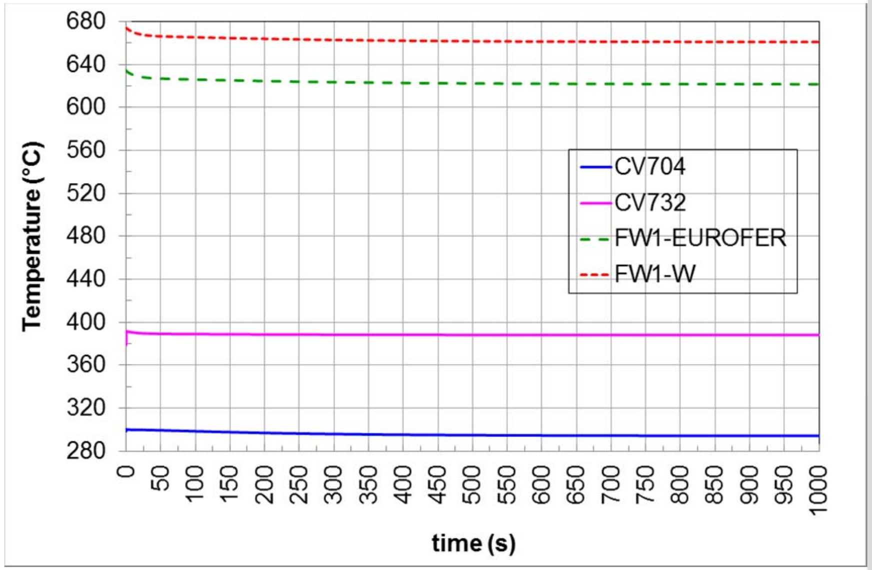
*Heat structure (HS) model for OB_4 incl. pebble beds volume, surface heat flux, nuclear heating and decay heat assumed as 1.7% of the full power.*

# **Simulation results** (V1.8.6, He as working fluid)

## Steady state (1000s)

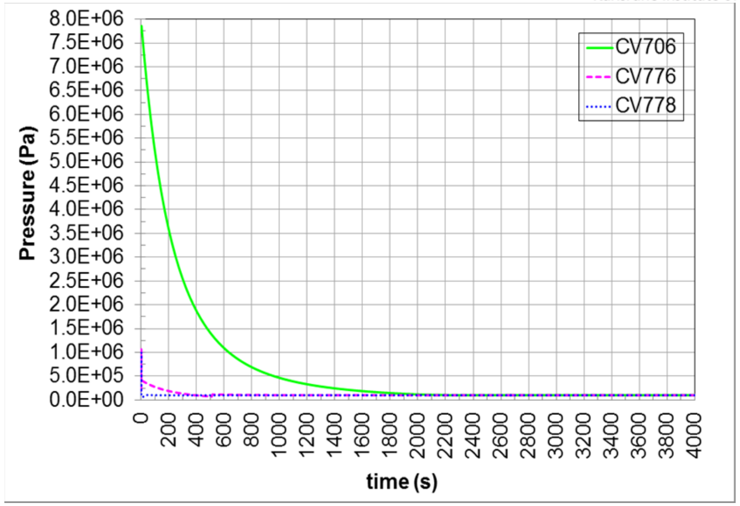
| Parameter | | | Results |
|---|---|---|---|
| He inventory of PHTS & 60 modules (kg) | | | **1016.7** |
| FW | ṁ (kg/s) | | 3.1805 |
| | Pressure inlet (MPa) | | 7.84 |
| | dp (kPa) | | 149.0 |
| | He | inlet (°C) | 294.2 |
| | | outlet (°C) | 364.6 |
| | EUROFER (°C) | | 621.8 |
| | W (°C) | | 661.1 |
| HG, VG, caps | ṁ (kg/s) | HG | 1.7143 |
| | | VG | 0.6642 |
| | | Caps | 0.8020 |
| | He outlet (°C) | | 388.1 |
| | EUROFER | HG (°C) | 433.0 |
| | | VG (°C) | 413.1 |
| | | Caps (°C) | 738.3 |
| | dp (kPa) | | 68.6 |

## Temperature in He flow and HS

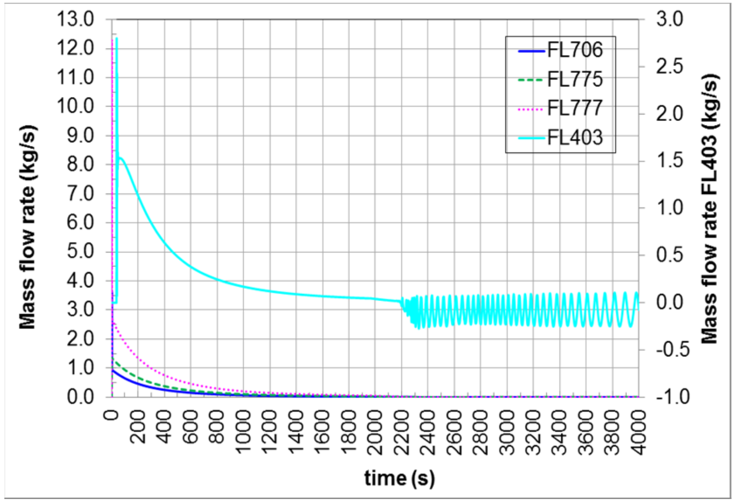


# Transient results

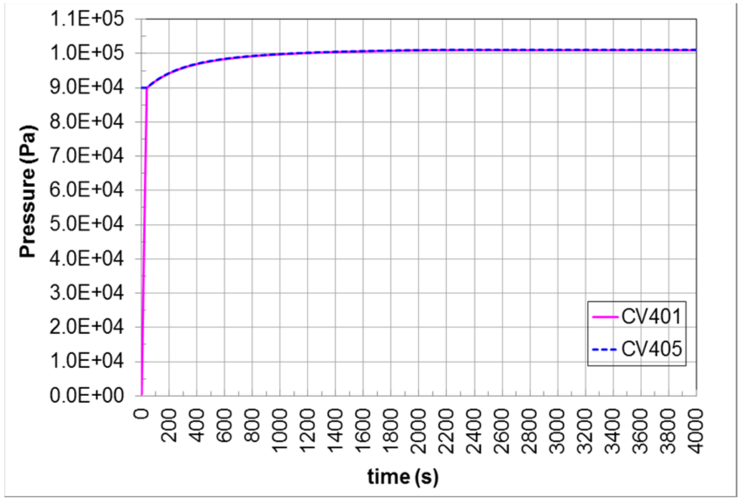
| **Case I** | | **Time (s)** |
|---|---|---|
| LOCA | | **0.0** |
| Pump shutdown | | 3.0 |
| FPSS | | 4.0 |
| Plasma disruption | | - |
| Results | p_CV778 > 1.0MPa | 1.0 |
| | p_CV401 > 90kPa | 38.0 |
| *Transient end* | | *4000* |
| *Time step dt* | | *5.0e-4* |



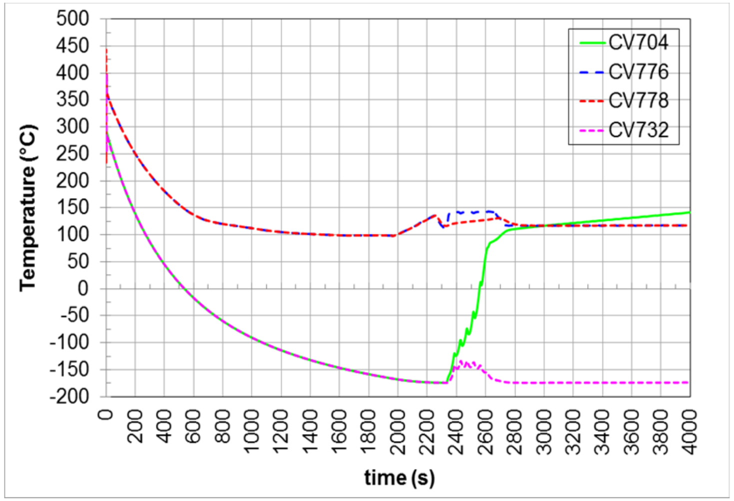
Pressure in OB_4



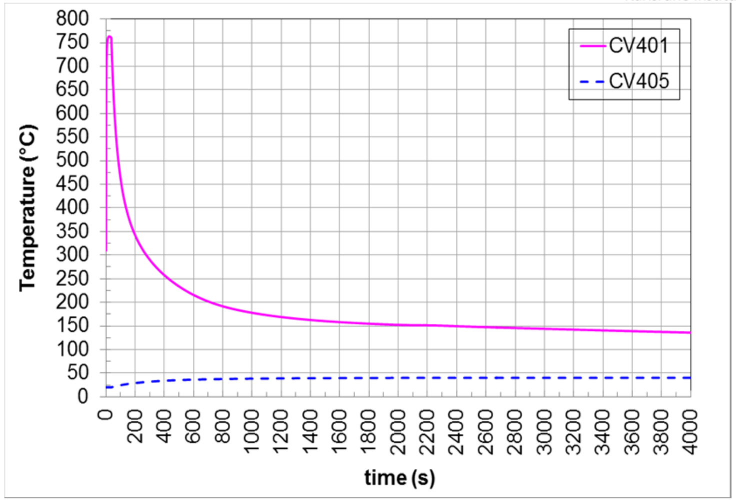
Mass flow rate in OB_4, at break to the BB, VV, & EV



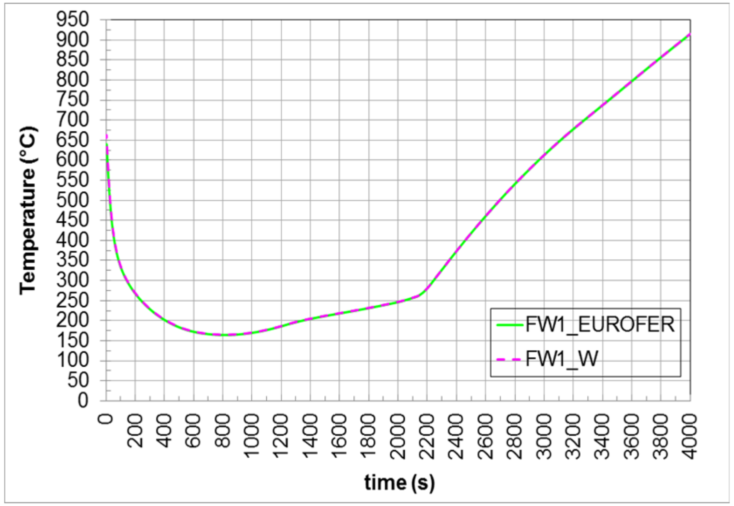
Pressure in the VV & EV



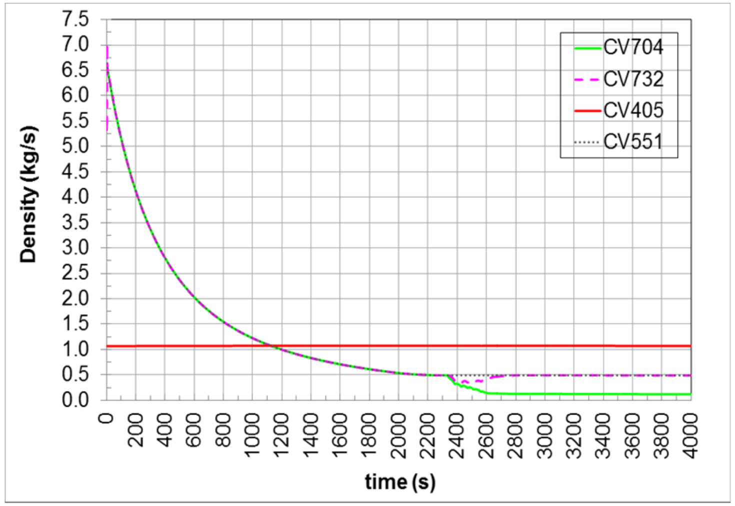
He temperature in OB_4



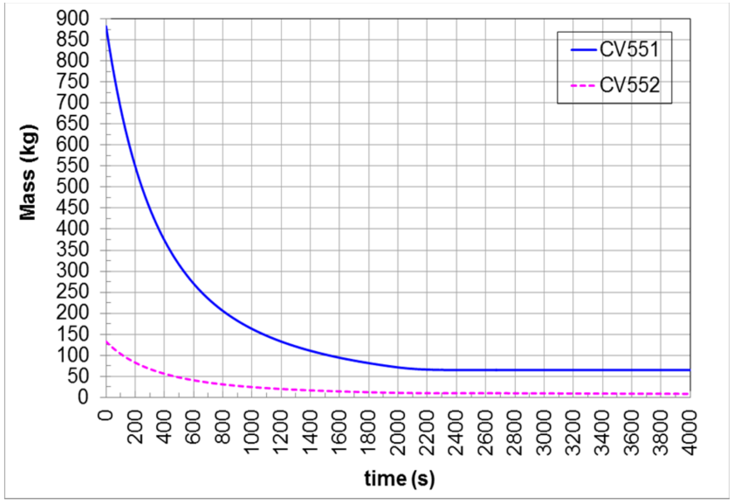
He temperature in the VV & EV



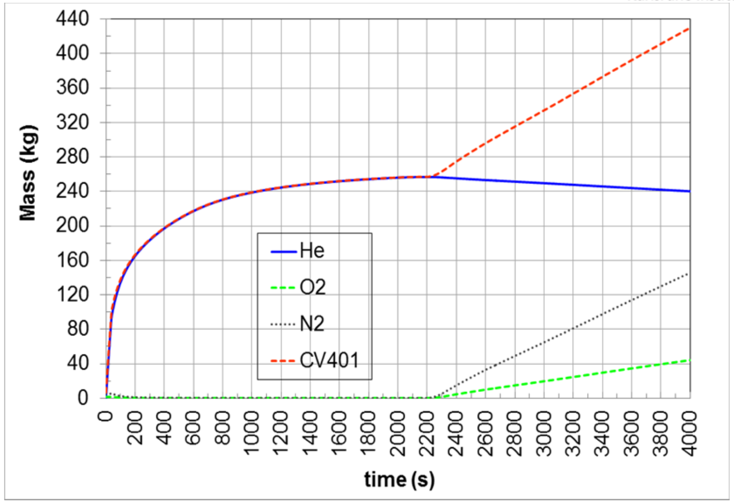
Temperature in HS



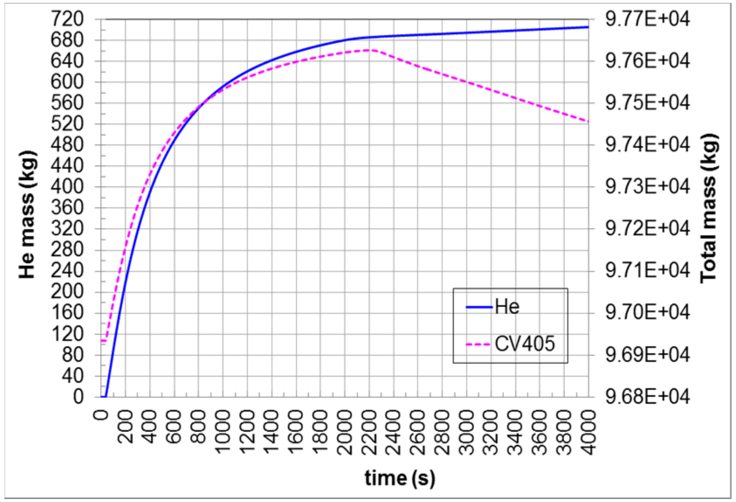
Density in OB_4, PHTS1 and EV



Mass in PHTS1 & 59 modules



Mass in the VV

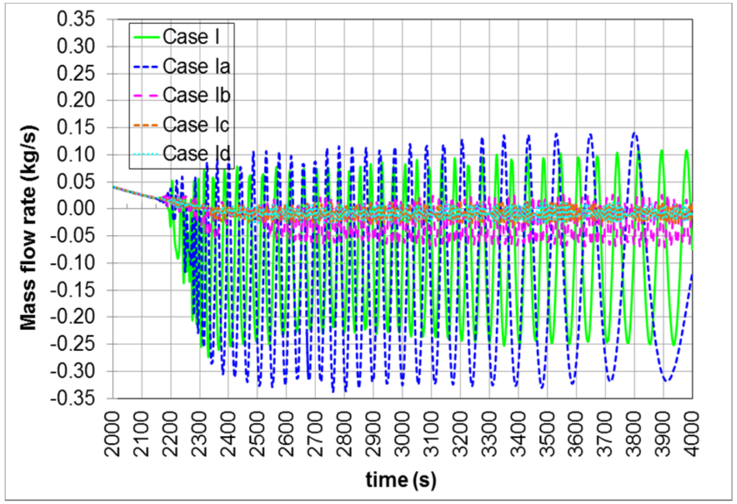


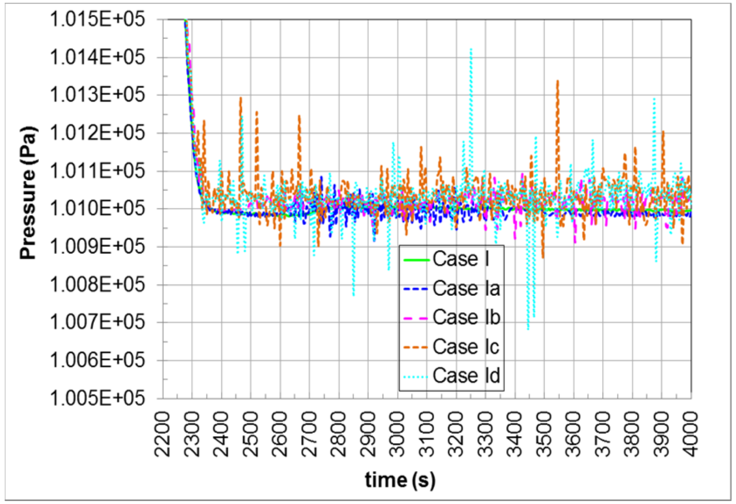
Mass in the EV

# Impact of time steps

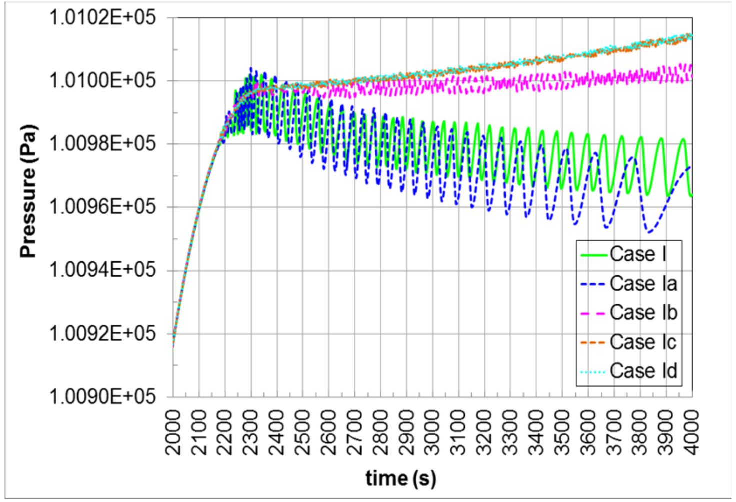
| Scenarios | dt (s) |
|---|---|
| Case I | 5.0e-4 |
| Case Ia | 5.0e-5 |
| Case Ib | 5.0e-3 |
| Case Ic | 5.0e-2 |
| Case Id | 5.0e-1 |

Mass flow rate to the EV (FL403), amplified





FW1 inlet pressure (CV706), amplified



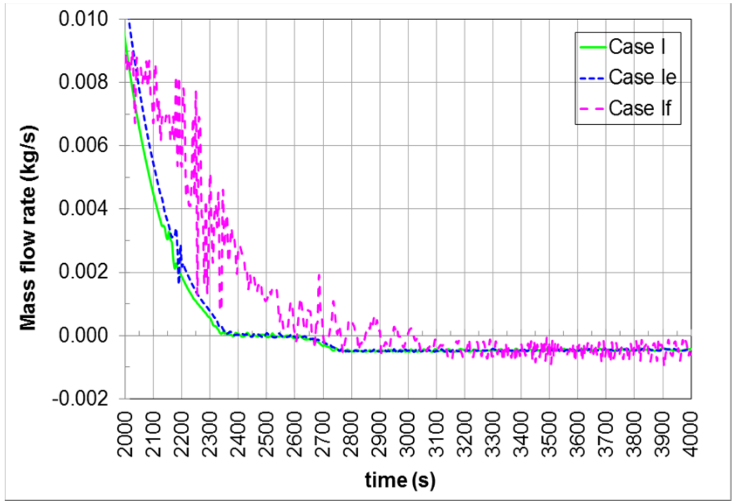
Pressure in the VV (CV401), amplified

# Impact of code versions

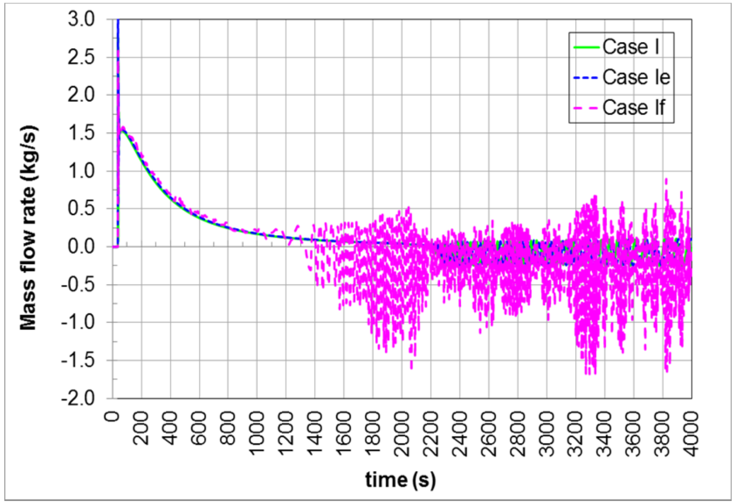
| Scenarios | Code | He | dt |
|---|---|---|---|
| Case I | MELCOR 1.8.6 | Working fluid | 5.0e-4 |
| Case Ie | | Noncondensable gas | |
| Case If | MELCOR 1.8.2 | Noncondensable gas | |

## Steady state results

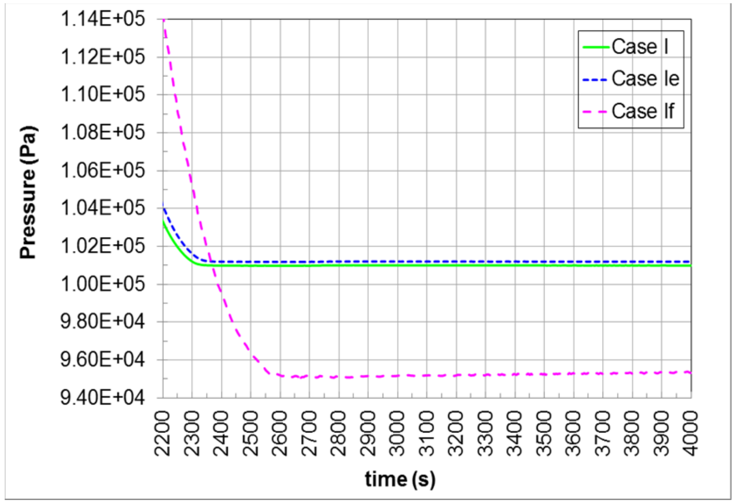
| Parameter | | | MELCOR 1.8.6 (case I) | MELCOR 1.8.6 (case Ie) | MELCOR 1.8.2 (case If) |
|---|---|---|---|---|---|
| He | Flow | | Working fluid | Noncondensable gas | |
| | Inventory of PHTS & 60 modules (kg) | | 1016.7 | 1035.0 | 1035.1 |
| FW | ṁ (kg/s) | | 3.1805 | 3.2084 | 3.2096 |
| | Pressure inlet (MPa) | | 7.84 | 7.85 | 7.88 |
| | dp (kPa) | | 149.0 | 149.0 | 149.0 |
| | He | inlet (°C) | 294.2 | 294.5 | 296.8 |
| | | outlet (°C) | 364.6 | 364.1 | 366.9 |
| | EUROFER (°C) | | 621.8 | 621.1 | 3721.3 |
| | W (°C) | | 661.1 | 660.4 | 3765.0 |
| HG, VG, caps | ṁ (kg/s) | HG | 1.7143 | 1.7295 | 1.7301 |
| | | VG | 0.6642 | 0.6701 | 0.6706 |
| | | Caps | 0.8020 | 0.8087 | 0.8089 |
| | He outlet (°C) | | 388.1 | 387.4 | 389.2 |



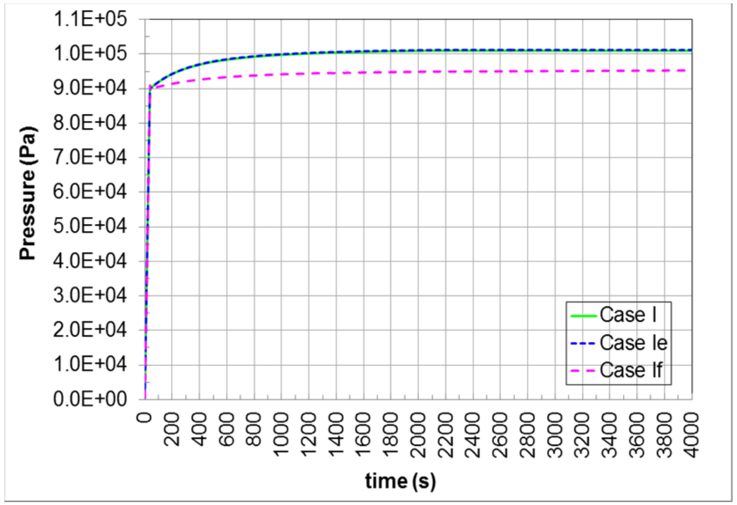
Module mass flow rate (FL706), amplified



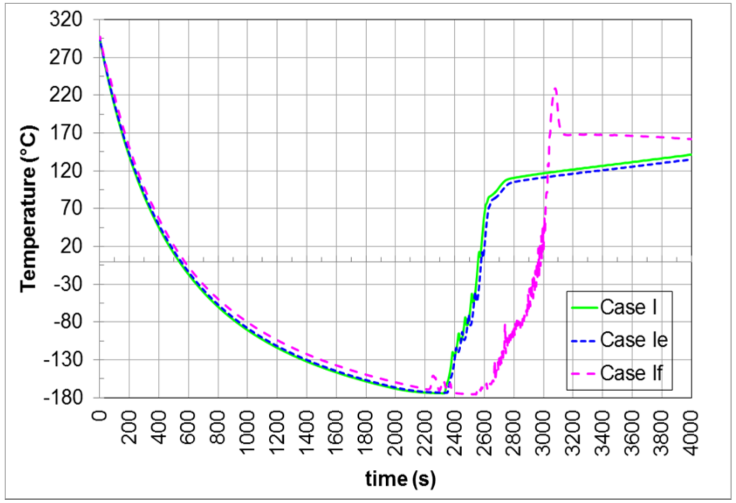
Mass flow rate to the EV (FL403)



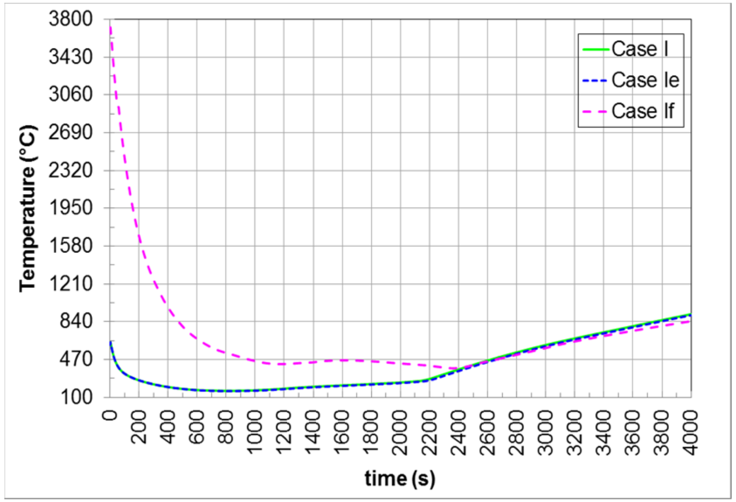
FW1 inlet pressure (CV706), amplified



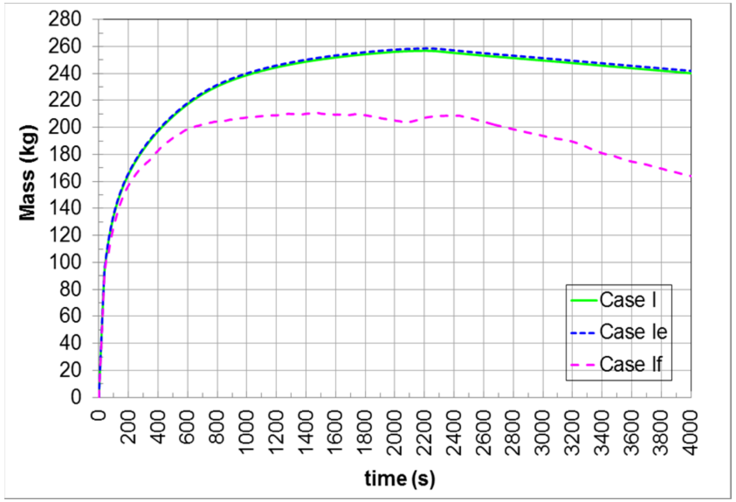
Pressure in the VV (CV401), amplified



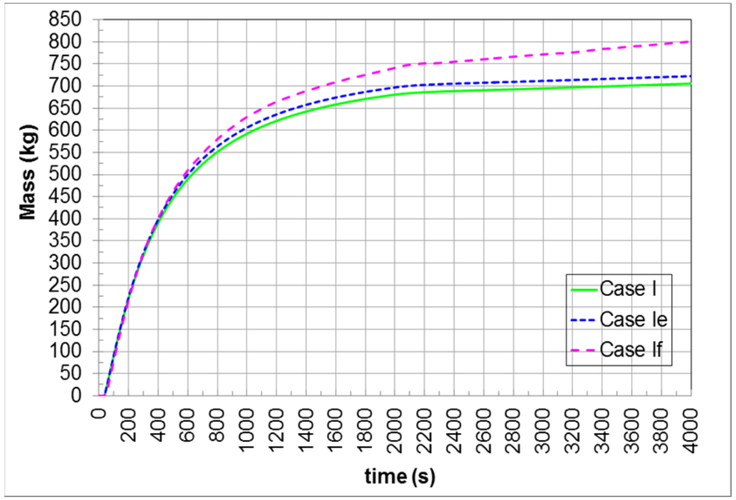
He temperature at the OB_4 inlet



FW temperature



He mass in the VV (CV401)



He mass in the EV (CV405)

# Conclusion

- ❑ Oscillation of the mass flow rate was observed after reaching the minimum He temperature below -170 °C. He properties are not the reason for the oscillation, since the results with He as noncondensable gas process in similar trend.
- ❑ Temperature recovered after reaching the minimum He temperature is not physically correct. *Probably it is influenced by MELCOR model for gases in the code.*
- ❑ Time step has no impact on the physically correct results, but on the results in the followed oscillation region. For large cross section small time step led to large oscillation of the mass flow rate. However, for small cross section large oscillation was caused by large time step.
- ❑ MELCOR 1.8.6 for fusion provides reliable results against MELCOR 1.8.2 due to the double precision.
- ❑ He properties produce precise results against He as noncondensable gas.

# Thank you !