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MELCOR modeling of FP scrubbing in experiments and in integral accident scenarios

EMUG meeting, Madrid, April 2017

Outline

- Scrubbing modeling with MELCOR/SPARC for experiments
  - POSEIDON experiments, for general SPARC behavior testing (older TEPCO-TOSHIBA-HITACHI experiments, for boiling conditions)
  - thermal-hydraulic behavior by MELCOR in experiments
  - aerosol retention with default/non-default SPARC settings

- Scrubbing modeling with MELCOR for integral "Fukushima-like" scenarios and FP behavior
  - thermalhydraulics
  - WW Mark-I scrubbing related phenomena for Cs and iodine compounds
  - with the same default/non-default MELCOR/SPARC settings

- Conclusions and outlook

SPARC and MELCOR/SPARC model and POSEIDON test series

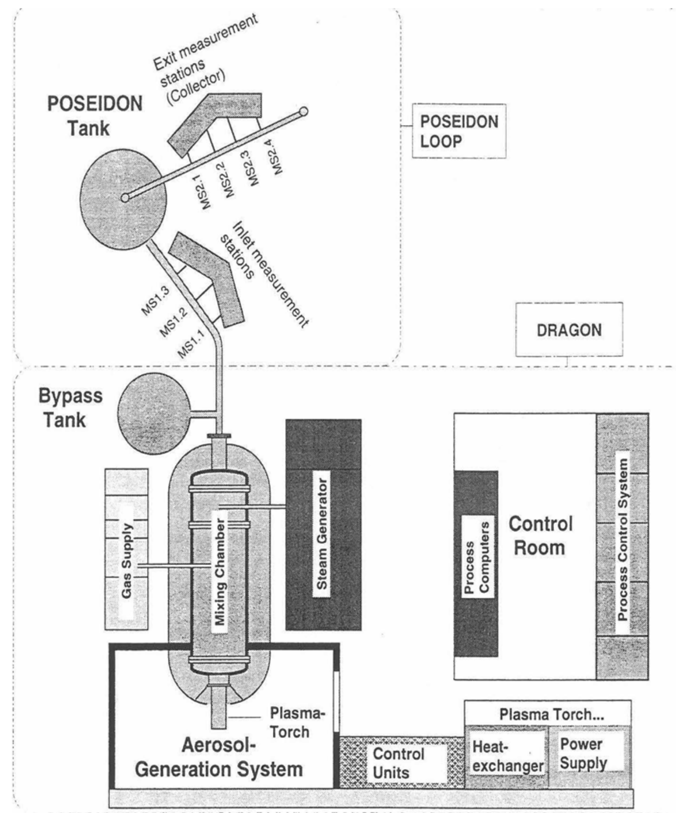
- SPARC (MELCOR/SPARC) --a relatively complex code written for aerosol retention calculations in WW water of a BWR (iodine vapors included)
  - what it is in MELCOR now is –to our knowledge- the same as original SPARC

- as all currently used scrubbing models, SPARC is rather old -yet, its validation is not great

- our aim was to use SPARC for scrubbing experiments having conditions prototypical to severe accidents and then in the same way for an integral BWR accident based on Fukushima U3; stand-alone BUSCA code used as well for comparison

- PSI POSEIDON test series chosen as first
  - very well documented
  - prototypic (high) flow rates of gases used in POSEIDON as well as other relevant conditions

POSEIDON Tank: 5m height, 1m diameter



Experimental parameters in POSEIDON tests and calculated DFs

Test	Gas Flow Rate (kg/h)	Steam Mass Fraction	Inlet Pressure (bar)	Gas Temp. (ºC)	Pool Temp. (ºC)	Pool Height (m)	Inlet Aerosol Flow Rate (g/s)	Outlet Steam Mass Fraction	Outlet AMMD (µm)	Outlet GSD	DF exp	calc. BUSCA	calc. DF (MELCOR / SPARC defaults)	calc. DF (non-default "sparger" option)
PA06	142.5	0.553	1.45	243.0	86.9	1.0	0.0118	0.518	0.36	1.64	7.3 ±1.4	5.5	1.2	12
PA07	142.5	0.553	1.42	267.7	86.3	0.3	0.0119	0.506	0.36	1.5	6.6 ±2.3	2.1	~1	~1.8
PA08	145.1	0.563	1.63	212.9	86.8	4.0	0.0096	0.525	0.28	1.34	21.4 ±6.7	183	~2	~240
PA11	137.9	0.043	1.46	256.1	75.3	2.0	0.0152	0.237	0.24	1.6	5.4 ±1.4	-	1.05	14
PA12	124.9	0.0	1.36	237.7	71.8	1.0	0.0161	0.249	0.3	1.55	3.4 ±0.6	2.8	~1	~5.5
PA15	94.3	0.719	1.30	305.2	85.4	1.0	0.0091	0.475	0.31	1.59	4.9 ±1.0	-	~1.4	~13
PA17*	91.8	0.747	1.30	310.8	88.0	1.0	0.0571	0.539	0.46	1.62	12.3 ±6.2	12	1.7	40

* inlet AMMD =0.54 µm in PA17, 0.3 µm in all other tests

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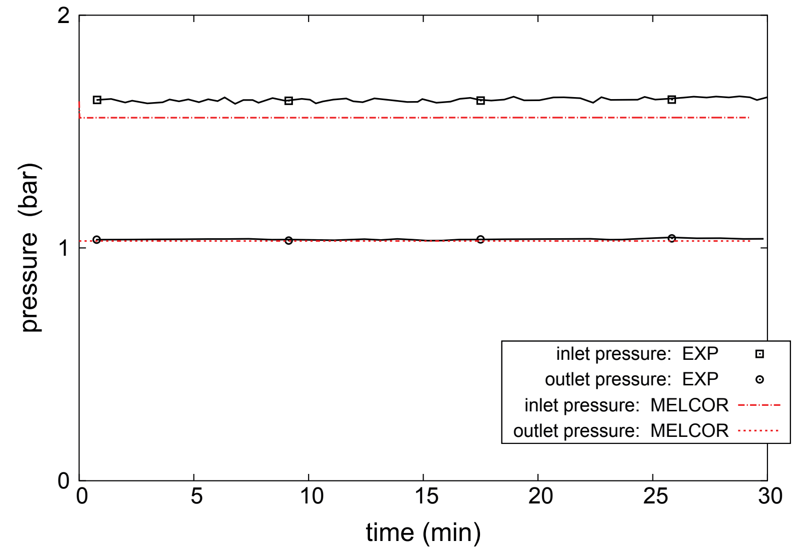
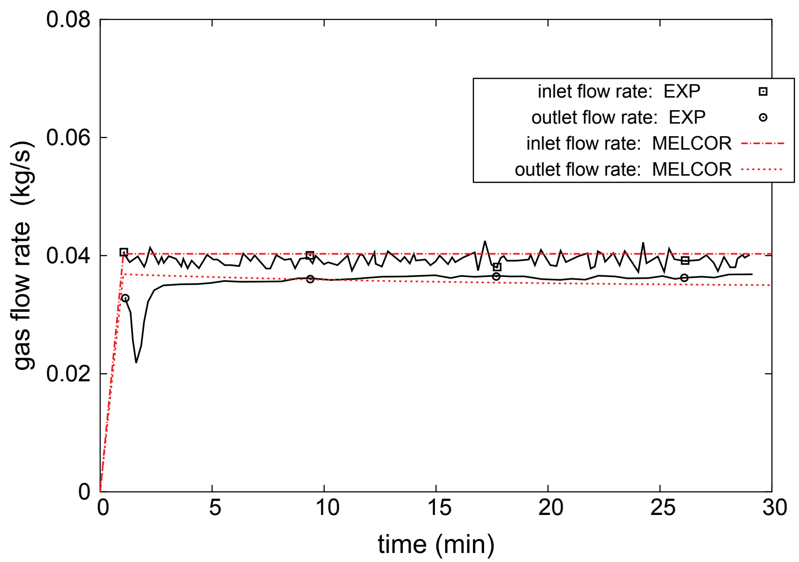
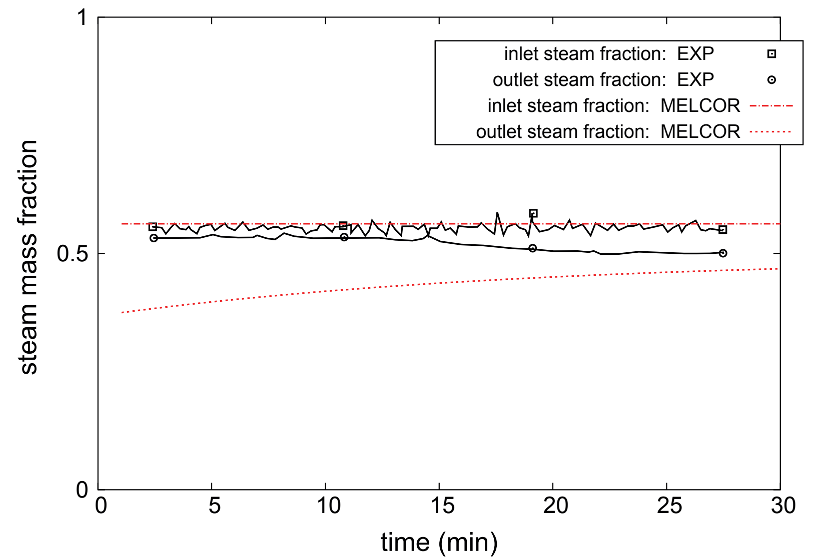
typical results of POSEIDON simulations – thermalhydraulics in PA08

- simple model used, similar to Sandia MELCOR test problems
- PA08: 4m of water, 86°C, inlet steam mass fraction 0.56, gas flow rate ~40g/s, 212°C, inlet aerosol concentration ~0.2g/m3, inlet AMMD=0.3µm
- **thermalhydraulics very well captured by MELCOR for all POSEIDON tests**

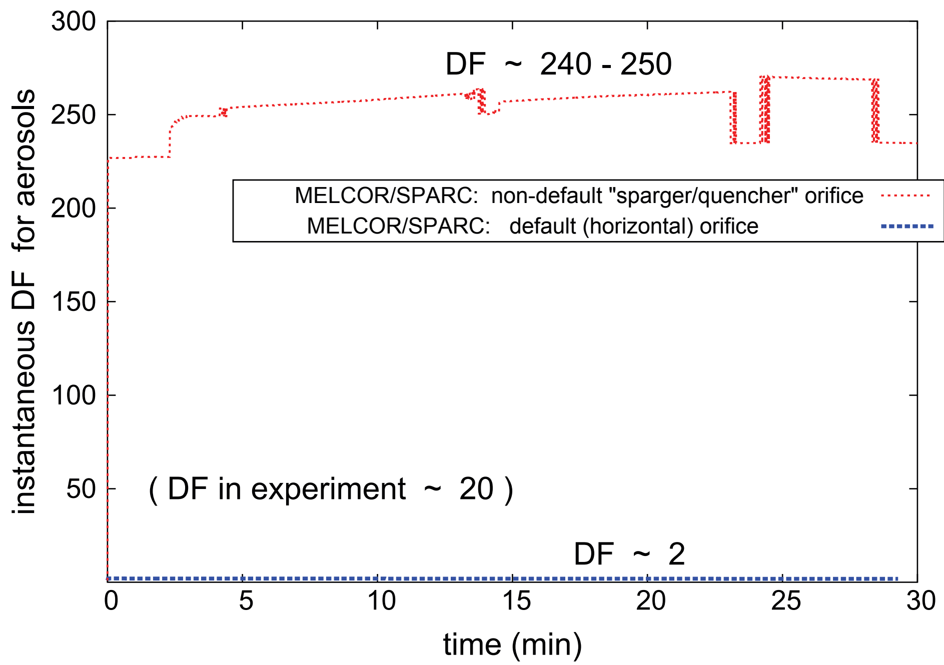




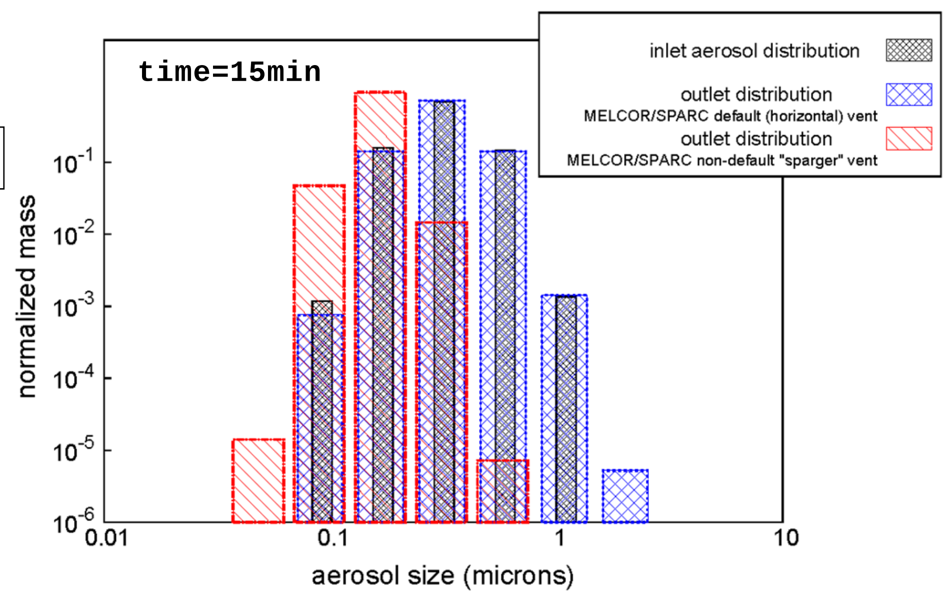


Decontamination Factors in POSEIDON simulations by MELCOR/SPARC

- trends in calculated DFs the same in all POSEIDON tests: the same **effect of submergence, steam content, particle size**
- by far **the most important sensitivity in calculations :**
  - default MELCOR/SPARC options versus non-default "quencher" (multihole) vent option
- large differences in predicted DF values whereas the thermohydraulics was calculated to be the same between the 2 runs; this same picture seen in calculations of all POSEIDON tests
- differences lie in description of the initial bubble formation for various vent types (original EPRI correlations)
- for all other calculated tests than PA08, which is of highest submergence, the agreement with experiment for DF values (with non-default SPARC settings) far better than in PA08

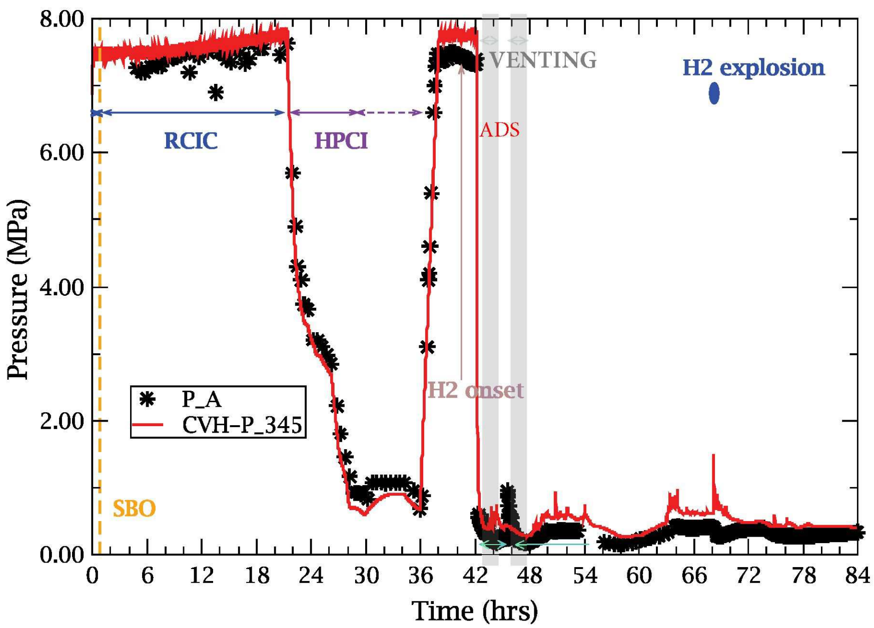


PA08 test calculation (4m of water)



BWR integral source-term calculations with MELCOR/SPARC

- differences seen in simulations of experiments may have significant impact on integral source term predictions for severe accidents at BWRs (e.g., with relevant systems at FU2 versus those at FU3)
  - DF~2 versus DF~200 (as in PA08 with high submergence) represents efficiency of 50% versus 99.5% of the aerosol mass scrubbed
- try to check it -with Cs and I- for "Fukushima-like" BWR SBO scenarios: prolonged operation of relevant core cooling systems => "Fukushima-like"

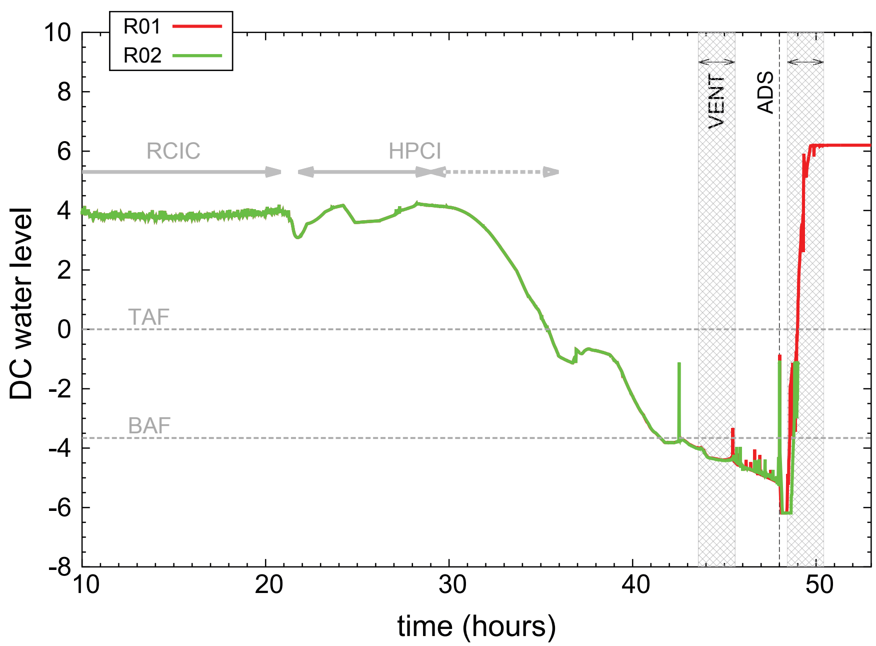


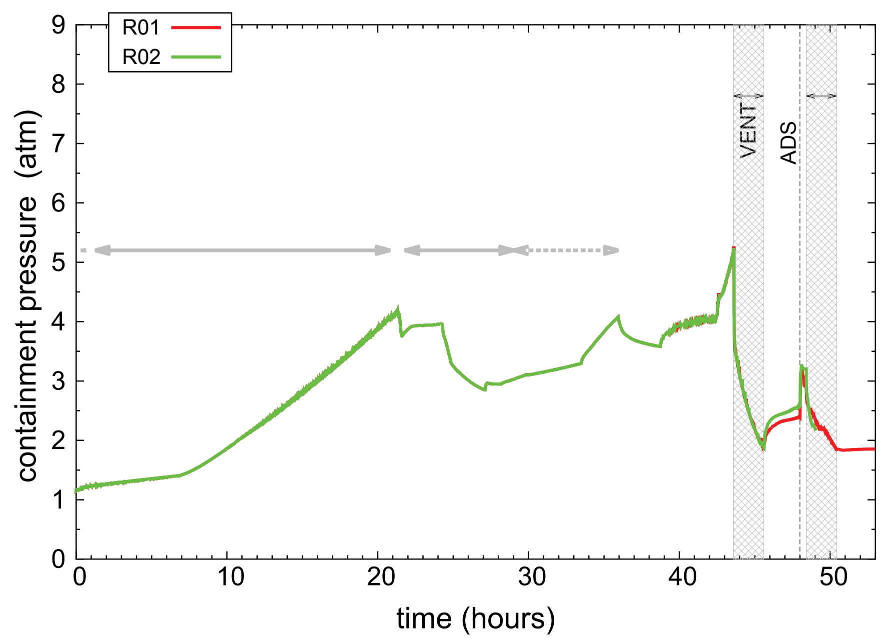
- our Fukushima-like sequence based on detailed FU3 simulations by PSI(*)
- at about 40h into the accident, things starting to "go definitively wrong" :
  - RPV water level below BAF
  - first hydrogen
  - beginning of FP release

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

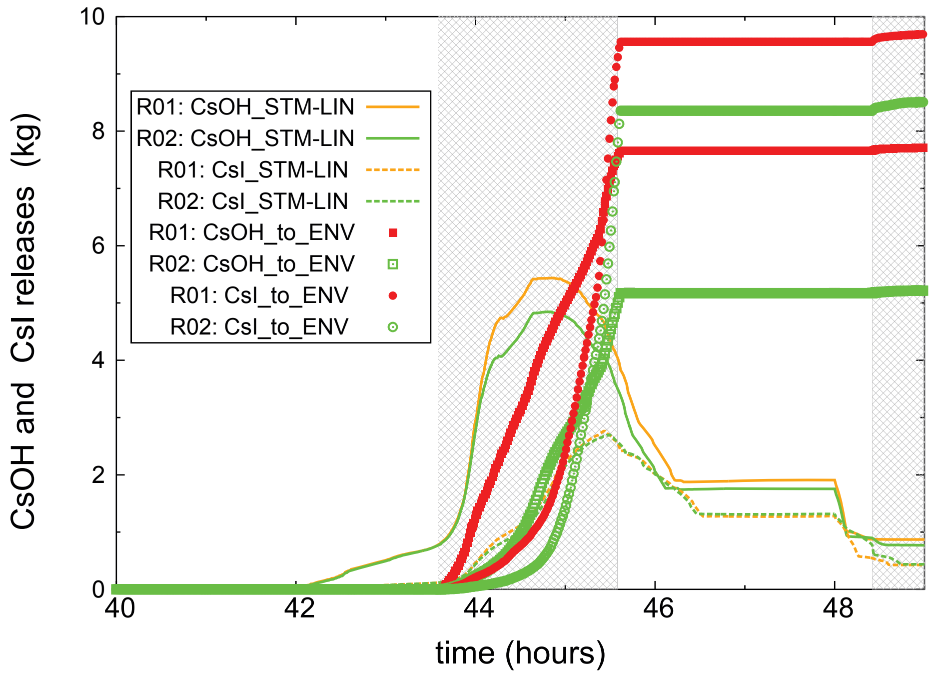
Comparison of the same BWR sequences with different MELCOR/SPARC settings

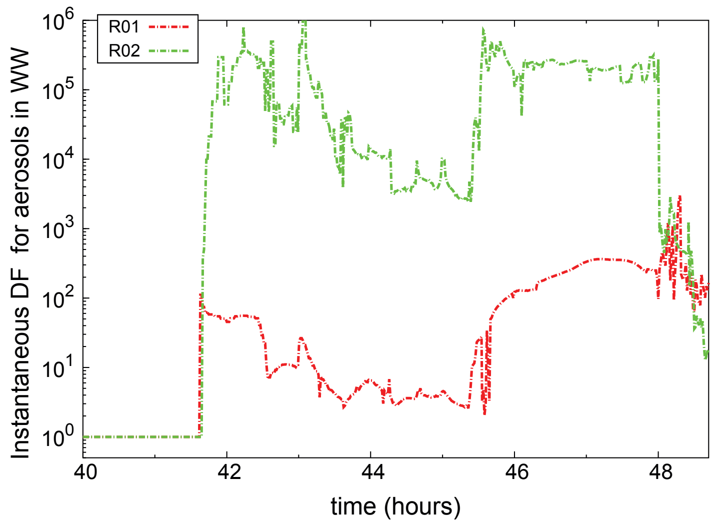
- calculated Fukushima-like scenarios with active containment venting operation (*NUTHOS-11 paper) defined such as to allow for the FP environmental release -and **Cs and I isotopes** in particular- only via WetWell water (Suppression Chamber) and then through ventilation lines
  - starting to deviate from FU3 case at about these 40h
- no head flange DryWell leakage, no other containment failures
- enables to compare more easily the FP retention in WetWell for different MELCOR/SPARC settings in an integral scenario
- again, like for experiments, calculated thermalhydraulics very similar between the 2 cases
  - **R01: defaults** in MELCOR/SPARC
  - **R02: non-default** MELCOR/SPARC **"sparger/quencher" vent**

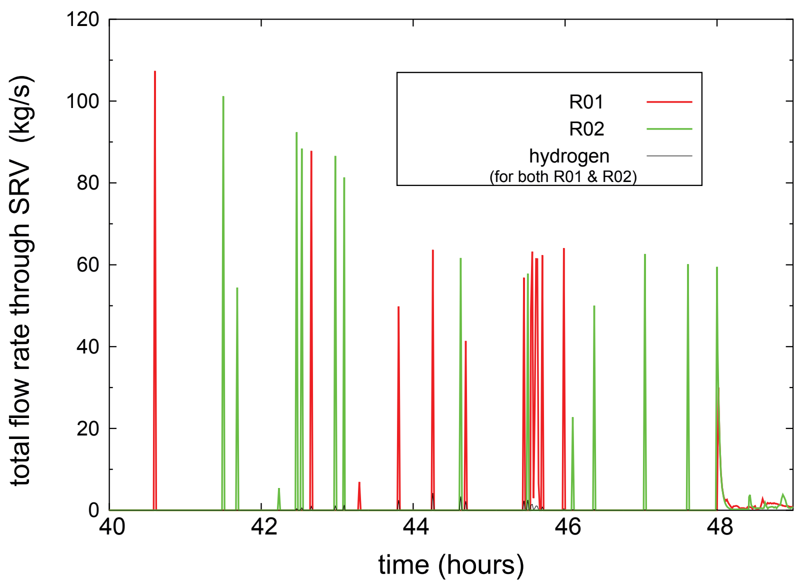


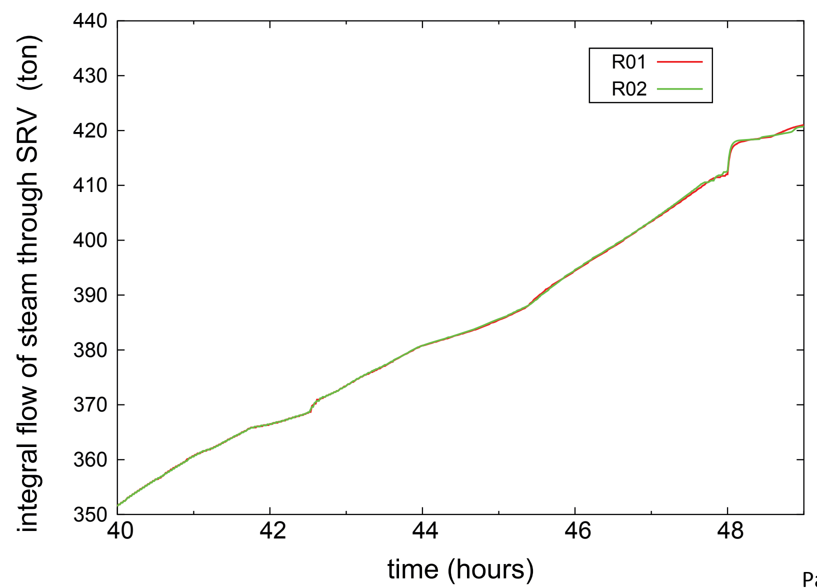


Cs behavior and retention in WW



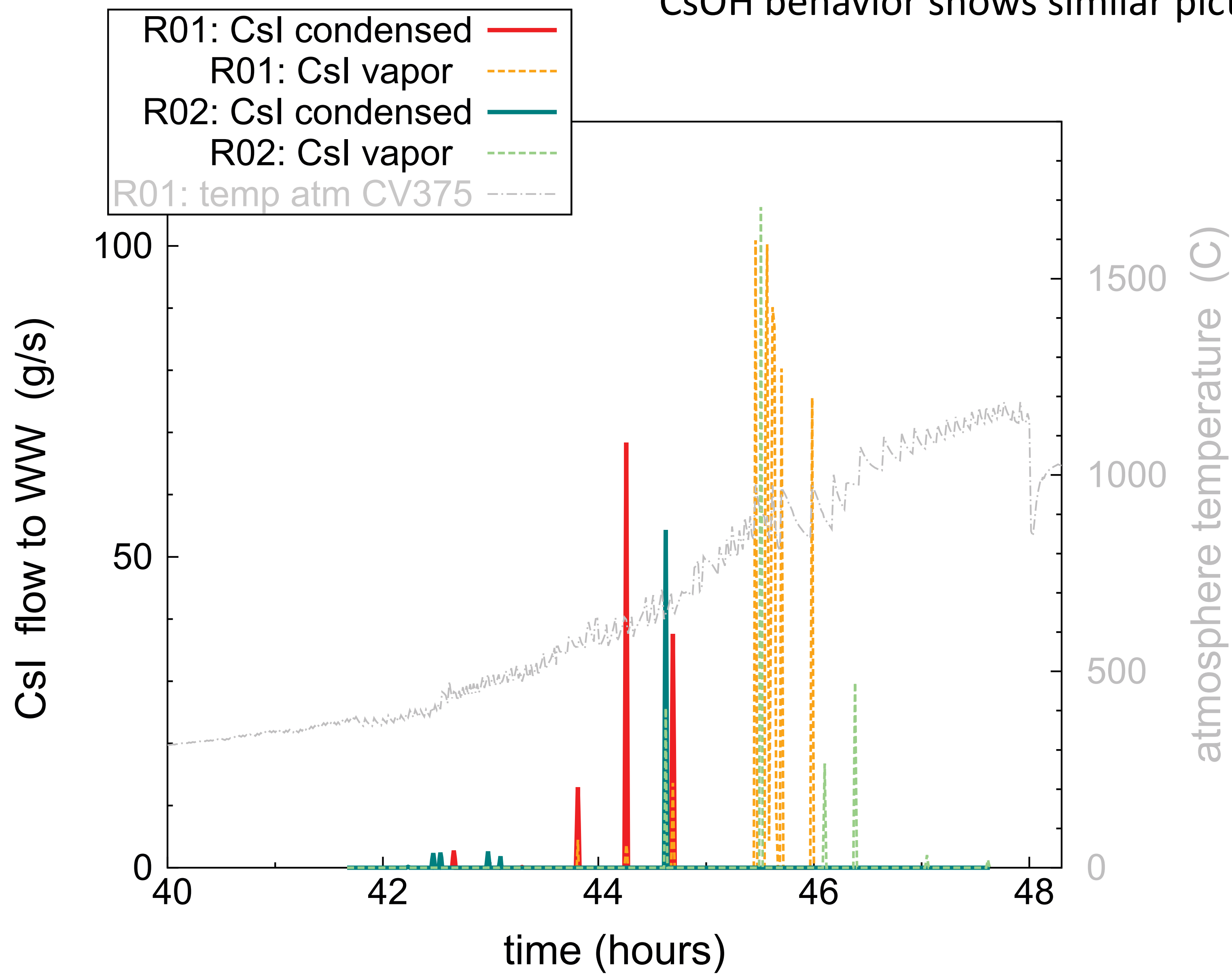




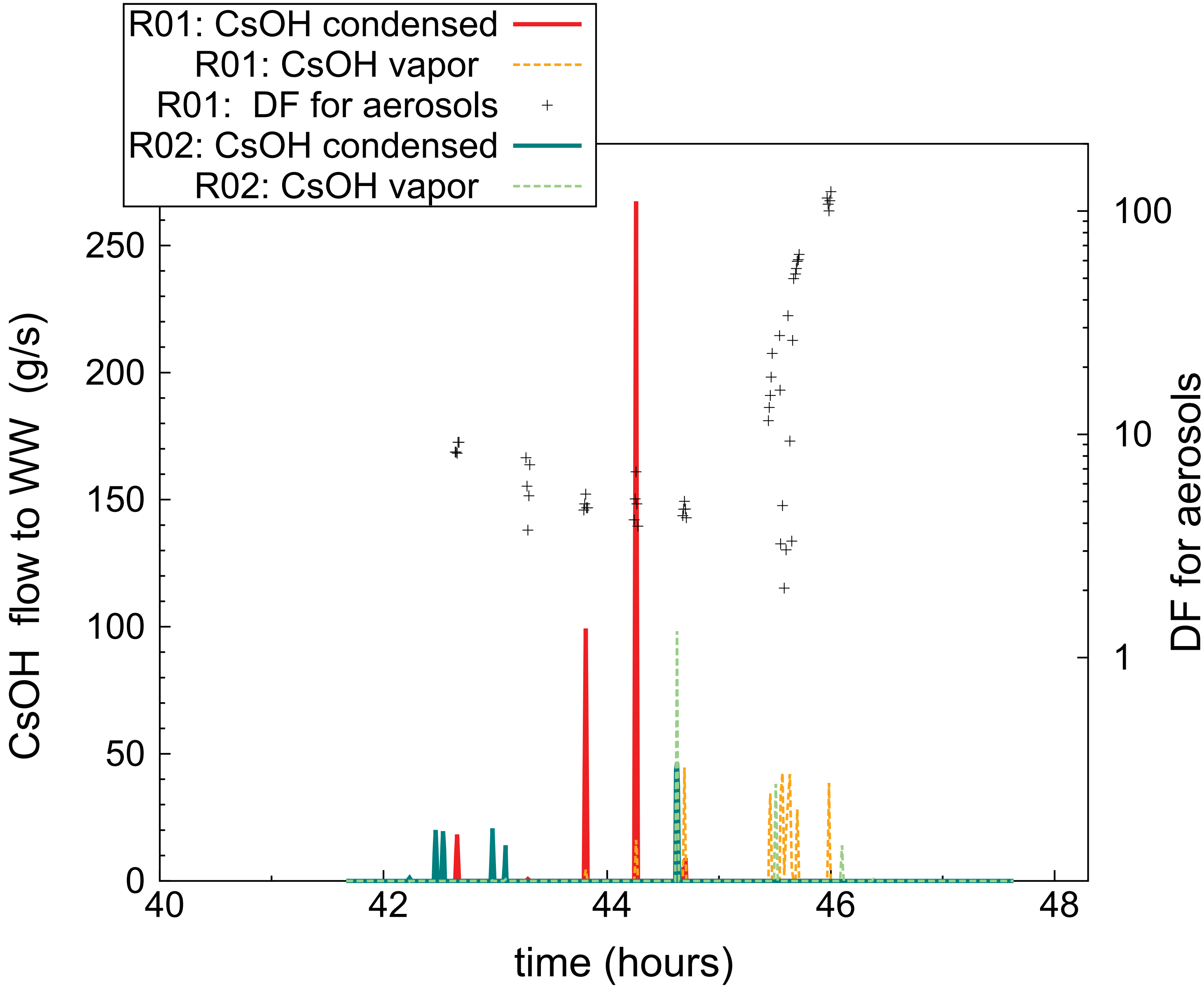


CsI behavior and retention in WW (contd)

CsOH behavior shows similar picture

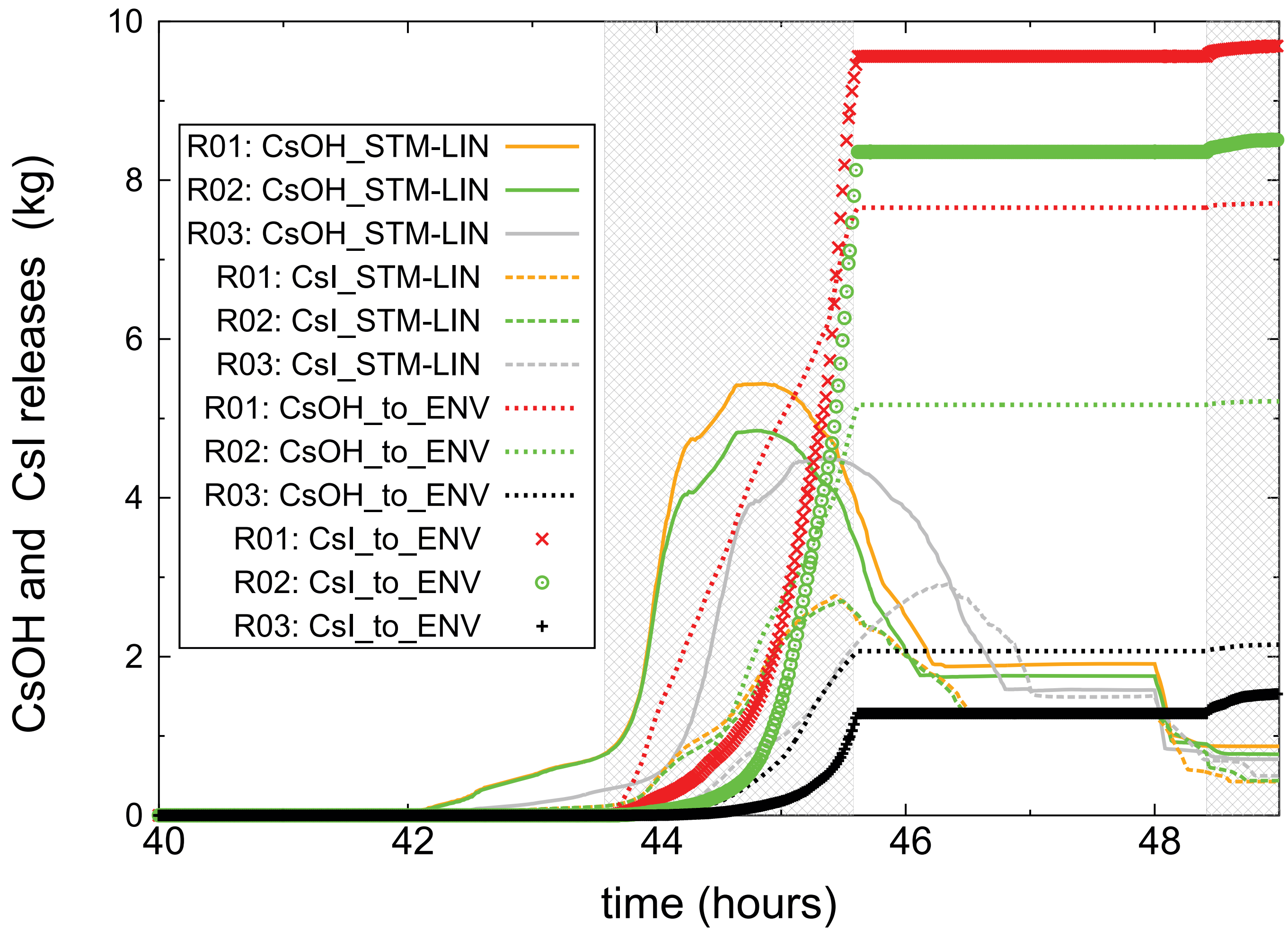


CsOH behavior and retention in WW (contd)



what would happen if also vapors are scrubbed?

(directions taken from an old Sandia CSARP presentation)



effect is huge, as one would expect,

but not a single word is written about this model in the code manuals!

Conclusions and outlook

- presented work consists of
  - aerosol scrubbing modeling by MELCOR/SPARC for POSEIDON experiments
  - FP transport modeling in an integral severe accident (BWR Mark-I, "Fukushima-like") with focus on Cs (I) behavior and its retention/scrubbing in WW
- MELCOR/SPARC calculates reasonably the thermalhydraulics in POSEIDON experiments (including steam condensation); aerosol retention calculations, on the other hand, were very sensitive to changes in default SPARC input options
  - proper use of different EPRI correlations in different areas of interest should be examined
- BWR "Fukushima-like" sequence and FP retention in WW
  - predicted aerosol DFs in WW sensitive the same way as for the experiments
  - FP releases from RPV to WW are discrete events, at least in this type of a scenario -other factors than just DFs can play a role in retention (timing, ...)
  - to understand the retention of Cs (or FPs in general) and its behavior one needs to study every given accident sequence in detail -here MELCOR is quite helpful
  - calculations also confirmed again that FP speciation is crucial (e.g., CsOH versus Cs2MoO4 in terms of their volatility)
  - we need to check MELCOR/SPARC treatment of FP vapors other than those of iodine

- work continues, first with looking at boiling conditions for aerosol scrubbing (TEPCO-TOSHIBA-HITACHI tests) and then with some newer Japanese scrubbing tests

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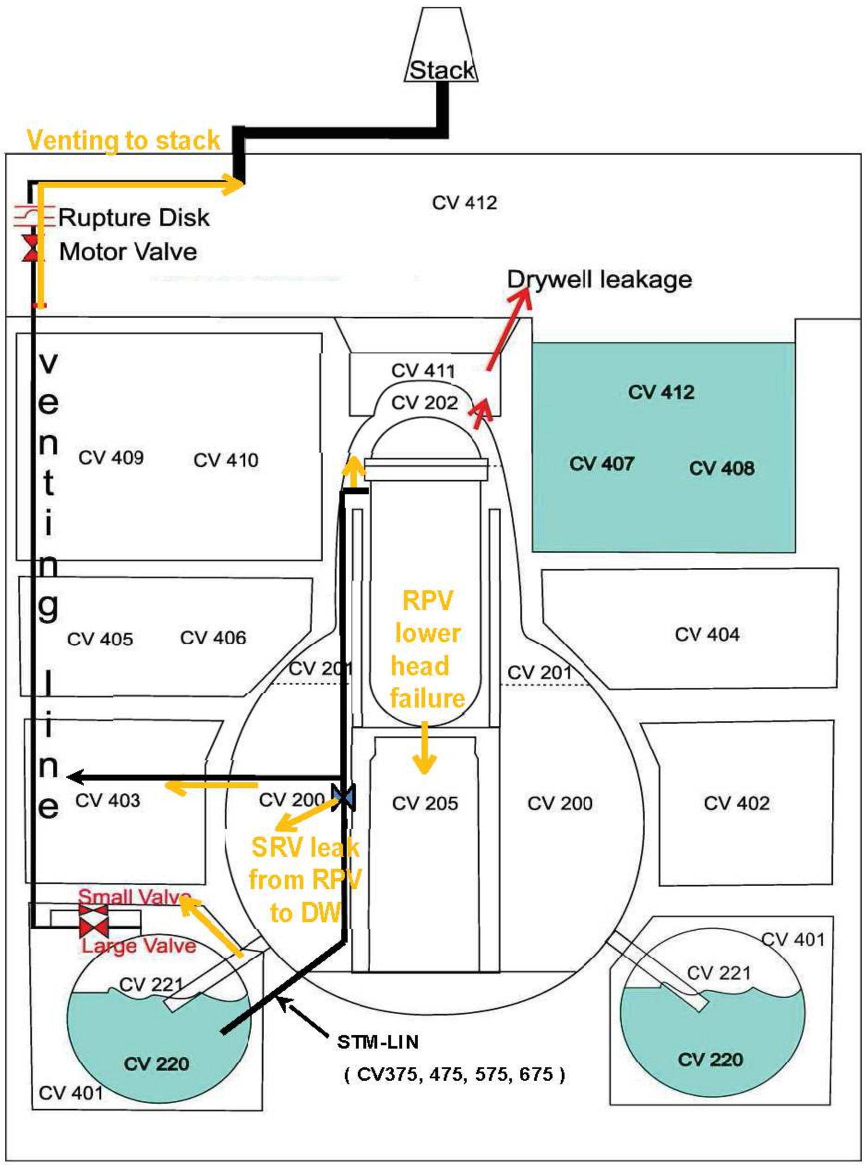
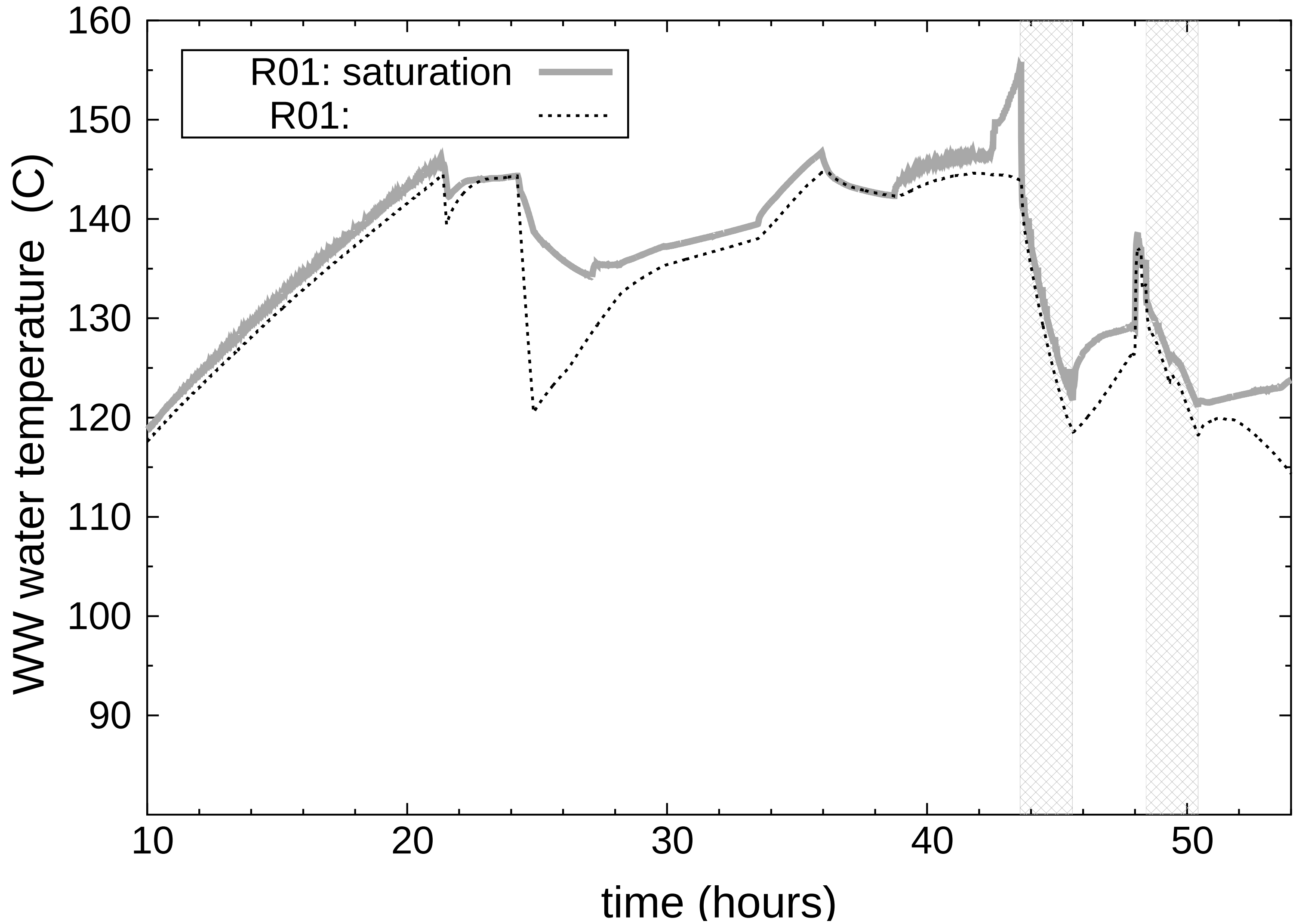
MELCOR nodalization



WW water temperature



Work planned

consists of four tasks:

(1) analyses of an extended duration BWR sequence
- integral scenario (up to approximately 6 days) with source term evaluations
- generic Mark-I BWR "Fukushima-like" sequence

(2) FP transport with special focus on Cs and iodine behavior in the integral BWR scenarios

(3) pool scrubbing models tested in experiments and in the integral BWR scenarios
- WW Mark-I scrubbing related phenomena

(4) iodine radiochemistry modeling relevant to iodine containment behavior at accidents
- small scale PSI test recalculations with dedicated tools (PSIodine, IODE part of ASTEC code(?), …)

WORK STARTED THIS YEAR with

- pool scrubbing modeling
  - for POSEIDON test series (and TEPCO-TOSHIBA-HITACHI experiments for boiling conditions -not yet finished)
  - and for corresponding WW scrubbing modeling in a "Fukushima-like" BWR scenario
- Cs and iodine transport modeling in the same integral scenario