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Topic F

Preliminary accident analysis of loss of vacuum in vacuum vessel of the European DEMO using the helium cooled pebble bed blanket concept

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Event of the loss of vacuum (LOVA)

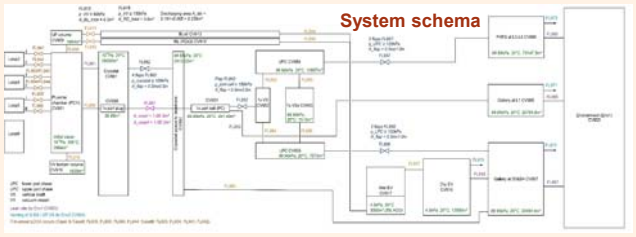
Design Basis Accident (DBA)

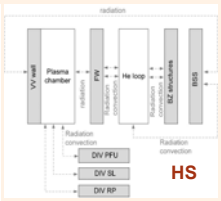
- LOVA in the VV occurs at a port seal of the closure plate in an equatorial port plug
  - A small leak of 1.0E-3 m² (CaseI)
  - A large break size of 1.0E-2 m² (CaseII, CaseIII)
- Air in one PC ingresses into the VV via the broken penetration
- VV pressurization → open BL at 90 kPa, RD at 150 kPa
- Fusion power termination by an unmitigated disruption within 1ms (CaseI & CaseII) or 3.7 s (CaseIII)
- Affected FW area of 1.0 m² in 2 sectors of Loop 4&5
- If T_FW increases to 1000 °C (T_{EF}) → FW fails (CaseIII)
- A loss of off-site power for 32 h (LOOP) as a concurrent event to coincide with the disruption
- Radioactive inventories (tritium → HTO, dust) will mobilize towards the VVPSS / cryostat / gallery / environment due to pressurization and leak rates.
- Venting systems ST-VS and S-DS trap tritium (99% efficiency) and dust (99.9%)

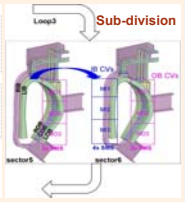
Reference design

- **DEMO baseline 2017 (16 sectors)**
- **HCPB_BL2017_v2:** 3xOB & 2xIB SMS per sector | Roof-shaped FW made of Eurofer | pins in the BZ with advanced ceramic breeder (ACB) & $Be_{12}Ti$ in block as neutron multiplier (NMM) | BB inlet 300 °C & 8 MPa, outlet 520 °C | Plasma heat flux, nuclear heating, decay heat | Radiation emissivity 0.3.
- **PHTS2020**: Loop1-8, 2xSEC/loop, Indirect Coupling Option, in- & outlet piping through the upper ports.
- **VV:** upper / bottom volume, plasma chamber (PCH), design pressure of 200 kPa (p_{VV_lim}), emergency cooling.
- **VVPSS2020**: 6xBL, 3xRD, wet EV, dry EV.
- **Tokamak building arrangement:** cryostat, cryostat space, PC, VS, LPC, UPC, gallery, PHTS vault, etc.
- **DIV2019:** shielding liner (SL) and targets.
- **Leak rate conditions** ~ITER
- **Radioactive inventories:** W-dust 1034 kg & 5 kg at disruption; tritium 2673 g in the VV, 4.17582E-3 g in BB coolant, 5.82418e-2 g in PHTS coolant.

Modelling using MELCOR1.8.6 for fusion

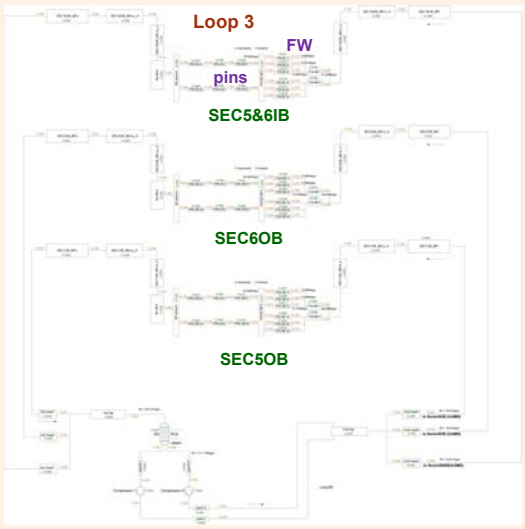






Time evolution

Sequence		Time (s)		
Case		I	II	III
LOVA		0.0024		0.0030
End of unmitigated dissruption / LOOP / DH start		0.0034	0.0034	3.7030
t_{EF} at T_{EF} (in-vessel LOCA)		not happen		3.7042
Open BL		31522.0	30482.2	7.3725
Open RD		not open		6.2623
$p_{VV} > p_{VV\_lim}$		not happen		46.206
Max. p_{VV}		31522.0 (9.0E4 Pa)	30482.2 (9.0E4 Pa)	66.87 (2.088E5 Pa)
Open PC to VS		not open		21.44
Open LPC to galleryB3&B4		not open		190.31
Open UPC to PHTS vault / cryostat to cryostat space		not open		
Open ST-VS		not open		201.37
Open galleryL1 S-DS		314.59	314.98	317.20
Open galleryB3&B4 S-DS		317.77	317.79	321.45
Open PHTS vault S-DS		2574.1	2574.1	2577.8
W-dust / HTO	VV	0.0074	0.0074	0.008
	PC	0.0	0.0	5.5
	Wet / dry EV	31525.0	30485.0	7.0
	cryostat	0.008	0.008	3.8
	cryostat space	0.0	0.0	14.0
	VS / UPC / LPC	0.0	0.0	22.0
	PHTS vault	0.0	0.0	0.0
	GalleryL1	0.0	0.0	7.0
	GalleryB3&B4	0.0	0.0	14.0
	Env1 (leak)	0.0	0.0	192.0

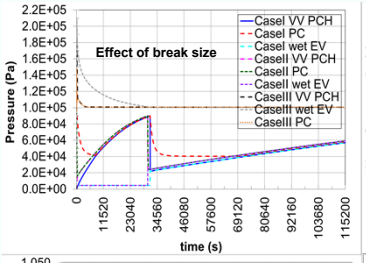


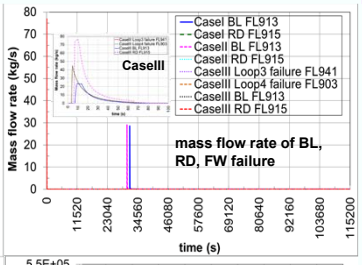
Modelling of PHTS
- 3x single loop: Loop 3, 4, 5
- 1x lumped loop of 5 single loops: Loop 6

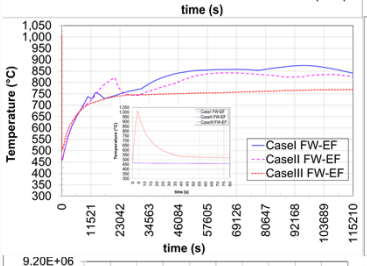
Modelling of DIV
- Open loops for PFU, SL, Reflector plates (RP). HS for PFU, SL, RP

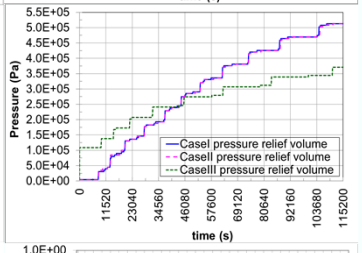
Pressure relief system
- to control pressure of cooling loop
- Assumption: the same size as the dry EV

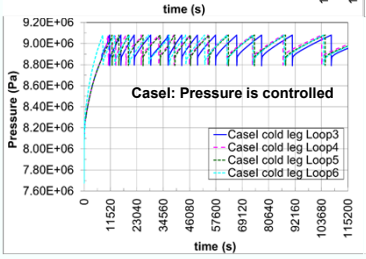
Transient

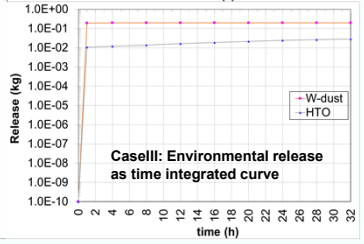












Dose at several distances (mSv)

CaseIII, 95%percentile	0.5 km	1 km	5 km	10 km
Early dose	6.6	3.9	0.17	0.063
ED with ingestion	31	17	1.3	0.85

- Dose assessments due to the consequences of accidental tritium release assessed with UFOTRI, and W-dust with COSYMA
- Historic weather conditions from Cadarache (ITER) in 1991 are applied for a probabilistic assessment
- **The early dose (7 days) exceeds 1 mSv up to several km from the release point, and it is dominated by tritium**
- **The ED near to the release is higher than 10 mSv, and drops below 1 mSv only at 10 km**
- **Contribution to the ED is similar for dust and tritium (higher)**

Abbreviation

A	Area, break size	LPC / UPC	Low / Upper Pipe Chase
BB	Breeding Blanket	MF	Manifold
BL	Bleed Line	MI	Module IB
BSS	Back Support Structure	MO	Module OB
BZ	Breeding Zone	PC	Port Cell
CB	Cassette Body	PFU	Plasma Facing Unit
CV	Control Volume	PHTS	Primary Heat Transfer System
DIV	Divertor	RD	Rupture Disk
ED	Effective Dose	S-DS	Stand-by Detritiation System
EF	Eurofer	SEC	Sector
Env	Environment	SMS	Single Module Segmentation
EV	Expansion Volume	ST-VS	Suppression Tank Venting System
FL	Flow Path	VS	Vertical Shaft
FW	First Wall	VV	Vacuum Vessel
HS	Heat Structure	VVPSS	VV Pressure Suppression System
IB / OB	Inboard / Outboard	W	Tungsten

Releases at t_{end}

Case		Mass (kg) I	II	III
Dust	Inventory		1039.0	
	VV	1036.9	1035.9	488.9
	PC	0.0	0.0	4.4378
	BL & RD	8.1641E-3	9.1051E-3	0.264
	Wet EV	1.0784	1.1493	345.32
	dry EV	0.6445	0.7864	158.84
	Cryostat	1.5807E-2	1.7222E-2	1.2052E-2
	Cryostat space	0.0	0.0	6.7371E-2
	UPC	0.0	0.0	14.253
	LPC	0.0	0.0	11.923
	8x VS	0.0	0.0	0.7606
	GalleryL1	0.0	0.0	0.2839
	GalleryB3&B4	0.0	0.0	4.4379
	PHTS vault	0.0	0.0	0.0
	Env1 (leak)	0.0	0.0	0.19106
	Env2 (venting)	0.0	0.0	4.0266E-3
	Env1+2 (total)	0.0	0.0	0.1951
HTO	Inventory		17.7455	
	VV	0.6358	0.5233	1.5843
	PC	0.0	0.0	2.0358E-2
	BL & RD	0.1342	0.1271	3.4941E-2
	Wet EV	0.5821	0.6931	3.0048
	dry EV	16.383	16.379	6.8185
	Cryostat	5.1218E-3	5.2904E-3	3.6078E-2
	Cryostat space	0.0	0.0	7.6812E-2
	UPC	0.0	0.0	0.4940
	LPC	0.0	0.0	0.2502
	8x VS	0.0	0.0	7.2523E-2
	GalleryL1	0.0	0.0	3.4273E-2
	GalleryB3&B4	0.0	0.0	1.2336
	PHTS vault	0.0	0.0	0.0
	Env1 (leak)	0.0	0.0	1.9927E-2
	Env2 (venting)	0.0	0.0	1.7754E-2
	Env1+2 (total)	0.0	0.0	2.8682E-2

The release data to the environment are applied as time-integrated values for dose calculation

Conclusion

- **At steady state, He inventory of one single loop is 1.2707E3 kg → 1.0166E4 kg in the whole HCPB blanket system and the PHTS.**
- **The main differences between CaseI and CaseII are due to the break size. Parameters of both cases have similar behavior in the long term.**
- **The difference due to the small leak in CaseI and the large break in CaseII is the speed of the PC depressurization and the VV pressurization. The common pressure level is achieved at 7995 s in CaseI and 445 s in CaseII. Thus the time difference is 2.10 h.**
- **T_{EF} is not reached on the affected FW by the very short plasma disruption (1 ms) and the decay heat in the long term (CaseI&II). With the frequent plasma disruptions of 3.7 s, the FW reach T_{EF} that an in-vessel LOCA occurs (CaseIII).**
- **In CaseIII, the VV pressure exceeds p_{VV_lim} at 46.2 s, reaches the maximum of 2.0882E5 Pa at 66.87 s, and decreases to 3.8134E5 Pa at t_{end}.**
- **In CaseI&II there are no releases to the environment. In CaseIII, dust released to the environment due to the leak (Env1) is higher than due to the venting (Env2), while HTO released to the environment due to the leak is lower than due to the venting.**
- **The most dust is remained in the VV and the most HTO is transported into the dry EV.**