Overview of fuel behaviour and core degradation, on the basis of modelling results

OECD-NEA Workshop on Accident Tolerant Fuels of LWRs,
10-12 December 2012

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OECD/NEA

Outline

- Objective of the overview
- Analytical studies with Severe Accident codes
  - References & disclaimer
  - Input data & methodology
  - Event sequence and safety functions
  - Comparison between calculated and measured data
- Zr-water reaction, oxidation and H_2 production, fuel melting
  - Kinetics of cladding oxidation and H_2 production
  - Progression of fuel melting
- Conclusion

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Objective of the overview

- After the Fukushima-Daichii accident, analyses by means of Severe Accident (SA) codes were carried out, aiming at:
  - Highlighting the key physical phenomena allowing a correct understanding of the sequence of events
  - Validating the current SA tools
  - Improve models & methods, in order to reduce the discrepancy between calculated and measured data
  - Supporting the future decommissioning phase
- In this context, the current overview aims at:
  1. Gathering the available elements on the **role of the fuel/cladding-water interaction (Zr + H_2O)**, that are available only through modelling, because of the absence of data directly related to fuel/cladding behaviour
  2. Drawing conclusions on the status of the modelling capabilities of current tools, particularly for the purpose of the foreseen application to ATF fuels

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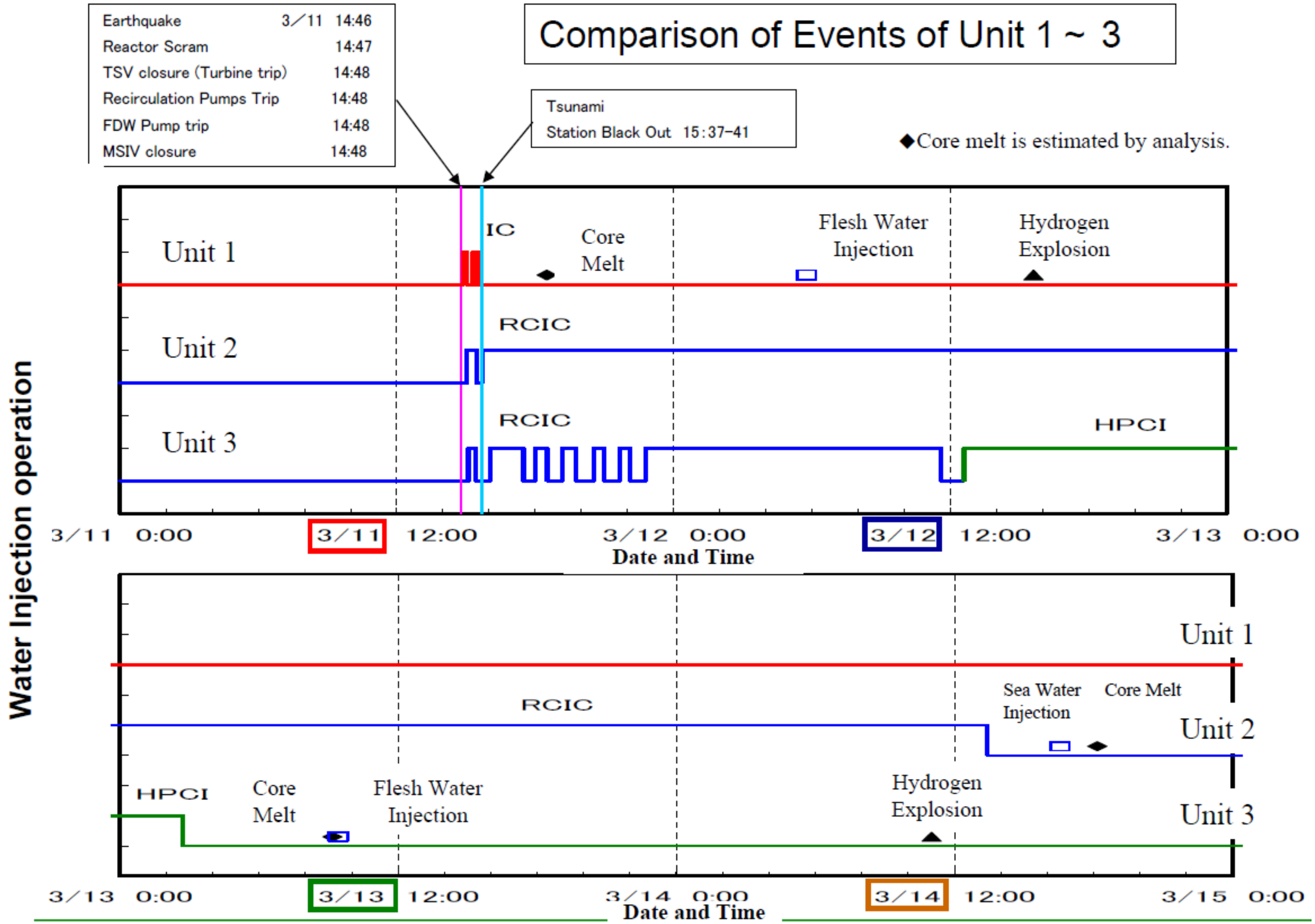
SA studies sources: References & Disclaimer

- This overview is based on different studies carried out with MELCOR, MAAP, THALES2, (RELAP5) presented at different technical workshops on Fukushima and at recent meetings hold at the OECD/NEA:
  - OECD/NEA Workshop on Fukushima Daiichi Accident Analysis (BSAF), 18-20 June 2012, Paris
  - OECD/NEA/Nuclear Science Committee Meeting, 13-15 June 2012, Paris
- The results presented are model results, not facts:
  - Obtained with the state-of-the-art methods and input data set available when these simulations were carried out
  - Not definitive, but subjects to continuous updating and improvements as new input data become available
  - In the rationale of this presentation, analyzed in a ***qualitative manner***

SA studies: Input data & Methodology

- Input data
  - BWR Mark-I Fukushima-Daichii Units 1, 2 and 3
  - Safety systems, including those playing a major role in the accident:
    - Isolation Condenser, IC
    - Reactor Core Isolation Cooling system, RCIC
    - High Pressure Core Injection system, HPCI
  - Operational data as reported by TEPCO
- Methodology
  - In case of incomplete or missing data or hypotheses, input data are adjusted to reduce the calculation/measurement discrepancy on measured data (timeline, plant parameter):
    - Venting flow rate, external water injection via fire protection system
    - Leakage from RPV with gas temperature > 450 C. (Unit 1)
    - No RCIC trip due to high water level for loss of electrical power (Unit 2)

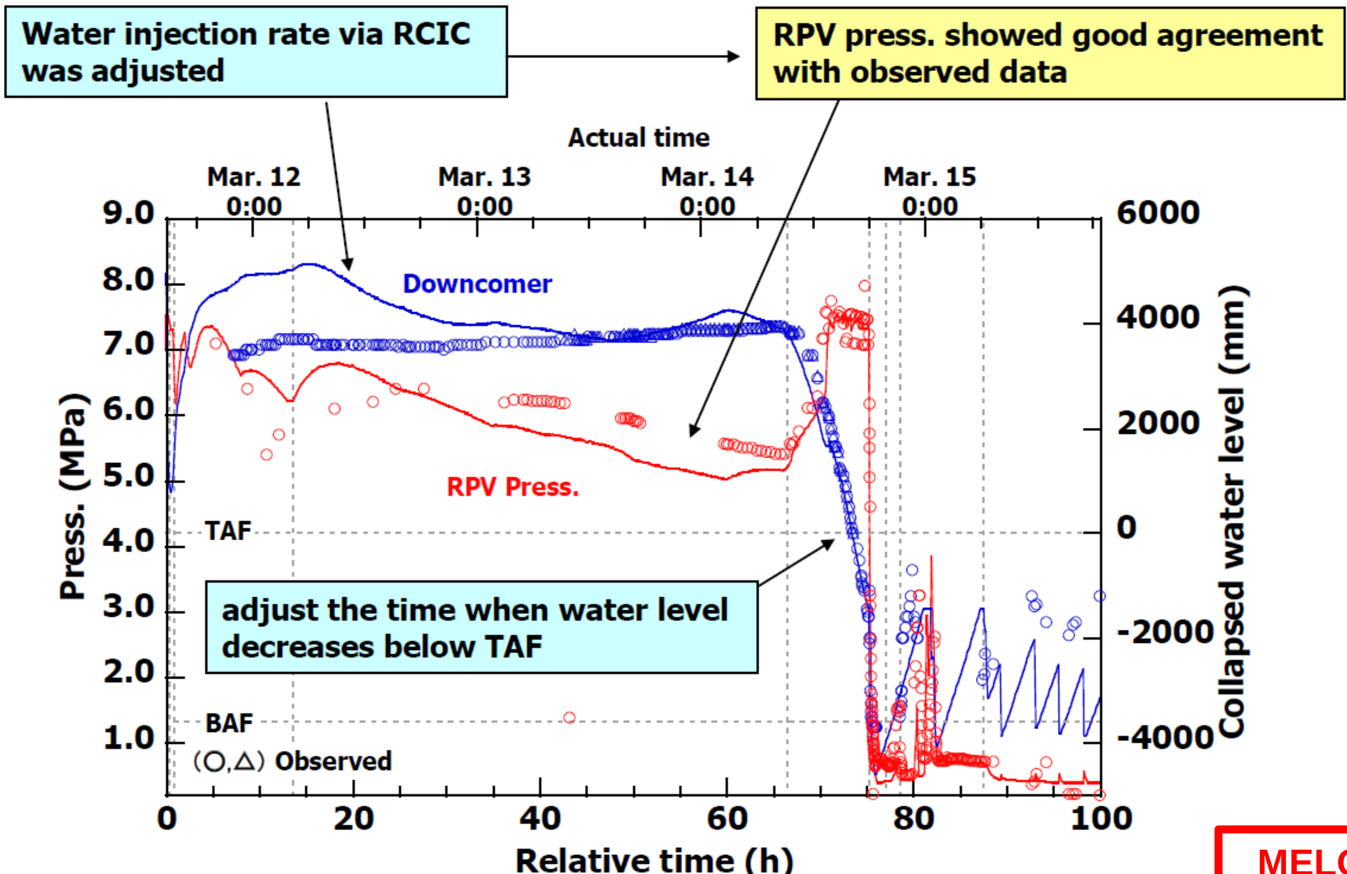
SA studies: Event sequence & safety functions



H. Ono (JNES), « Initial event analysis of TEPCO's Fukushima Dai-ichi NPS accident », NEA Workshop, 18-20 June 2012, Paris

SA studies: Comparison between calculated and measured data (1 / 4)

RPV Press. and Water Level of Unit 2

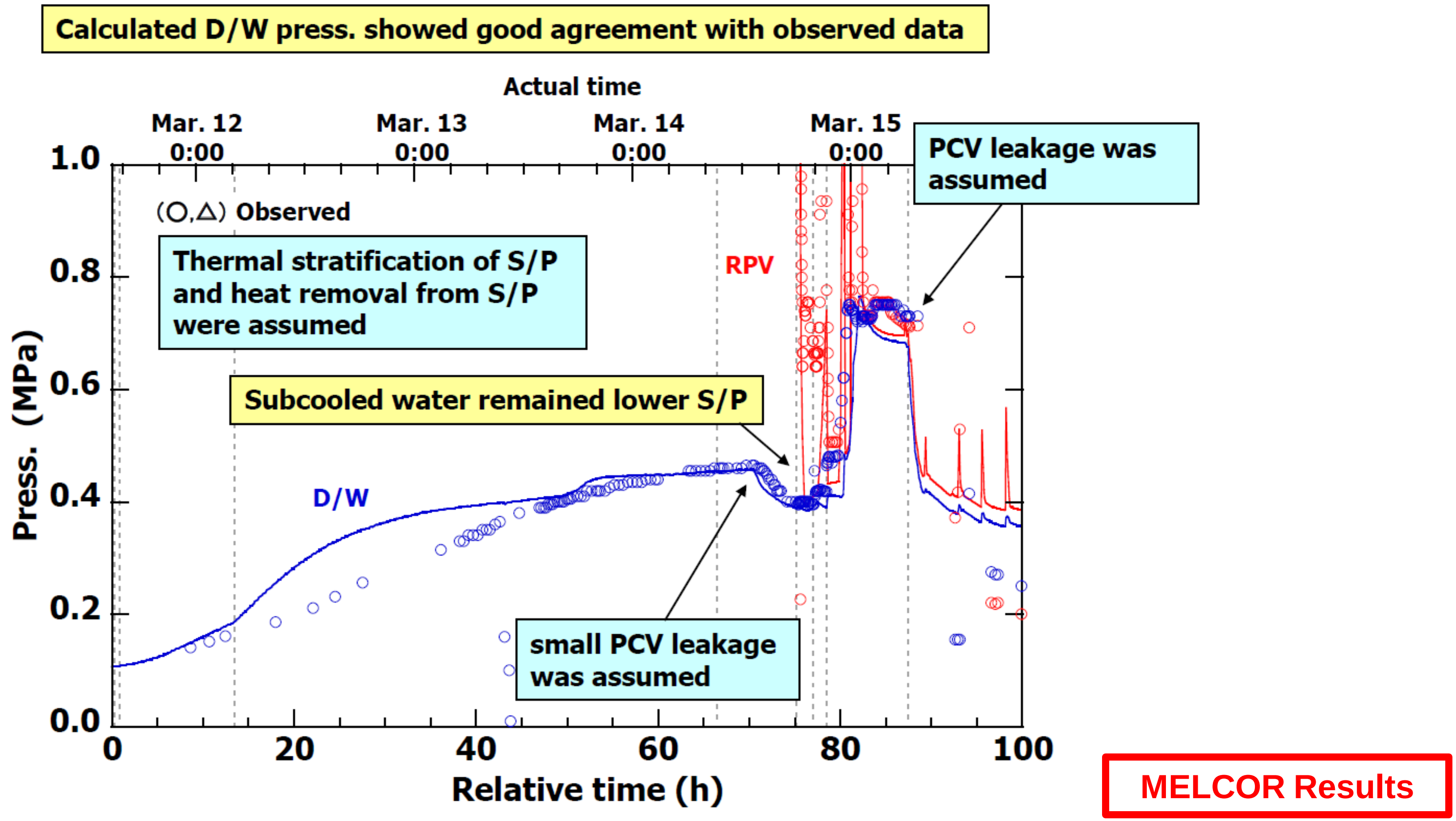


MELCOR Results

H. Hoshi (JNES), « Severe Accident Analysis on TEPCO's Fukushima Dai-ichi NPS », NEA Workshop, 18-20 June 2012, Paris

SA studies: Comparison between calculated and measured data (2 / 4)

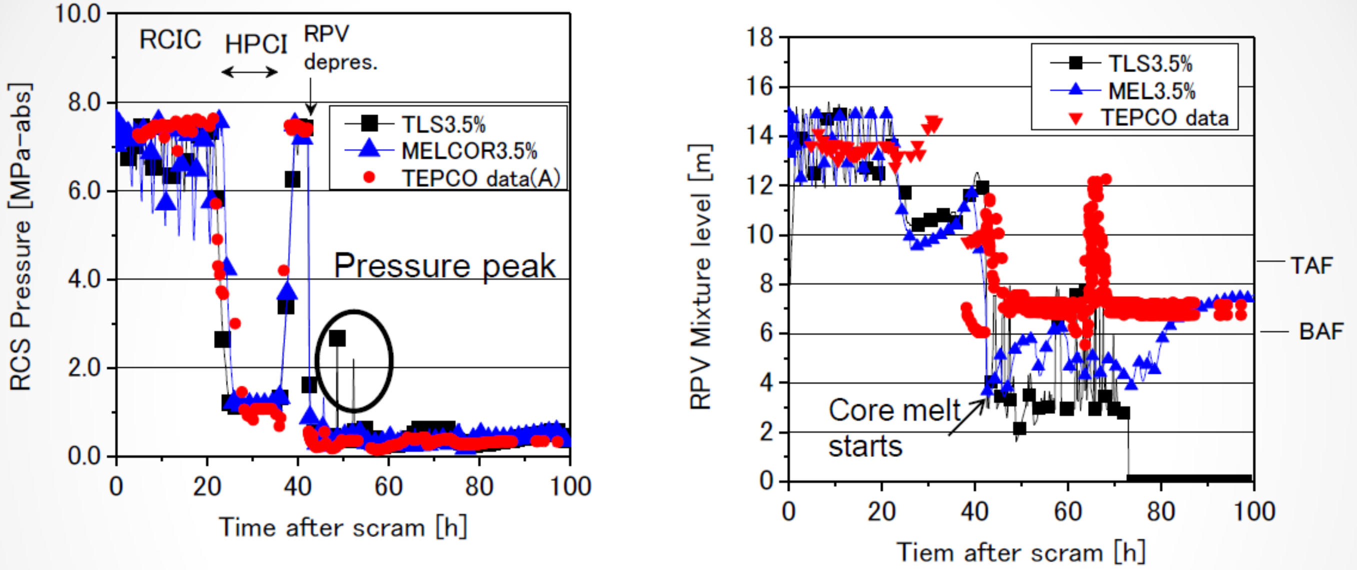
RPV Press. and D/W Press. of Unit 2



H. Hoshi (JNES), « Severe Accident Analysis on TEPCO's Fukushima Dai-ichi NPS », NEA Workshop, 18-20 June 2012, Paris

SA studies: Comparison between calculated and measured data (3 / 4)

RPV Pressure and Liquid Level (BC)



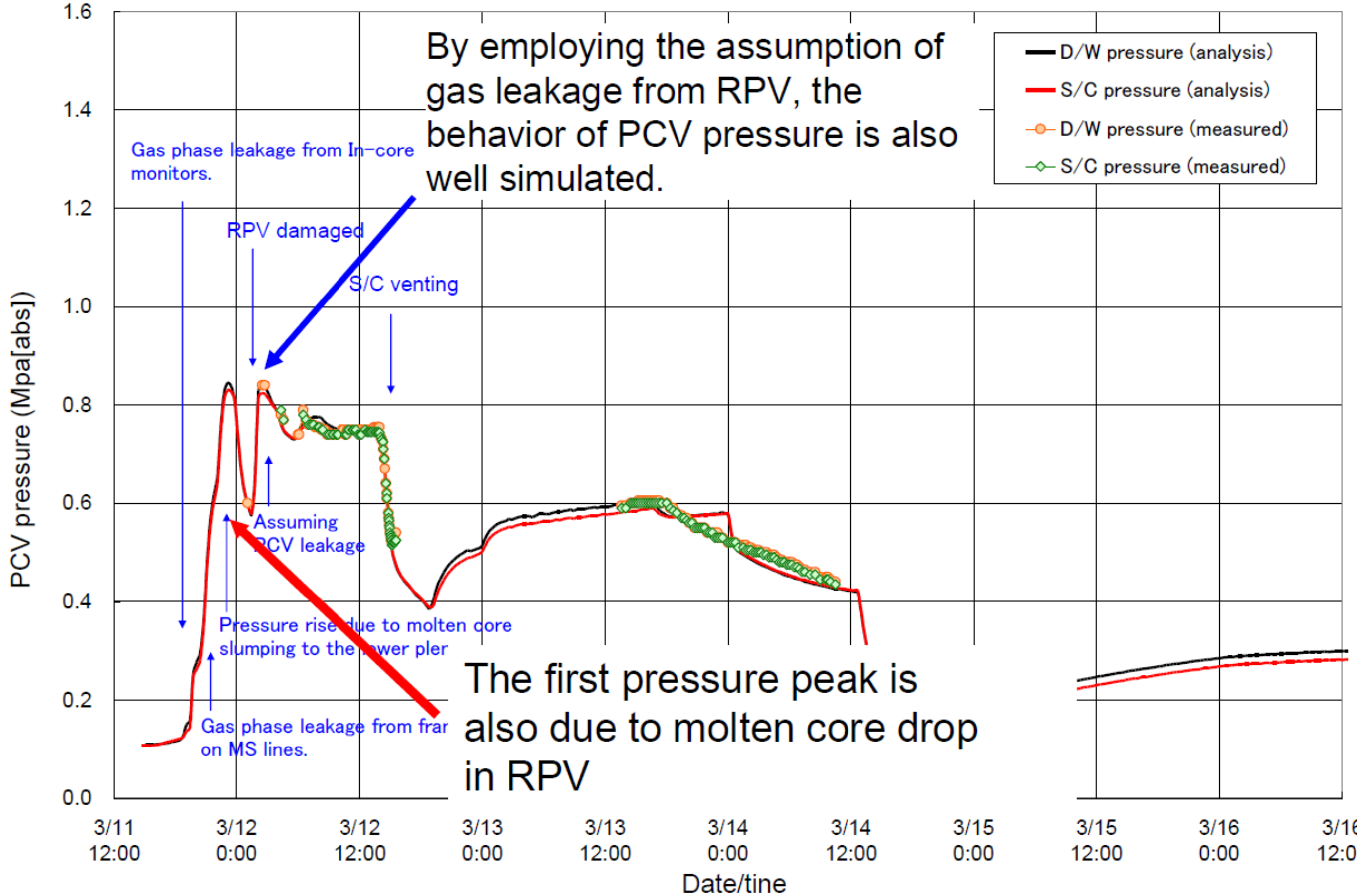
- ◆Results from two codes are similar before core melt starts.
- ◆The relocation of molten core into water existing lower plenum results in several RPV pressure peaks in THALES2 analysis.

MELCOR & THALES2 Results

J. Ishikawa (JAEA), « Analysis for Fukushima-Daiichi NPP (Unit 3) with THALES2 and MELCOR codes », NEA Workshop, 18-20 June 2012, Paris

SA studies: Comparison between calculated and measured data (4 / 4)

3. Analytical results on Unit 1 (PCV pressure)



MAAP Results

Y. Yamanaka (TEPCO), « Severe Accident Analysis on Fukushima-Daiichi NPP by using MAAP Code », NEA Workshop, 18-20 June 2012, Paris

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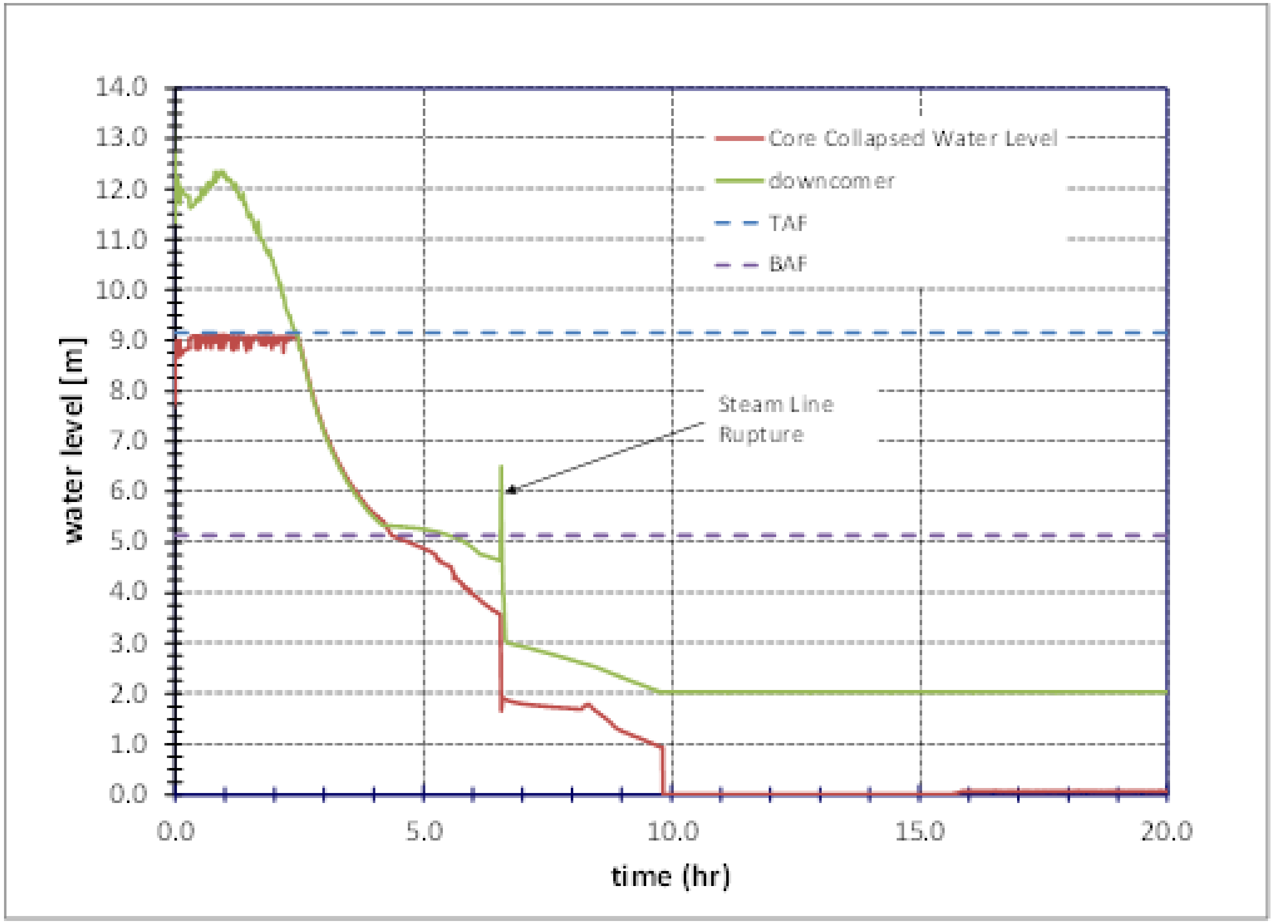
Vessel Water Boil-Down in Unit-1

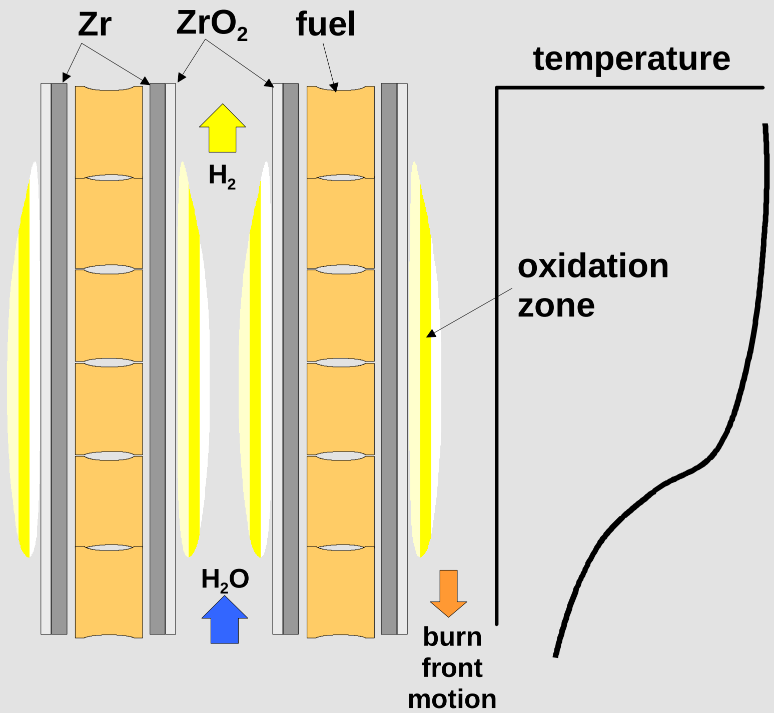


- MELCOR predictions
- Top of fuel uncovered by 3 hr
- Steam line rupture at 6.5 hr
- Vessel dry at 10 hr

MELCOR Results

R. Gauntt (SANDIA Nat. Lab.), « Fukushima-Daiichi Accident study: MELCOR Analyses and Results », NEA/NSC Meeting, 13-15 June 2012, Paris

Steam Oxidation of Zr in Fuel Assemblies



$$Zr + 2H_2O \longrightarrow ZrO_2 + 2H_2 \quad 5.8\times10^6 \text{ joule/kg}$$

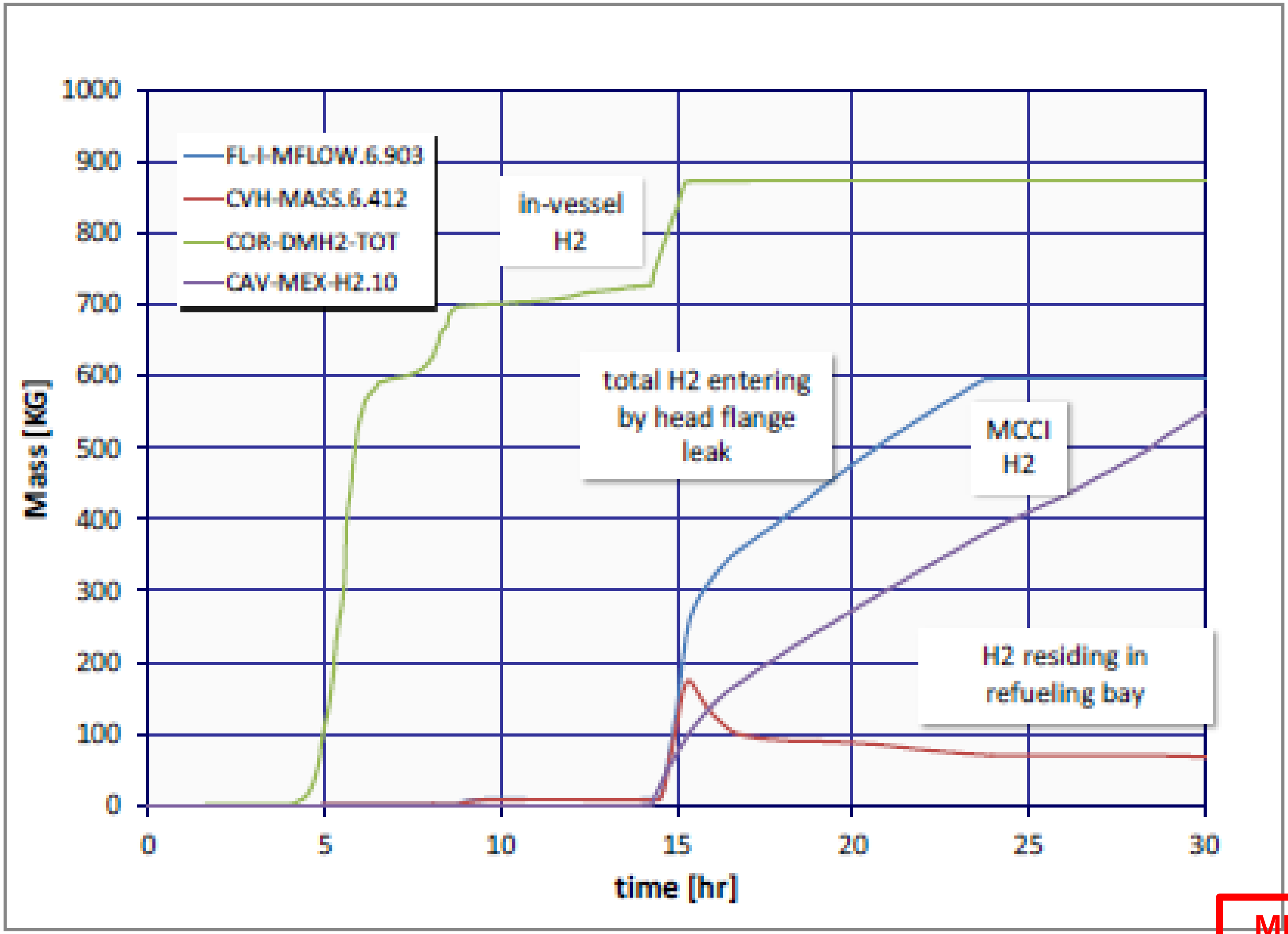
$$\frac{dT}{dt} = \frac{1}{mC_p}\left[Q_{ox}(T) - Q_{loss}(T)\right] \quad \text{heatup rate}$$

- Decay heat initially heats uncovered fuel a few ~7K/min
- Chemical heat from Zr-oxidation drives heatup rate to over 30 K/min
- Hydrogen is produced in steam oxidation

MELCOR Results

R. Gauntt (SANDIA Nat. Lab.), « Fukushima-Daiichi Accident study: MELCOR Analyses and Results », NEA/NSC Meeting, 13-15 June 2012, Paris

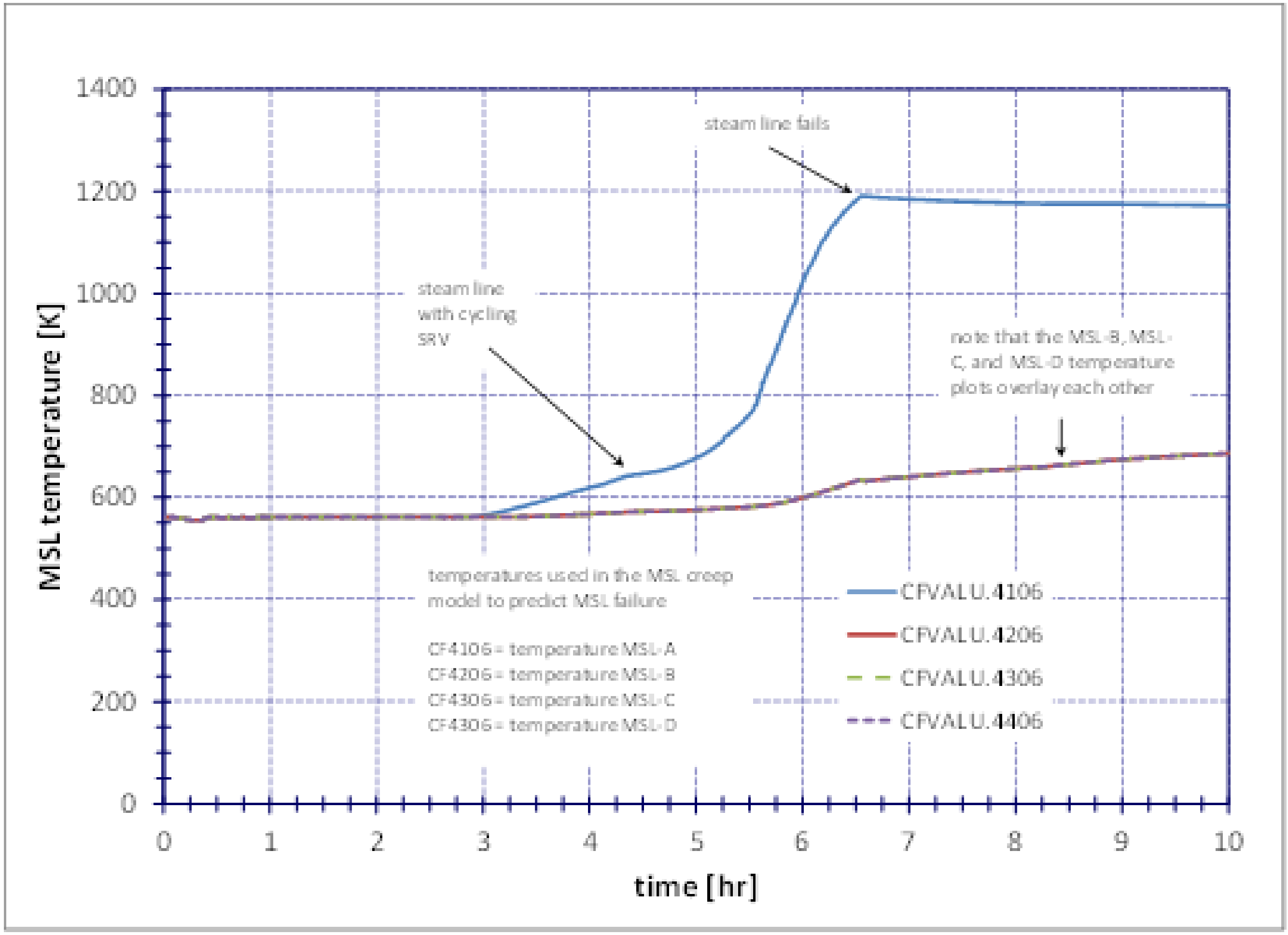
Hydrogen in 1F1



MELCOR Results

R. Gauntt (SANDIA Nat. Lab.), « Fukushima-Daiichi Accident study: MELCOR Analyses and Results », NEA/NSC Meeting, 13-15 June 2012, Paris

High Gas Temperature Weakens Steam Line

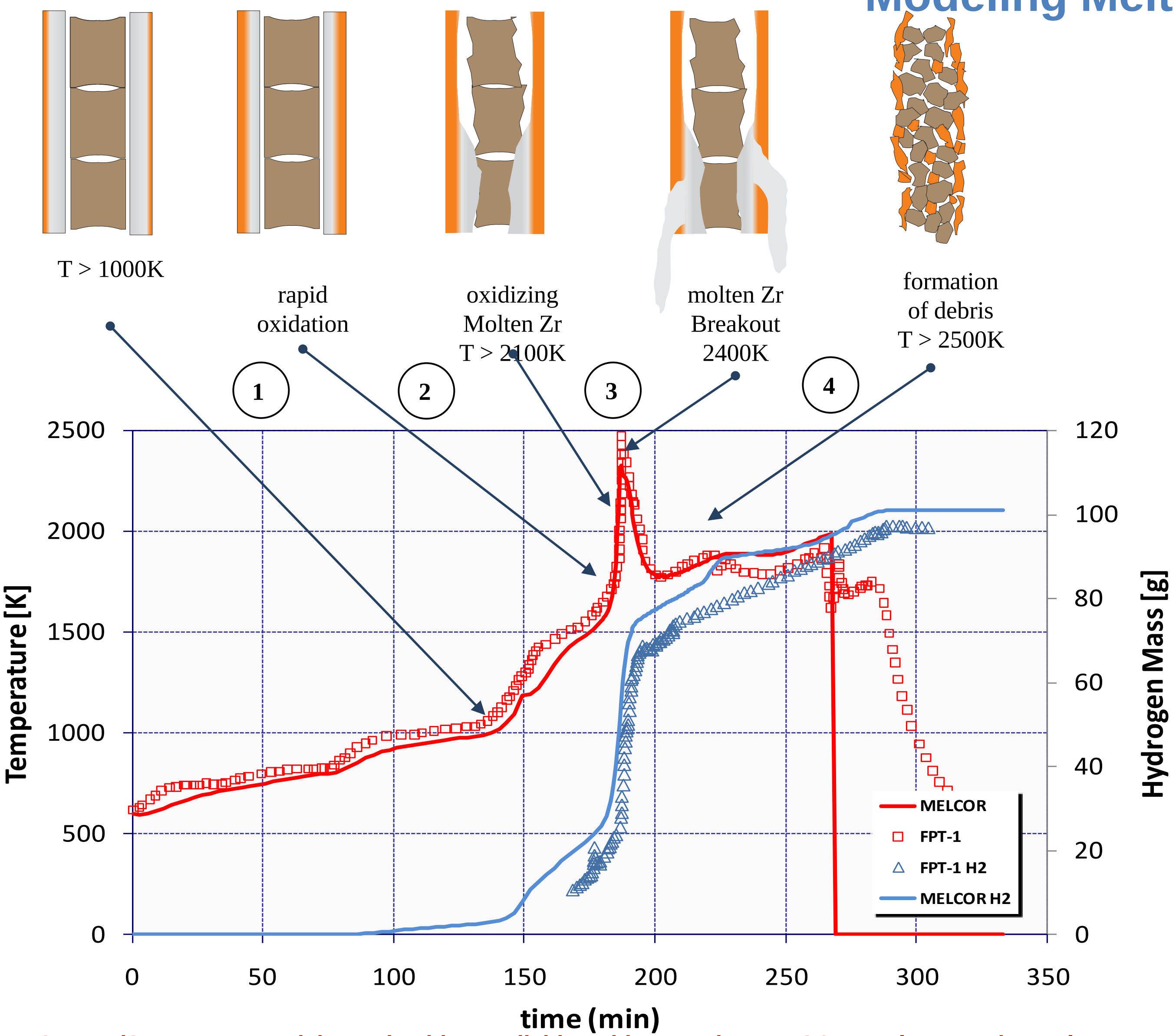


- Zr oxidation produces hydrogen and high gas temperature
- Cycling SRV vents hot gas through steam line and into suppression pool
- High RPV pressure ruptures weakened steam line
  - Larson-Miller

MELCOR Results

R. Gauntt (SANDIA Nat. Lab.), « Fukushima-Daiichi Accident study: MELCOR Analyses and Results », NEA/NSC Meeting, 13-15 June 2012, Paris

Modeling Melt Progression Stages



MELCOR Modeling Parameters

1. *oxidation kinetics*
2. *fuel liquefaction fraction*
3. *Zr-melt breakout temperature*
4. *Debris formation temperature*

Parameters Affect:

1. *fuel heatup rate*
2. *melt progression*
3. *hydrogen generation and peak temperatures*
4. *core degradation and slumping*

MELCOR Results

R. Gauntt (SANDIA Nat. Lab.), « Fukushima-Daiichi Accident study: MELCOR Analyses and Results », NEA/NSC Meeting, 13-15 June 2012, Paris

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Synthesis & Conclusion (1 / 2)

- The behaviour of the Fukushima-Daichii accident is well known on a ***qualitative*** level. For a full understanding also on the ***quantitative*** level, the recourse to modelling is mandatory
- The use of numerical modelling codes raises concerns on:
  - Validation of physical models
  - Completeness of input data and modelling hypotheses
- Some issues may be solved by adjusting input data and hypotheses to better fit the measured data
- In this context, severe accident tools allow a good comprehension of the physical phenomena
  - Good agreement on timeline and plant parameter in most of the analyses, especially in the phase before fuel melting
  - Much higher uncertainties on the post-melting phase and the final status of the RPV
  - The Zr+water reaction remains accessible only through modelling

Synthesis & Conclusion (2 / 2)

- The application of Severe Accident codes for advanced Accident Tolerant Fuels requires efforts on:
  - Input data for advanced fuel and cladding materials
  - Adaptation/improvement of physical models
  - Overall validation, strengthening the need of experimental programs
  - The development of advanced modelling techniques, including multiscale modelling
- Gathering elements on how to address these needs is one of the objectives of this Workshop