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FUKUSHIMA DAIICHI UNIT 1 (MELCOR 1.8.6)

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Introduction

- **Not part of the BSAF OECD Benchmark Project**
  - Did not receive undisclosed information from TEPCO / JAEA
  - Relying only on publically available input data
  - No legal restrains for usage & publication (**project and export control**)
- **Why**
  - Test of simulation capabilities (**code and user**) and as MELCOR 1.8.6 to 2.x conversion test base
  - Support for training courses (accident awareness trainings for crisis team members and sometimes operators)
  - Improvement of Severe Accident Management Guidelines (SAMG)
  - Optimization of usage of severe accident hardware
    (Passive autocatalytic recombiners, Filtered containment venting systems)
  - Contribution to the international MELCOR community
- **Model description report containing all input data (FGF_D02-ARV-01-111-828)**
  - **revision B** (hardcopy) on EMUG2018
  - **revision C** (electronically) and the MELCOR input model at CSARP/MCAP 2018. **(planned)**

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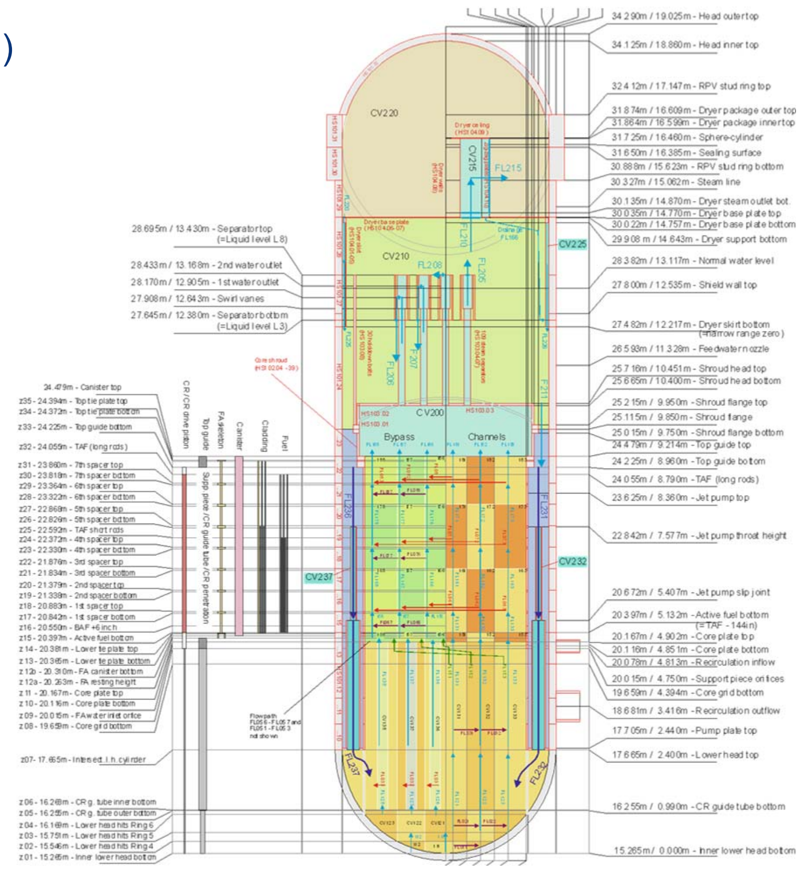
Overview of the MELCOR model for 1F1

- **RPV & Core**
  - Typical GE BWR RPV geometries (well standardized)
  - Generic 7x7 fuel assemblies

- **Experimental (non-recommended) features**
  - RPV leakage before failure via TIP dry tubes
  - More CVH volumes in lower plenum
  - Separating lower plenum in channel & bypass, representing the control rod guide tubes
  - Fuel assembly skeleton as supporting structure
  - Maximizing the COR detail depth to 7 rings and 35 levels (more leads to crash)
  - Additional core collapse criteria (collapse of fully oxidized assemblies without lateral support)
  - Maximum void 0.4 -► 0.7 (RPV water inventory)
  - Time-dependent oxidized rod collapse model (Critical thickness of unoxidised Zr -► 0.0)



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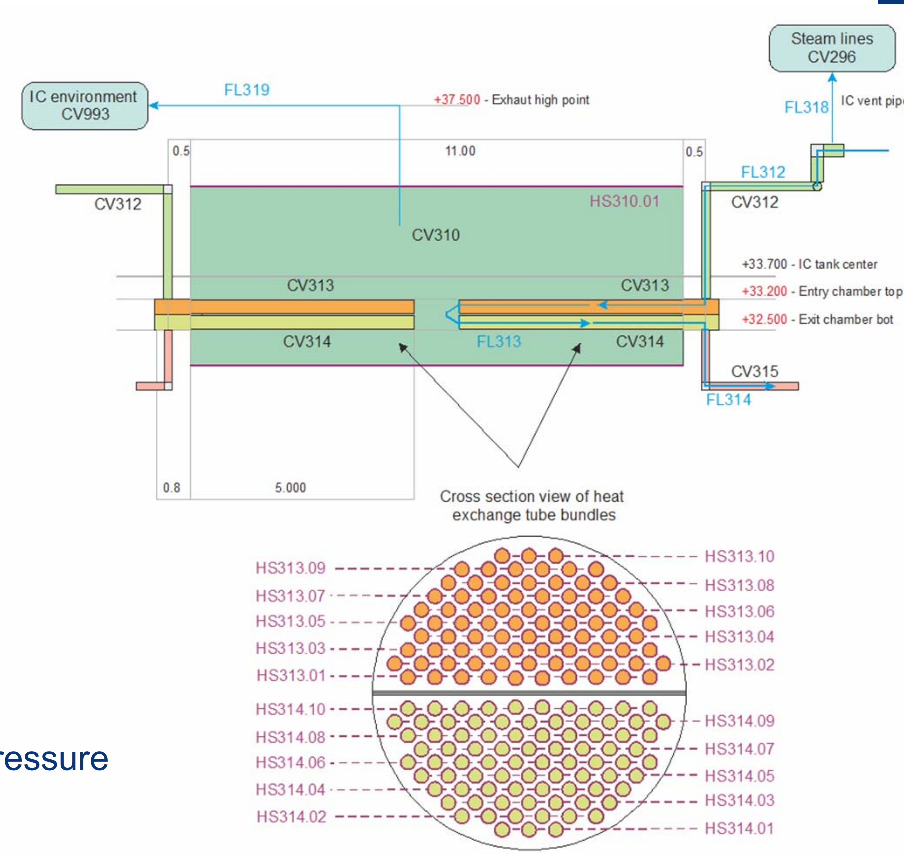
Overview of the MELCOR model for 1F1

- **Nuclear systems**
  - Operational systems like main steam, feedwater (steady state initiation)
  - Safety systems like Isolation Condenser, core spray, External water injection (fire engines)
  - RPV liquid level measurement system (failure of the measurement)

- **Noticeable from core spray system**
  - Spray package can malfunction at high pressure

- **Noticeable from IC modelling:**
  - MELCOR overestimates departure from nucleate boiling at low pressures
  - IC operation did not work until secondary side pressure was increased from 1 bar-abs to 2 bar-abs



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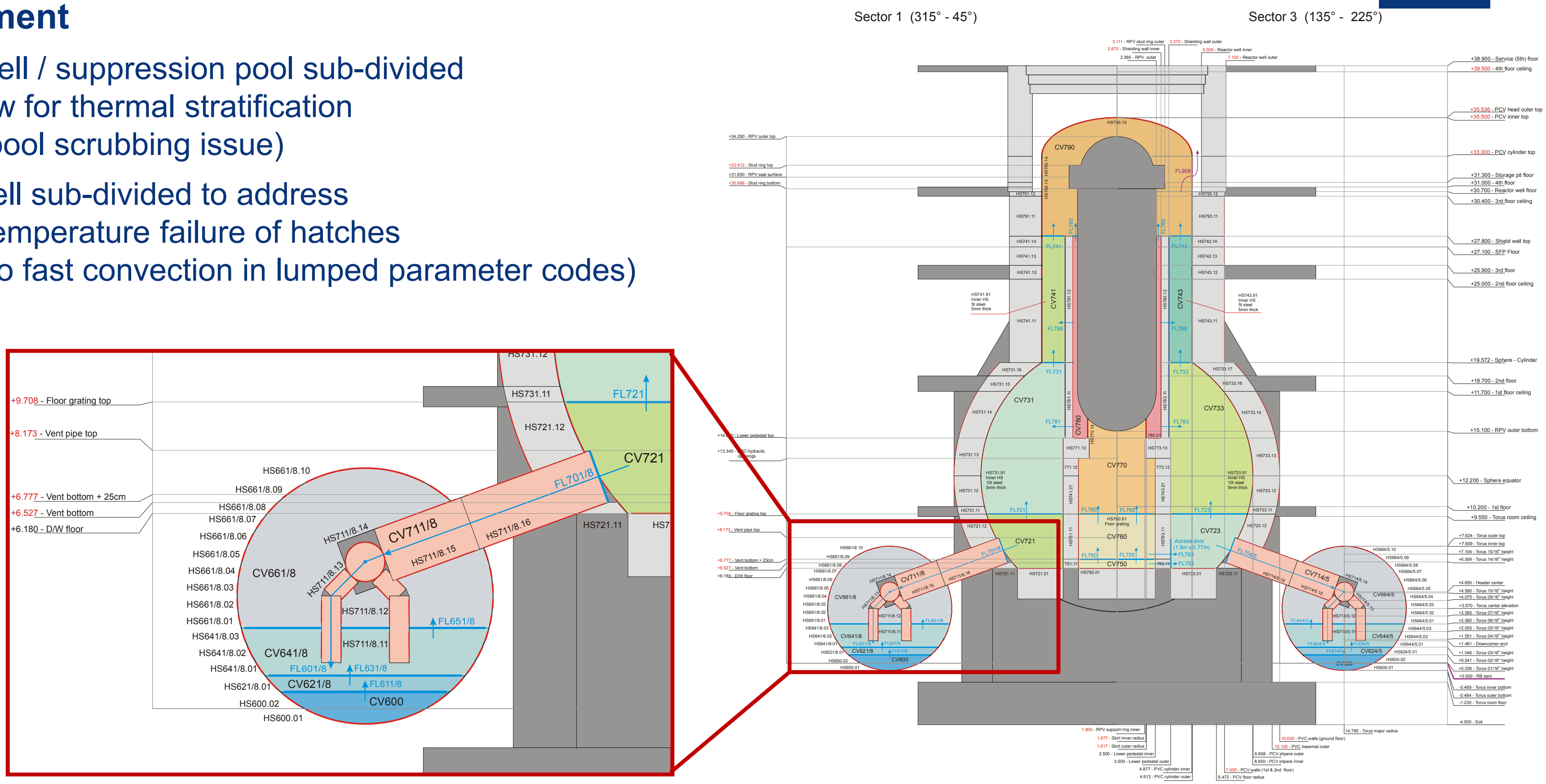
Overview of the MELCOR model for 1F1

- **Containment**
  - Wet-well / suppression pool sub-divided to allow for thermal stratification (-► spool scrubbing issue)
  - Dry-well sub-divided to address over-temperature failure of hatches (-► too fast convection in lumped parameter codes)



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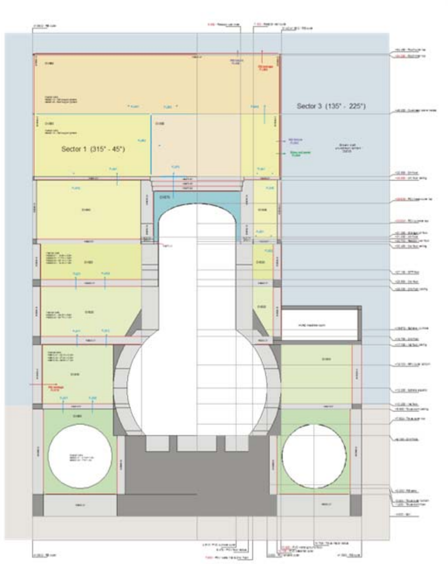
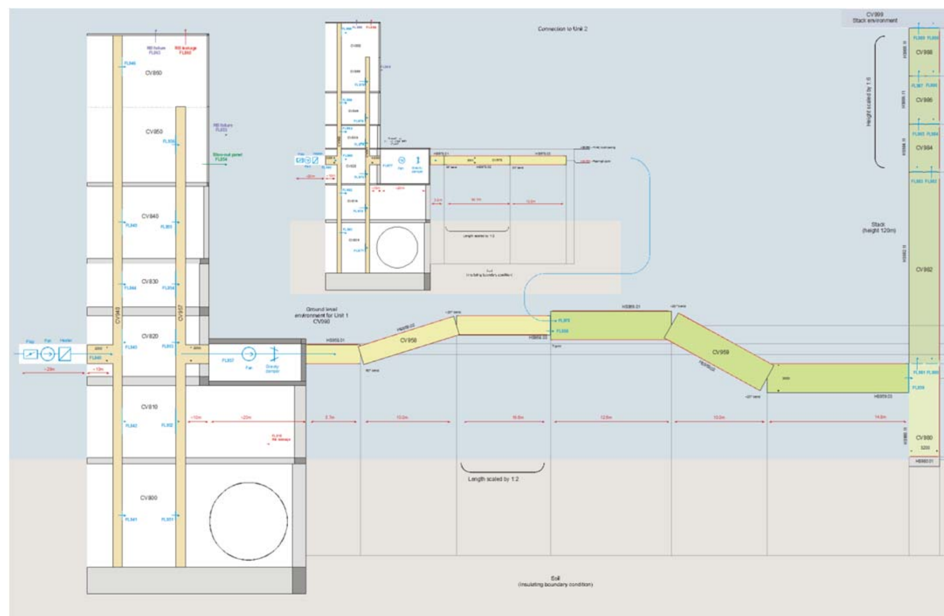
Overview of the MELCOR model for 1F1

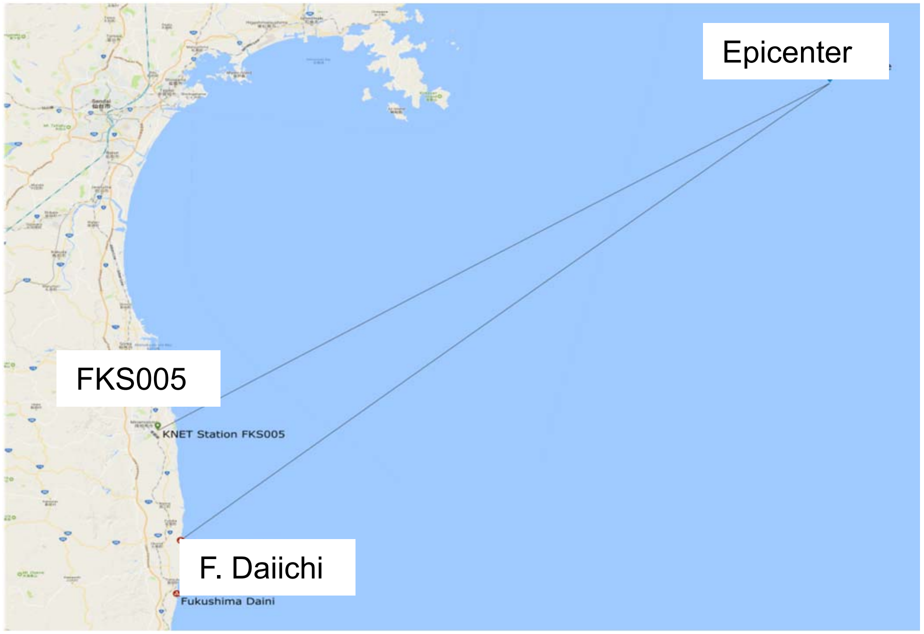
- **Surroundings**
  - Reactor Building (-► CF-based add-on to calculate **dose rate in building**)
  - HVAC, SGTS & stack (deposition and release of radionuclides)
  - Filtered Containment Venting System (**fictional**, for “what-if” studies)
  - Spent fuel pool (heat-up, boil-off, RN deposition)





First hour of the Incident in 1F1

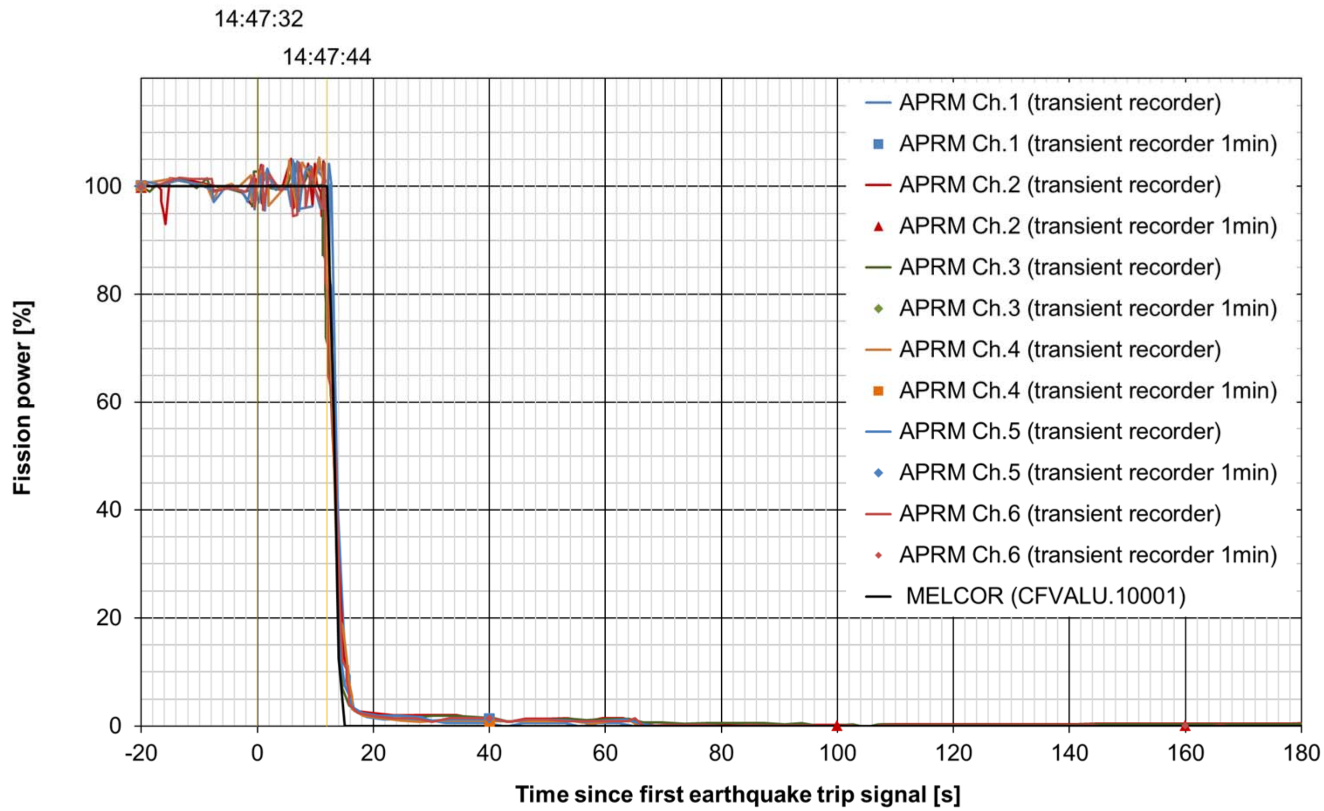
- **14:46:23 - Tohoku earthquake about 150 km from Fukushima Daiichi**
  - Based on seismic readings of the KNET Station FKS005[(1)] relative distance to the Fukushima site and wave propagating speed ~4 km/s, seismic trip threshold reached in Fukushima Daiichi at 14:47:32 ±1s
  - 1F1 alarm recorder[(2)] states first seismic scram signals 14:46:46
  - Correction of the alarm recorder clock by **46 s** (consistent with TEPCO timing)
  - Correction of the 1F1 transient recorder[(3)] by additional **33 s**
  - Timing of the paper strip recorders manually corrected



(1) http://www.strongmotioncenter.org/cgi-bin/CESMD/iqrStationMap.pl?ID=Japan_11Mar2011_usc0001xgp
(2) http://www.tepco.co.jp/en/nu/fukushima-np/index10-e.html#anchor02
(3) http://www.tepco.co.jp/en/nu/fukushima-np/index10-e.html#anchor05

First hour of the Incident in 1F1

- **14:47:32 - First seismic trip signals**
- **T + 12 s - 2 out of 2 signals causes SCRAM, terminating nuclear fission**



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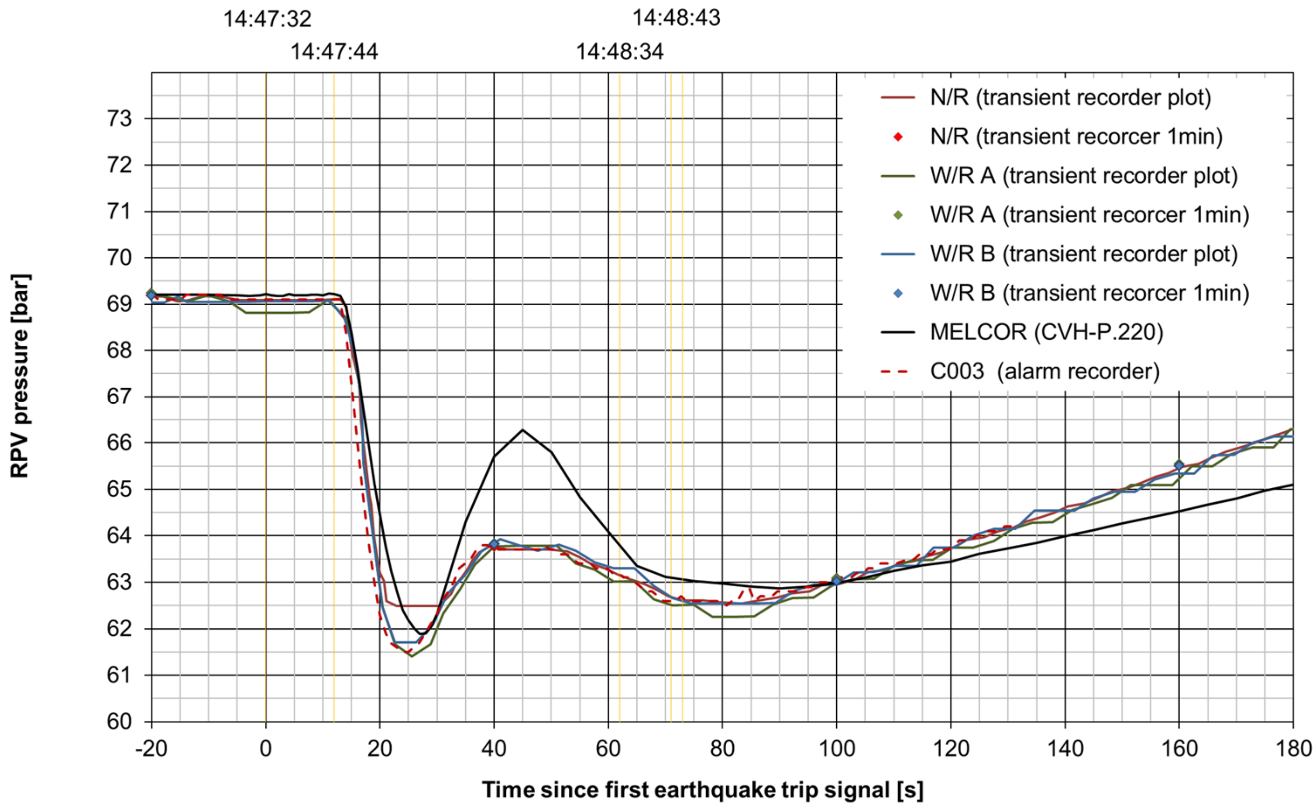
First hour of the Incident in 1F1

- After SCRAM steam generation stalls, but turbine still draws steam
- T + 15 s - RPV pressure drops



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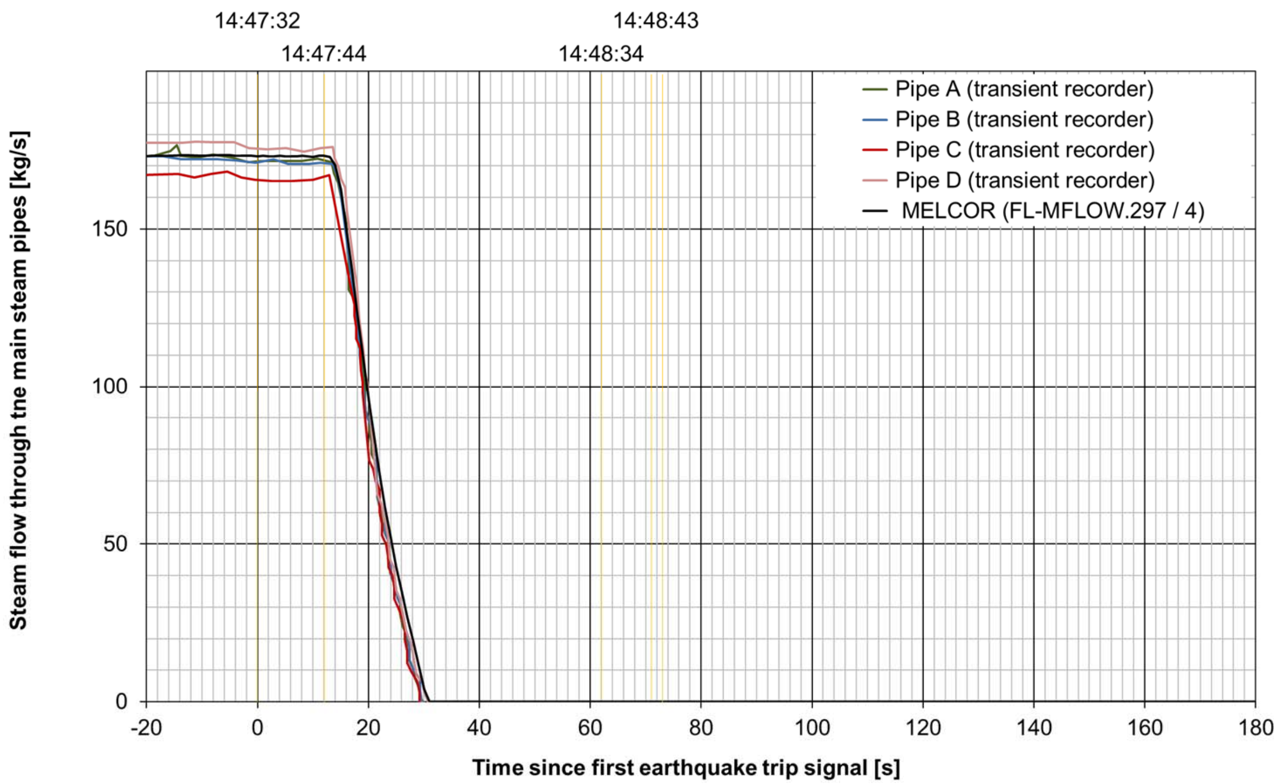
First hour of the Incident in 1F1

- Turbine control valves automatically close to stabilize PRV pressure
- T + 30 s - Steam flow to turbine stops and RPV pressure stabilizes



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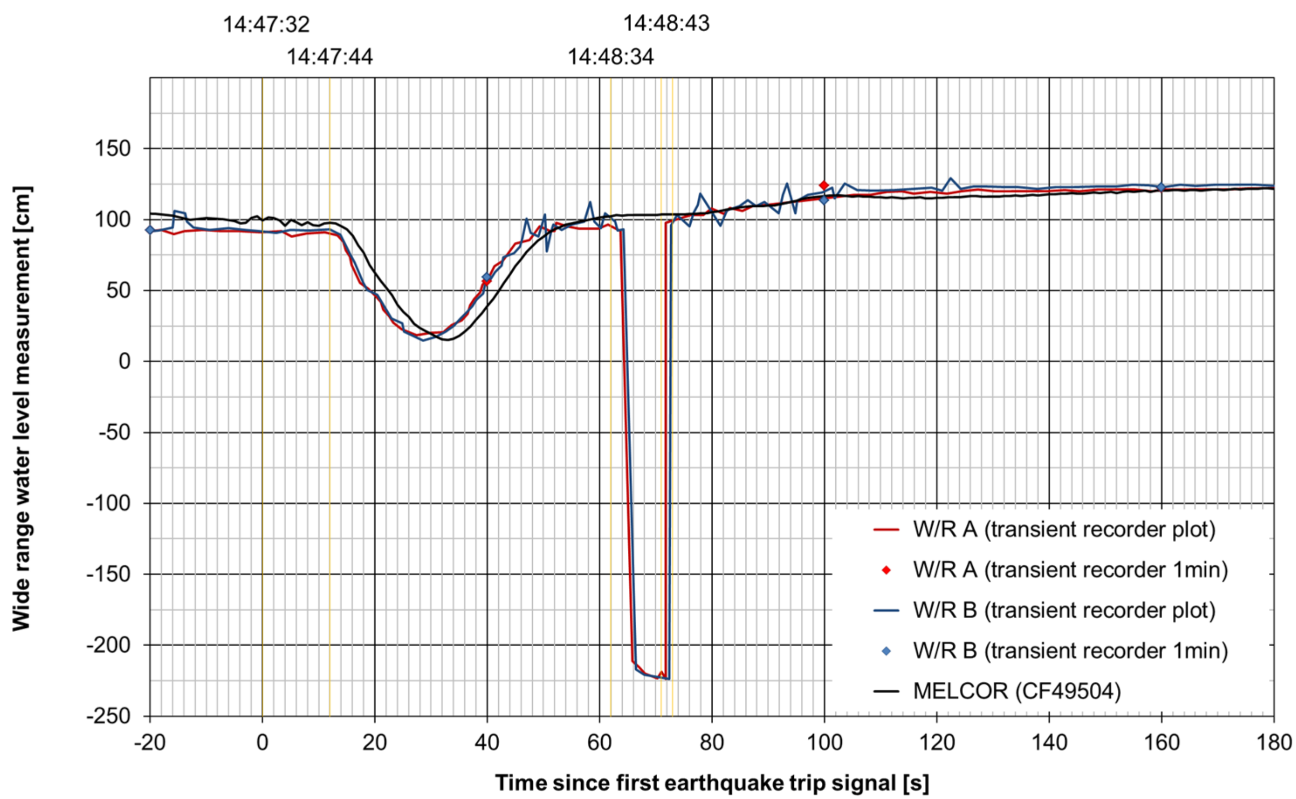
First hour of the Incident in 1F1

- T + 30 s - Void in the RPV core collapses, seemingly decreasing the RPV liquid level
- Measurement malfunctioning between loss of offsite power and start diesel generators



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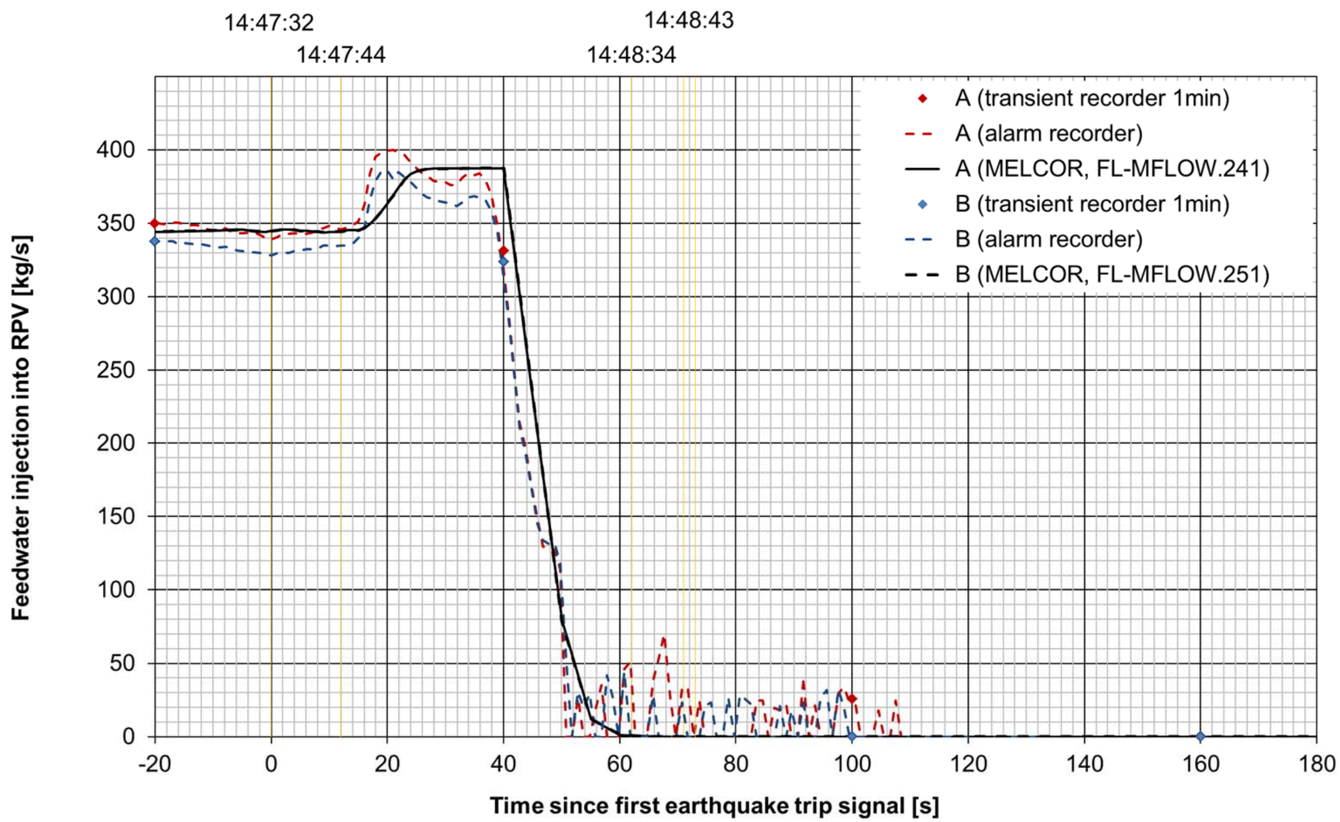
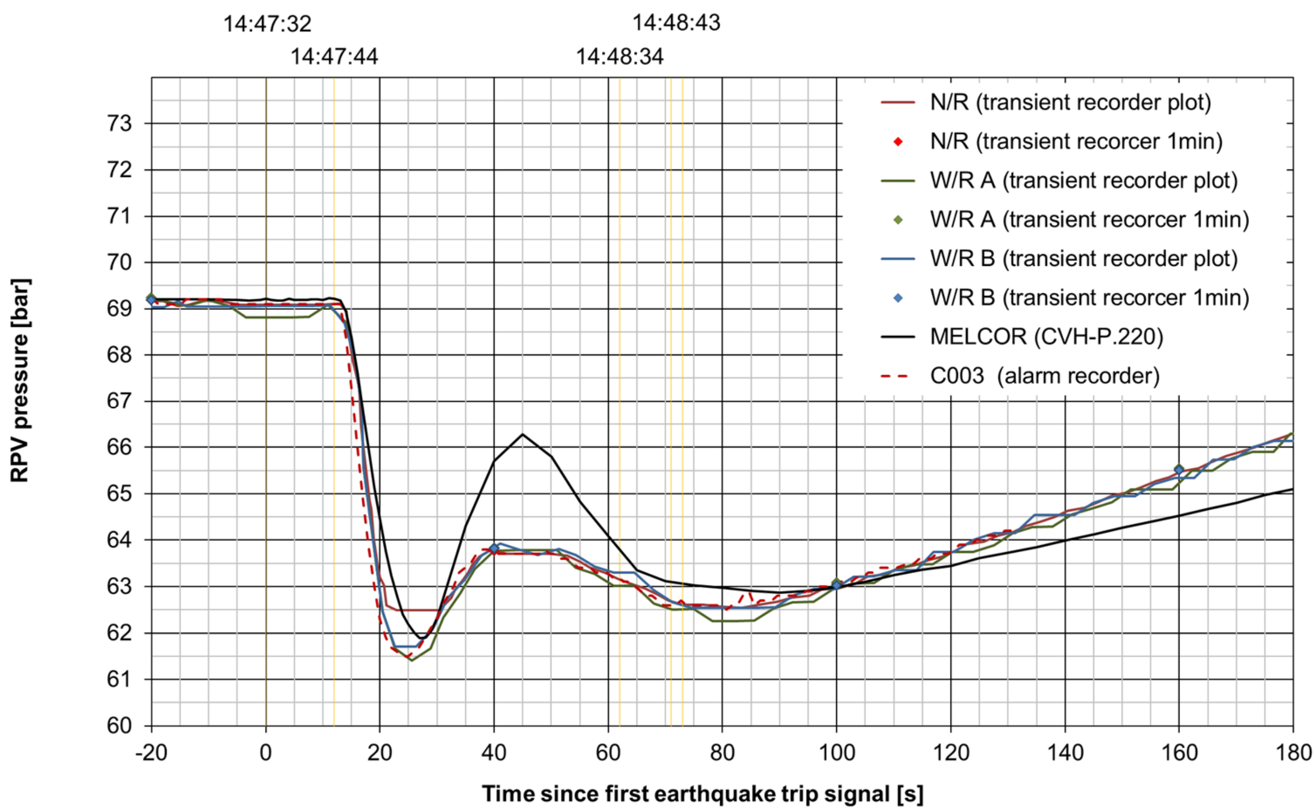
First hour of the Incident in 1F1

- T + 30 s - Lower RPV level causes automatic ramp-up of the feedwater injection



First hour of the Incident in 1F1

- **T + 40 s - Increased feedwater injection causes RPV pressure transient**



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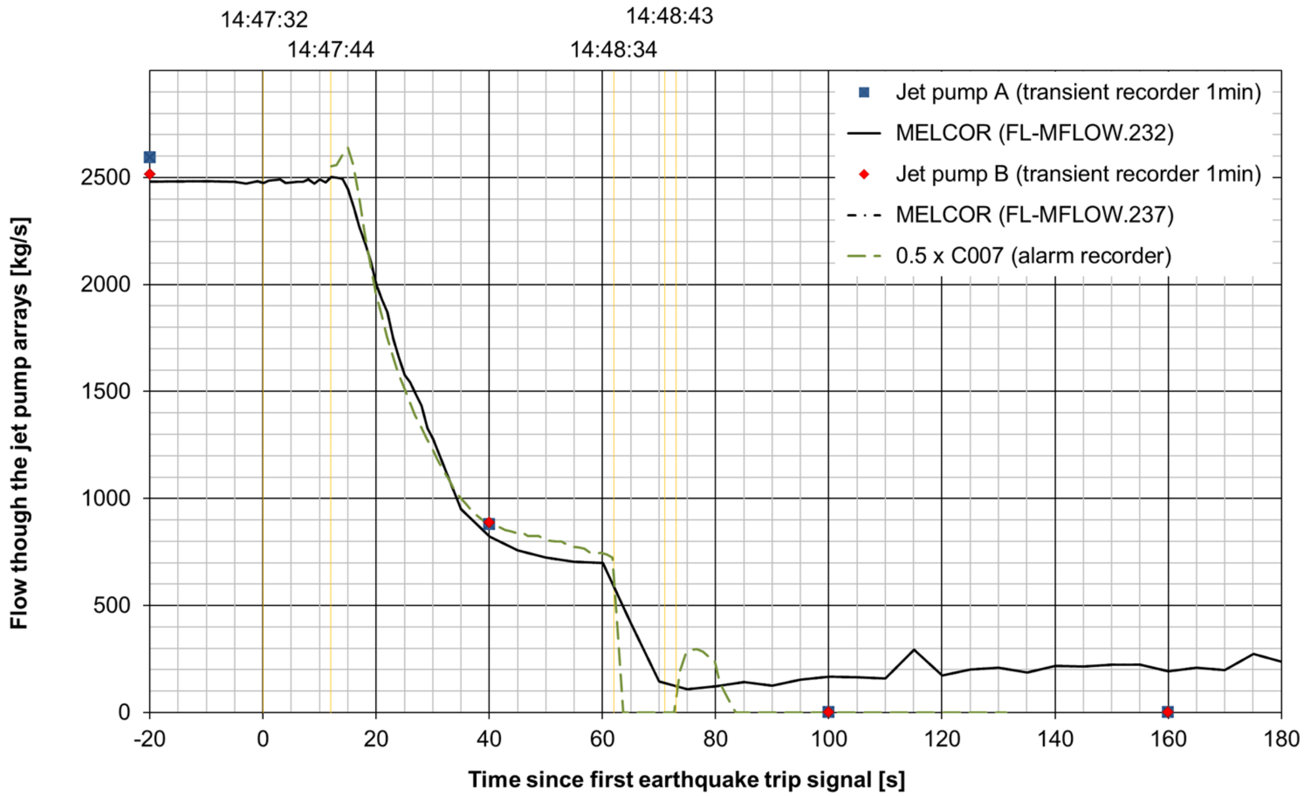
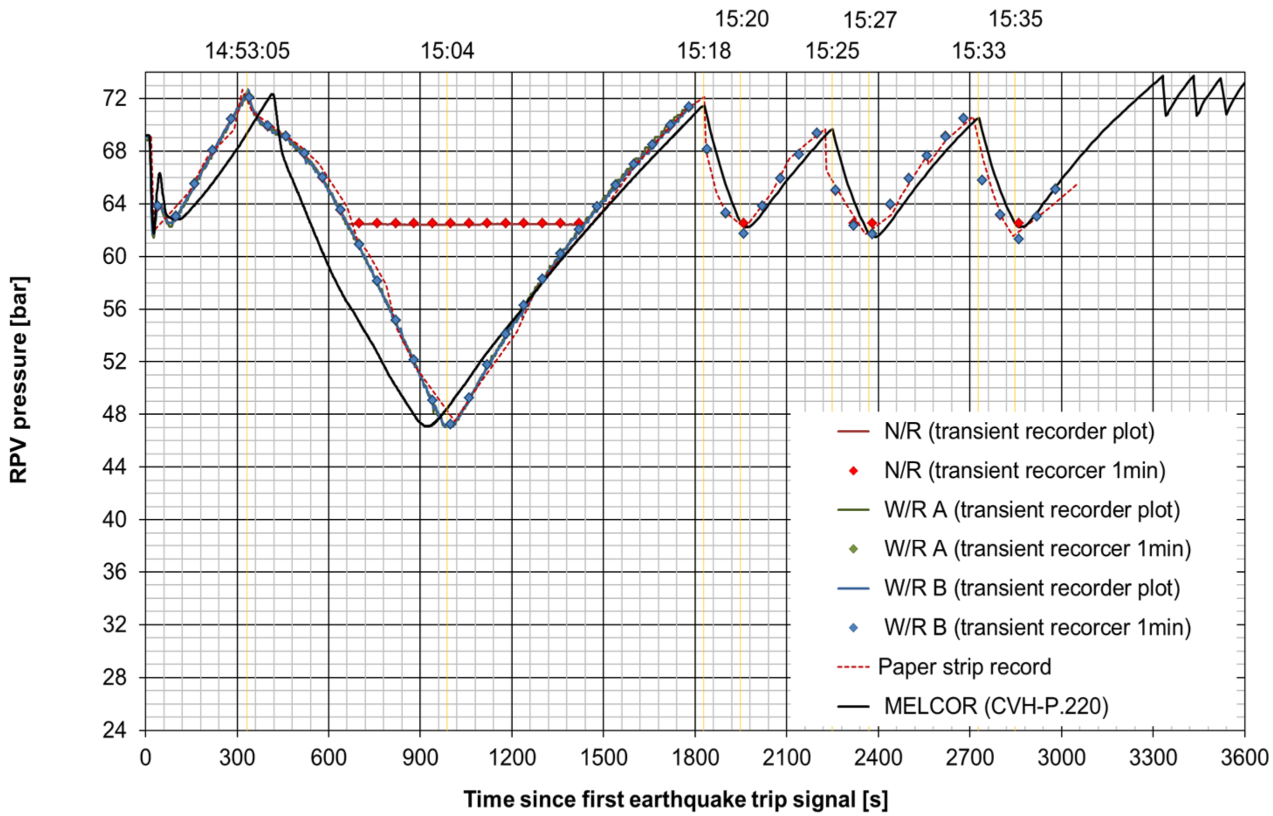
First hour of the Incident in 1F1

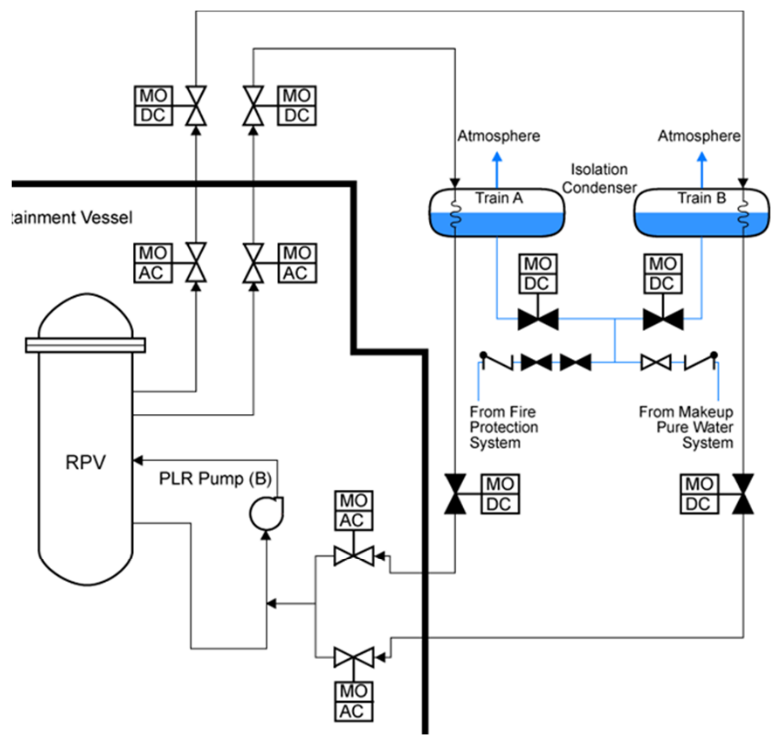
- T + 20 s – RPV recirculation system runs down to 30% after SCRAM
- T + 63 s – Recirculation pumps stops at LOOP



First hour of the Incident in 1F1

- **14:53:05 (T +333 s) – RPV pressure exceeds 72.2 bar, automatic activation of the Isolation Condenser (IC) train A & B**





First hour of the Incident in 1F1

- **Plant situation prior the arrival of the Tsunami**
  - Plant is in a stable hot-shutdown state, decay heat controlled by operating the IC
  - RPV is filled with water (significantly more than during power operation)
  - Small water injection into RCS by pump seal / CRD purge water (supplied by diesel generators)
  - Slight PCV heat-up / pressure rise by stop of dry-well cooling system (not supplied by diesel)
- **Analytical aspects of initial transient**
  - Transient timing and bottom lying physics is well understood
  - The MELCOR thermohydraulics corresponds well to the time-corrected plant data
  - Based on deviations between simulation and recorded measurements
    a timing error of ±15 min can be expected for predictions of the start of core damage
- **Fit parameters within the MELCOR model**
  - Closure time of the turbine control valves (direct fit to measurements)
  - Run-down of the primary loop recirculation pumps (direct fit to measurements)
  - Feedwater flow dependence on RPV liquid level (simplified modelling)
  - Flow/Void within and outside the RPV steam separator tubes (no detailed design knowledge)

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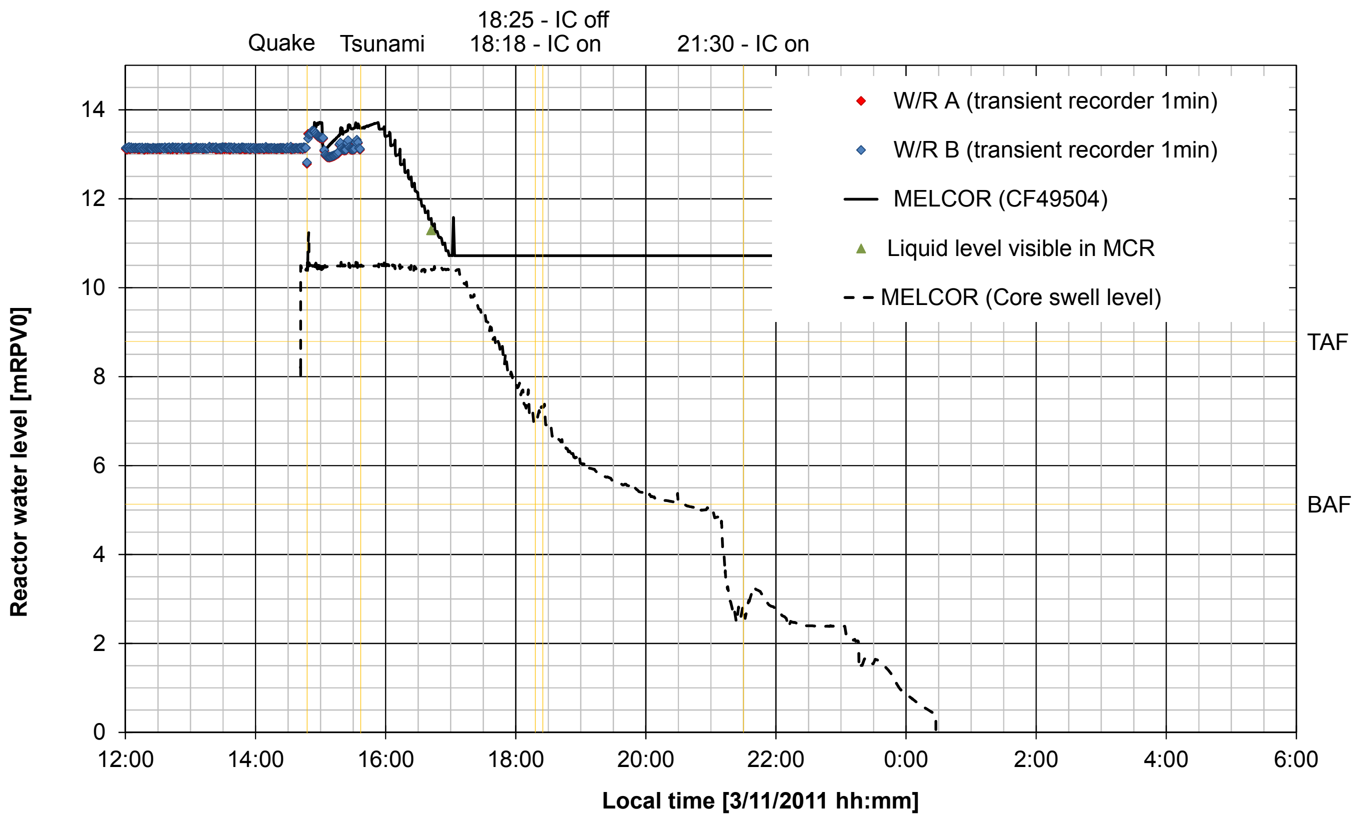
Escalation into an Accident

- **15:37 to 15:38 Tsunami flooding of the plant site**
  - Loss of instrumentation and control
  - Loss of all core cooling functions
  - IC currently inactive, and if it would have been active, fail-safe tube rupture signal would have shut it down

- **Further accident progression**
  - Decay heat ~10 MW vaporizes coolant
  - PRV pressure rises until a SRV opens
  - Coolant is discharged into the wet-well
  - RPV liquid level drops

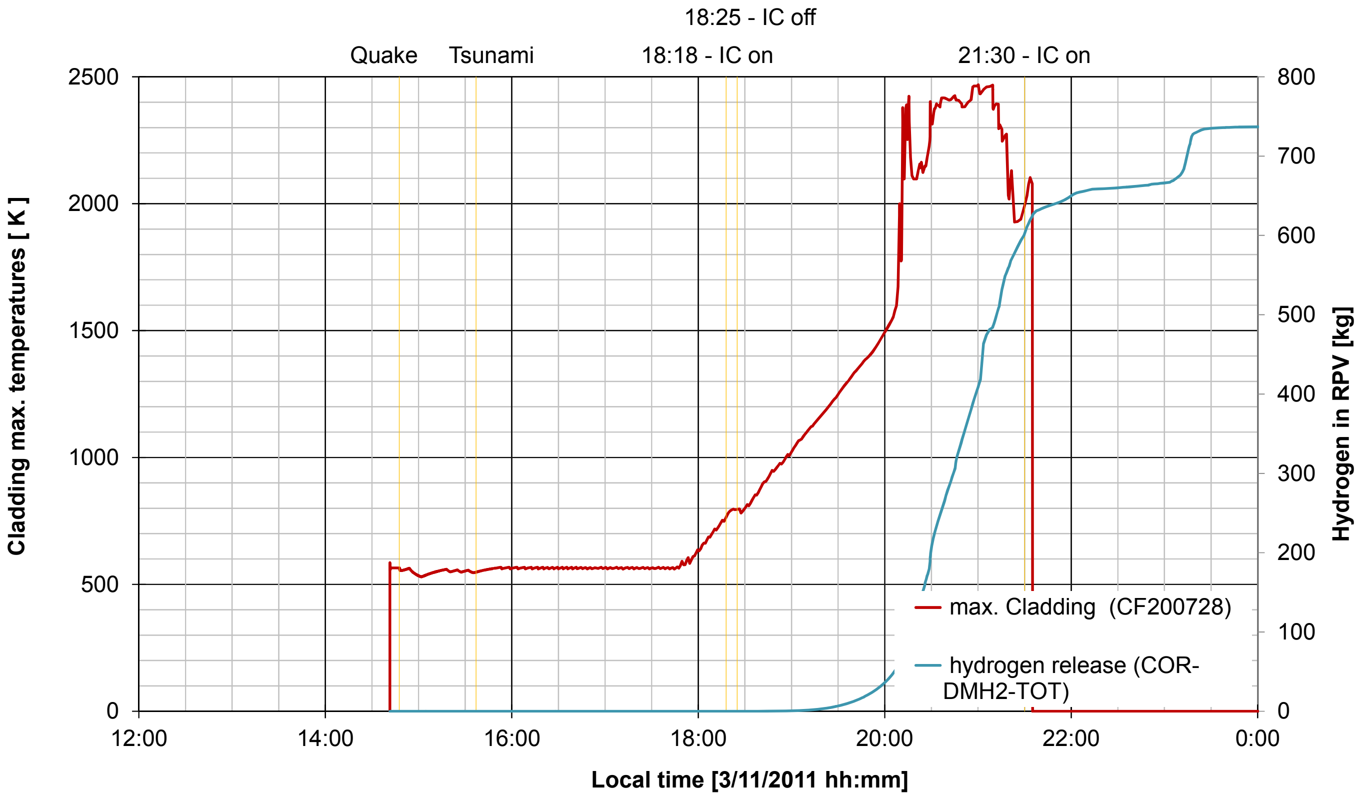
Escalation into an Accident

- **17:45 (T+2.5h) Top of active fuel (TAF) is reached**



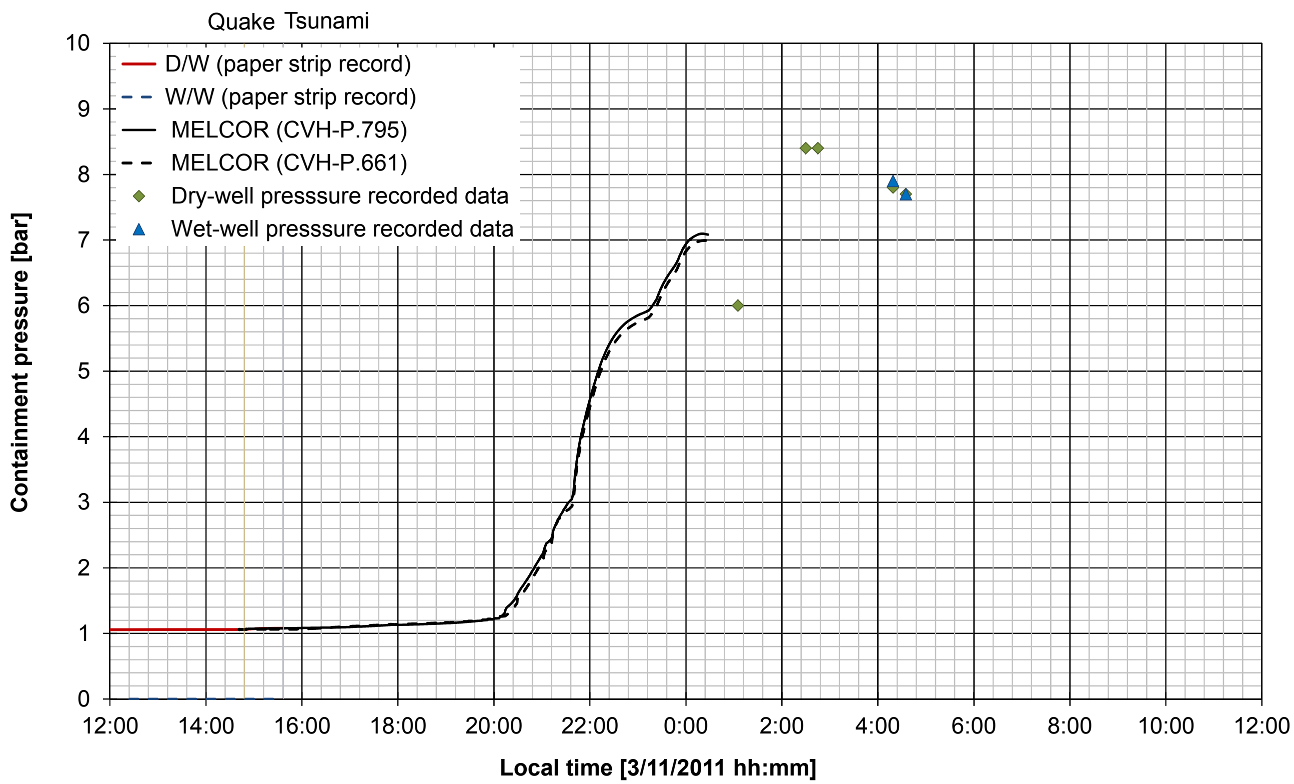
Escalation into an Accident

- **Core oxidation releases large amounts of hydrogen**



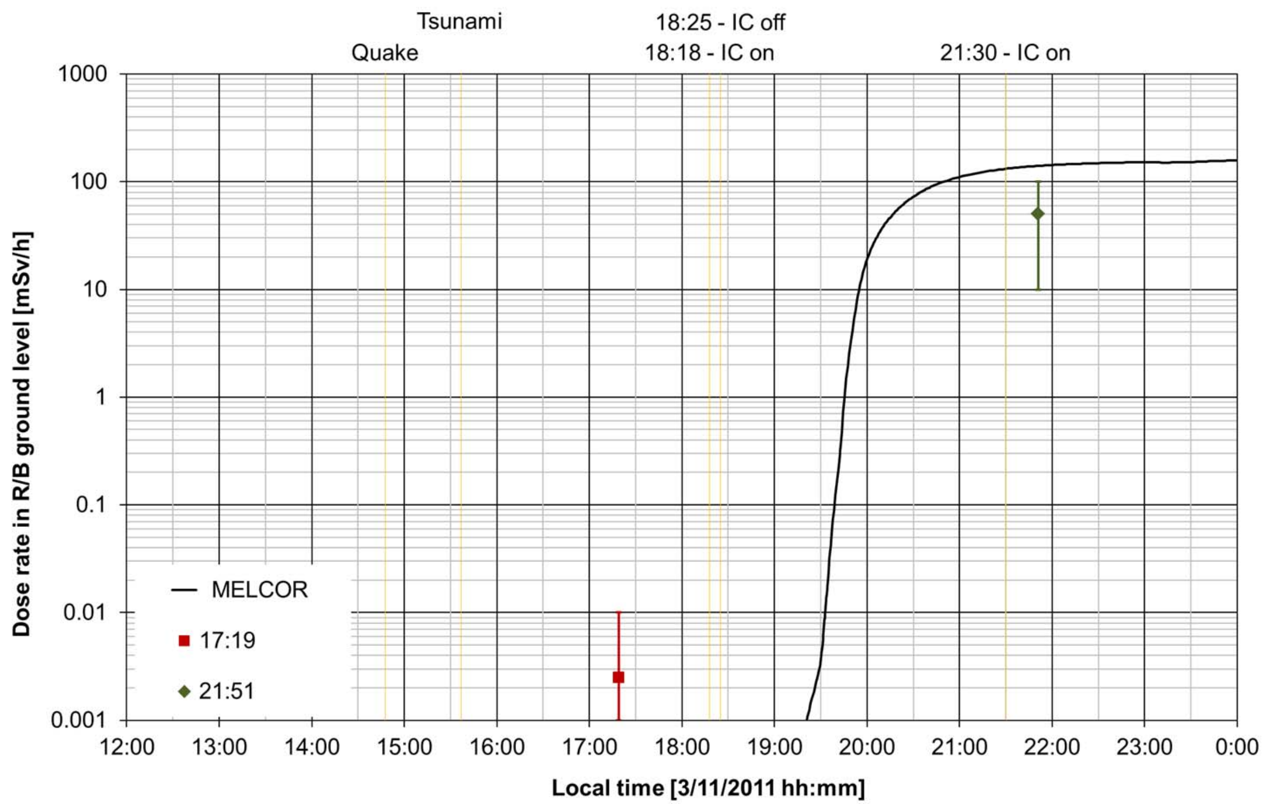
Escalation into an Accident

- **Hydrogen causes strong pressure buildup in BWR containments**



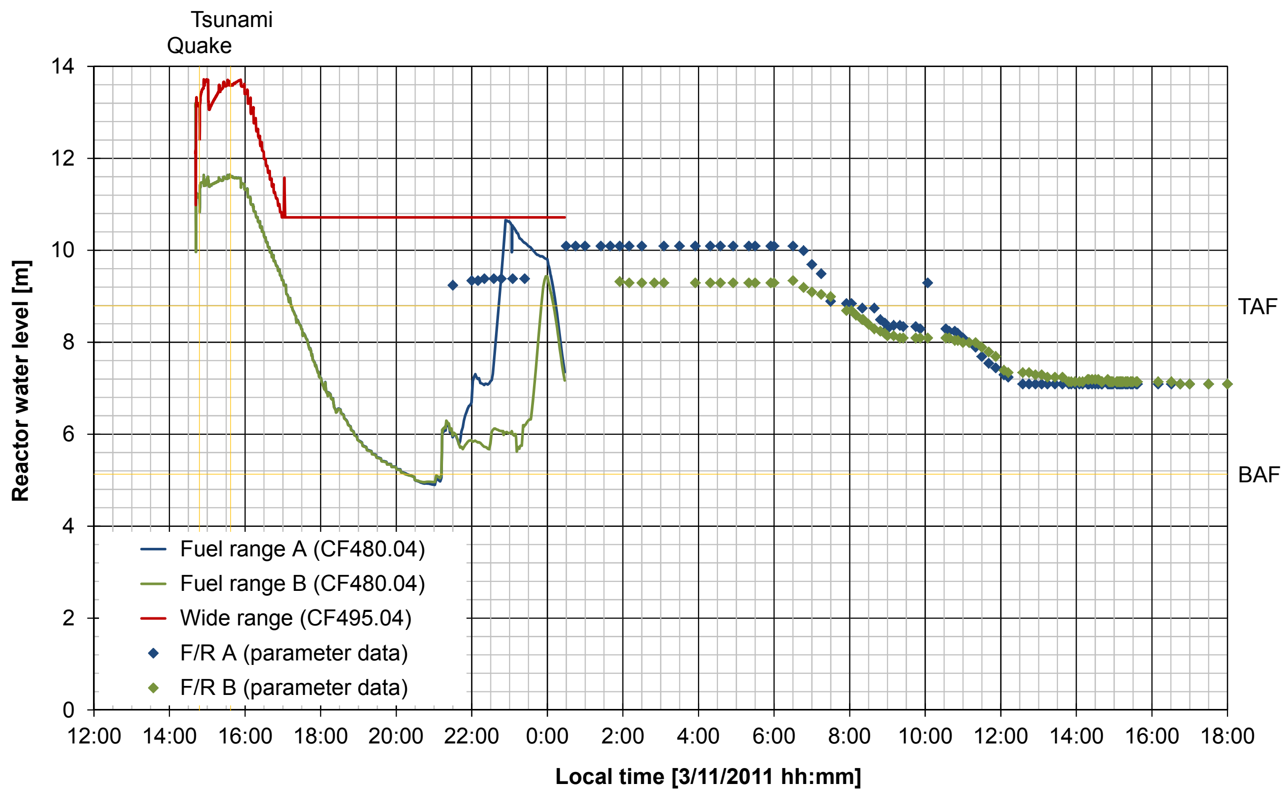
Escalation into an Accident

- **Observed vs. calculated dose rates in RB due to containment design leakage**



Escalation into an Accident

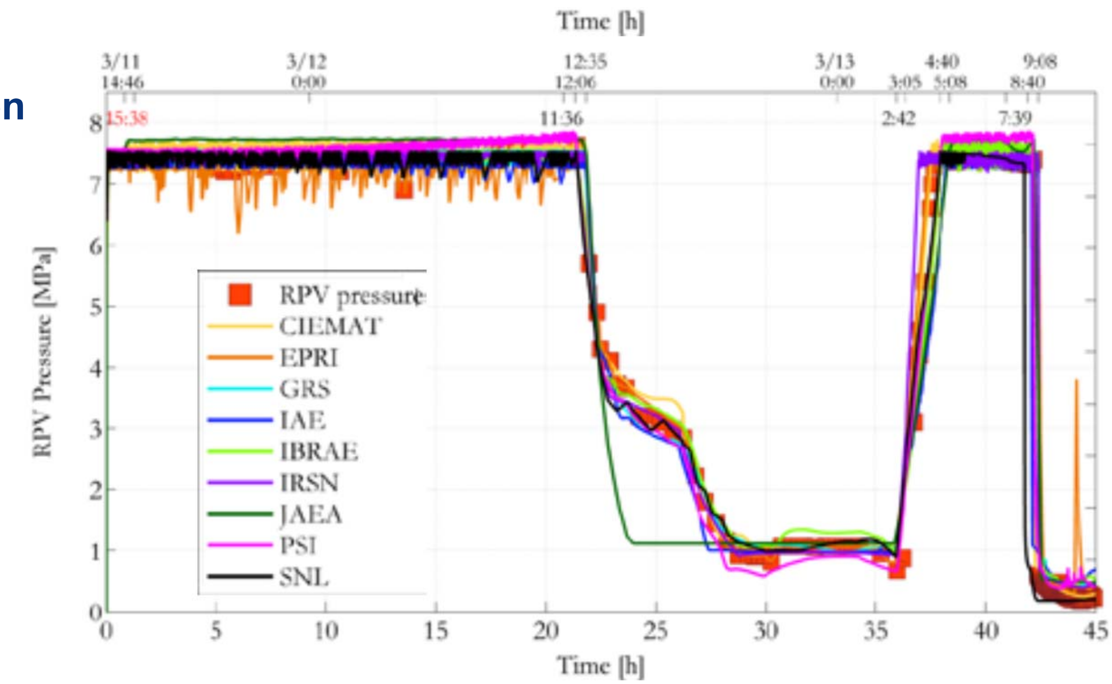
- **Failure of water level measurement only achievable by early RCS leakage, not by bare heat-up of containment through intact RCS walls**



2. SCIENTIFIC CONDUCT

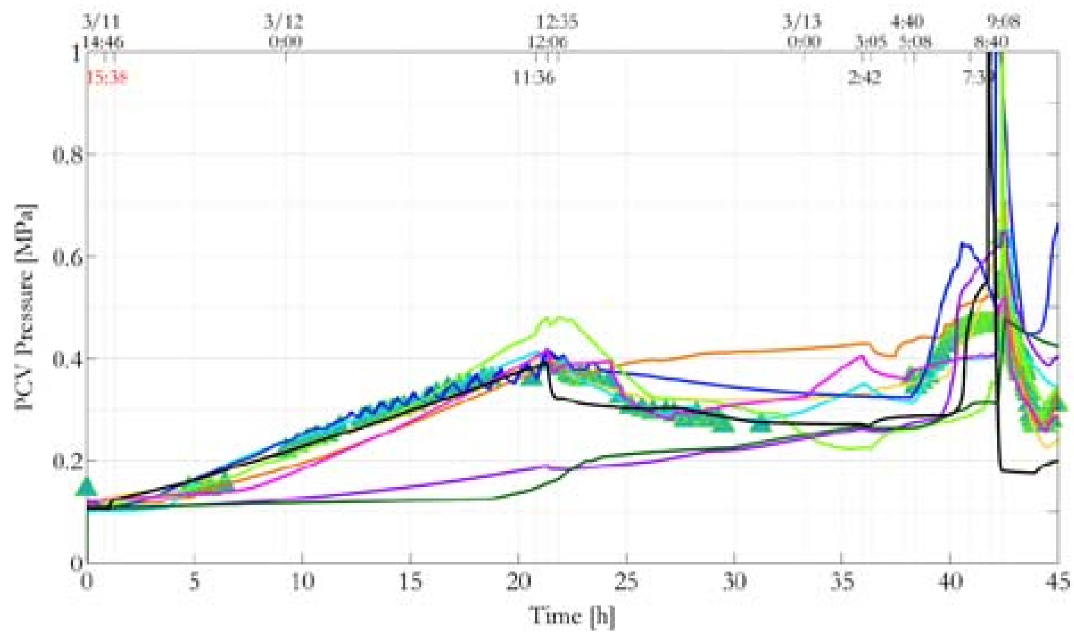
Scientific Conduct

- Example BSAF – RPV pressure Unit 3
- What do we see here:
  Fit of the simulations to measured pressure values
- What is NOT-necessarily seen:
  Numerical simulated accident progression in U3 with a high degree of accuracy
- Every model (good or bad) can be forced onto plant data
- Such pictures can suggest a higher accuracy than one really have
- Over-confidence in simulations can result in "negative training"



Scientific Conduct

- **Fitting is not worthless!**
  - With fitting one can access unknown information
  - Fitting allows to assume a certain situation, and **then one can evaluate derivative quantities**
- **Example BSAF - PCV pressure of U3 as result of the fitted RPV pressure**
- **Good practices when Fitting**
  - Disclose the fit
  - Do not state a fit / boundary condition as simulation result
  - Evaluate the invasion strength on the simulation
  - Choose a reasonable fit parameter (e.g. not an opening/closing containment leakage area to fit PCV pressure)



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3. EXAMINATION OF THE NUCLEAR FALLOUT

Examination of the Nuclear Fallout

- **Database for Radioactive Substance Monitoring Data**
  - by of the Japan Atomic Energy Agency
    http://emdb.jaea.go.jp/emdb/en/
- **Deduction of the core release fraction from the fallout isotope composition**
- **Insights into the core degradation**
  - ~ 2400 K to release silver
  - << 2800 K to not release americium
  - Sub-stoichiometric melts, and probably no large-scale liquefaction of oxides
  - No ruthenium release due to lack of oxygen (RuO2 boils at 1200°C, but Ru can not be oxidized by steam)
  - Low niobium but high molybdenum release, but in MELCOR both are the same class -► Cs2MoO4 class definition

Element	Release fraction from Core
Iodine, Cesium, Tellurium, Technetium, Molybdenum	up to 100 %
Silver	up to 100 %
Antimony	~ 5 %
Barium	~ 1 %
Niobium, Barium, Strontium	~ 0.1 %
Ruthenium	< 0.1 %
Americium	< 5E-4
Uranium, Plutonium	Not measurable

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Examination of the Nuclear Fallout

- **Plutonium release of high public interest**
  - Numerous papers claim to have observed reactor plutonium
- **Plutonium background from surface nuclear weapon test**
- **Separation of reactor plutonium from weapon plutonium by different isotope composition**
- **Signal vanishes with increasing signal strength -▶ measurement errors?**