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MELCOR source term modeling for BWR "Fukushima-like" scenarios with containment venting

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Outline

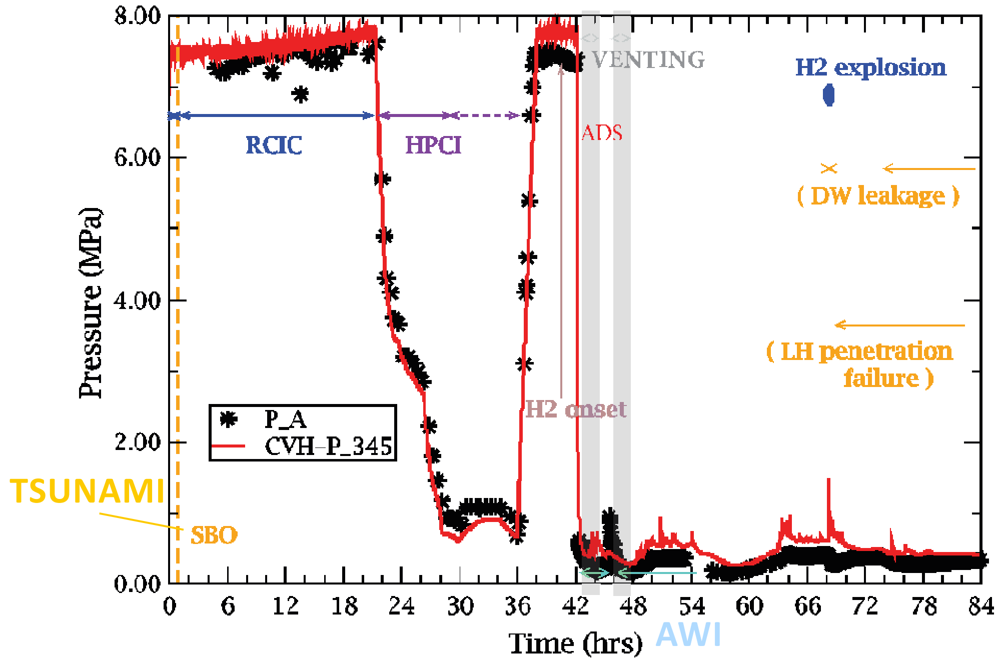
- BWR "Fukushima-like" scenarios with containment venting
- plant model and initial stage of sequence progression
- sequences with different times of ADS and containment venting
- sequences with changing times of the second period of venting
- different approaches to Cs and I modeling
- conclusions and outlook

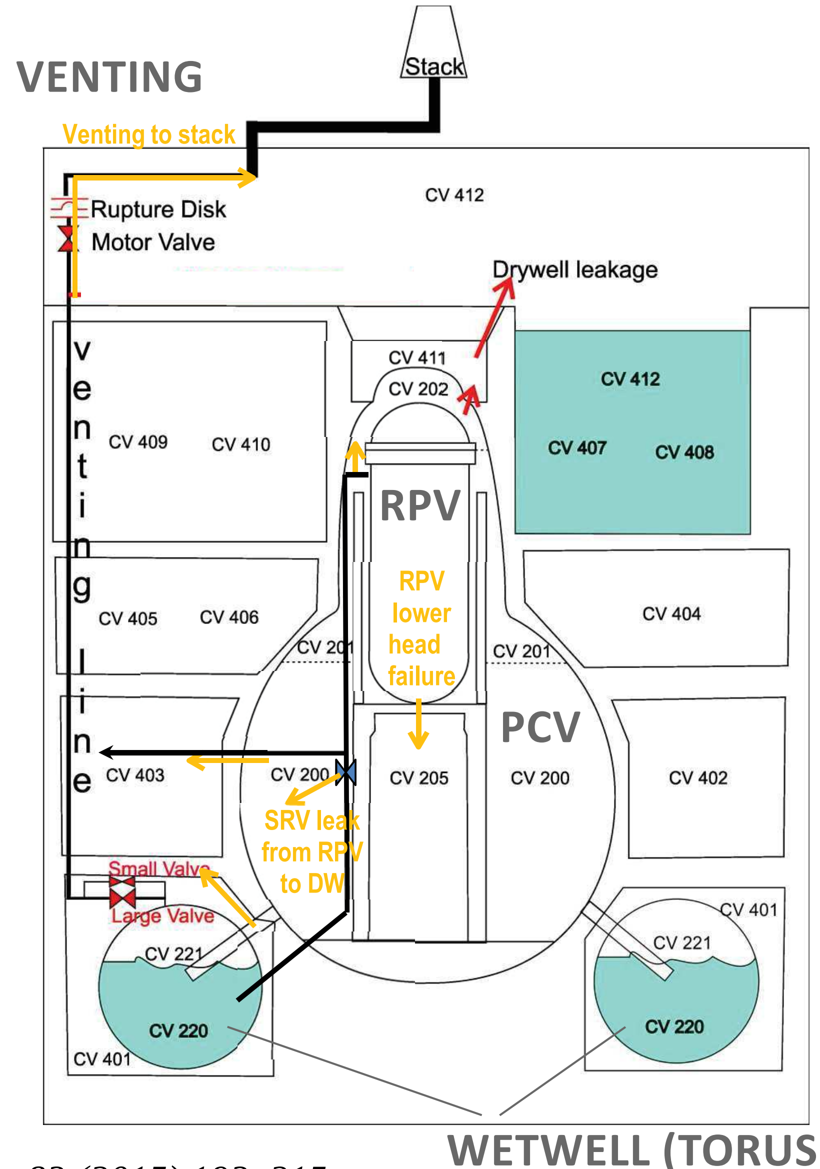
BWR "Fukushima-like" scenarios with containment venting

- SBO in generic Mark-I BWR
- Prolonged operation of relevant core cooling systems => "Fukushima-like" (FU2, FU3)
- Role of some mitigative safety systems can be even more important here than for a fast progressing accident
  -example: CONTAINMENT VENTING (containment protection)
- Current studies look at the impact of various containment venting strategies, different timings as well as link to RPV depressurization
- Whole-plant integral calculations with MELCOR_2.1, including source-term analyses (emphasis on Cs) for both
  – hardened, non-filtered system
  – and hypothesized filtered venting (with DF =1000 for aerosols)

Plant model and "Fukushima-like" sequence

- BWR Mark-I plant model based on Peach Bottom NPP deck (Sandia SOARCA), with enormous amount of modifications through some years allowing to simulate Fukushima accidents
- sequence based on extensive PSI analyses of FU3 accident for the OECD-BSAF project (*)





(*) *L.Fernandez-Moguel, J.Birchley, Annals of Nuclear Energy, 83 (2015) 193–215*

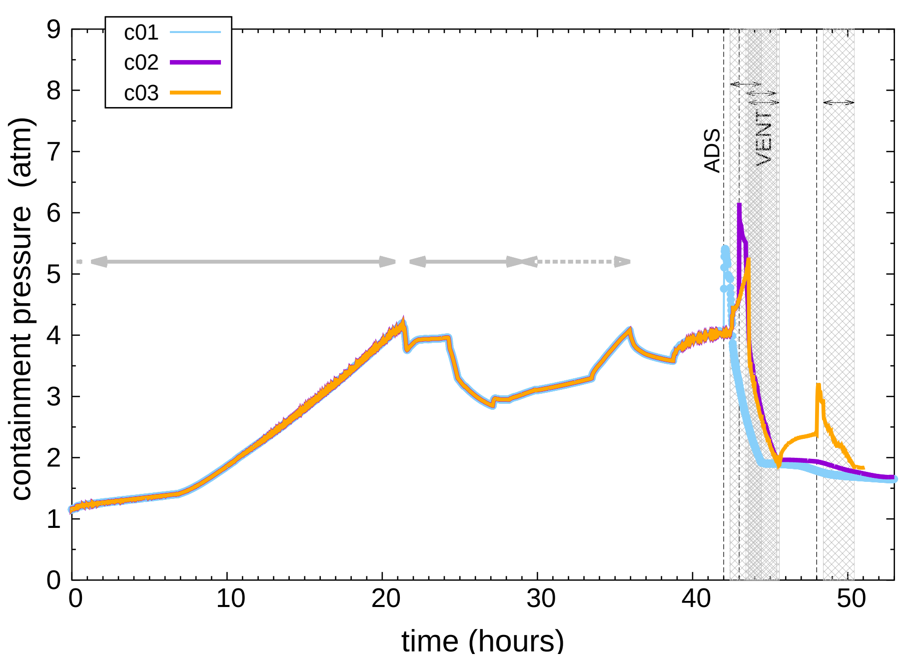
Containment venting studies and cases considered

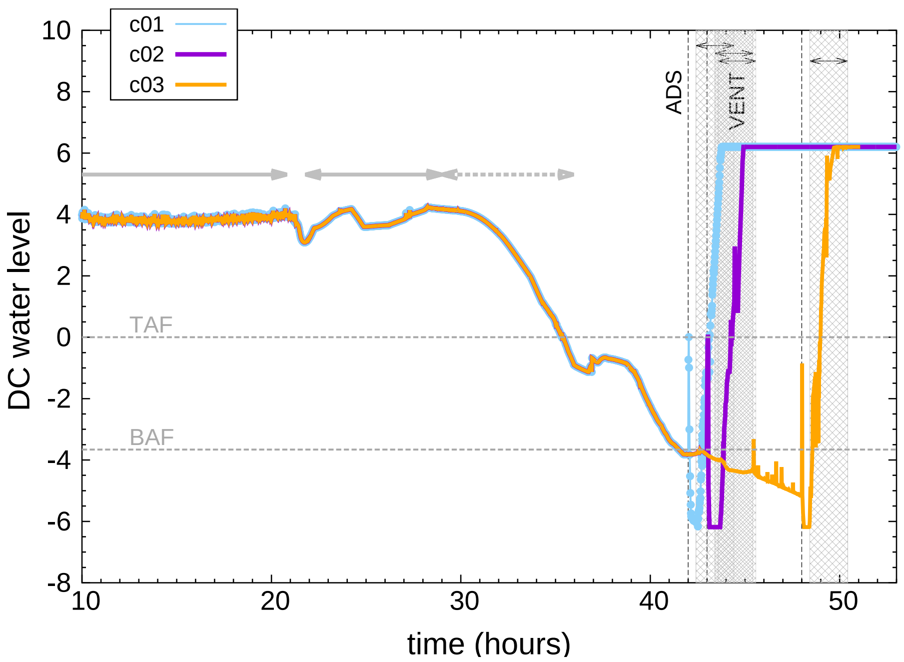
- containment venting closely linked to RPV depressurization (for FU3, ADS at ~42h)
- roughly at 40h into the accident, things starting to "go definitively wrong" :
  - RPV water level below BAF (Bottom of Active Fuel)
  - first hydrogen
  - beginning of FP (Fission Product) release
- for **containment venting studies (venting from WW),** intention was to
  - shift ADS by 1hr steps (42h, 43h, 44h, …), followed always –after 25min- by venting

    or
  - activate venting on reaching 5atm in the PCV
- and analyze the **impact on TH** (and possible accident recovery) **and on FP release to environment,** mostly for noble gases (NG), Cs, and I
- simpler (boundary) conditions than for FU3 used to see the impact clearly: fixed venting period time, **AWI always at full delivery** when RPV pressure allows, no DW head flange leak, …

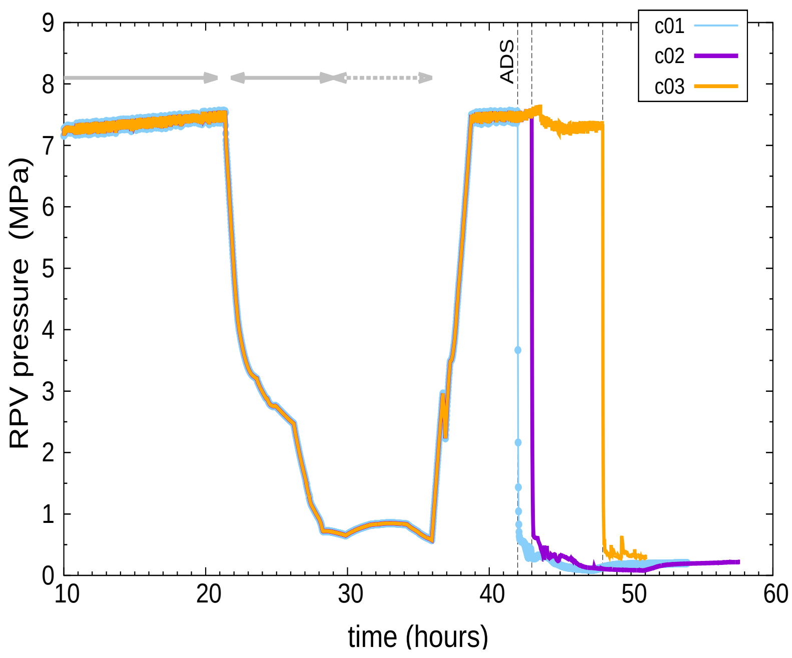
- first **set of calculations**
  - scenario c01: ADS at 42h, followed by venting
  - scenario c02: ADS at 43h, followed by venting
  - scenario c03: reached 5atm in containment at 43h 35min, WW venting initiated without prior depressurization, ADS shifted to the latest time where recovery still possible (~48h)
- for every case, always 2 full-length sequences calculated, both for unfiltered venting (DF=1 for aerosols) and filtered (DF=1000)

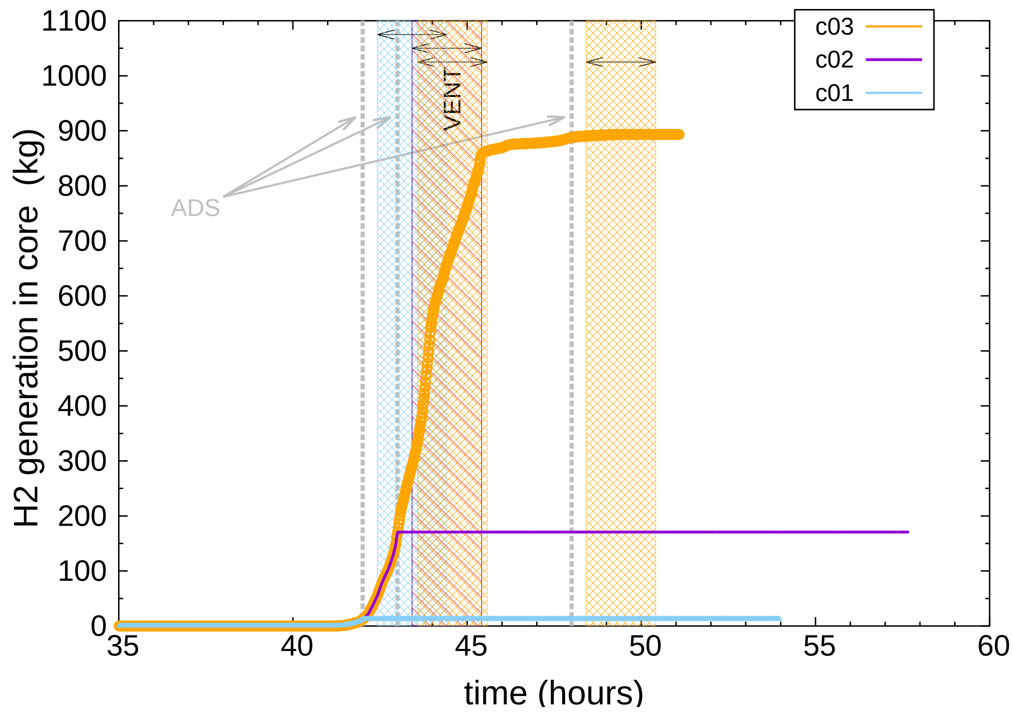
Containment pressure and reactor water level for different times of ADS and containment venting





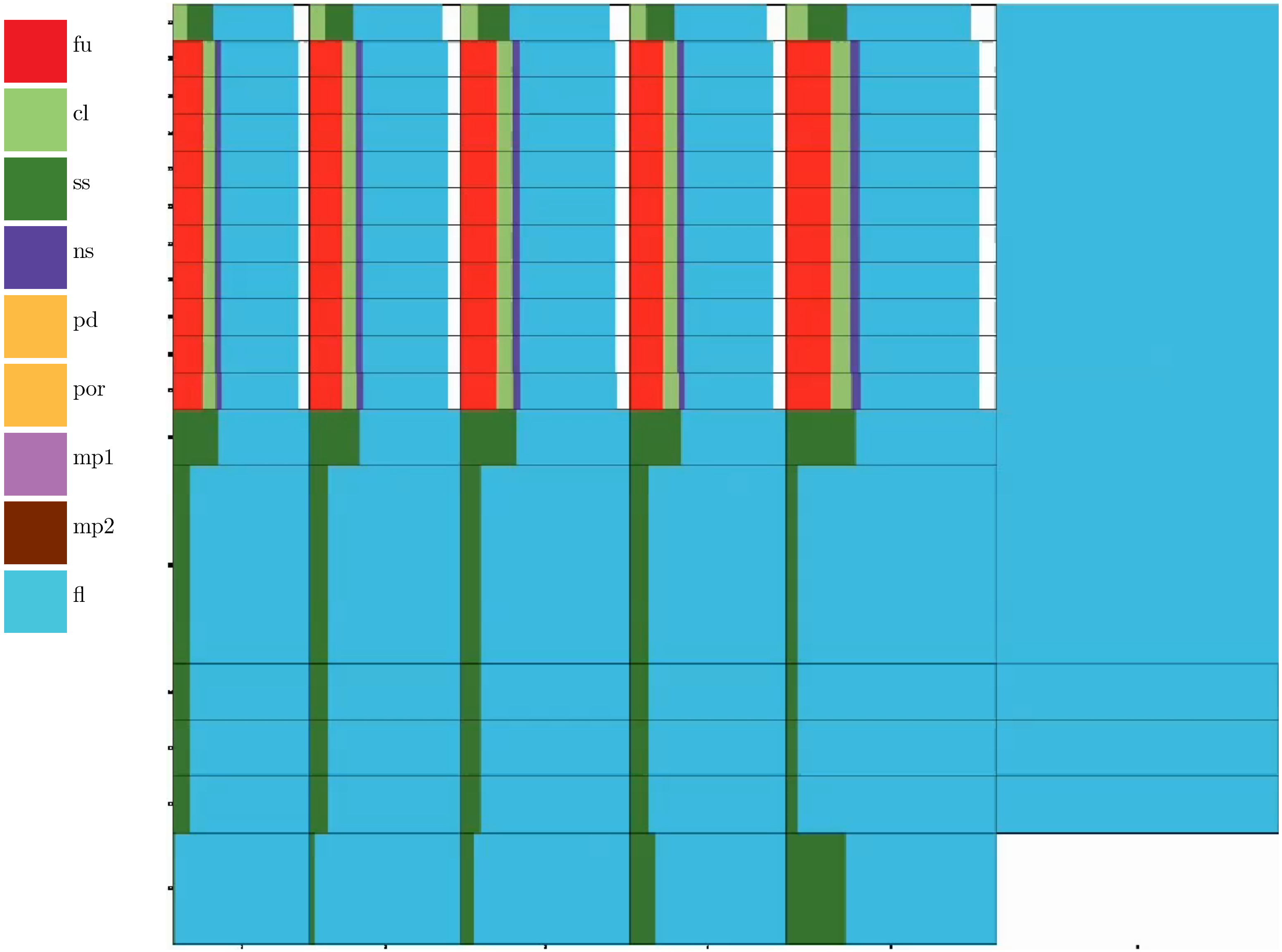
RPV pressure and hydrogen generation in-vessel





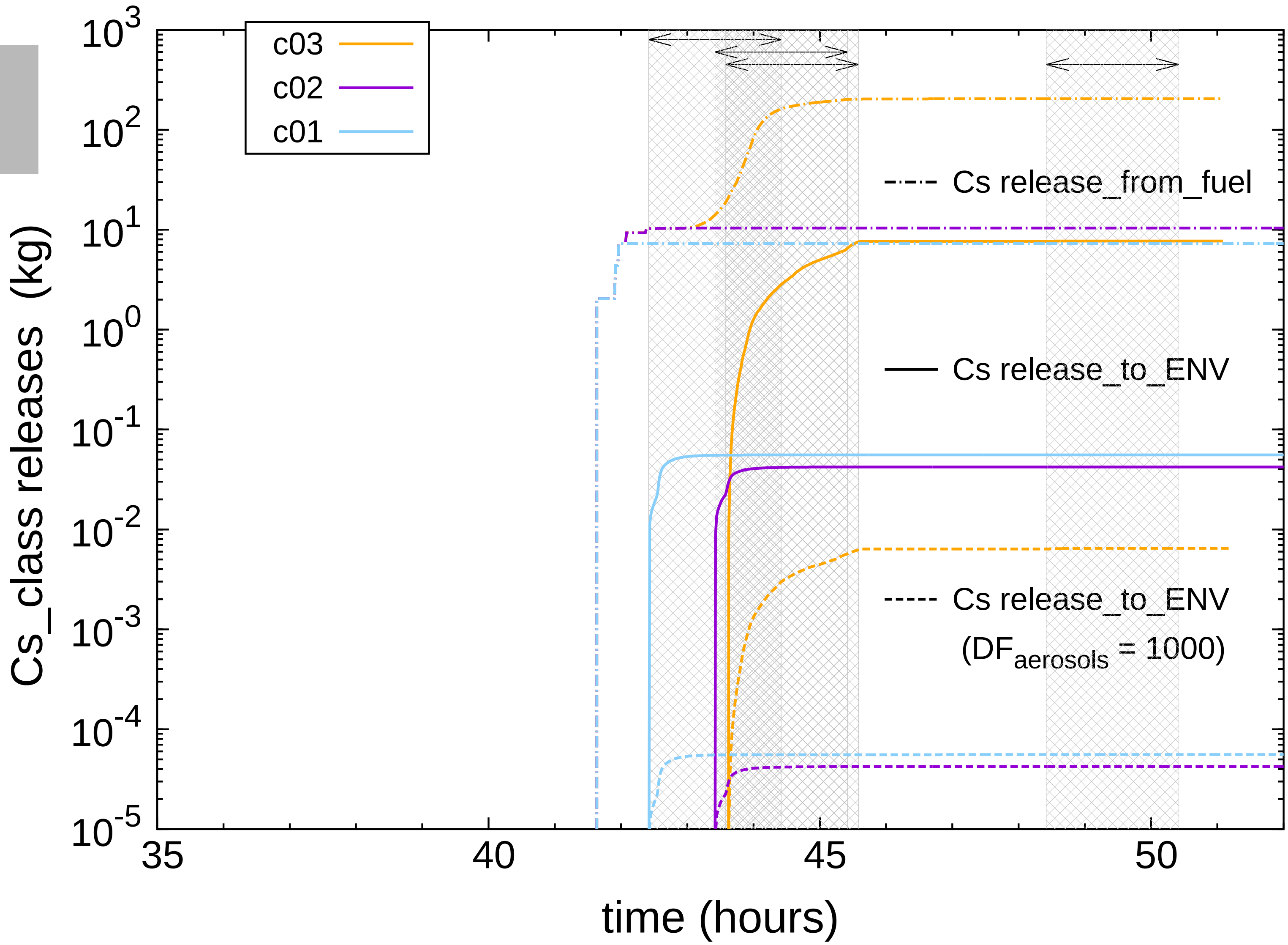
in-vessel accident progression with the base-case scenario

video for scenario c03, ca. 20h - 51h



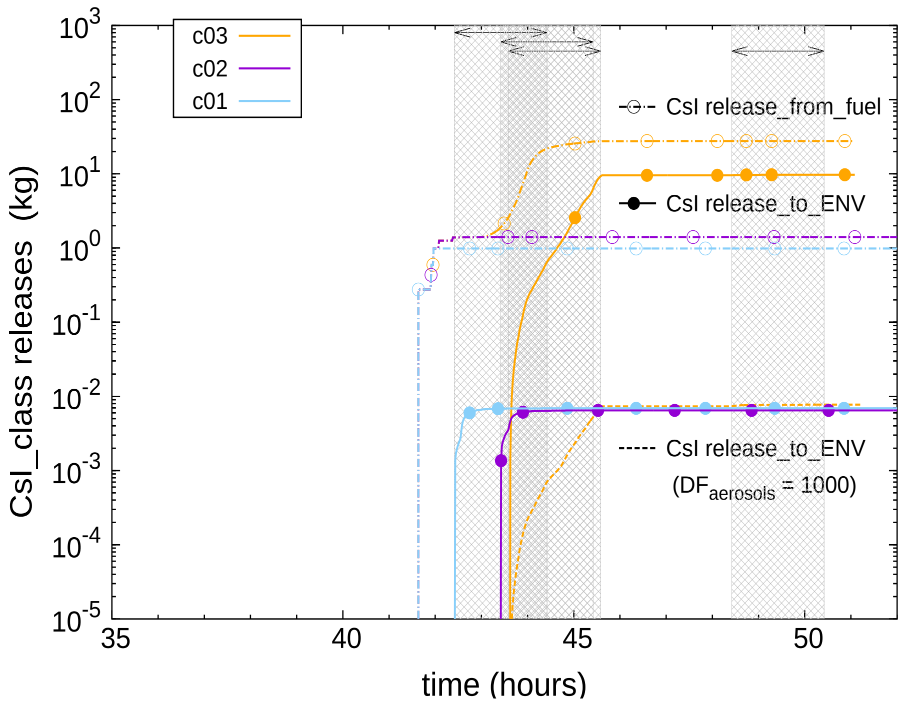
Source Term: Cs_class radionuclides behavior

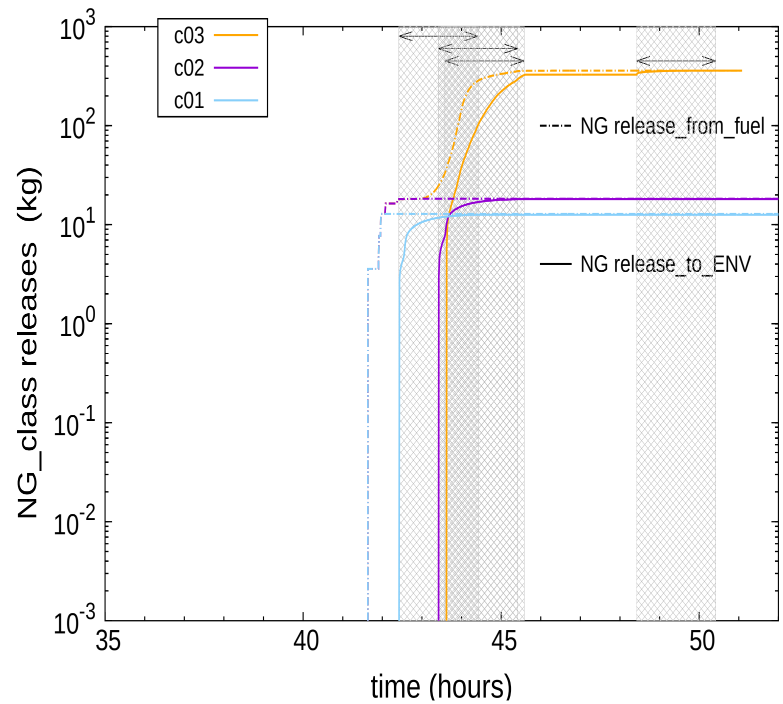
major assumption here: Cs behaving mostly like CsOH



~4% of the initial Cs inventory

noble gases and iodine (CsI)



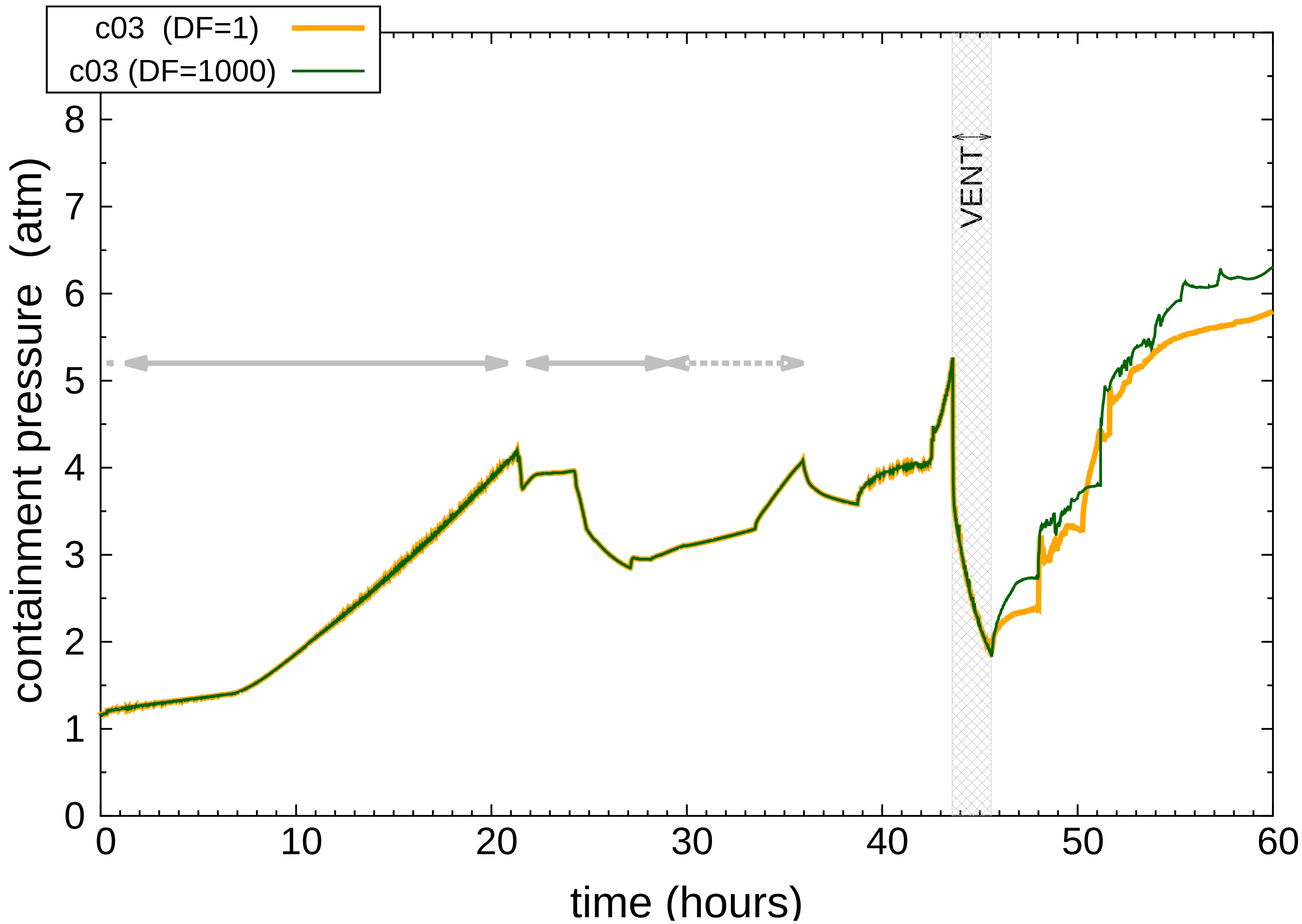


- calculated aerosol (CsI) scrubbing efficiency in WW (SPARC code default) very low ?!
  – code calculates boiling in WW in the decisive periods of time –can be one of the reasons, but the whole thing rather unclear: MELCOR thermohydraulic predictions for WW very uncertain (distinct stratification there ?), scrubbing itself uncertain, particle sizes and distribution are rough estimates, etc, etc -needs more work
  – for CsOH (also on aerosols) this has been masked with its (irreversible) trapping on steel surfaces inside RPV and in the steam lines -will be discussed with the Cs behavior models

differences in progression of very similar scenarios –MELCOR related

c03 scenario without the second period of venting

–base line calculations for further restarts



Scenarios with changing the second period of venting

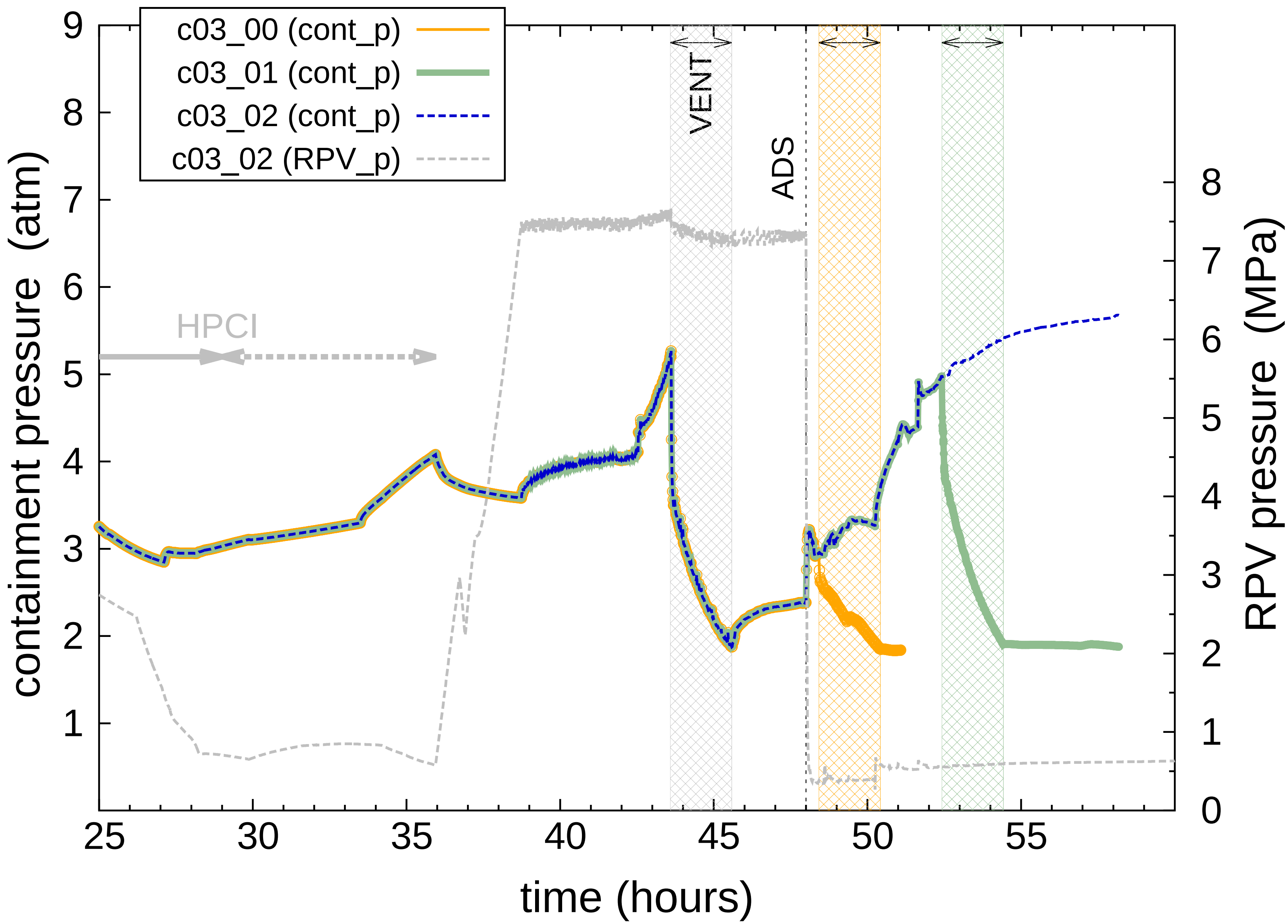
- what if venting right after ADS is unsuccessful (attempted venting in Fukushima accidents not always success)

- second set of scenarios
  - scenario c03_00
    - original c03 (with second period of vent, 25min after ADS at 43h)
  - scenario c03_01
    - second period of vent shifted to the time of significant containment pressurization
  - scenario c03_02
    - without second period of vent   => accident recovery unlikely (!)

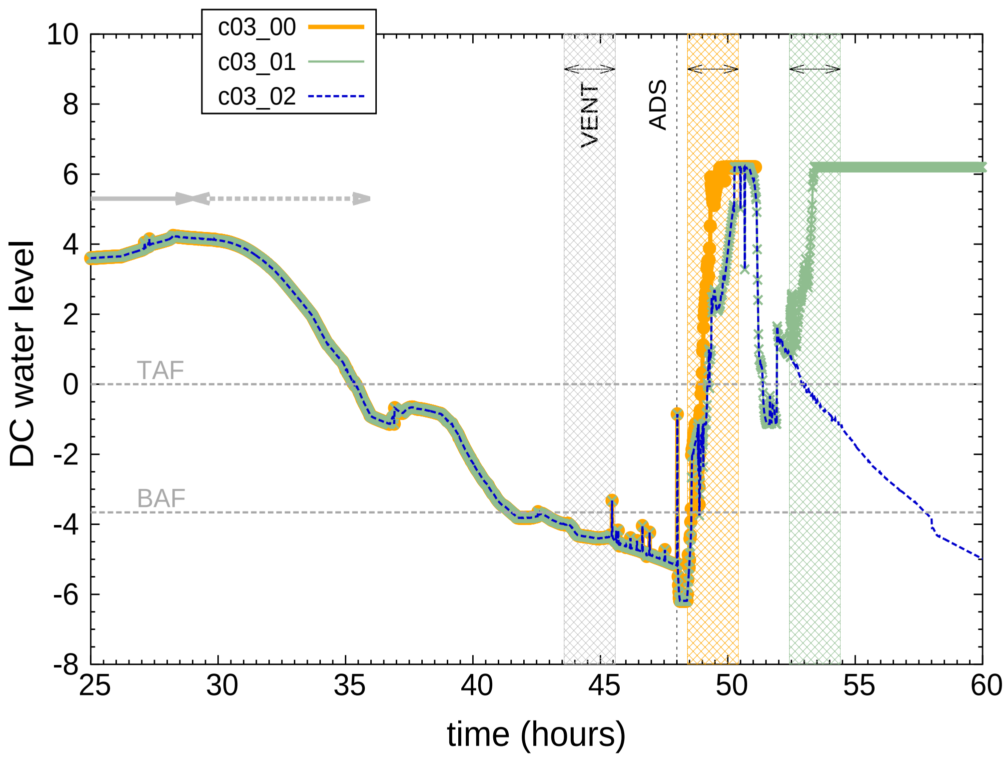
- again, all of them calculated for both filtered and unfiltered venting

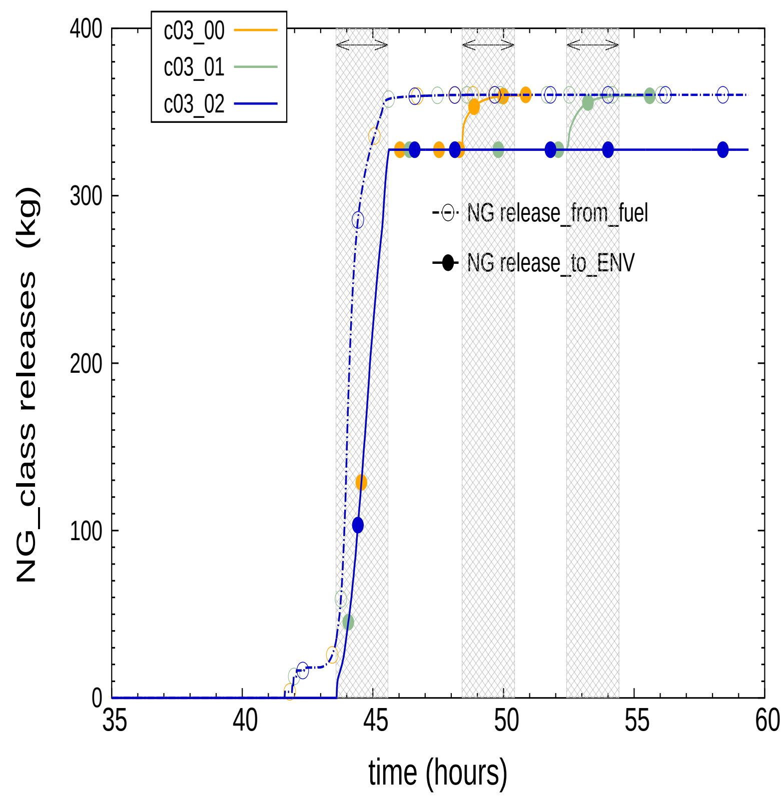
- no real difference found for aerosol-borne FP release before anticipated Vessel Failure at c03_02 scenario, only for NG

containment pressure and RPV pressure



RPV water levels and FP release





Different approaches to Cs modeling

- important aspect of FP modeling: uncertainties with Cs behavior/modeling (dating back to PHEBUS FP test interpretation)
- one approach: Cs behaving mostly as CsOH (equivalent part of Cs also in CsI)
  - our "c03" sequence
  - CsOH expected to be adsorbed on stainless steel. But how much?
  - fast, irreversible chemisorption of CsOH being default treatment in M2.1 (partially based on AEA VICTORIA code modeling) versus almost no sorption as an original approach to Cs modeling, also in M1.8.6 - impact is huge, deeper insight needed

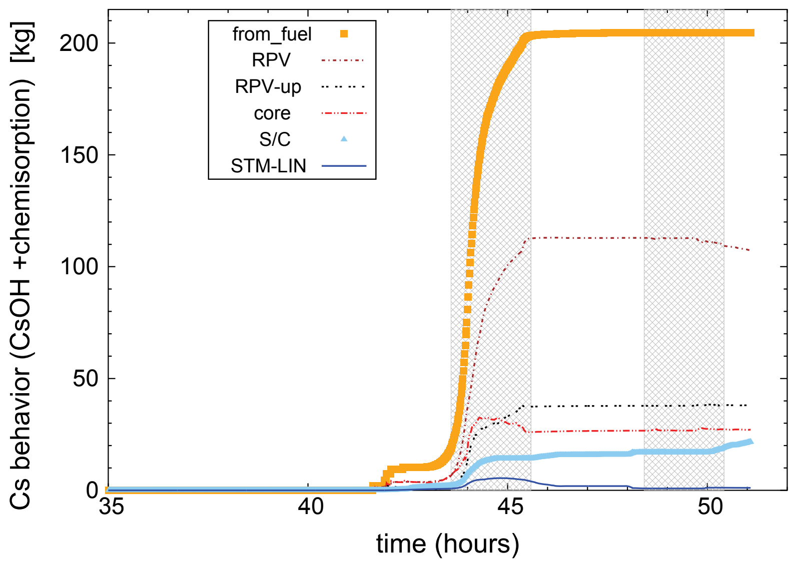
$$\frac{\mathrm{d}}{\mathrm{d}t} m_{d,i} = k_i c_g$$

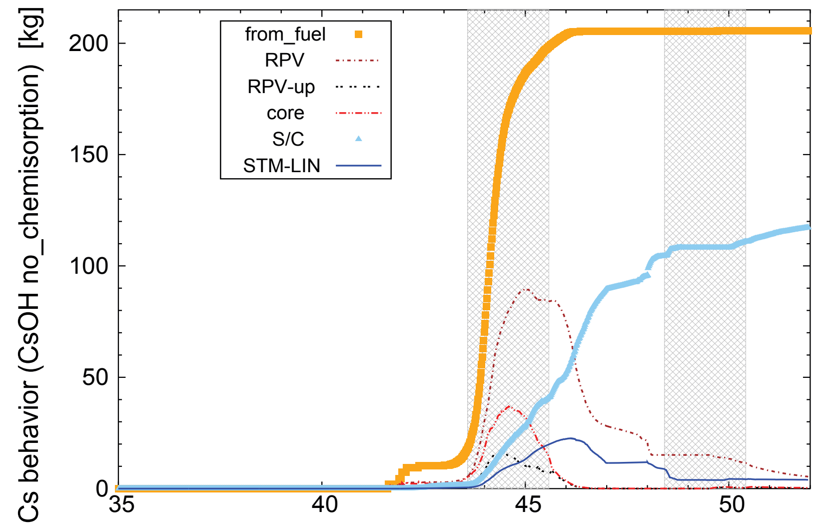
(in the model, mass transfer through boundary layer assumed to be much faster than the chemisorption itself)

$$k_i = a_i \exp\left(-\frac{E_i}{RT}\right)$$, a_i = 0.139 and E_i = 5.96x10^7 (R = 8314 J/kg.K)

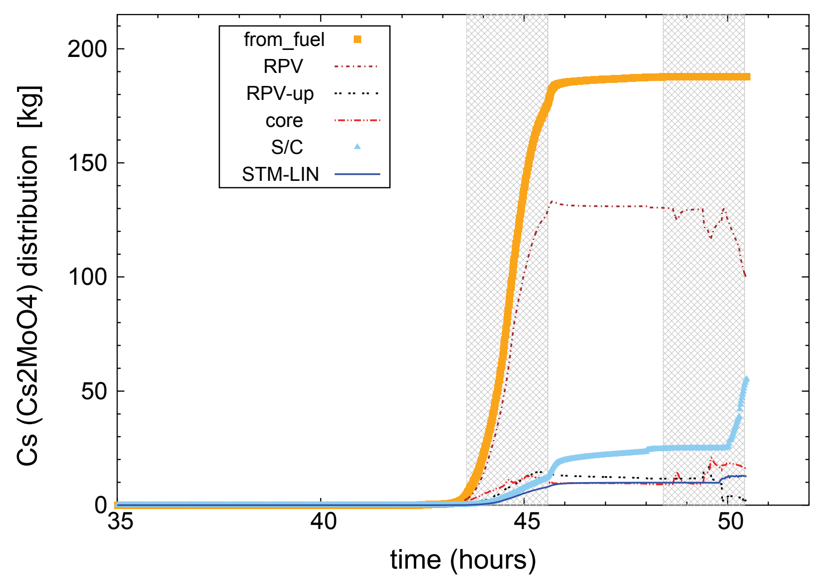
- Cs2MoO4 as the primary Cs species: rather new approach, at least from the modeling point of view, still not firmly established
- the same questions (what is the Cs speciation, how the sorption would look like, …) asked right now with the analyses of Fukushima accidents

Impact of different approaches to Cs modeling





- Cs mostly in CsOH, default M2.1 treatment of CsOH sorption - our "c03" sequence
- Cs mostly in CsOH, sorption negligible (default in M1.8.6)
- yet another way, Cs2MoO4 as the primary Cs species (small fraction still remains in CsOH)
  - this simulation not analyzed in detail so far
- CsOH cases versus Cs2MoO4 cases would also use different models for release from fuel (CORSOR versus Booth model)



Conclusions and outlook

- BWR "Fukushima-like" scenarios with containment venting and FP behavior
  - whole-plant calculations performed for different strategies/timing of containment venting (filtered, non-filtered), linked also to RPV depressurization
  - if fire pumps injection reaches RPV at its full capacity –and DW/WW pressure is sufficiently low after successful venting(!)- recovery at this late stage of a Fukushima-like accident is possible
    - uncertainties as for vessel failure/penetration failure still rather high
  - early ADS followed by venting helps to keep FP releases reasonable
  - venting based on high DW/WW pressure led to significat source term for volatile FPs in our simulations
  - filtered venting very effective for aerosol-borne activity in relevant cases
  - uncertainties related to Cs speciation and behavior at an accident also high, can have a huge impact on source term prediction; crucial also for Fukushima modeling
    - CsOH versus Cs2MoO4 as a principal Cs species, chemisorption of CsOH, …

Conclusions and outlook (contd)

- in general
  - presented analyses might be rather difficult to perform without an integral code => MELCOR can be useful in some instances :)
  - in whole-plant analyses, MELCOR is still very sensitive "beast", as shown clearly with our BSAF FU3 calculations -e.g., tiny differences in the amount of injected water, AWI, would drive the sequence ex-vessel (as compared to recovered one which was our best estimate case)
    - one needs to exercise caution

- outlook
  - looking in more detail into WW retention/scrubbing of FPs –we've started
  - thermohydraulic behavior of WW (S/C), with particular regard to impact on aerosol retention
  - issues with Cs behavior and its modeling, linked also to iodine
  - all in close connection with on-going Fukushima analyses

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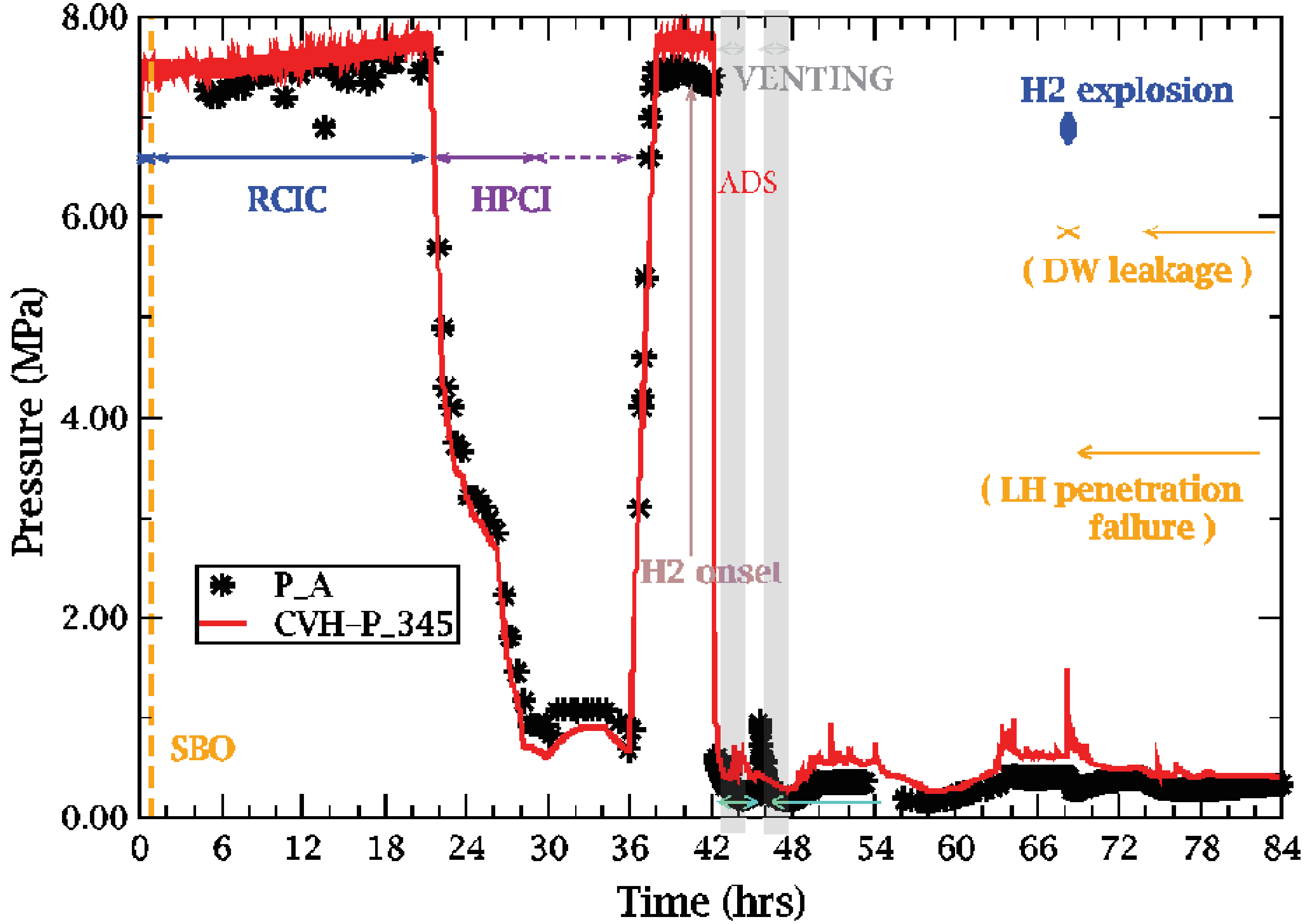
Wir schaffen Wissen – heute für morgen

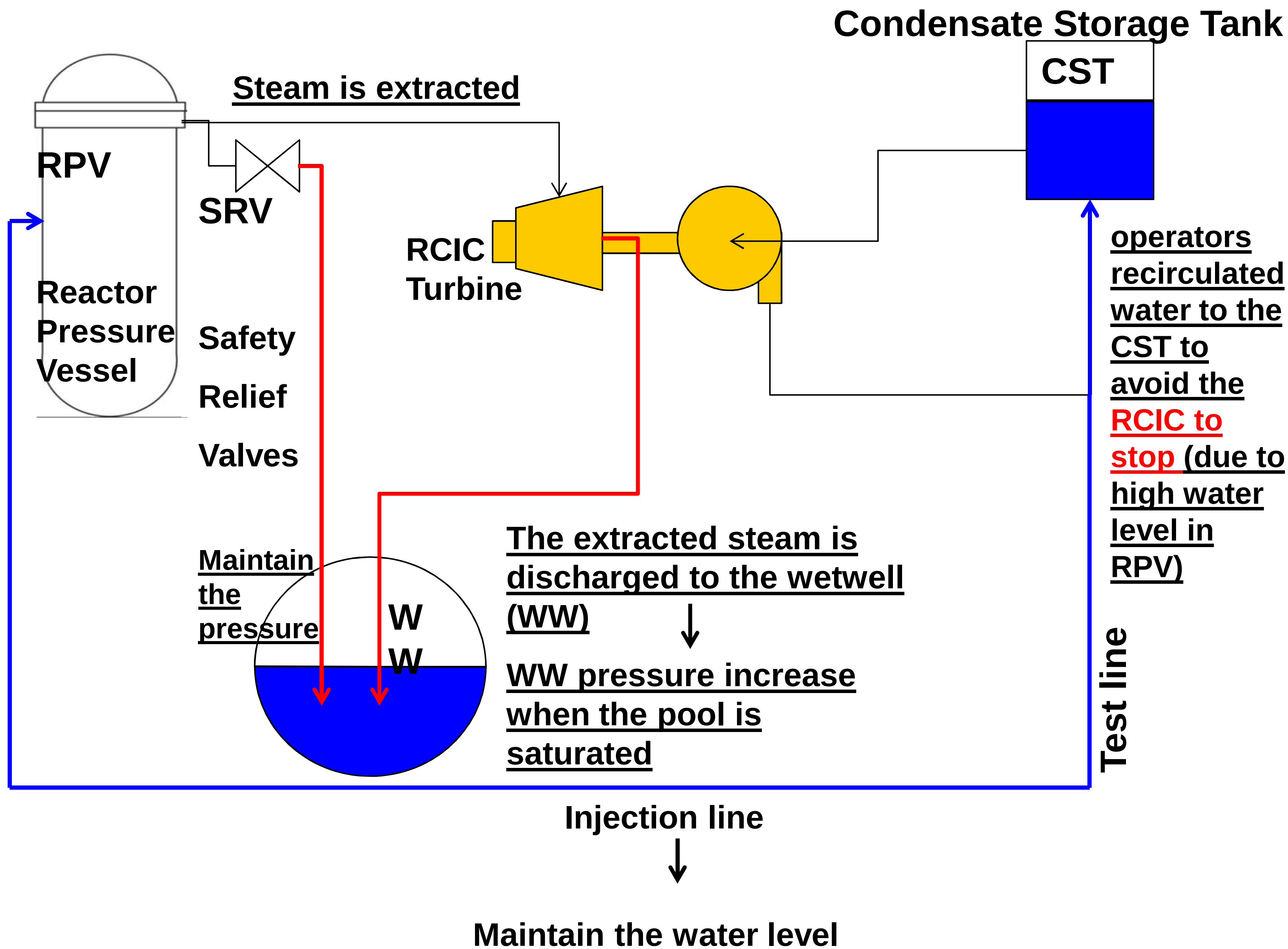
thank you

for your atttention

containment pressure and RPV pressure



Reactor Core Isolation Cooling (RCIC)



in-vessel accident progression