SAFETY ANALYSIS FOR THE EUROPEAN HCPB TBM SYSTEM USING PEDIGREED MELCOR182

One selected case in long term behavior & Tritium, dust and ACP transport

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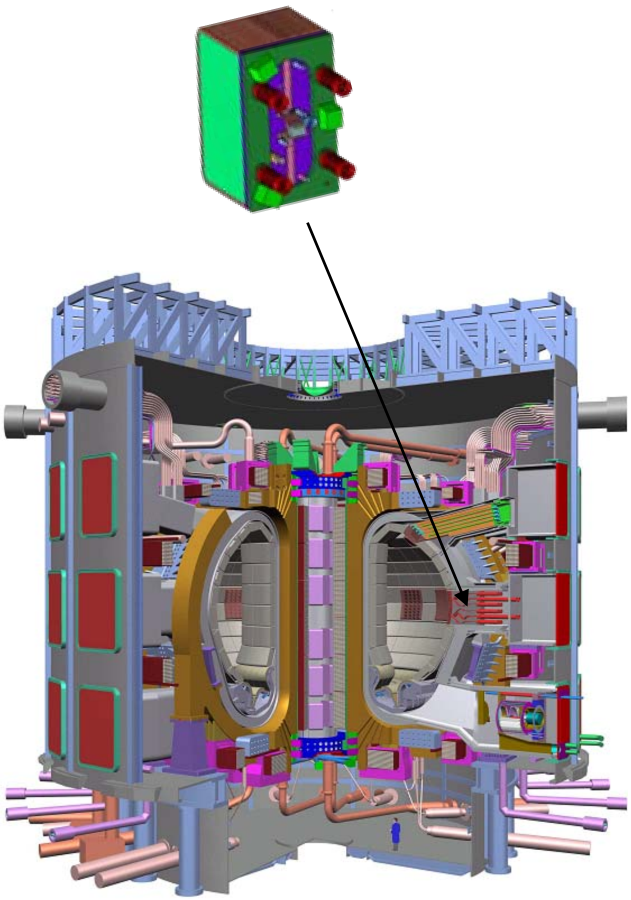
Outline

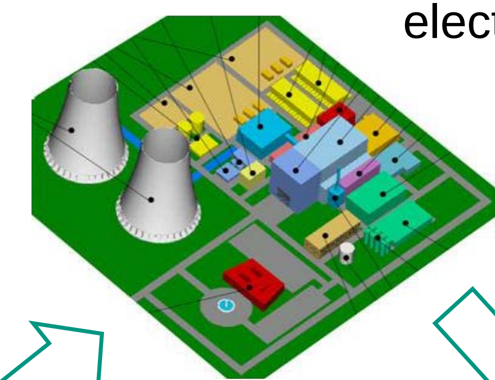
- Pedigreed MELCOR182 for ITER
- Description of the safety analysis case: ex-vessel LOCA with failure of the plasma shutdown system
  - ➢ Phase 1 „He blow-down“ (RELAP5/MOD3.2)
  - ➢ Phase 2 „Delayed plasma shutdown“ (ANSYS V10)
  - ➢ Phase 3 „Long term behavior“ (MELCOR182)
- MELCOR study for the most severe case in phase 3 and results
  - ➢ Simultaneous failures of VV, TBM box and water cooled component of ITER ⇨ air and steam reactions with Be pebbles.
- MELCOR calculation for Tritium, dust and ACP transport
- Summary & open issues

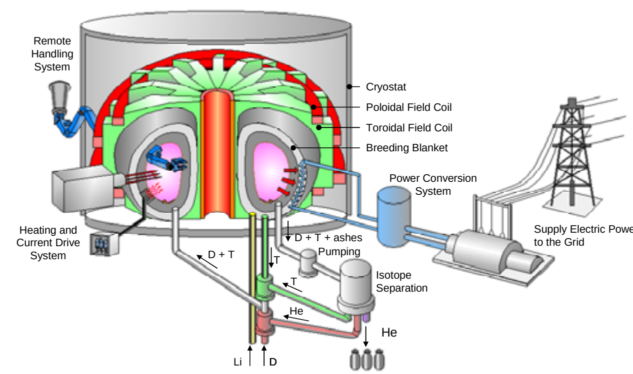
ITER (International Thermonuclear Experimental Reactor)

European HCLL & HCPB TBM



DEMO: 1st fusion reactor for electrical power generation





ITER: scientific study of fusion technology

HCLL: He Cooled Lithium Lead
HCPB: He Cooled Pebble Beds
TBM: Test Blanket Module

Fusion Power Plant (FPP): economical, safe and environmentally friendly

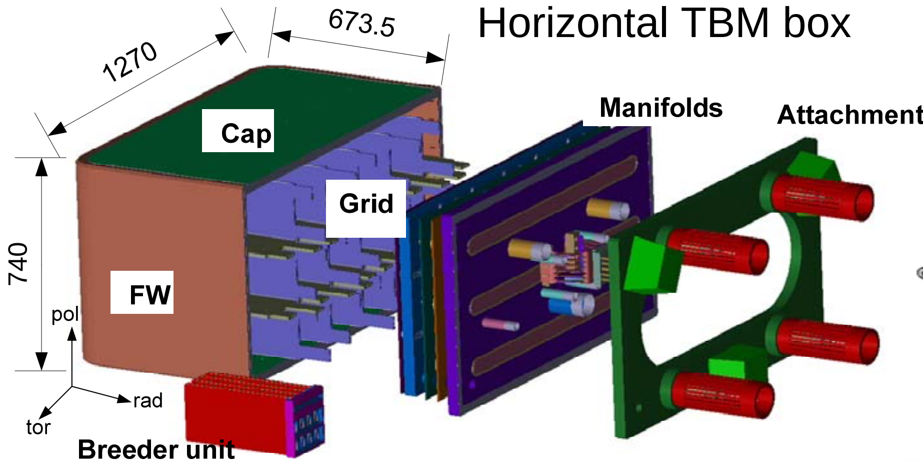
Pedigreed MELCOR182 for ITER

- The version was obtained in June 2007 for the safety analysis cases:
  - Design Base Accident (DBA)
  - Beyond Design Base Accident (BDBA)
- The version modified by INEEL (Idaho National Engineering and Environmental Laboratory) is used for ITER purposes*:
  - chemical oxidation reactions of steam with Be, C and W,
  - extension of water properties below its triple point temperature for Loss Of Coolant Accidents (LOCAs) into cryostats,
  - the cryogenic He or air as the primary fluid,
  - convective boiling,
  - HTO transport,
  - enclosure radiant heat transfer.

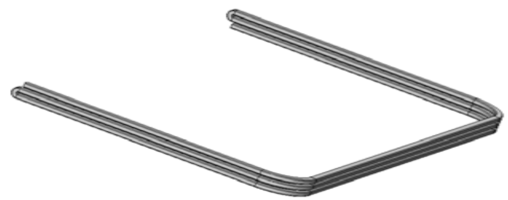
* B.J. Merrill, Modifications to the MELCOR code for application in fusion accident analyses, Fusion Engineering and Design 51-52, 2000.

HCPB TBM and the combined HCS

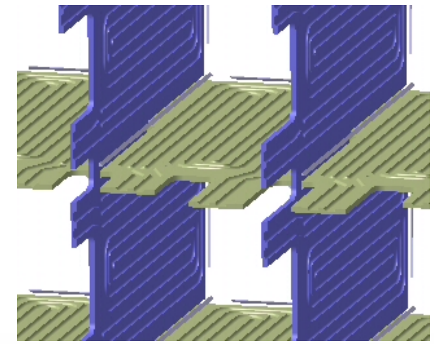
Horizontal TBM box



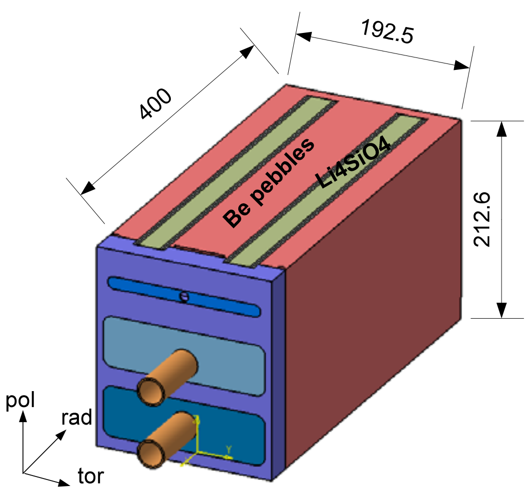
Three-sweep-channel in FW



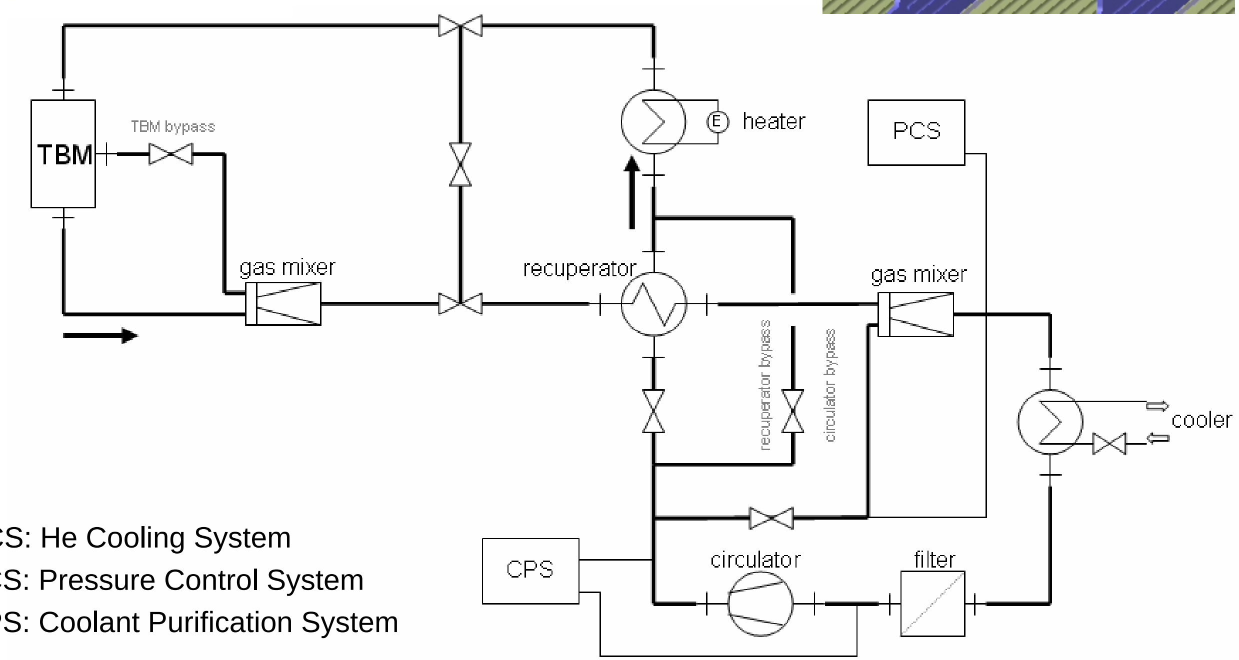
Cooling channels in grids



Breeder Unit (BU)



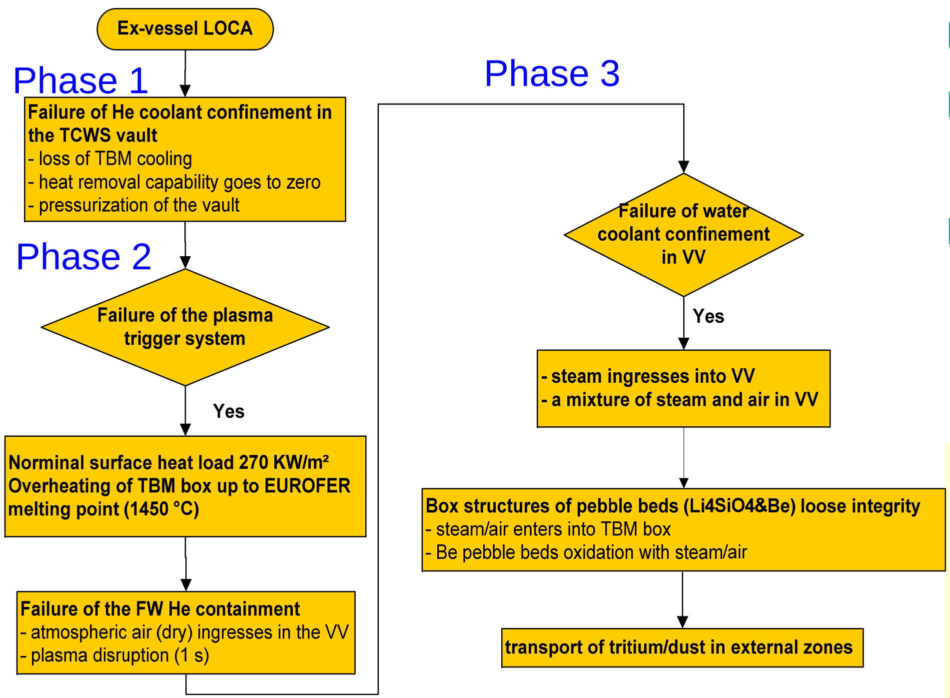
HCS



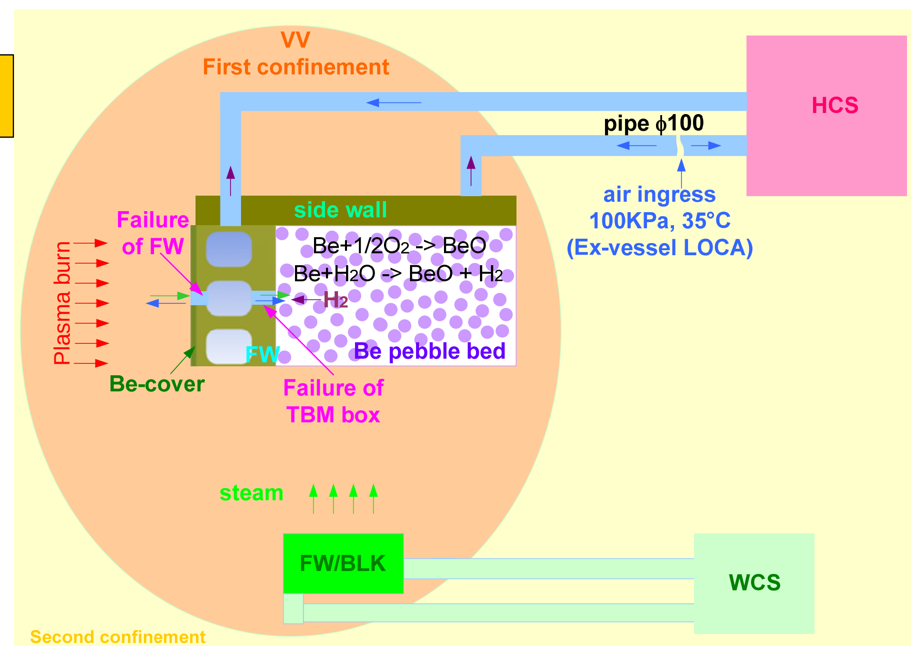
HCS: He Cooling System
PCS: Pressure Control System
CPS: Coolant Purification System

Ex-vessel LOCA with failure of the plasma shutdown system

Karlsruhe Institute of Technology



- **Phase 1 He blow-down**
- **Phase 2 delayed plasma shutdown** ***(heating-up, plasma disruption)***
- **Phase 3 long term behavior** ***(decay heating)***



TCWS: Tokamak Cooling Water System
VV: Vacuum Vessel
BLK: Blanket
WCS: Water Cooling System

Material properties

T (° C)	EUROFER*		Be-cover**	
	cp (J/kgK)	λ (W/mK)	cp (J/kgK)	λ (W/mK)
100	477	32.5	2295	145
300	544	33.4	2497	129
400	586	33.0	2660	116
500	644	32.7	2791	106
600	728	32.3	2898	98
800	803	29.2	3071	85

T (° C)	Be pebble***			Li ceramic***		
	cp (J/kgK)	λ (W/mK)		cp (J/kgK)	λ (W/mK)	
		He	air		He	air
300	2520	10.0	9.0	1789	0.917	0.362
500	2739		7.8	2076	1.016	0.442
700	2909		6.8	2365	1.115	0.522
900	3062		6.2	2656	1.214	0.602
1000	3135		6.2	2801	1.264	0.642
1200	3277		6.2	3093	1.363	0.722

* F. Tavassoli, DEMO interim structural design criteria, Appendix A material design limit data, A3.S18E EUROFER steel, draft, CEA/DEN/SAC/DMN, D0.155.21/06/02.

** SADL-V5.1.1

*** J. Reimann, Material Assessment Report on Beryllium pebble beds for EU HCPB test blanket module, TW4-TTBB-001D2, 7.11. 2005.
Technical note: thermal conductivity of Li4SiO4 and Be pebble beds in air, personal information, 24.10.2006.
L. V. Boccaccini (Ed.) dt al. Materials Assessment Report, 4.1.2 Ceramic breeder pebble beds for EU HCPB test blanket module, G74 MA 10 00-11-10 W 0.1.

Be and H_2 inventory in the pebble bed of HCPB TBM

		TBM box
Be mass (kg)		**228.2**
Total energy (GJ)	**air**	**15.5**
	steam	**9.4**
H_2 production (kg)		**50.7**

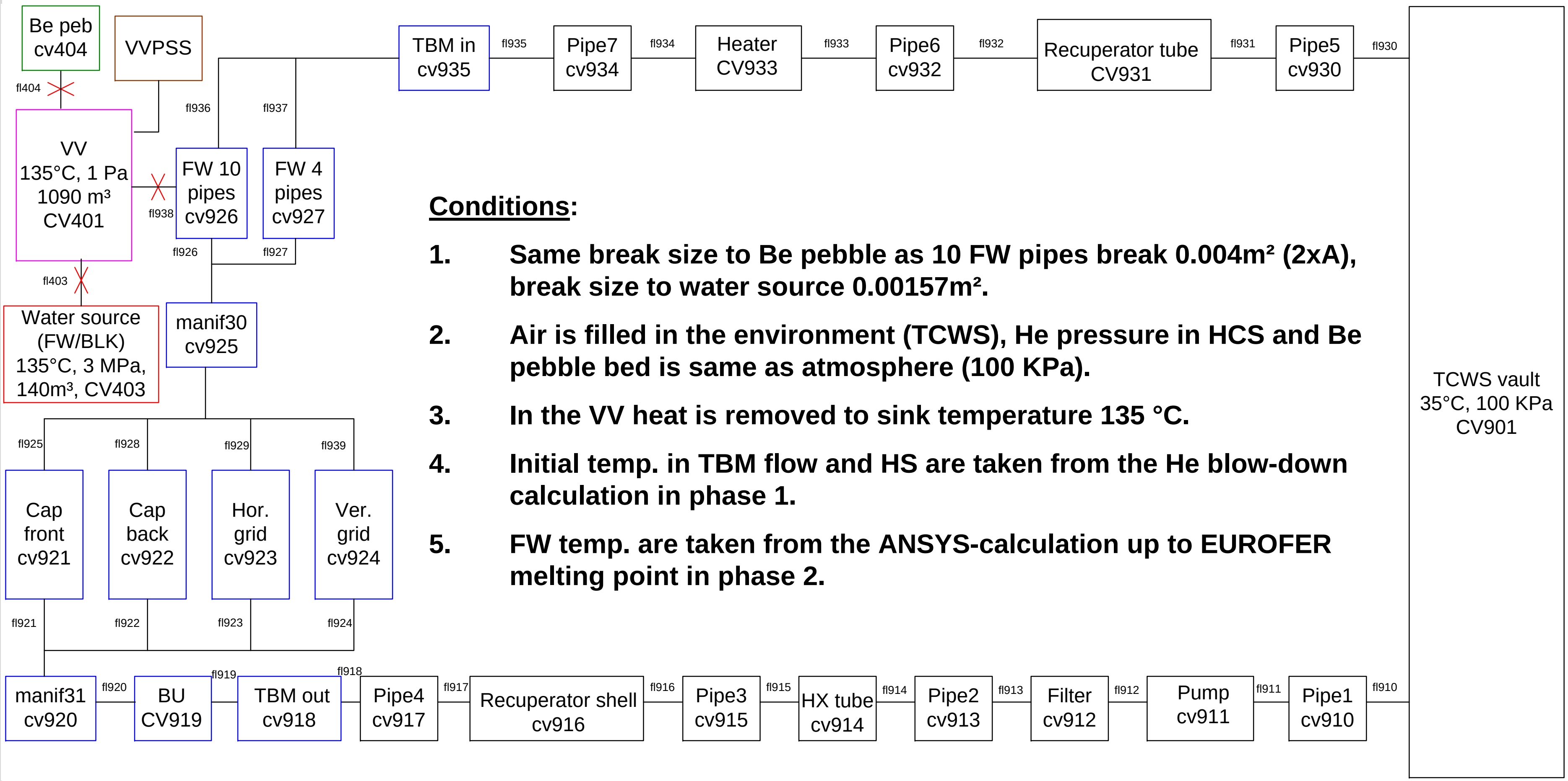
→ safety critical

Be oxidation:

$$Be + \frac{1}{2}O_2 \rightarrow BeO \quad -610 KJ/mol, \quad T > 300^\circ C$$

$$Be + H_2O \rightarrow BeO + H_2 \quad -370 KJ/mol, \quad T > 300^\circ C$$

MELCOR Modeling for the TBM and HCS

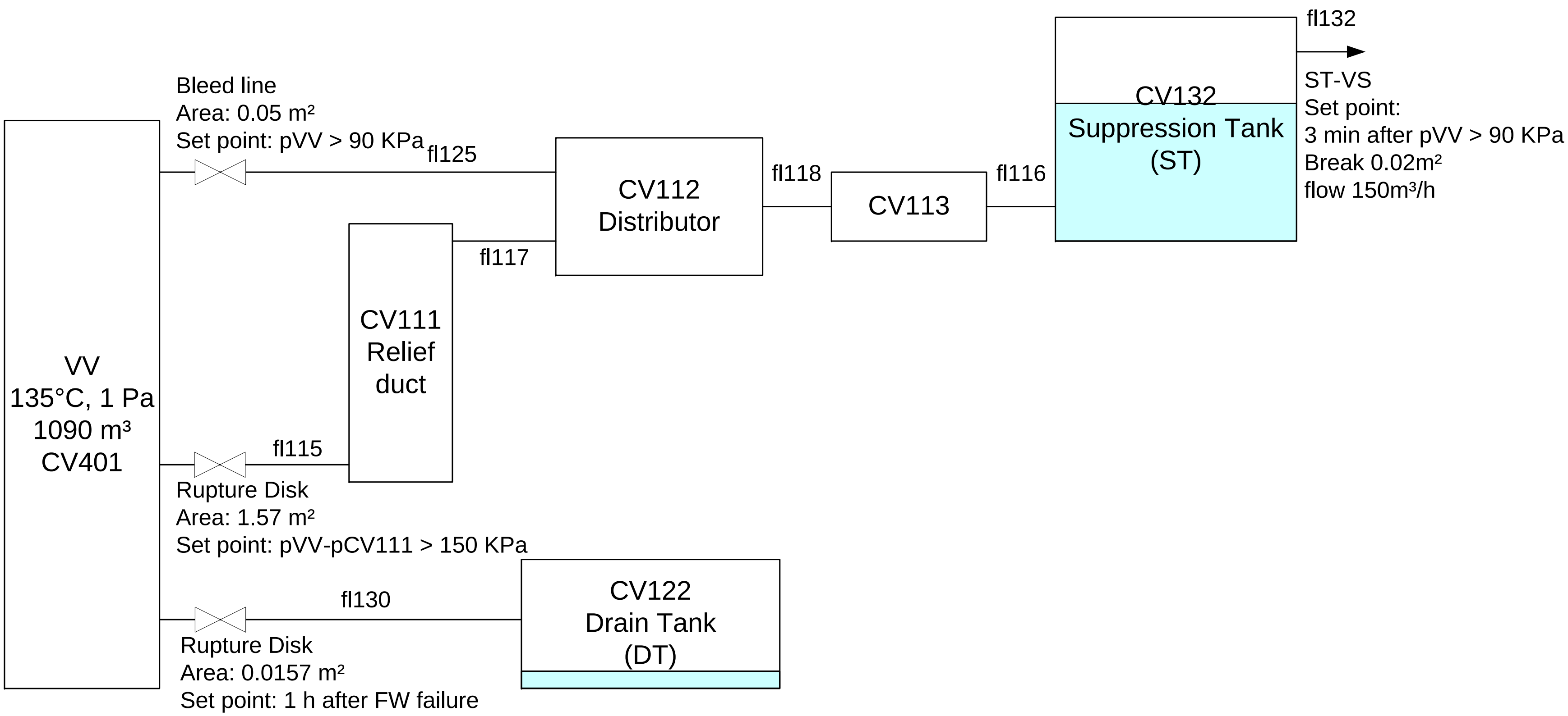


<u>Conditions</u>:

1. **Same break size to Be pebble as 10 FW pipes break 0.004m² (2xA), break size to water source 0.00157m².**
2. **Air is filled in the environment (TCWS), He pressure in HCS and Be pebble bed is same as atmosphere (100 KPa).**
3. **In the VV heat is removed to sink temperature 135 °C.**
4. **Initial temp. in TBM flow and HS are taken from the He blow-down calculation in phase 1.**
5. **FW temp. are taken from the ANSYS-calculation up to EUROFER melting point in phase 2.**

VVPSS: Vacuum Vessel Pressure Suppression System

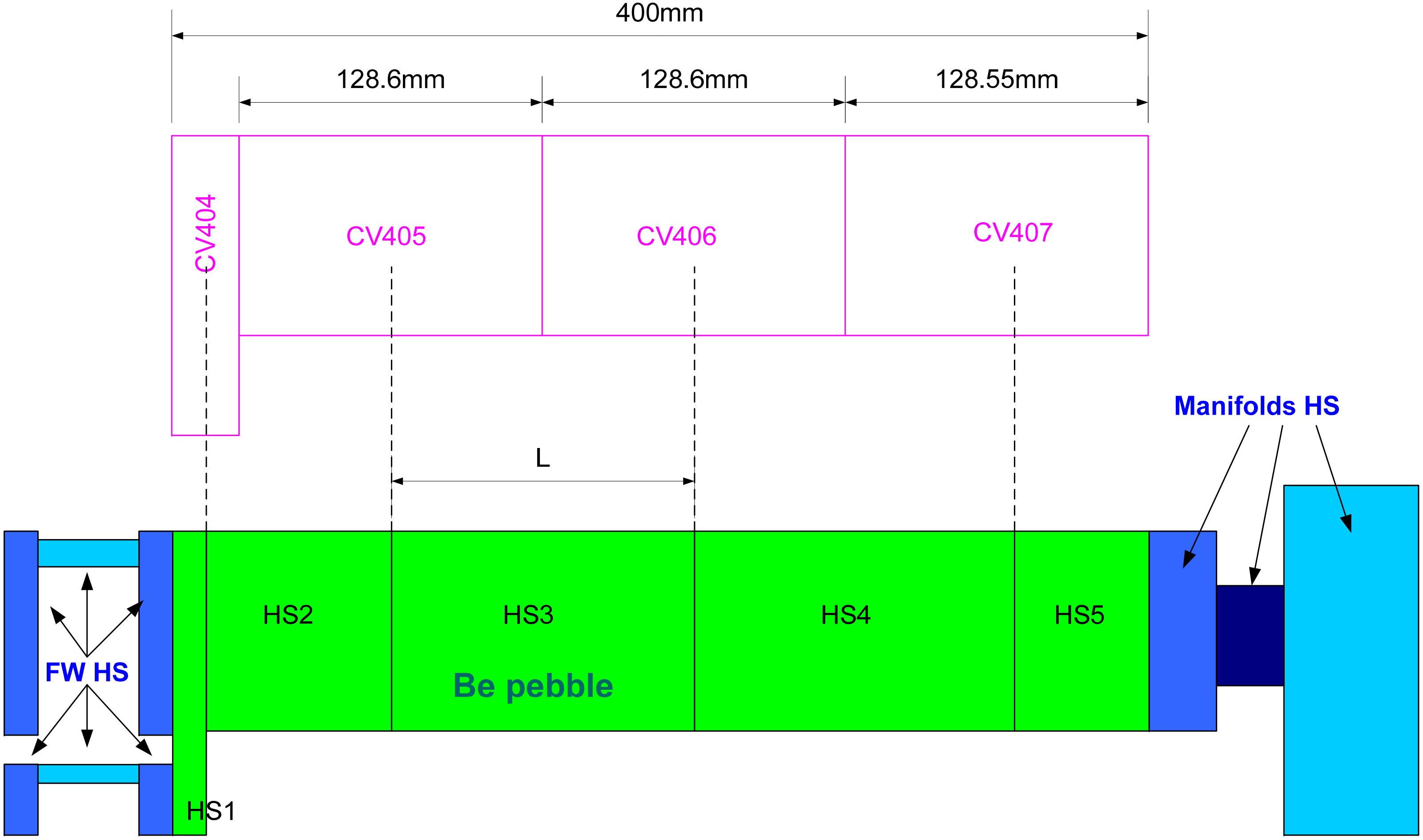
MELCOR Modeling for the VVPSS*



* Modeling of VVPSS is taken from L. L. Sponton in safety analyses for HCLL TBM.

VS: Venting System

MELCOR modeling for Be pebbles



CV: Control Volume; HS: heat structure

HS modeling for Be pebbles*

- Material Beryllium
- modeling for 1 peb d_{1peb} = 1 mm, HSMULT = ($N_{peb,CVL}$ + $N_{peb,CVR}$)/2, internal power source: decay heat as table function ~ time,
- LB is adiabatic (pebble midpoint), RB is bounded to CV.
- Radiation at RB: gray-gas-a, emissivity 0.65.
- Surface data at RB: a convective boundary condition is applied with the heat transfer coefficients calculated by the HS package (7XXX). Surface power source (W) is given by CFXXX.
- CFXXX = CFYYY / NP_Y + CFZZZ / NP_Z
- CFYYY = FUN1 = Ac*[p*K*(T1-T2)/L+(1-p)*eps*sigma*(T1^4-T2^4)],

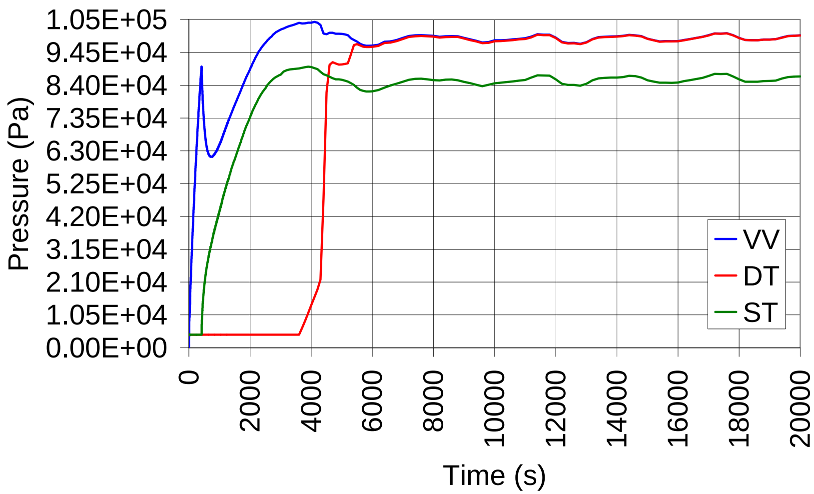
  Ac cross section area, p packing factor 63.5%, eps emissivity, sigma Boltzmans constant,

  T1 = T_{CVL}, T2 = T_{CVR}, K = conductivity of Be pebble in air.
- CFZZZ = $-CFYYY_{CV+1}$

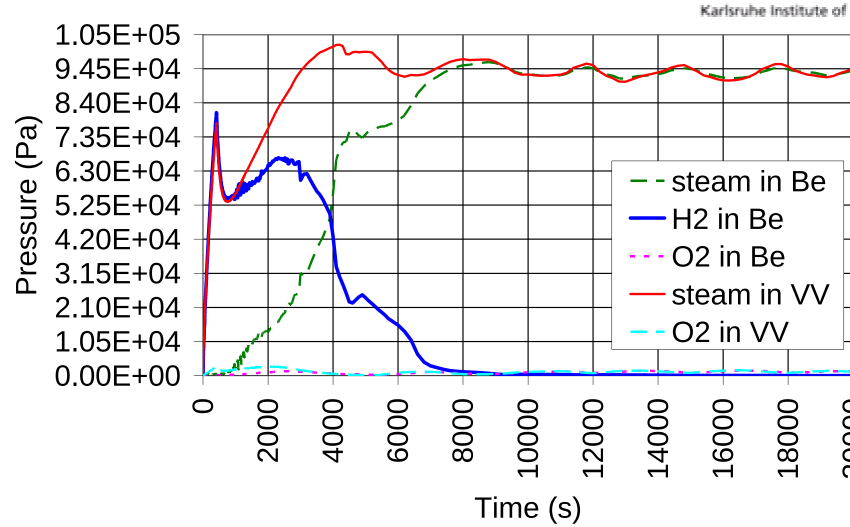
* B.J. Merrill, personal information, 2007.

CVL: Left Control Volume
CVR: Right Control Volume
LB: Left Boundary
RB: Right Boundary
CF: Control Function
NP: Number of Pebbles

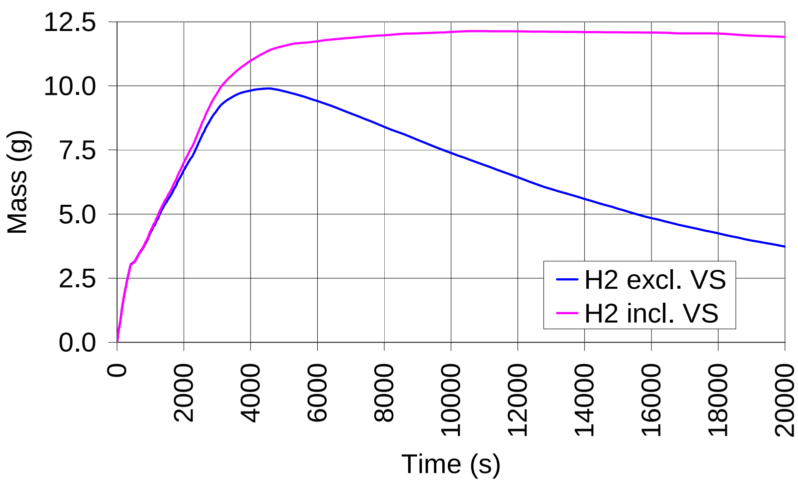
MELCOR results for the selected case (BDBA)



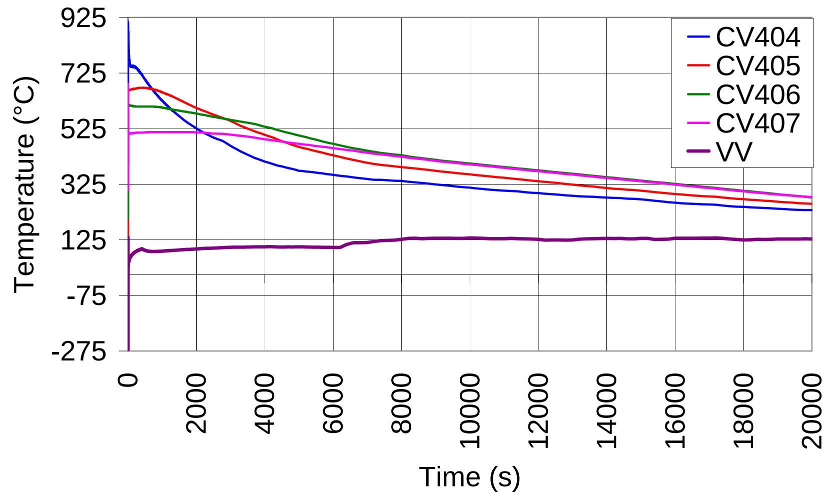
Pressure in VV, ST, DT



Air and steam pressures in VV and Be pebble bed



H_2 production



Temperature of CVs in Be pebbles and VV

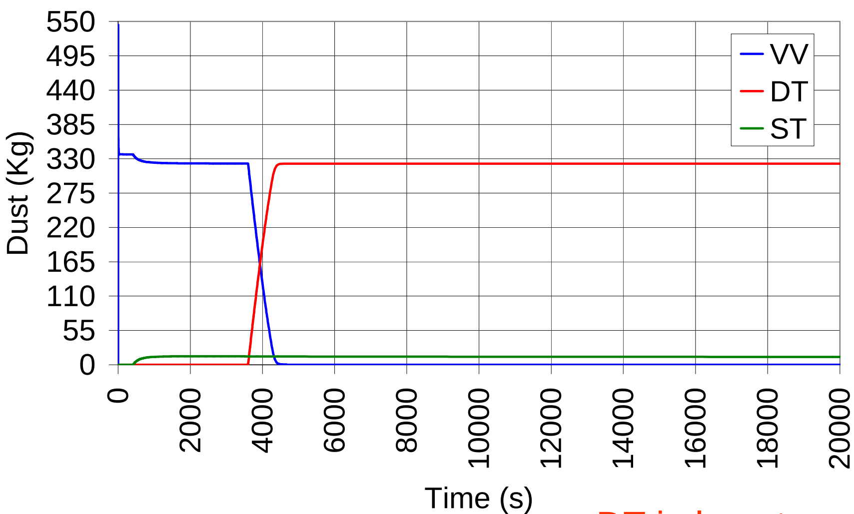
Tritium, dust and ACP transport without failure of TBM box

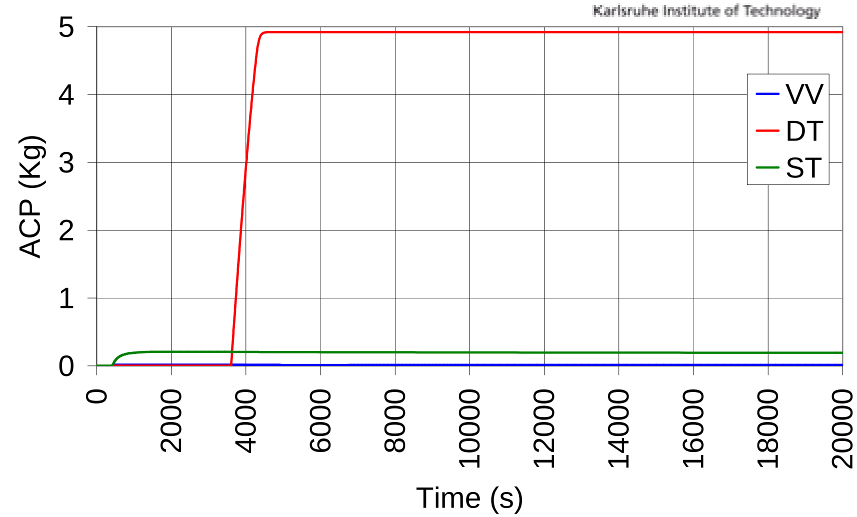
- Failure of VV and water cooled component of ITER
  - ⇨ air and steam ingress

Implementation of RadioNuclide (RN) Package in the VV (CV401):

1. W dust 350 kg, Be dust 100 kg, C dust 200 kg and mobilized dust produced by the plasma disruption 5 kg released within 1 s.
2. Activated Corrosion Products (ACP) source 10 kg/loop released within 1 s.
3. HTO : 440 g Tritium + 120 g Tritium immediately released within 1 s, 440 g Tritium over 6 h.

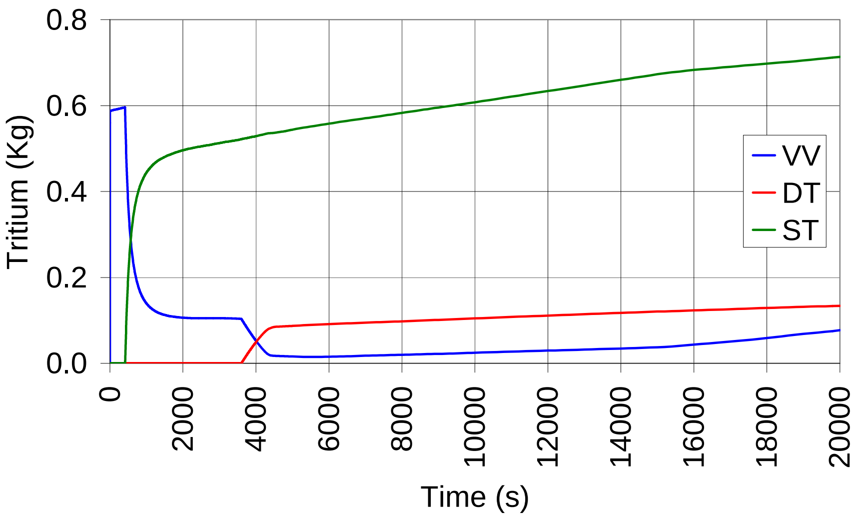
MELCOR results for Tritium, dust and ACP transport

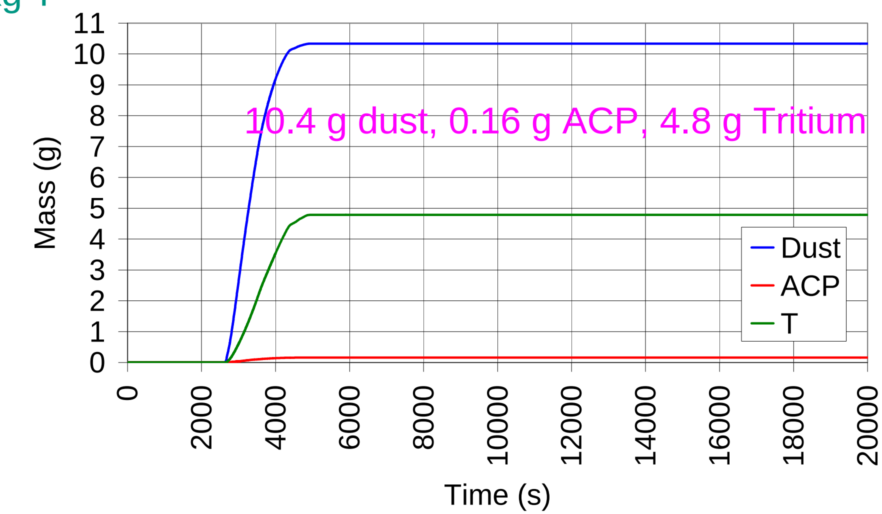




DT in long term: 322.4 kg dust, 5 kg ACP

ST in long term: 0.7 kg T





Products in the TCWS vault

Summary

The MELCOR calculations for the selected accident case in long term behavior are concluded as follows:

- Steam ingress is dominant during the accident evolution against air ingress. The steam pressure in the VV can exceed the atmospheric pressure.
- The long term cooling of the TBM can be assured without melting of the Be pebble bed.
- H_2 production (12.14 g) is within the ITER limitation.
- Tritium, dust and ACP can be transported to the TCWS vault. According to the allowed limitations the transported amount cannot affect the ITER safety.

The presented MELCOR calculations were completed in 2007. In case of new activities for safety analyses in Fusion Program, MELCOR study will be continued.

Open issues

Modeling Be pebbles in 8 CVs instead of 4 CVs:

- Running at the same timestep (DTMAX = 0.005 s), fluctuation of results was observed.
- Much smaller time steps were required, but it was not tested because of too high computational costs.
- The refinement of CVs led to the increase of H_2 production (87 g).
- To obtain good results in very fine grids, modeling method has to be improved in discussion with INEEL, and it will be tested for the new HCPB TBM version.