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 H₂ 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.
MELCOR-Modelling (1 of 3)
German PWR 1300 MW Class

Extended operation of FCVS in German PWR – EMUG Meeting – Löffler – 2014-04-16 –
MELCOR-Modelling (2 of 3)
Wet (venturi scrubbing) filter

Stack

Containment

metal fiber filter

venturi scrubber
MELCOR-Modelling (3 of 3)

Dry (metal fiber) filter

Stack

Containment

1st filter layer
2nd filter layer
3rd filter layer
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? 

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

Phase of core oxidation 
(H₂ & O₂ present)

- Steam
- Nitrogen
- Oxygen
- Hydrogen

PAR depletes O₂
H₂ accumulates
(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

Shapiro looks equal for dry and wet filter
(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

![Graph showing liquid level in scrubbing tank over time for different pressures](image)
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 cannot 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)
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
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
(4) What are the radiologic consequences?

(2 of 3)

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)
(4) What are the radiologic consequences?

(3 of 3)

**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

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Counts/Core inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs136</td>
<td>~1.E-10</td>
</tr>
<tr>
<td>Cs134</td>
<td>~1.E-10</td>
</tr>
<tr>
<td>I132</td>
<td>~1.E-11</td>
</tr>
<tr>
<td>I131</td>
<td>~1.E-10</td>
</tr>
<tr>
<td>Tc99m (marker for Mo99)</td>
<td>~1.E-10</td>
</tr>
<tr>
<td>Nb95</td>
<td>~1.E-13</td>
</tr>
<tr>
<td>Te132</td>
<td>~1.E-10</td>
</tr>
<tr>
<td>Ba140</td>
<td>~1.E-13</td>
</tr>
</tbody>
</table>

**Main release by CsI**

**Release by Cs$_2$MoO$_4$**

**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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End of Presentation: Evaluation of Filtered Containment Venting Systems with MELCOR for Extended Operating Conditions in German PWR

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