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Evaluation of Filtered Containment Venting Systems with MELCOR for Extended Operating Conditions in German PWR

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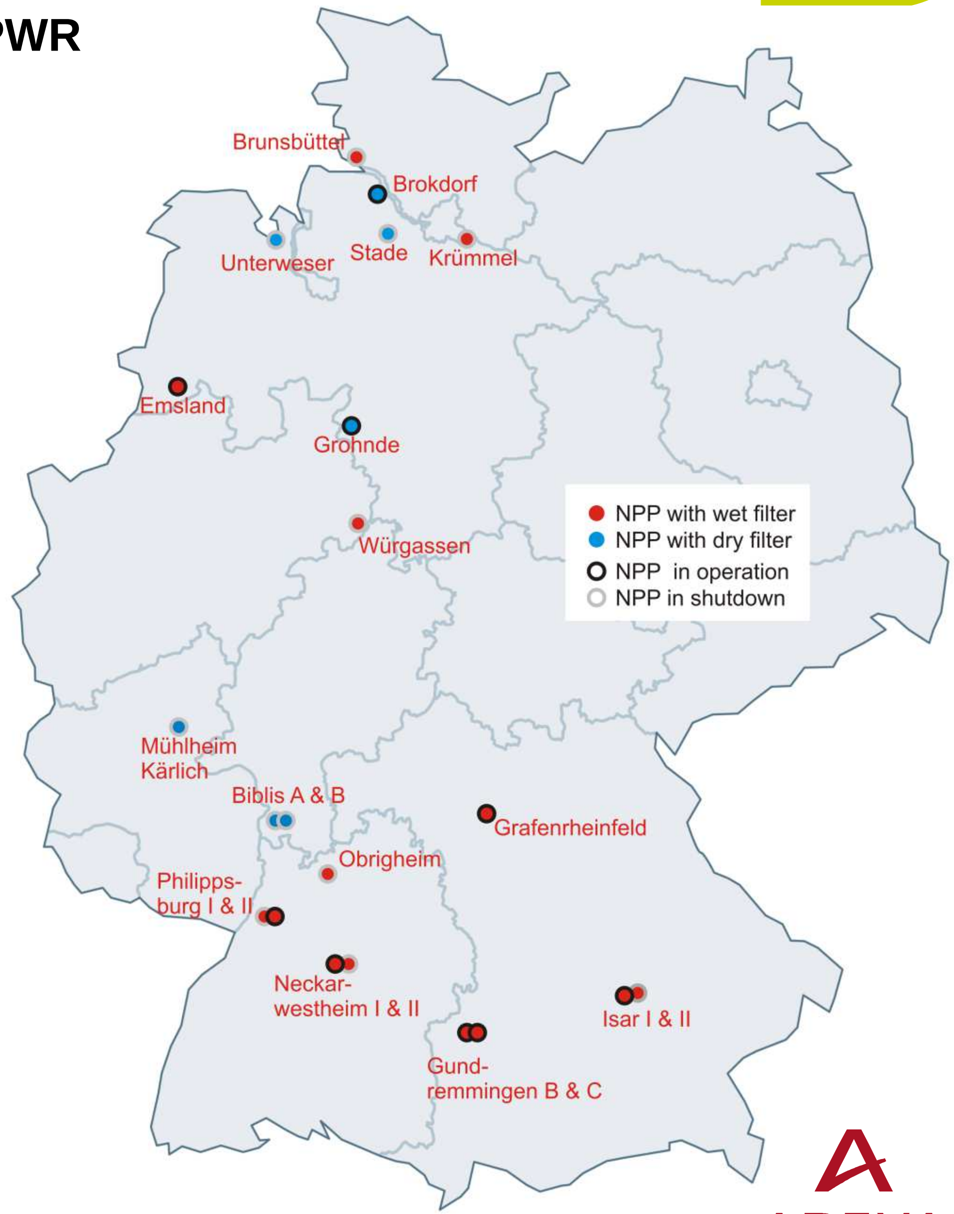
- **After Chernobyl, back-fitting of all (West-)German PWR with filtered containment venting systems (FCVS)**

- **Two filter systems in use**
  - **„Wet“ venturi scrubber filters**
  - **„Dry“ metal fiber filters**

- **Anticipated usage for „late“ venting after containment pressure > design limit**
  - **High containment pressure ~7 bar-abs**
  - **No oxygen in containment (due to PAR)**
  - **High concentration of H_2 and CO (due to MCCI)**
  - **Low concentration of airborne radioactive aerosols**

- **Question: Are the installed FCVS capable to allow for early venting?**

  For example in case that the containment experienced design-exceeding loads and may be weakened



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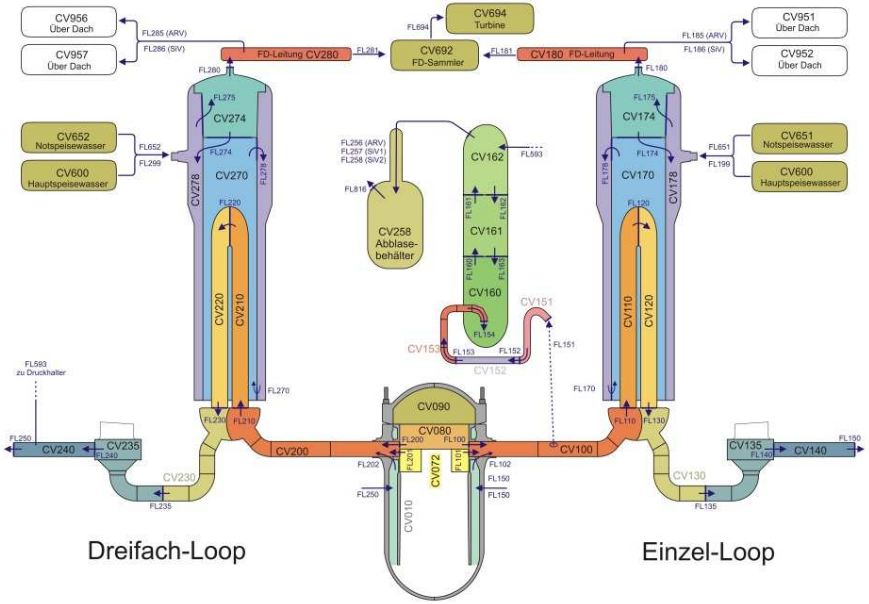
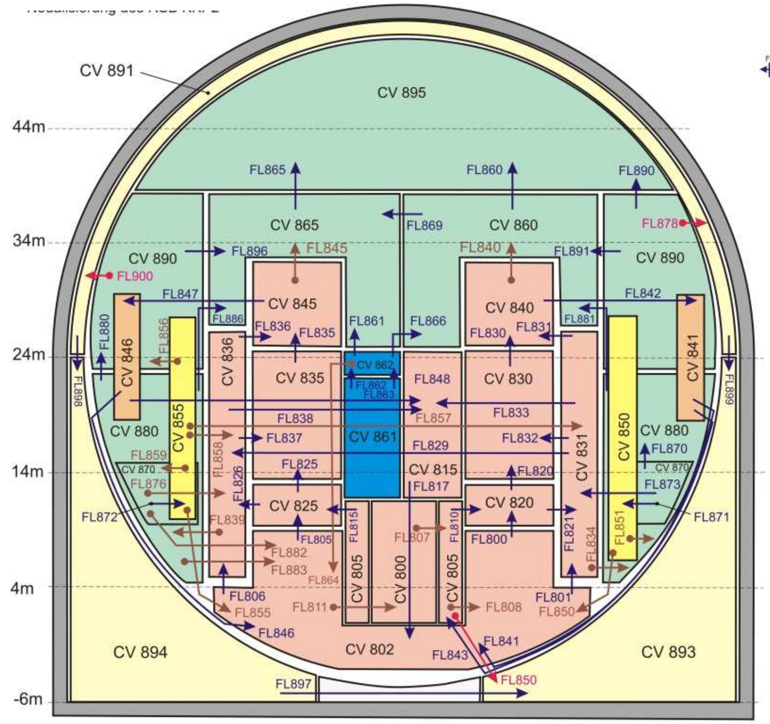
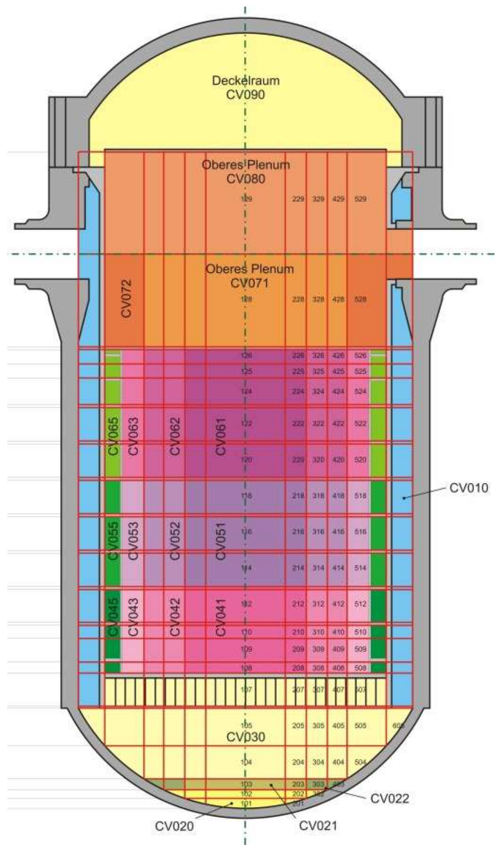
MELCOR-Modelling (1 of 3)
German PWR 1300 MW Class







- Anlagenräume
- Betriebsräume
- kl. Anlagenräume
- Lüftung
- Ringraum
- BE-Becken

CV Volumen (Control Volumes)
FL Verbindungen (Flow Path)

- offene Verbindungen
- druckabhängige Verbindungen (Klappen, Türen, Berstelemente und Folien)
- Lecks, Öffnung durch Versagen

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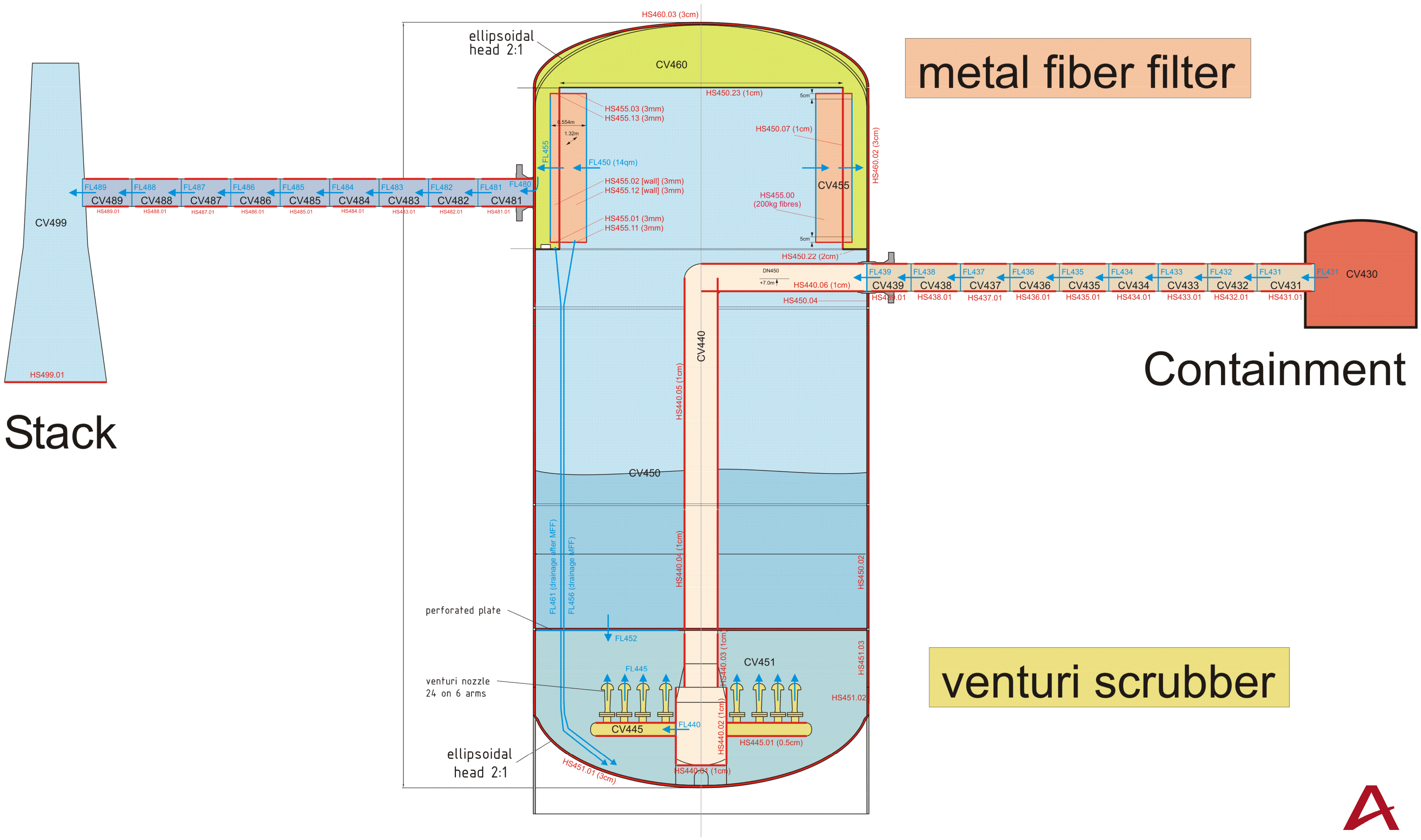
MELCOR-Modelling (2 of 3)
Wet (venturi scrubbing) filter



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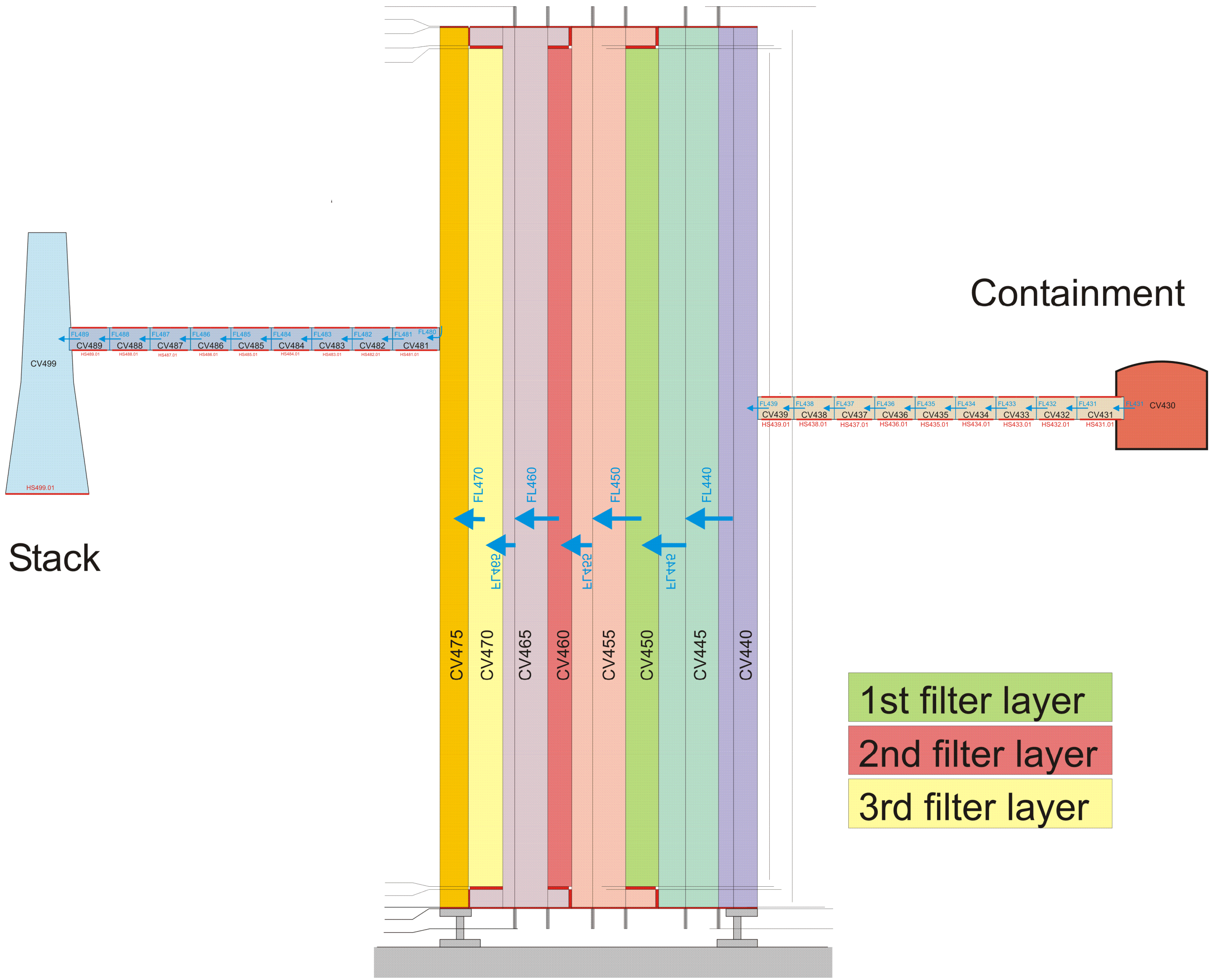
MELCOR-Modelling (3 of 3)
Dry (metal fiber) filter



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Are the installed venting systems capable to allow for an early venting?

1. **Can combustible gas mixtures be formed in the system during Filtered Containment Venting?**

2. **Can the FCVS handle low containment pressures ~ 2–3 bar-abs?**

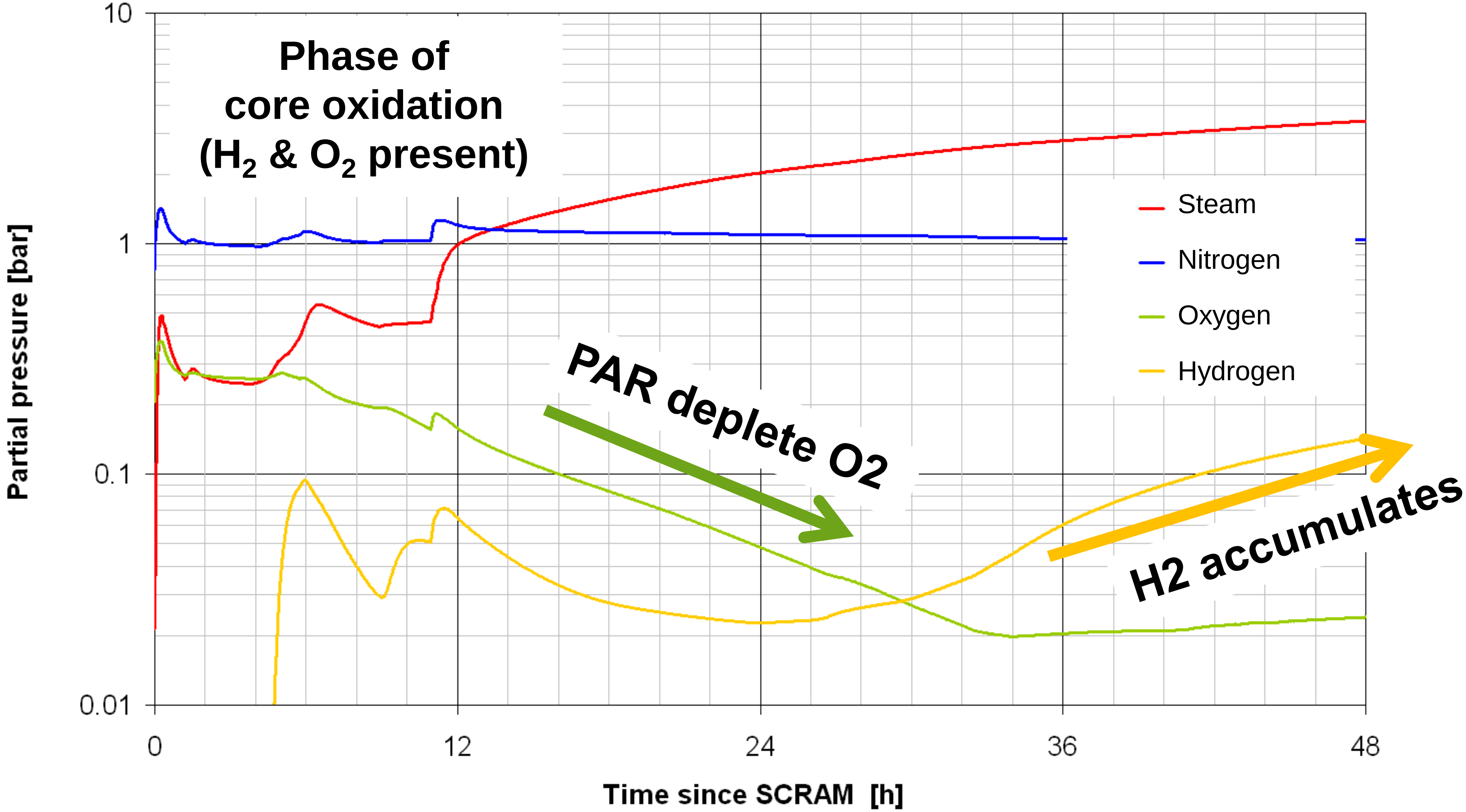
3. **What mass & power loads on the filter must be expected?**

4. **What are the radiologic consequences?**

(1) Can combustible gas mixtures be formed in the system? (1 of 2)

- **Containment atmosphere in a PWR1300 (MELCOR full plant simulation)**

  Choosing the worst case for venting, i.e. about 1 h after start of core oxidation



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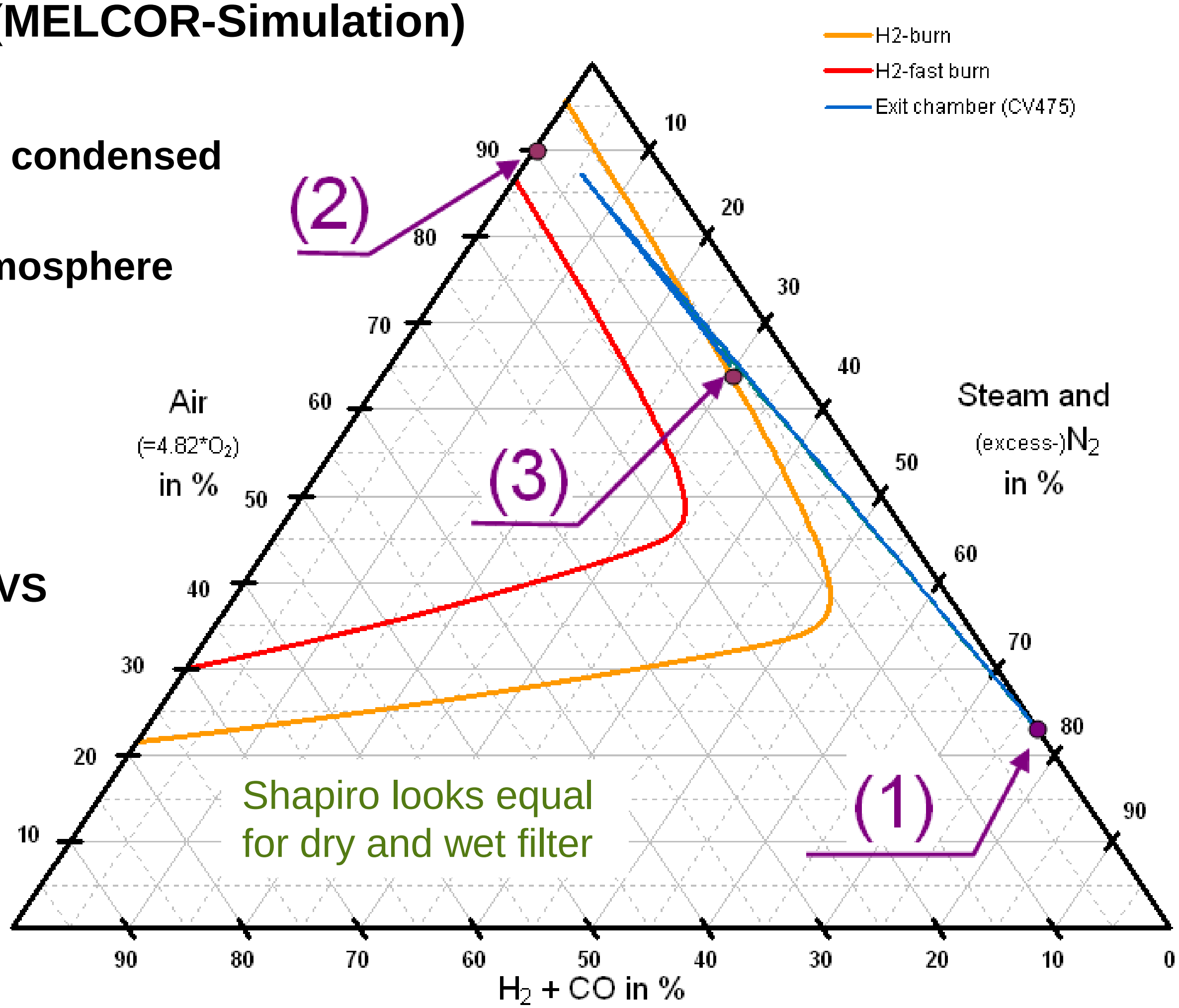
(1) Can combustible gas mixtures be formed in the system? (2 of 2)

- **Shapiro Diagram for gas inside the FCVS (MELCOR-Simulation)**
  - **(1) Initially FCVS is inerted by N_2**
  - **(2) At start of venting, inflowing steam gets condensed**
  - **(3) After heat-up phase,**
    atmosphere inside FCVS = containment atmosphere
  - **Duration of combustible phase**
    (governed by heat capacity of FCVS)
    - Wet Filter ~ **10–30 min**
    - Dry Filter ~ **1–5 min**
  - **Pressure loads if combustion occurs in FCVS**
    - Wet Filter ~ **0.8 bar**
    - Dry Filter ~ **0.4 bar**
  - **Over-Pressure qualification**
    - Wet Filter **> 10 bar**
    - Dry Filter **< 0.5 bar**



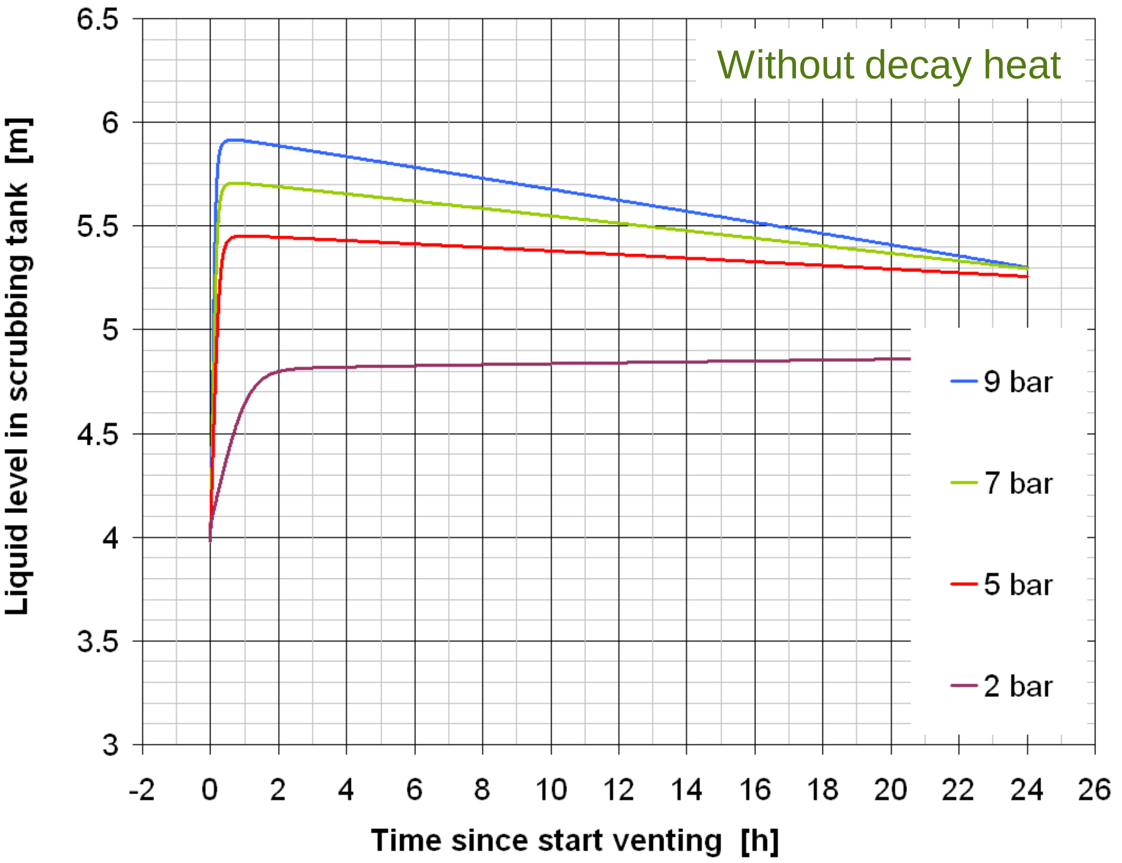
Conclusions

- **For wet filters such an early venting is possible but should be used with care**
- **For dry filter systems from such an early venting is strongly discouraged**

(2) Can the FCVS handle low containment pressures ~ 2–3 bar-abs? (1 of 2)

- **Competition between evaporation and condensation inside the FCVS**
  - **Superheating of steam by isenthalpic expansion (by pressure drop) causes evaporation**
  - **Heat loss via pipe/vessel walls promotes condensation**

- **Wet (venturi scrubber) filter**
  - **Throttle after venting tank**
    ➔ steam superheated in exhaust pipe
  - **Condensation / evaporation causes shift in water level in venting tank**
  - **MELCOR-simulation shows low impact of containment pressure on filter liquid level**
  - **Can not vent below 1.5 bar-abs due to hydrostatic pressure of scrubbing liquid**



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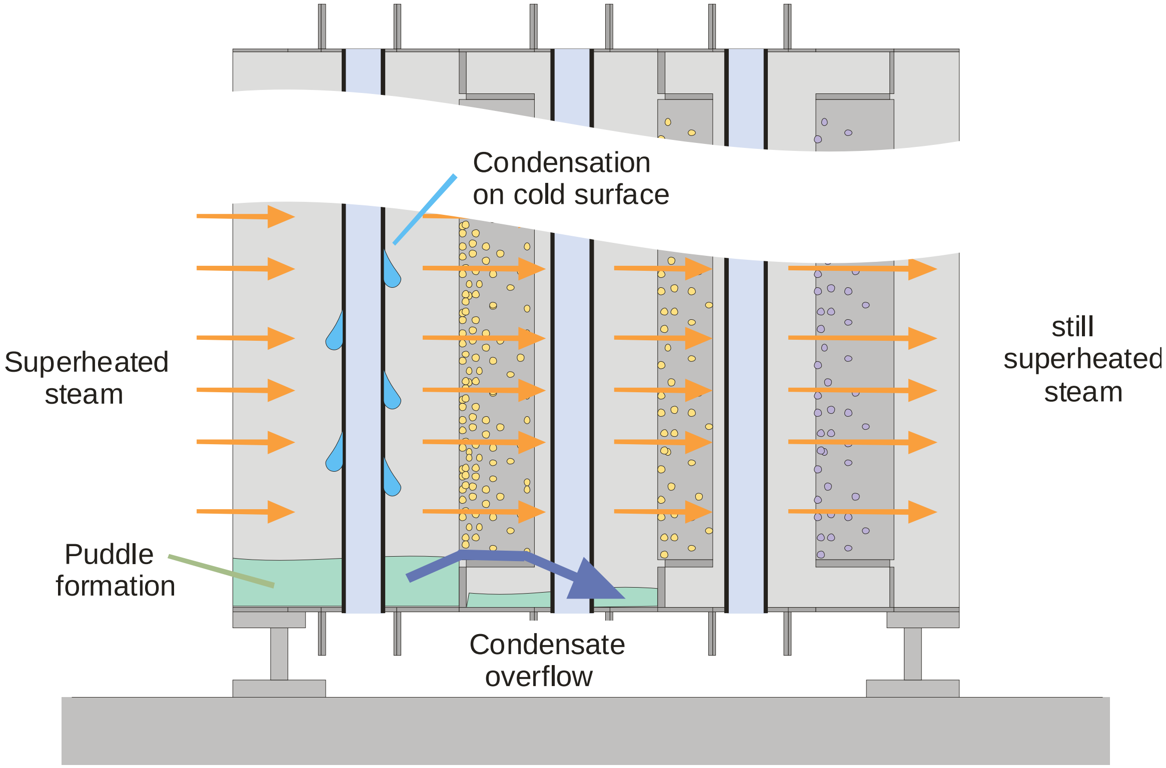
(2) Can the FCVS handle low containment pressures ~ 2–3 bar-abs? (2 of 2)

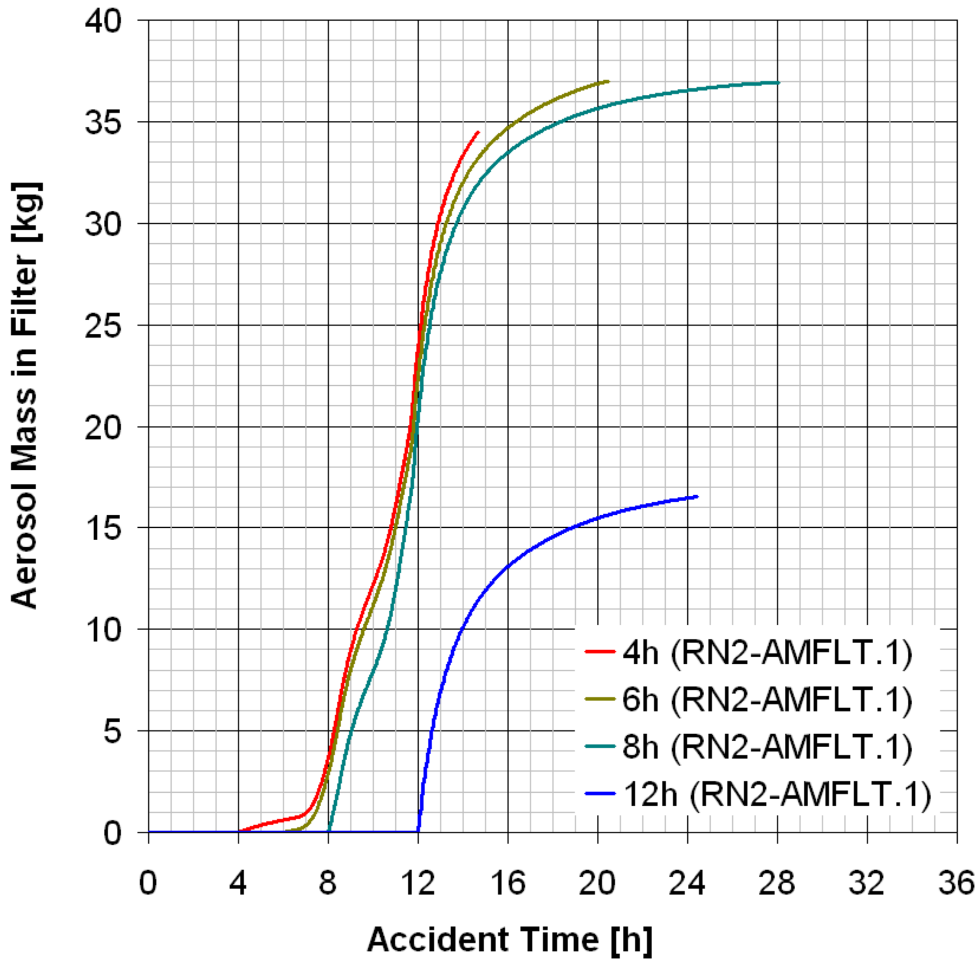
- **Competition between evaporation and condensation inside the FCVS**
  - **Superheating of steam by isenthalpic expansion (by pressure drop) causes evaporation**
  - **Heat loss via pipe/vessel walls promotes condensation**

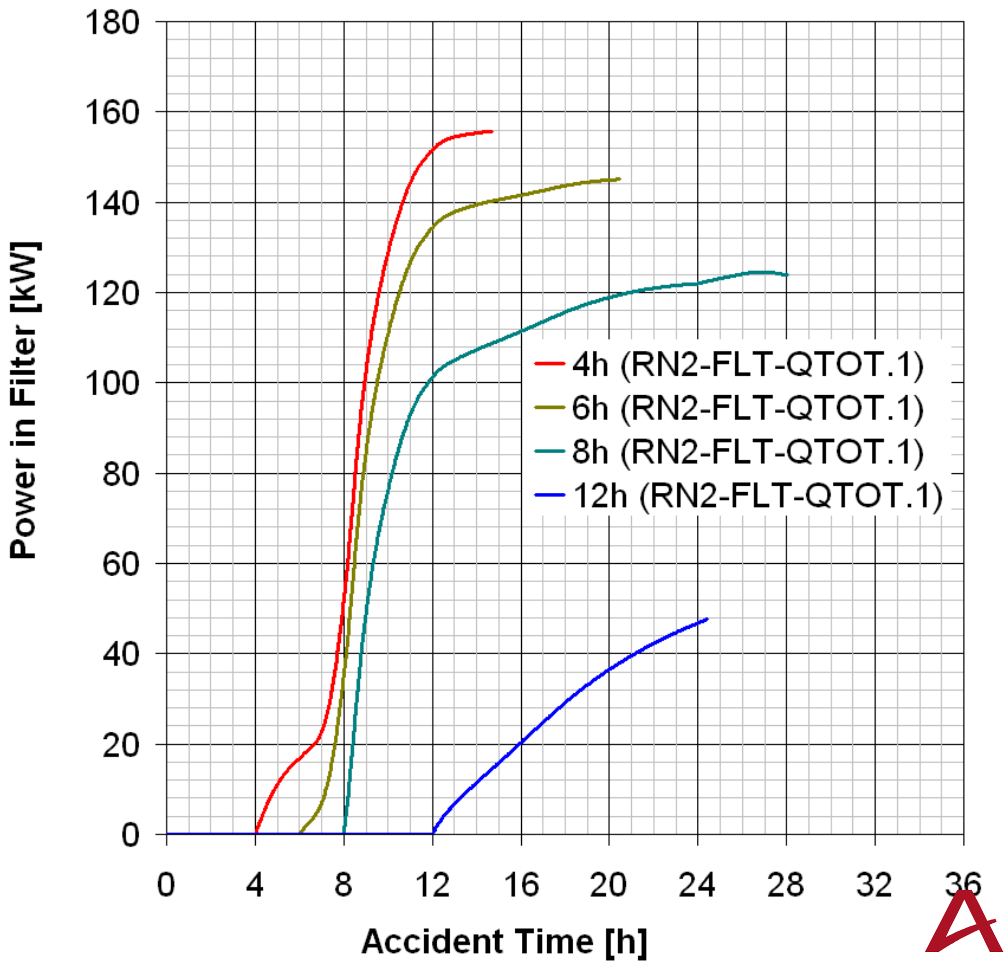
- **Dry (metal fiber) filter**
  - **Throttle in front of filter to keep the filter fibers as dry as possible**
  - **With decreasing containment pressure, superheating effect gets smaller**
  - **MELCOR-simulations show that at pressures < 3 bar-abs the superheating can not avoid condensation at filter walls**
  - **As condensate impairs the filter, from low-pressure vent is strongly discouraged**



(3) What mass & power loads on the filter must be expected? (1 of 2)

- **MELCOR-simulation: SBO in PWR1300 with induced rupture of surge line**
  - **Variation of venting time 4 h, 6 h, 8 h and 12 h after accident start (core damage ~6 h after SCRAM)**
  - **About 6 h after core damage, filter loads drop significantly (160 kW ➔ 60 kW)**

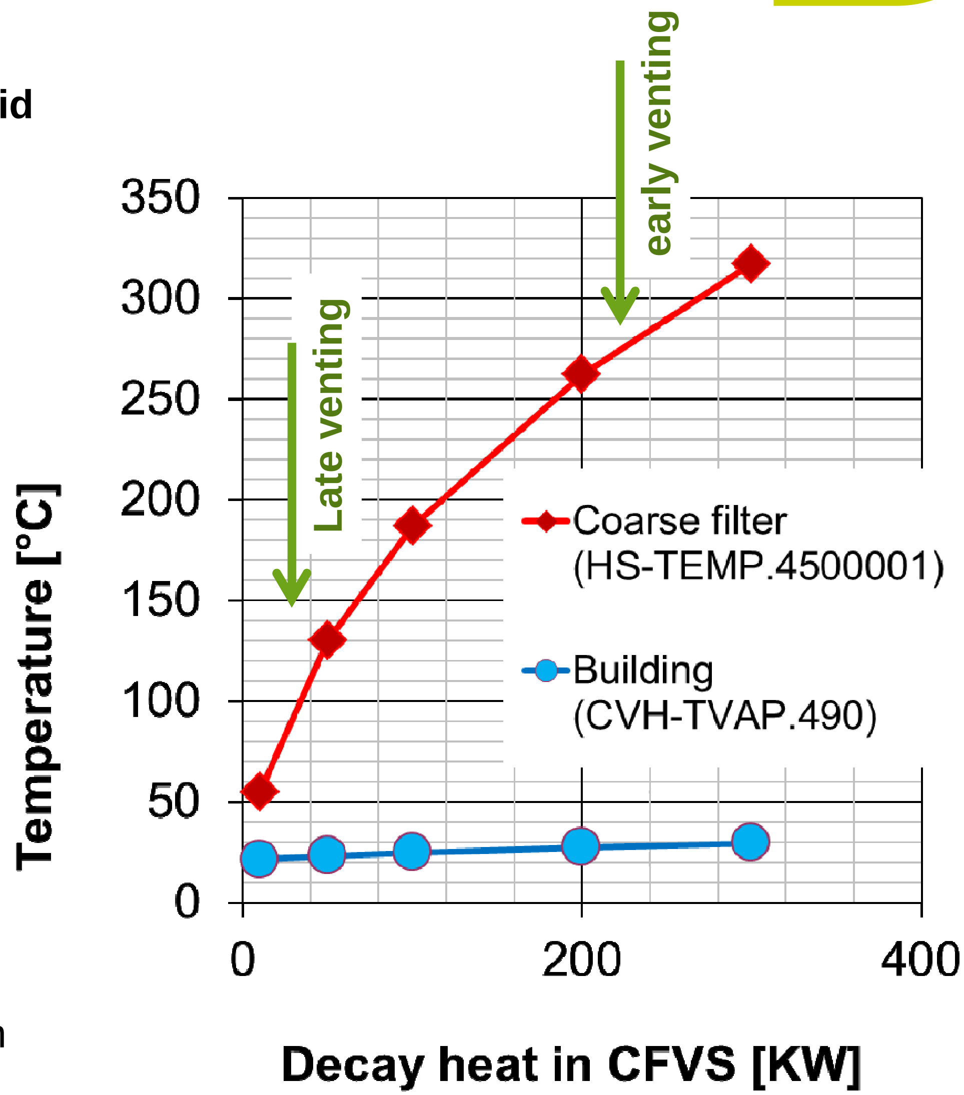




(3) What mass & power loads on the filter must be expected? (2 of 2)

- **Wet (venturi scrubber) filter**
  - **Decay heat removal by evaporation of scrubbing liquid**
  - **~ 50 t water inventory & 200 kW decay heat**
    ➔ grace period ~1 week till dry-out of venting tank
  - **After 24 h venting cycle, anticipated back-flushing of scrubbing liquid back into containment**

- **Dry (metal fiber) filter**
  - **During venting, decay heat is removed from filter by forced flow of gas through FCVS**
  - **After venting, decay heat must be dissipated by heat loss via filter walls (➔ high temperatures)**
  - **MELCOR-simulations to determine peak-filter temperature vs. decay heat load (boundary condition is a ventilated building)**
  - **Intrinsic challenge of dry filters**
    - High heat losses allows for coping with decay heat
    - Low heat losses allow for avoidance of condensation



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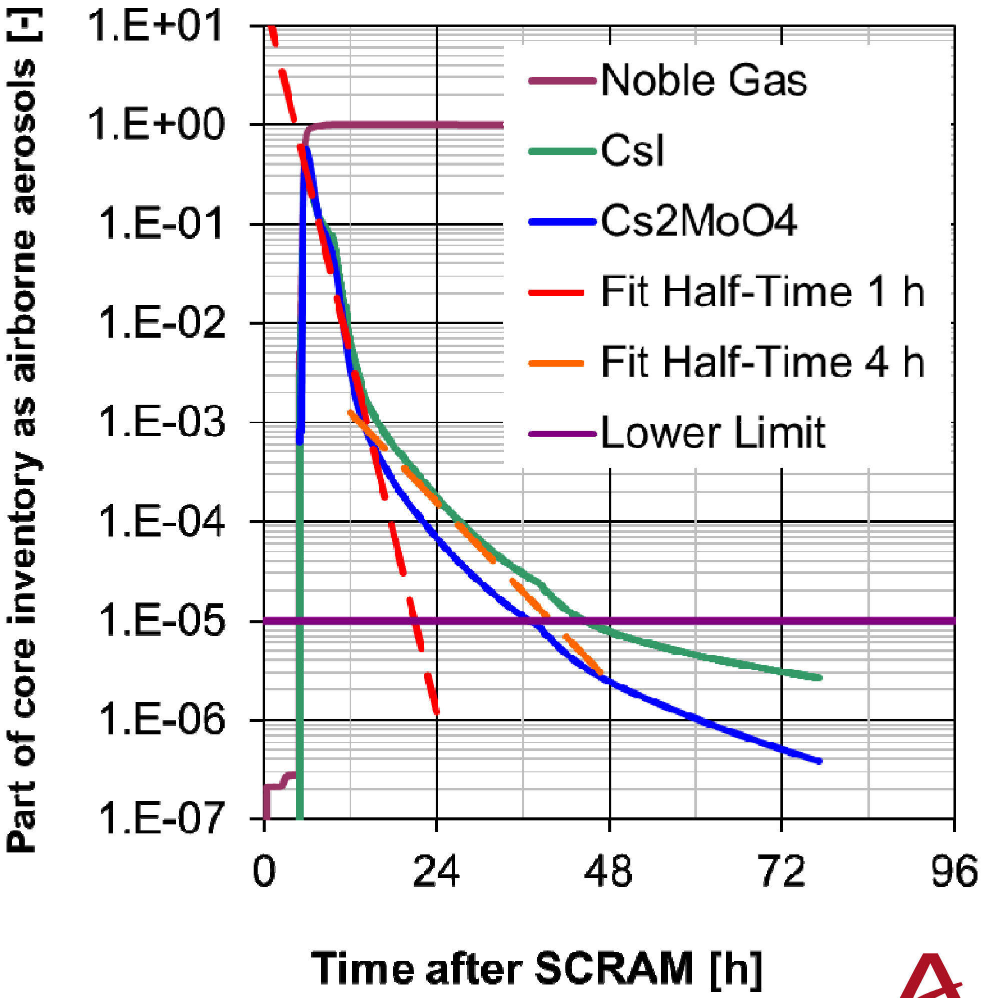
(4) What are the radiologic consequences? (1 of 3)

- **MELCOR does not include re-release of aerosols**
  - **Systematic under-prediction of source terms, especially for late venting**
  - **Fix by post-processing**
    - FP-release not determined by RN-Inventory of environment-CV
    - Instead integrating aerosol concentration in containment times flow rate through FCVS
    - Imposing lower concentration limit (for entrainment estimated to ~1.-E-5)



- **Iodine model in MELCOR is weak**

Fix by transcribing COCOSYS-calculations for the EPR

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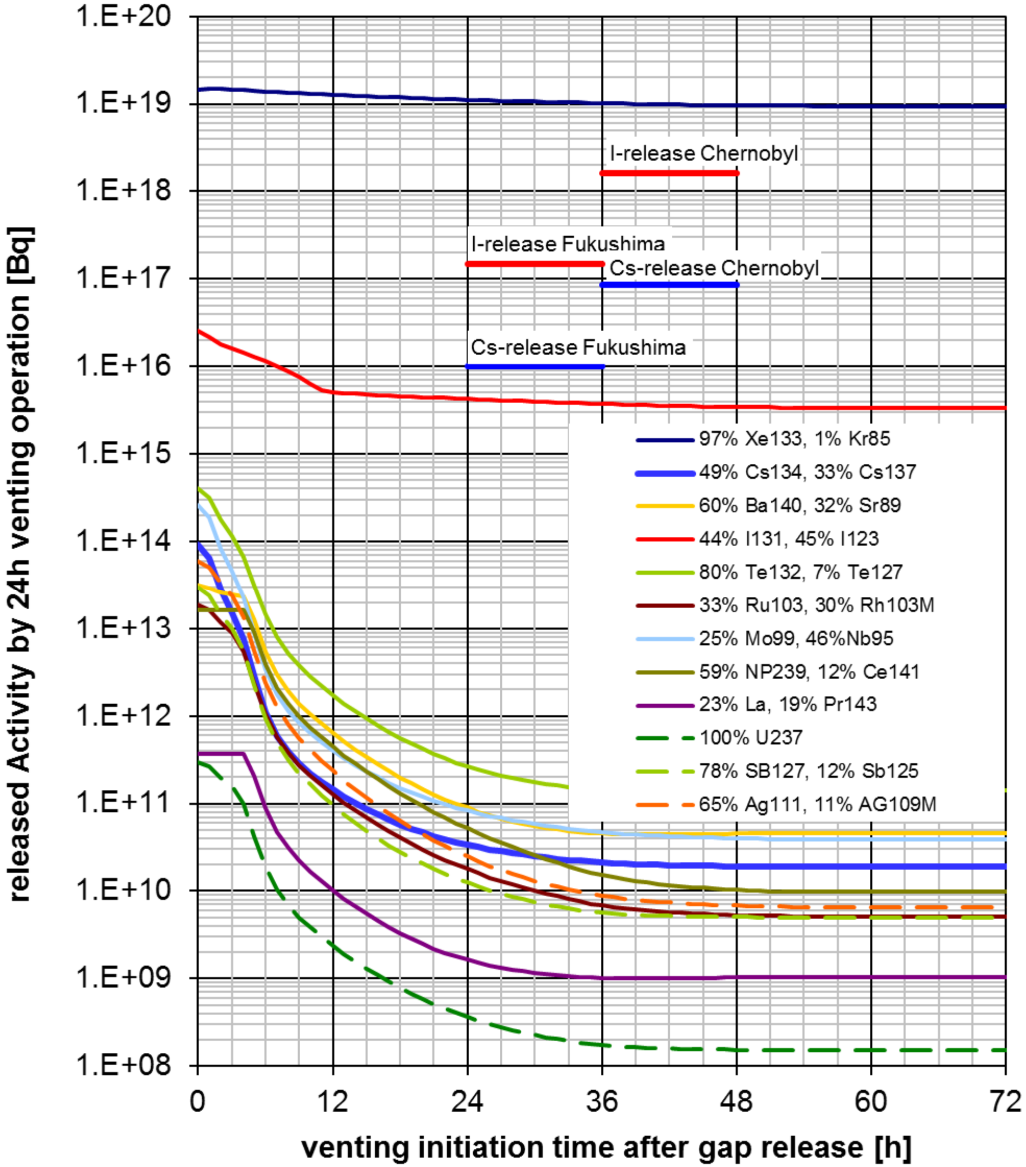
- **Fission product release based on MELCOR**
  - **Corrected for re-suspension by entrainment**
  - **Corrected for iodine behavior**
  - **Conservative filter factors for FCVS 1.E3 for aerosols, 1.E1 for iodine**

Conclusion

- **Early venting with FCVS causes a FP-release of about 0.01 times Fukushima release (possibly acceptable)**
- **Delaying the Venting past 24 h after gap release does not improve FP-release (release dominated by re-suspension)**



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MELCOR-release check by Fukushima fall-out gamma-spectroscopy

- **Saegusa et al. - Observation of gamma-rays from fallout collected at Ibaraki, Japan Applied Radiation and Isotopes 77 (2013) 56–60**
- **Order-of-magnitude evaluation of measured counts / core inventory 1 month after SCRAM**

Isotope	Counts/Core inventory
Cs136	~1.E-10
Cs134	~1.E-10
I132	~1.E-11
I131	~1.E-10
Tc99m (marker for Mo99)	~1.E-10
Nb95	~1.E-13
Te132	~1.E-10
Ba140	~1.E-13

Main release by CsI

Release by Cs_2MoO_4

Low Release by $CsNbO_3$ even though Mo & Nb are in same RN-Group

Low Release by Ba

Conclusions, Open Questions and Current Work

- **Filtered Venting**
  - **Condensate formation and re-evaporation are important phenomena during the venting process**
  - **Hydrogen can be a challenge in case of early venting (German plants are equipped with severe accident hydrogen mitigation systems)**

- **The MELCOR calculations of the filtered venting system were done without fission products**
  - **Source term calculation was done with filter factors without detailed venting system**
  - **In future calculations with combination of integral NPP input and FCVS system are desired**

- **MELCOR RN-Package**

  Missing entrainment model significantly underestimates airborne fission product concentrations in containment in long calculations, e.g., release from containment and venturi scrubber
  ➔ assumptions in filter factors required

- **Current Work**

  Translation of a German PWR1300 Model from 1.8.6 to 2.1
  and comparison of the results for selected scenarios

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Thank You!

End of Presentation:
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