

Preliminary accident analysis of the loss of heat sink for the European DEMO HCPB blanket concept

Xue Zhou Jin

Events of the loss of heat sink (LHS)

- LHS due to the loss of condenser in the PCS, the thermal power removed by SGs goes to 0.0.
- DBA (Casel, Loop3, 4, 5 are modelled)**
 - Detection of the LHS at 9.15MPa on the cold leg.
 - 3.0s later activation of the FPS system
 - Mitigated plasma disruption (0.75MJ/m², 10ms)
 - Affected FW area of 1.0m² in 2 sectors of Loop4&5
 - A loss of off-site power for 32h (LOSP)
 - If T_{FW} increases to 1000°C (T_{EF}), => FW fails
- BDBA (Casell, Loop3, 4, 5 are modelled)**
 - FPS fails that the plasma burns continuously
 - FW reaches T_{EF} => aggravating in-vessel LOCA
 - Unmitigated PD (rise: 1ms, 3MJ; decay: 3ms, 7MJ)
 - Affected FW area of 5.0m² in Loop4&5
 - A loss of off-site power for 32h
 - Open BL at 90kPa, RD at 150kPa
 - Source terms transport (tritium, dust, Caselld)
 - Caselll**: add Loop6 lumped by remaining 5 loops

Reference design

- DEMO baseline 2017 (16 sectors)**
- HCPB2018**: Single Module Segmentation (SMS), 3x outboard (OB) & 2x inboard (IB) in one sector. Roof-shaped FW made of Eurofer (EF), pins in the BZ with advanced ceramic breeder (ACB) & Be12Ti in block as neutron multiplier (NMM). Inlet 300°C, 8MPa, outlet 520°C. Plasma heat flux (HF), nuclear heating, decay heat (DH). Emissivity 0.3.
- PHTS2019**: Loop1-8, 2 sectors / loop, direct coupling with the SG, in- & outlet piping through the upper ports.
- Vacuum Vessel (VV)**: upper / bottom volume, plasma chamber (PC), design pressure (p_{vw}) of 200kPa.
- VVPSS2019**: 3xBL, 3xRD, wet expansion volume (EV) with 5% water, dry EV.
- TCR**: 60700m³, 30°C, 98kPa.
- Leak rates conditions ~ITER**
- Radioactive inventories**: W-dust 1034kg & 5kg at disruption; tritium 2673g in the VV, 4.17582E-3g in BB coolant, 5.82418e-2g in PHTS volume.

DBA time evolution

Sequence	Time (s)	
Scenario	la	lb
LHS	0.0	
t _{at} at 9.15MPa (la) / 8.8MPa (lb)	2.3663	1.5703
FPS	5.3663	4.5703
DH start	5.3683	4.5723
End of MPD / Comp. shutdown	5.3763	4.5803
If T _{FW} reaches T _{EF}	no	no
Comp. restart	115205.38	115204.58
End of transient t _{end}	119000	

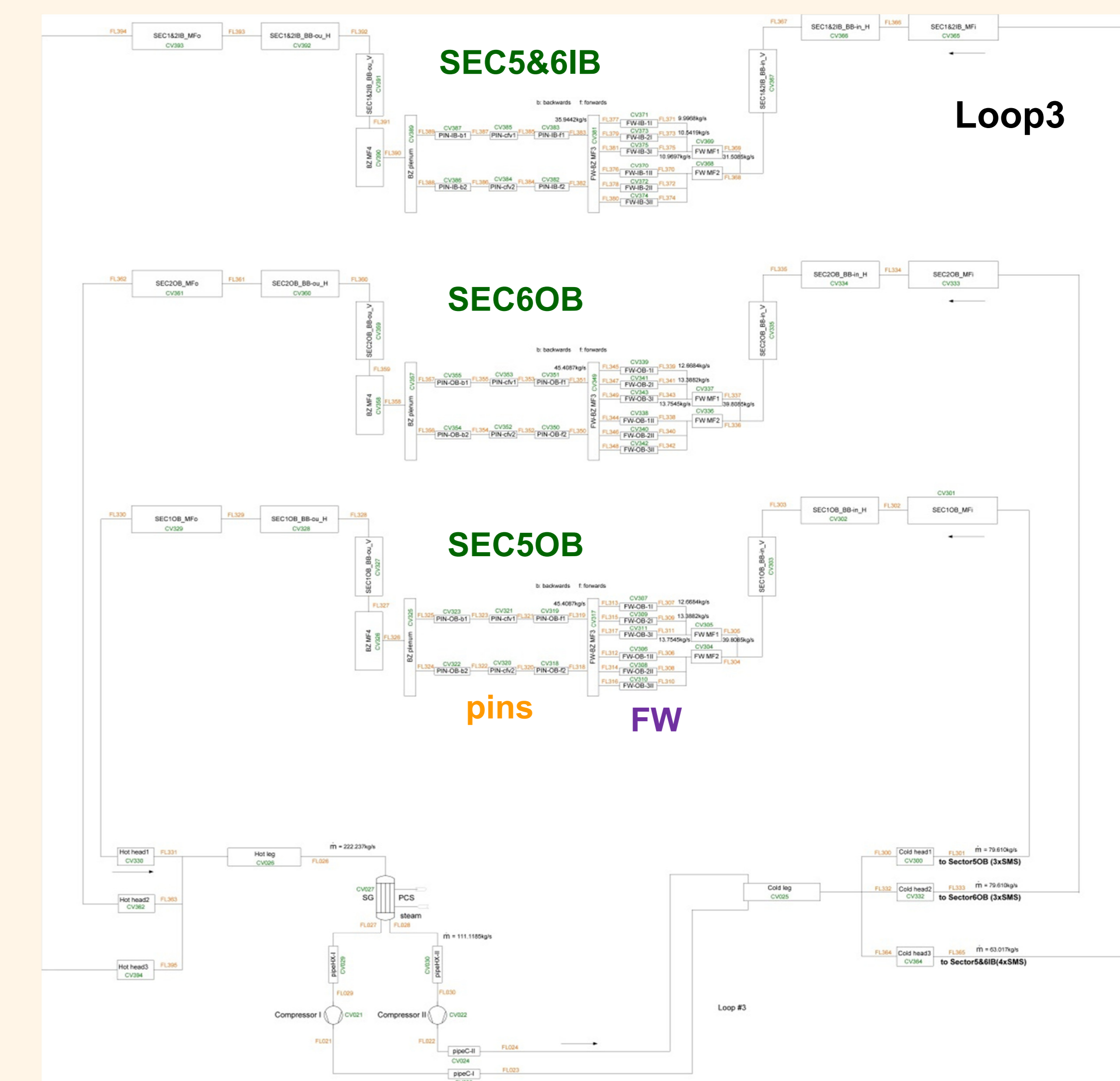
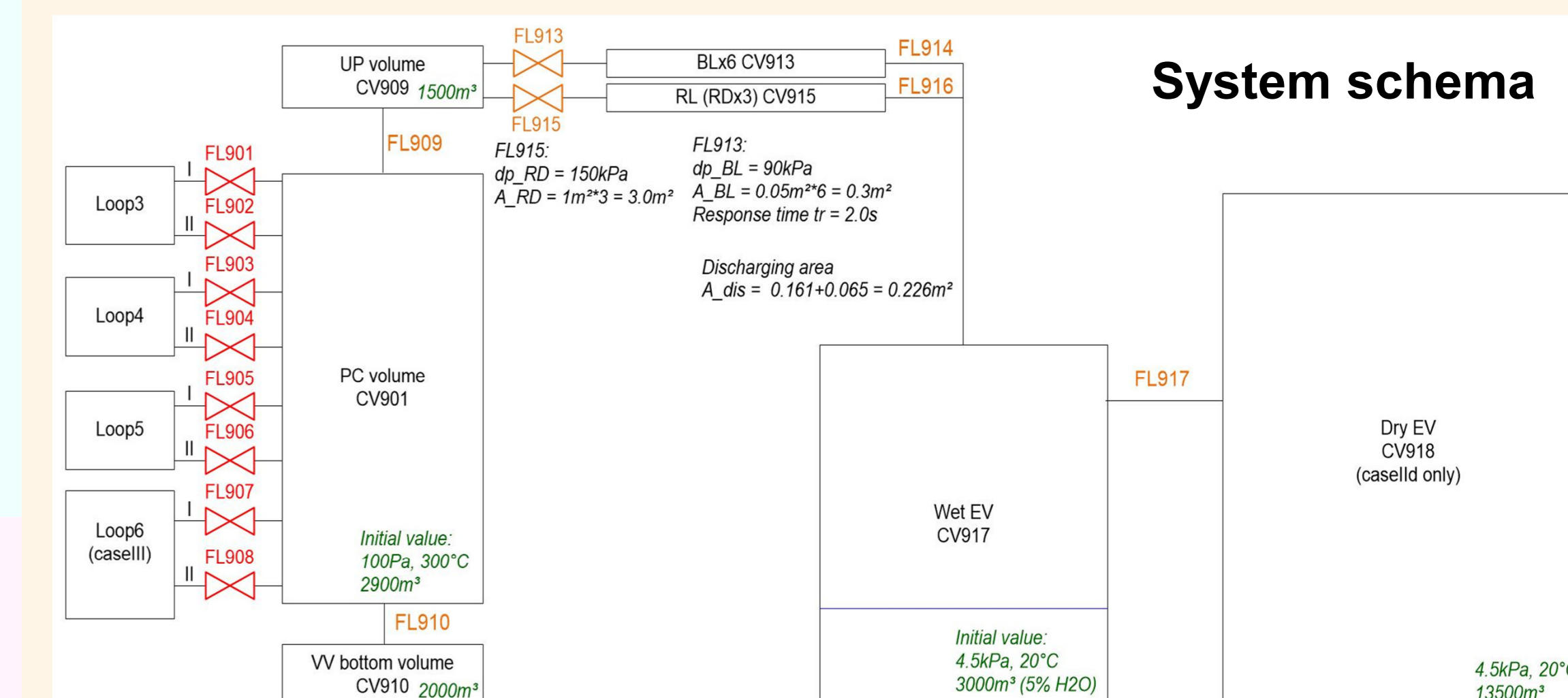
Releases at t_{end} (Caselld)

	VV	438.00
Dust (kg)	BL	6.2091e-2
	RD	5.2956e-1
	Wet EV	533.59
Tritium (kg)	TCR	1.4926
	Environment	3.0043e-3
	VV	1.1176
	BL	1.6011e-4
	RD	1.5127e-3
Tritium (kg)	Wet EV	1.3743
	TCR	4.6080e-3
	Environment	1.0649e-5

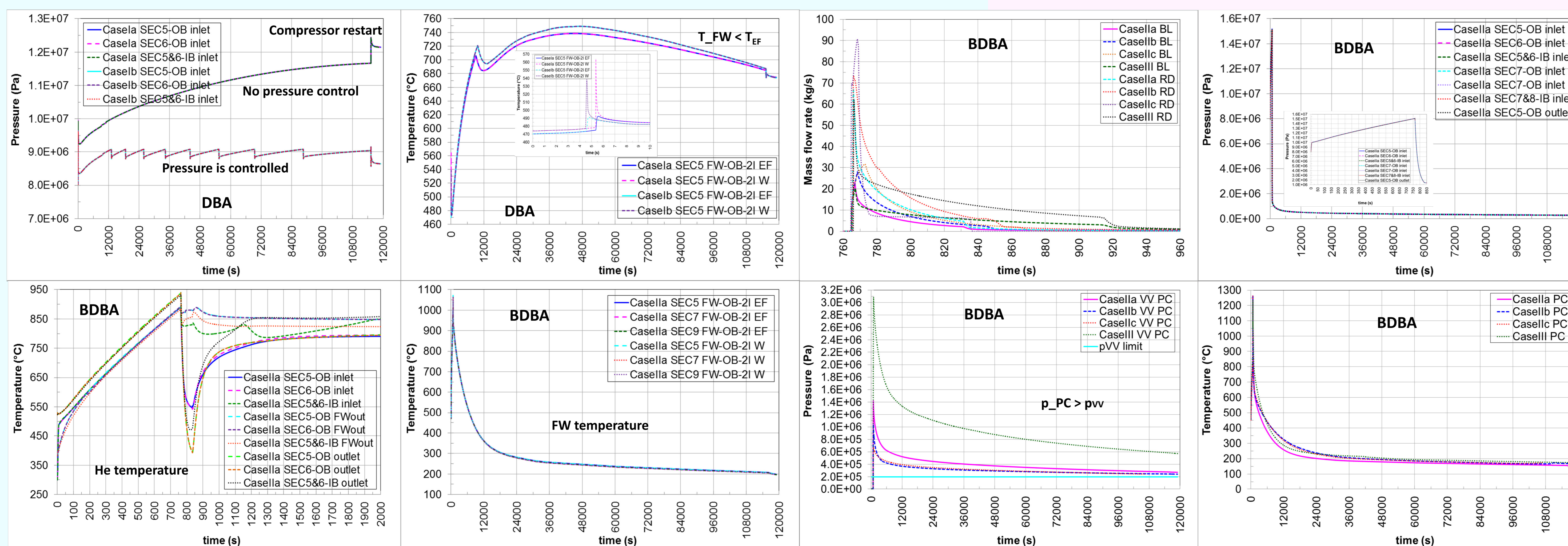
BDBA time evolution

Sequence	Time (s)					
Scenario	lla	llb	llc	lld	lll	
LHS	0.0					
T _{FW} reaches T _{EF}	763.6111	763.6022	763.6022	763.6022	763.4464	
PD	End of rise	763.6121	763.6033	763.6033	763.6033	763.4474
	End of decay	763.6151	763.6063	763.6063	763.6063	763.4504
DH start / Comp. shutdown	763.6151	763.6063	763.6063	763.6063	763.4504	
t _{al} by opening BL	764.8954	764.8879	764.8877	764.8882	765.0562	
t _{rd} by opening RD	765.4990	765.4894	765.4892	765.4915	765.9241	
Comp. restart	115963.62	115963.61	115963.61	115963.61	115963.45	
End of transient t _{end}	119000		106755	28745	119000	
Tritium / dust	VV	763.6				
	Wet EV	764.9				
	TCR	765.0				
	Environment	4645.0				
EV	wet	wet x 2	wet + dry	wet	wet	

Modelling using MELCOR1.8.6 for fusion



Transient



Conclusion

- He inventory of one single loop is 1.7280e3kg, 8.6597e3kg in the lumped Loop6, => 1.3844E+04kg in the whole HCPB blanket system and the PHTS at steady state.
- The LHS DBA with the FPS does not lead to the FW failure, since T_{FW} is below T_{EF}, and the blanket pressure can be well controlled via pressure control / relief system.
- After the compressor shutdown He flows forwards or backwards in different branching and sub-divisions at low mass flow rates due to pressure differences.
- Compressor restart for 1h after the LOSP does not recover normal operation due to the LHS all the time.
- In the BDBA the FW reaches T_{EF} at 763.6s which leads to the aggravating in-vessel LOCA in all loops of the PHTS.
- The designed VVPSS incl. the wet and dry EVs cannot suppress the VV pressure below p_{vw} in the studied scenarios.
- T_{OB-pin_EF} reaches T_{EF} at 1445s that the in-box LOCA takes place. At that time p_{blanket} of 1.0991MPa will affect the purge gas system & tritium extraction removal (TER) system.
- The leak rates between VV & TCR, TCR & environment lead to p_{TCR} > p_{atmosphere} => 3.0043e-3kg dust and 1.0649e-5kg tritium release into the environment at t_{end}.

Abbreviation

- Ab break size
- BL bleed line
- BZ breeding zone
- Comp. compressor
- CV control volume
- FL flow path
- FPS Fast Plasma Shutdown
- FW first wall
- HS heat structure
- MF Manifold
- MI Module IB
- MO Module OB
- MPD mitigated plasma disruption
- PCS power conversion system
- PFC plasma facing component
- PHTS primary heat transfer system
- RD rupture disk
- SEC sector
- SG steam generator
- TCR tokamak cooling room

