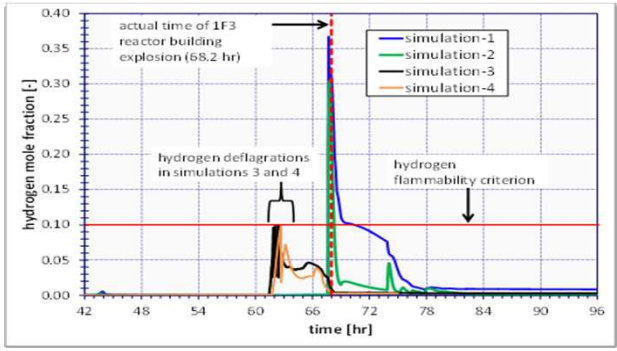
SAND2012-9742C

Exceptional service in the national interest

Sandia National Laboratories



MELCOR 2.1 Simulations of Fukushima Unit 3

Jeff Cardoni

2012 ANS Winter Meeting and Nuclear Technology Expo

San Diego, CA. November 11-15, 2012

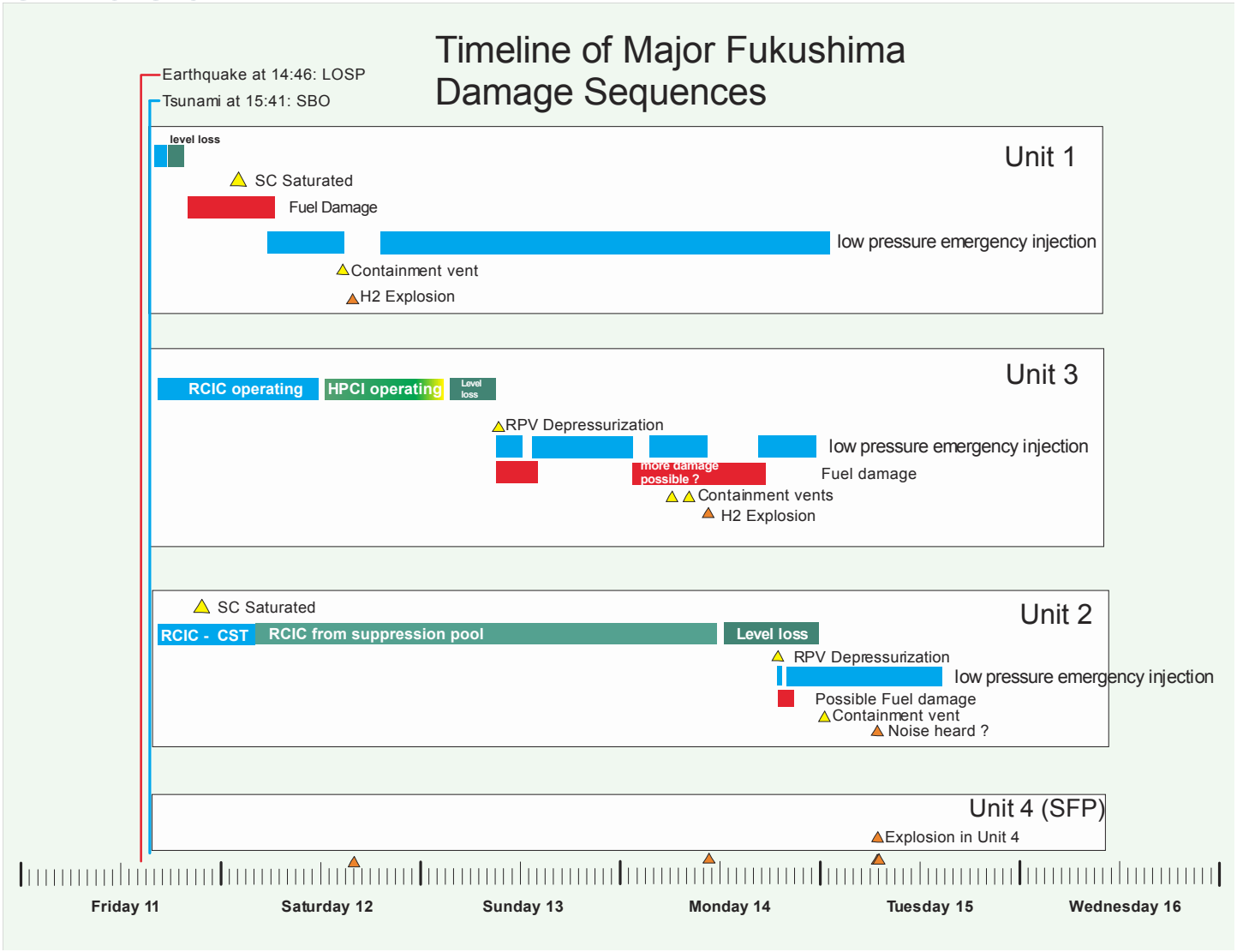
U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Timeline of Major Fukushima Damage Sequences

Sandia National Laboratories



Unit 3 MELCOR events and system availability

Time after scram (hr)	Event
0.0	Reactor scram (quake 1 min. before)
0.30	RCIC starts
0.63	RCIC stops
0.67, 0.80	1st and 2nd tsunami waves
0.85	Loss of AC power
1.27	RCIC starts
20.8	RCIC stops
21.8	HPCI starts; ***S/C sprays start***
35.9	DC battery depletion
35.9	HPCI stops
42.1	RPV depressurizes via SRV
42.5	First S/C vent open
42.6	Injection starts
44.5	S/C vent close

*DW sprays possibly used around 41-54 hours; however, there is no obvious response in the DW pressure.

MELCOR system/action	Status
RCIC	Available
HPCI	Available
RHR – S/C cooling	**Unavailable**
RHR – LPCI	**Unavailable**
RHR – drywell sprays	**Unavailable***
Core sprays	**Unavailable**
Drywell venting	**Unavailable**
S/C sprays	***available***
Wetwell (S/C) venting	Available
Alternative injection	Available

HPCI Modifications: Unit 3

Sandia National Laboratories

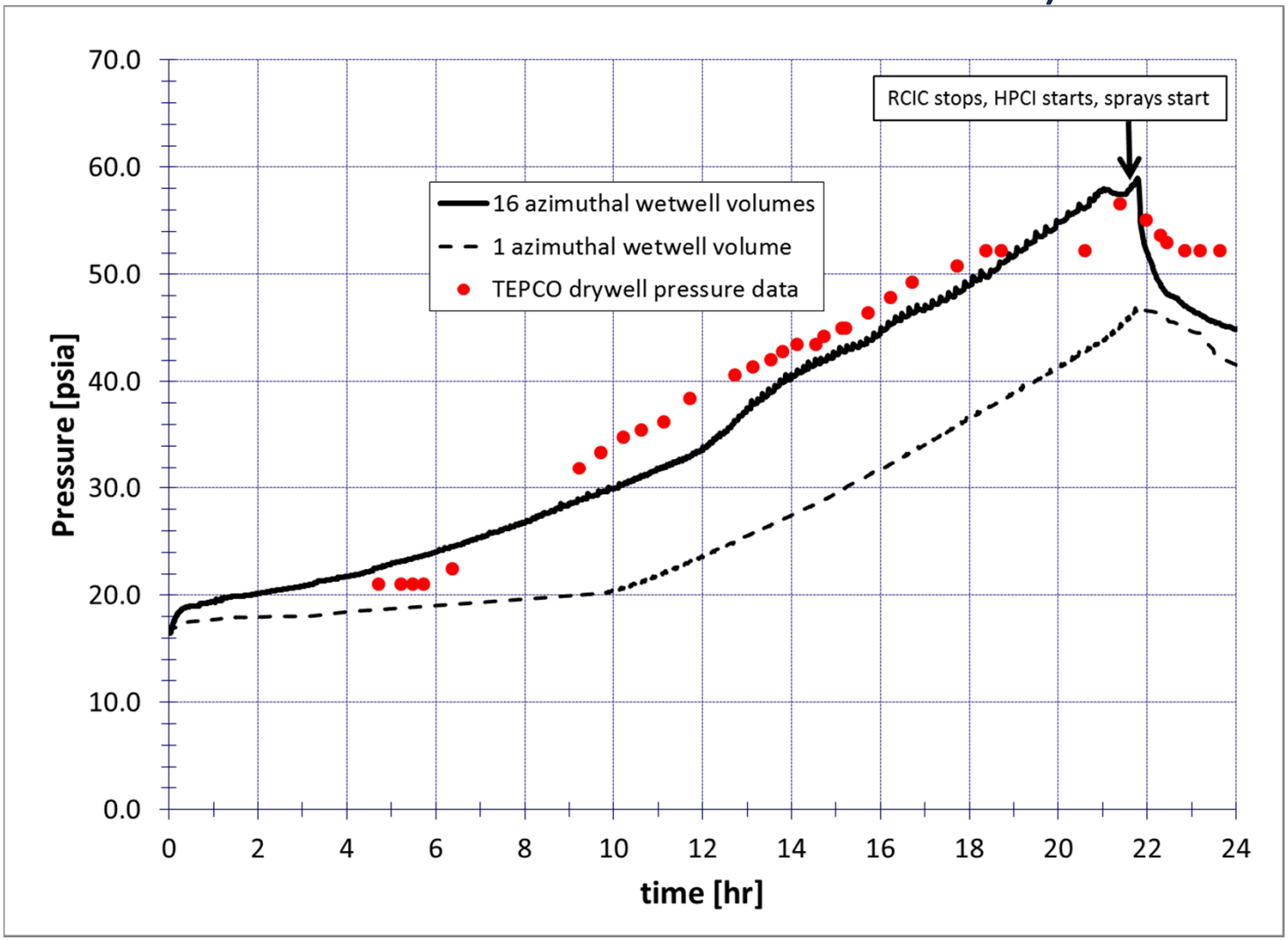
- Based on operator actions and computer analyses, it is believed that RPV pressure was reduced by continuous operation of the HPCI turbine.

- Operation procedures state that continuous operation of HPCI shall *not be inhibited by repetitive start and stop due to low/high water level in the downcomer*.

- SOARCA model for HCPI revised to allow continuous operation of the HPCI

- HPCI injection is throttled using the *test flow line*
  - Fraction of injection diverted back to the CST continuously, OR
  - Injection maintains RPV water level between upper and lower levels, making the levels 'tight' mimics continuous injection by the HPCI and throttling by the test flow line

Azimuthally asymmetric wetwell heating and local wetwell saturation, primarily by SRV-1 cycling (does not model axial thermal stratification)



Reactor building explosion at 1F3 *possible scenarios*

Sandia National Laboratories

1. **H_2 generated around 40 hours**
   - Stored in containment and not released by initial venting attempts
   - Trapped in piping for ~24 hours from initial venting attempts
   - Reactor building full of flammable gases since 40 hours, but no ignition source until 68 hours

2. **Ex-vessel accident**
   - Core debris ejected from the vessel is of sufficient mass and temperature to generate core-concrete non-condensable gases (H_2 and CO)

3. **H_2 generated later, around 60 hours**
   - Leaks out of containment at 64-68 hours due to high pressure (*penetration leak*, head flange leak, etc.)
   - Containment venting attempted near 68 hours, vent line leaked into the reactor building

‘Successful’ MELCOR calculations to date

Sandia National Laboratories

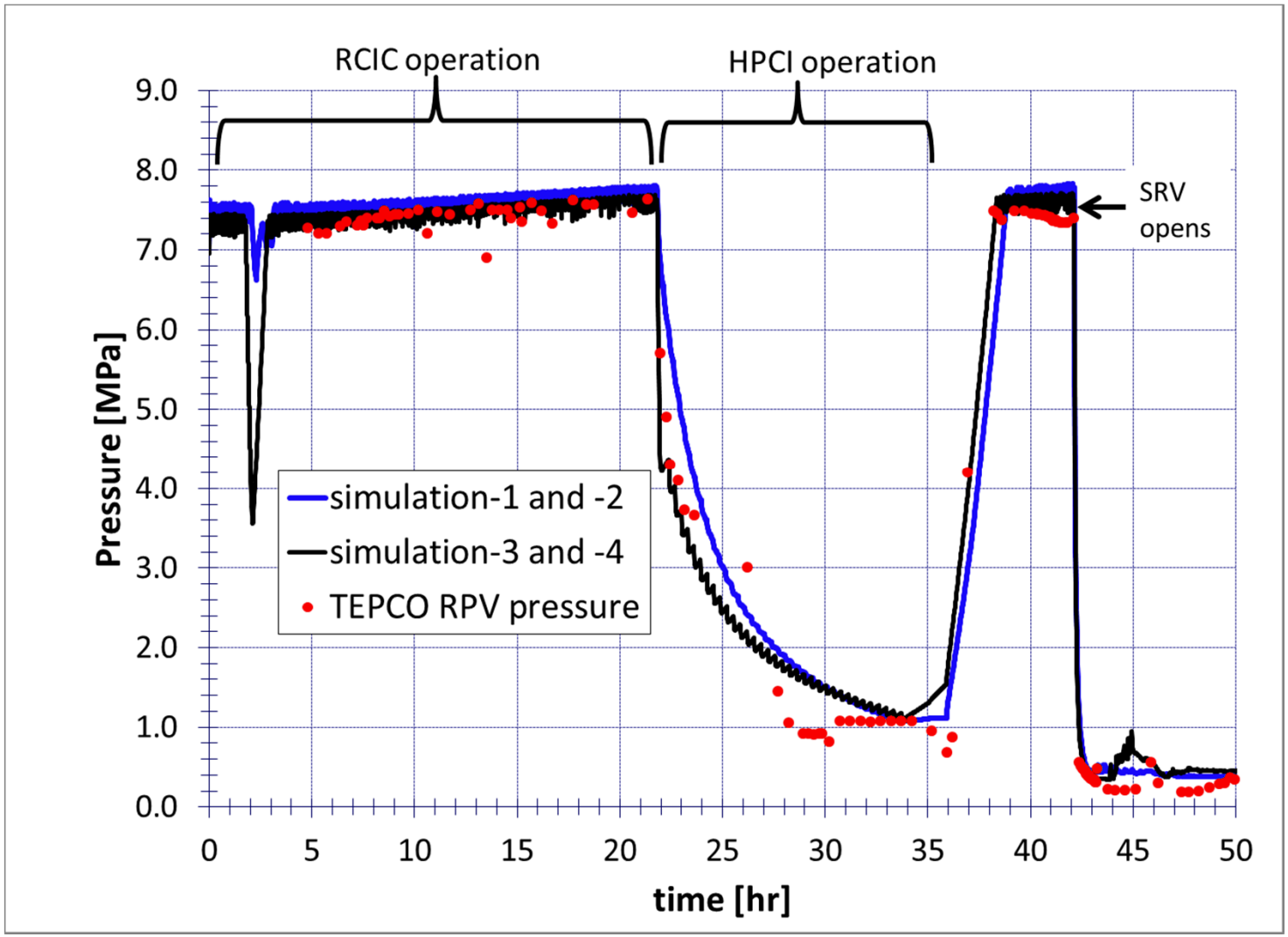
Origin of flammable gas for explosion	Timing (hours)	Gas transport from containment to reactor building
In-vessel H_2	35 – 44	Trapped in piping for 24+ hours (SGTS system), leaks to building
	57 – 68	**Ruptured S/C vent, S/C vent flows to building [*Simulation-1 and simulation-2*]**
		S/C penetration leakage, S/C vent flows to environment [*Simulation-3 and simulation-4*]
Ex-vessel H_2 and CO	60 – 68	Indeterminate: SGTS leak, vent leak, penetration leakage

Four MELCOR models/simulations attain explosive conditions in the reactor building *near* 68 hours

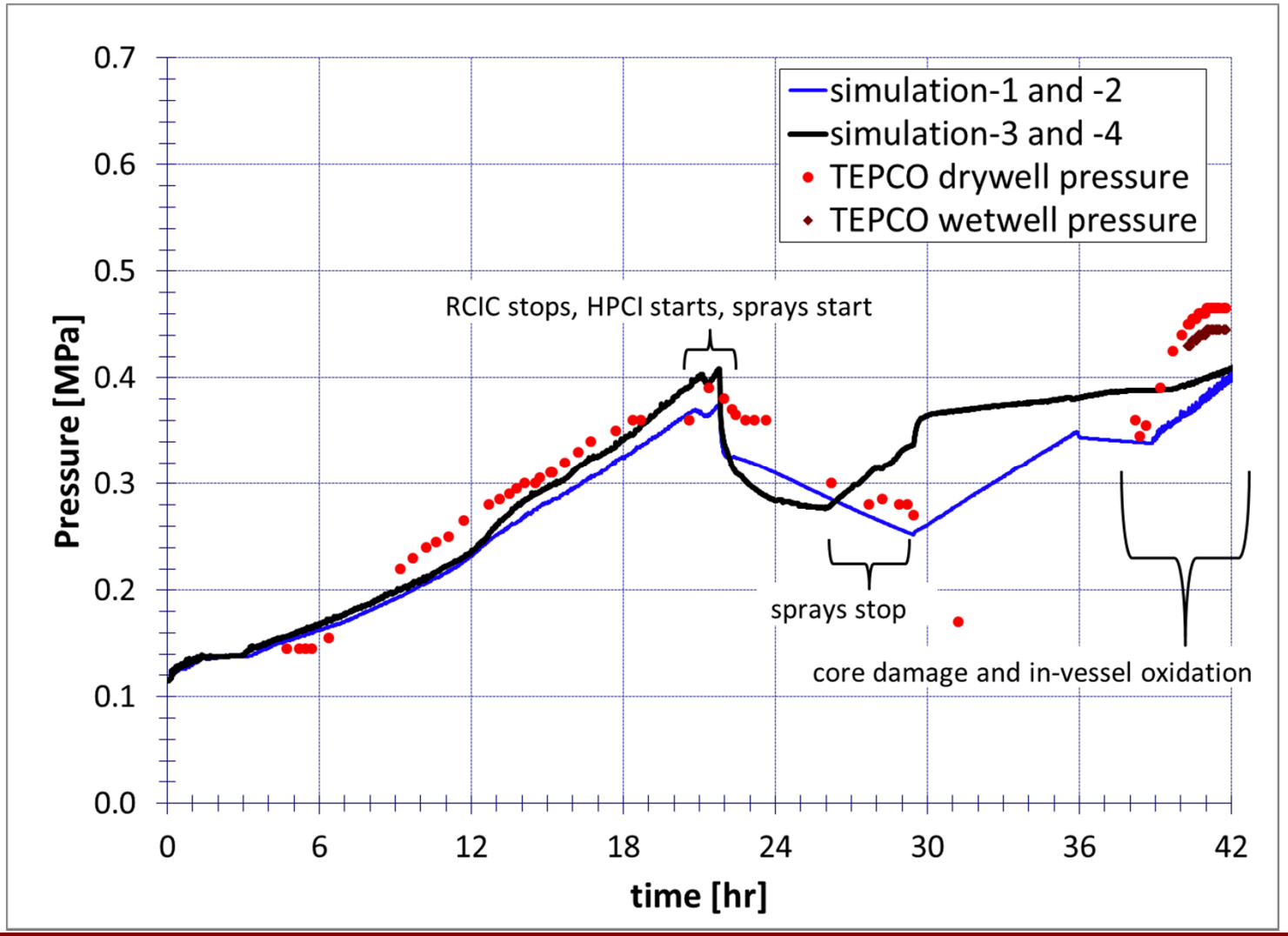
Sandia National Laboratories

Sim. #	H_2 transport from containment to reactor building	Termination of HPCI injection (hours)	MELCOR BUR package
1	Ruptured S/C vent	33	Off
2	Ruptured S/C vent	33	Off
3	S/C penetration leakage	35	Active
4	S/C penetration leakage	34	Active

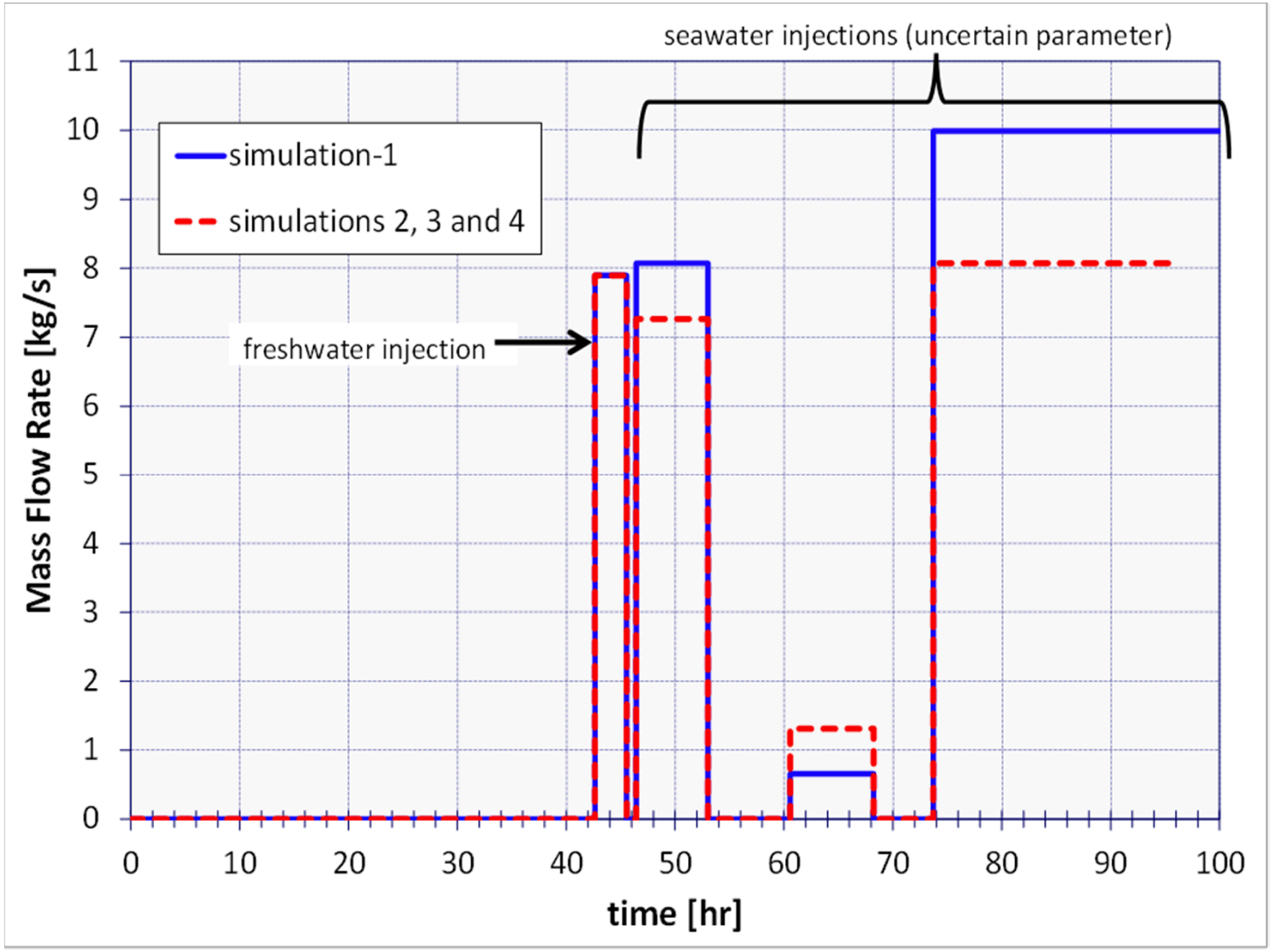
RPV pressure



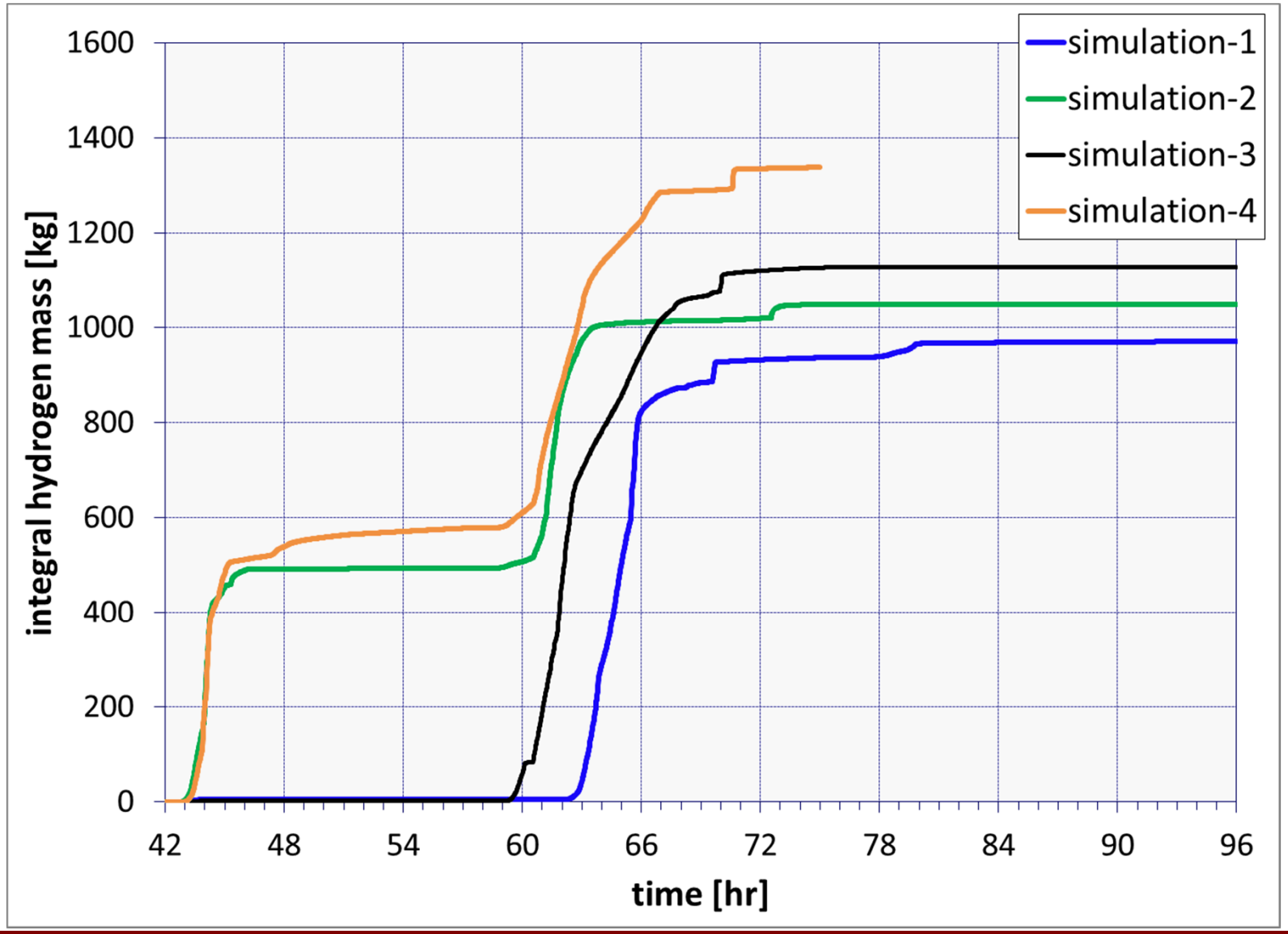
Containment pressure 0 – 42 hr



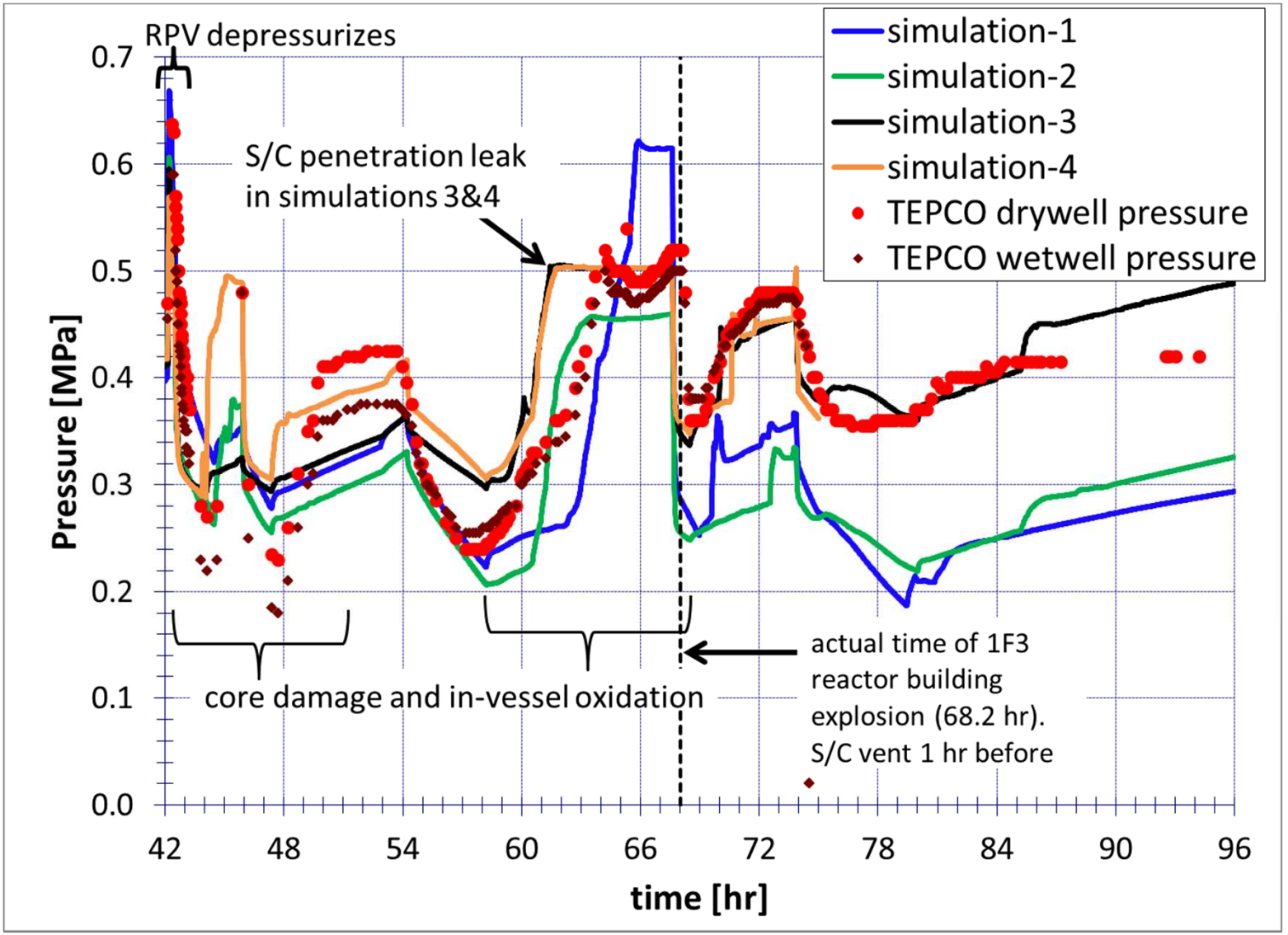
Seawater injection: uncertain parameter varied to support attaining flammable conditions in Rx bldg..



In-vessel hydrogen generation

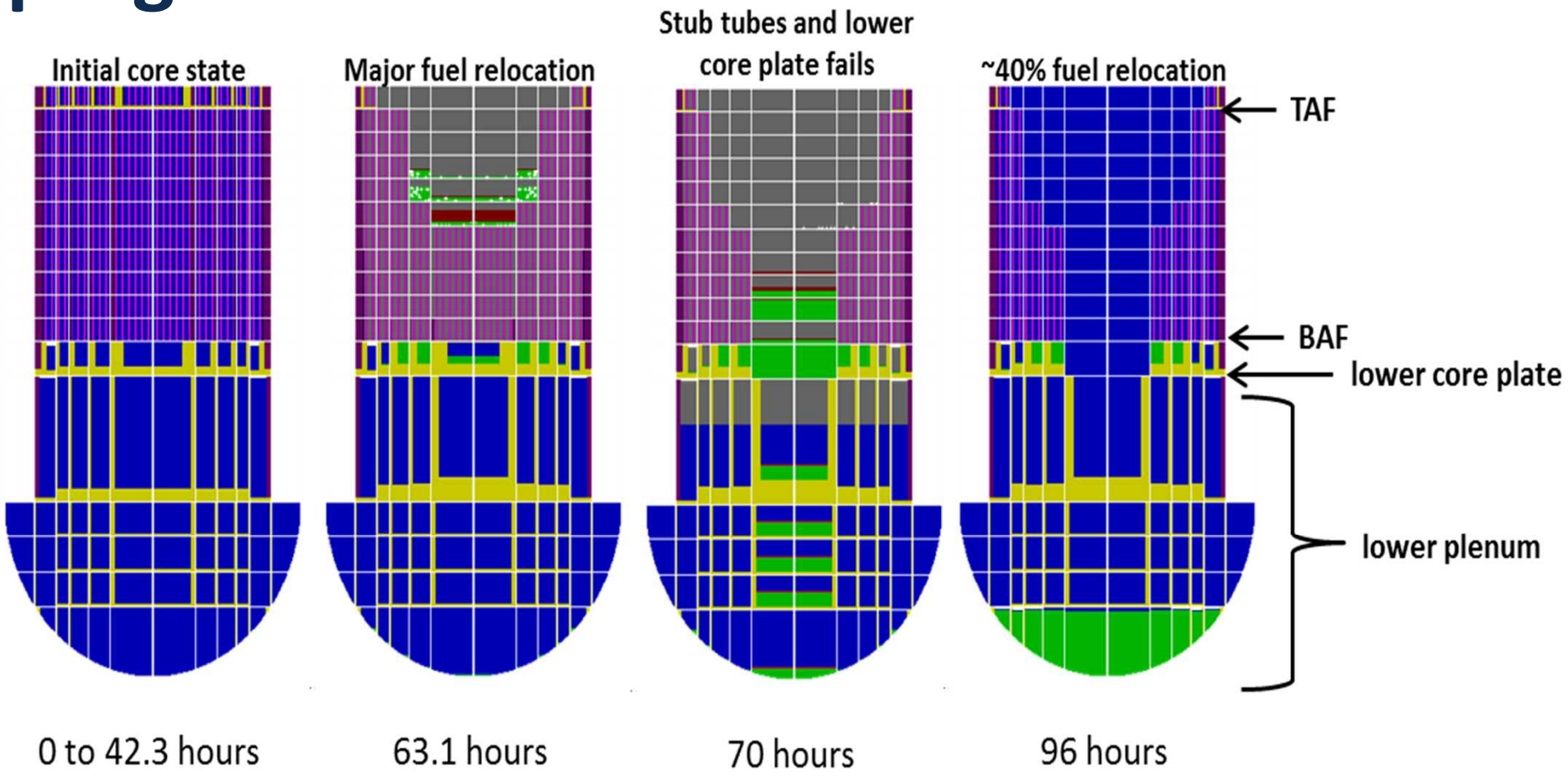


Containment pressure, 42 – 96 hr

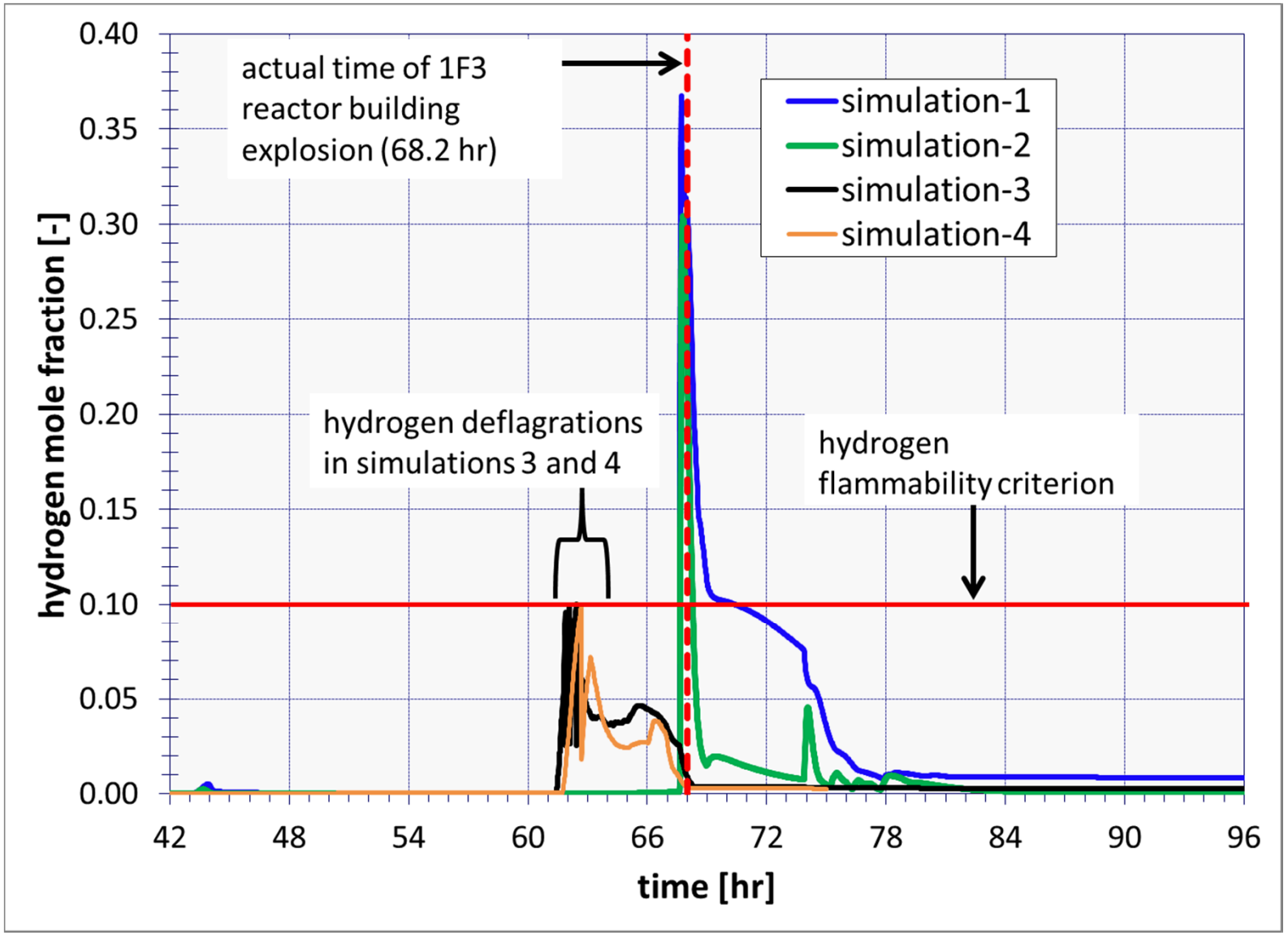


MELCOR calculation of core damage progression

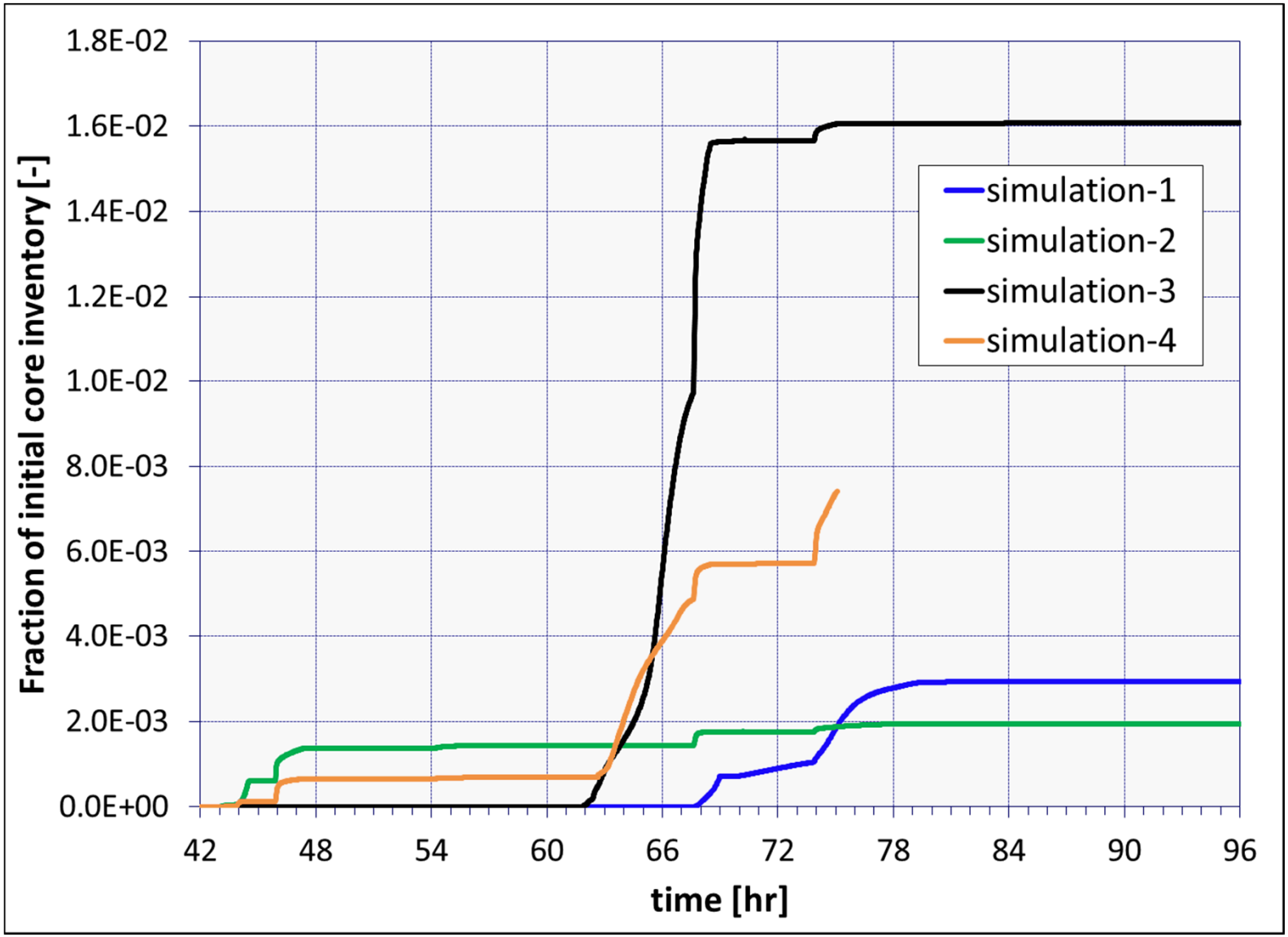
Sandia National Laboratories



Max. hydrogen in reactor building



Radionuclide release: CsI class

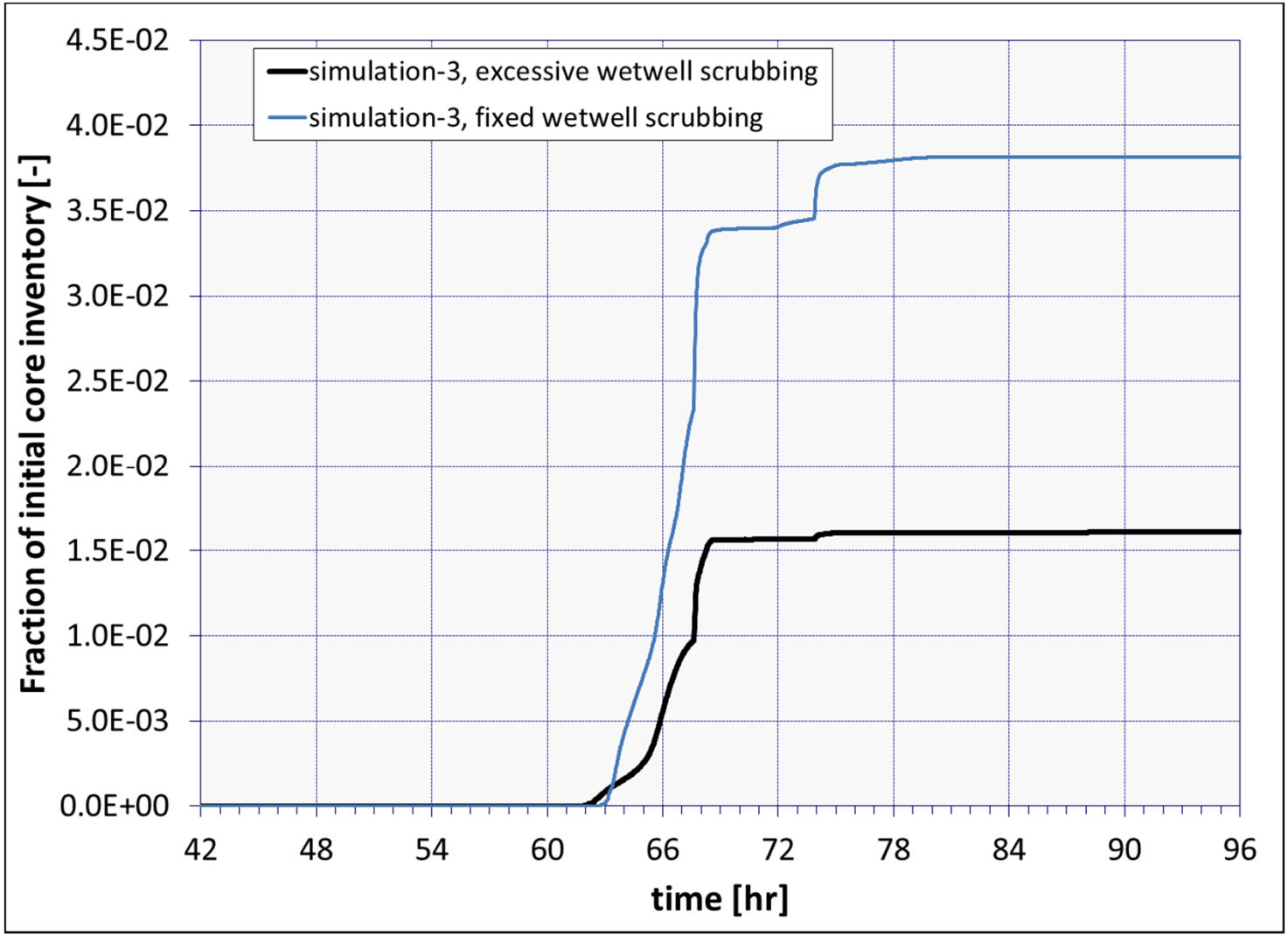


Quantity	TEPCO estimate (PBq)
Cs-134 release for *all units*	~10
Cs-137 release for *all units*	~10
I-131 release for *all units*	~500
INES-based estimate for *all units*	900
1F1 INES release	130
1F2 INES release	360
1F3 INES release	**320**
Indeterminate excess activity	90

Quantity	SNL 1F3 model (Simulation-3)
Initial Cs-137 inventory (PBq)	232.4
Initial Cs-134 inventory (PBq)	318.0
Initial I-131 inventory (PBq)	2368.1
Overall cesium class release fraction	1.61E-03
Overall iodine class release fraction	1.62E-02
Total cesium release (PBq)	0.89
Total iodine release (PBq)	38.4
Total Cs-137 and I-131, INES I-131 equivalent (PBq)	**53.3**

Sandia National Laboratories

Effect of removing interior wetwell-to-wetwell radionuclide scrubbing (input bug): CsI release



Comparison to TEPCO radioactivity releases

Sandia National Laboratories

	Report model	Simulation-3	Simulation-3, RN scrubbing fix in WW	TEPCO estimate
INES I-131 and Cs-137 release (PBq)	25.7 →	53.3 →	125.8 →	320

Improved T-H response, BUR package

Fix interior WW-WW scrubbing

-Vessel breach?
-Lack of detonation modeling?
-TEPCO conservatism given early predictions were lower?
-Wetwell scrubbing efficiency?
-Filtered vs. unfiltered releases

Conclusions

- The models qualitatively produced accident sequences that followed the general trends in the TEPCO data and observed events
- Good quantitative comparisons to the TEPCO data are found in portions of all three model results

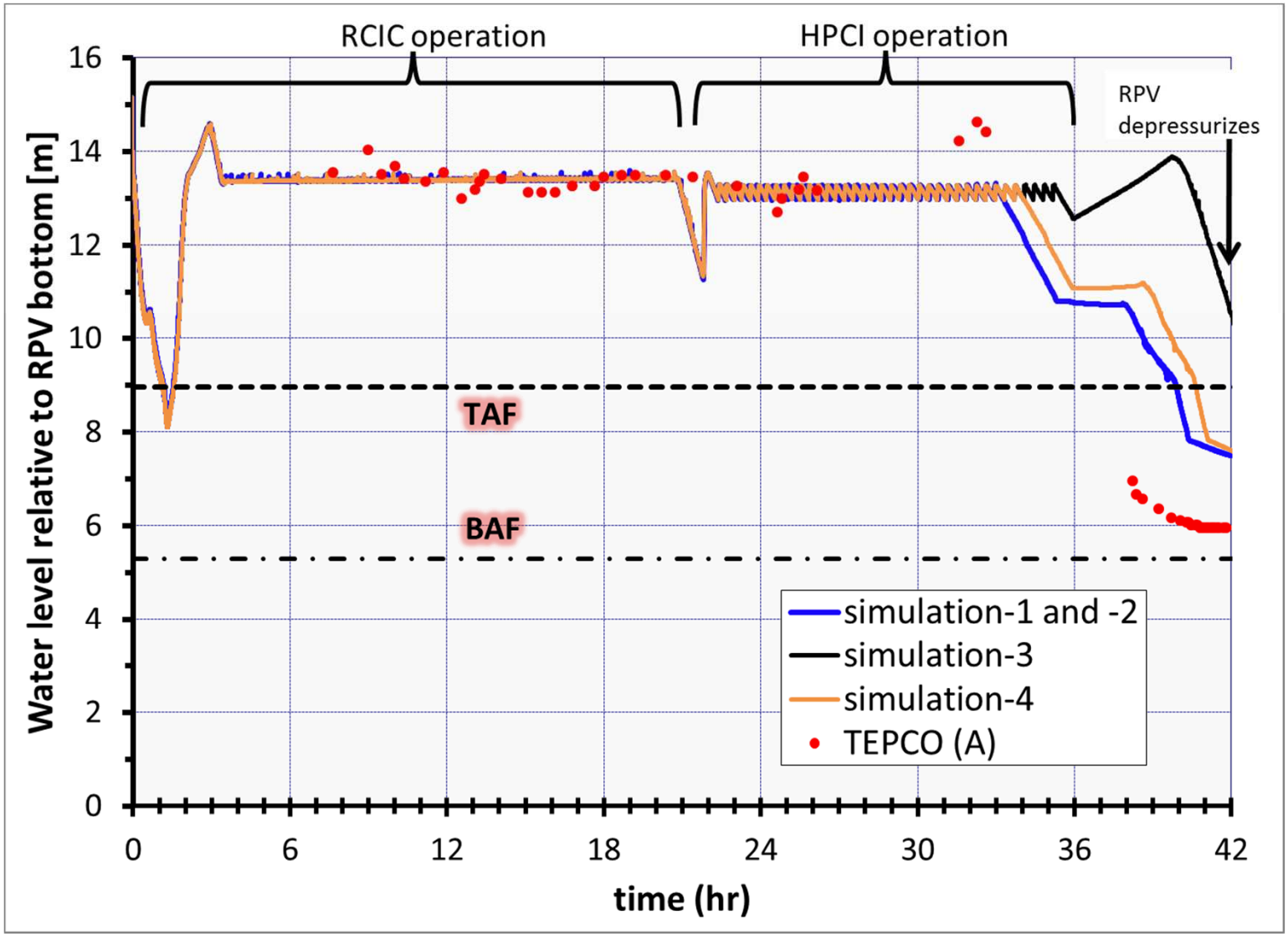
Sandia National Laboratories

MISCELLANEOUS

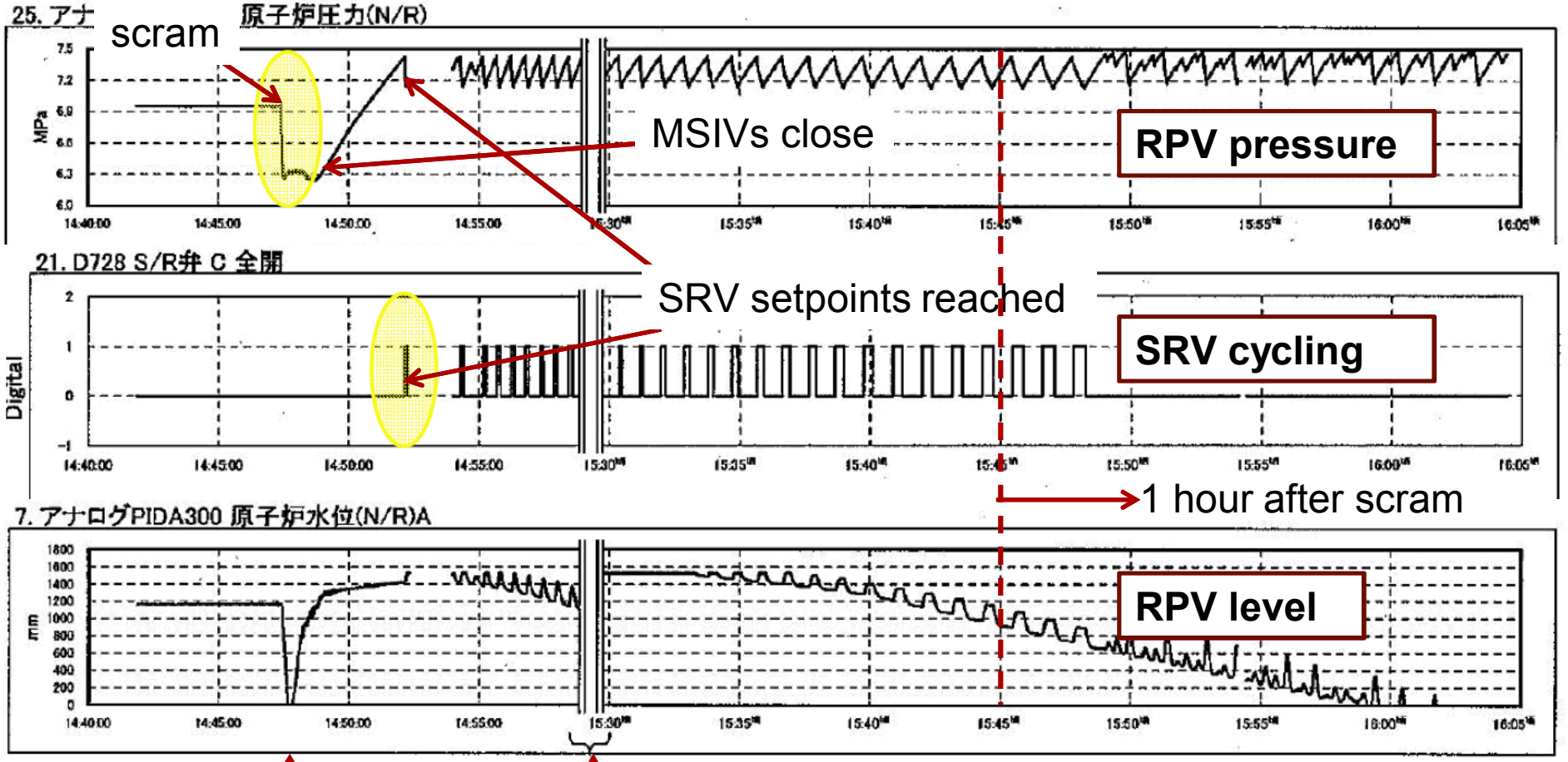
RPV water level, 0 – 42 hr

RCIC does not activate until 1.5 hours according to timeline data

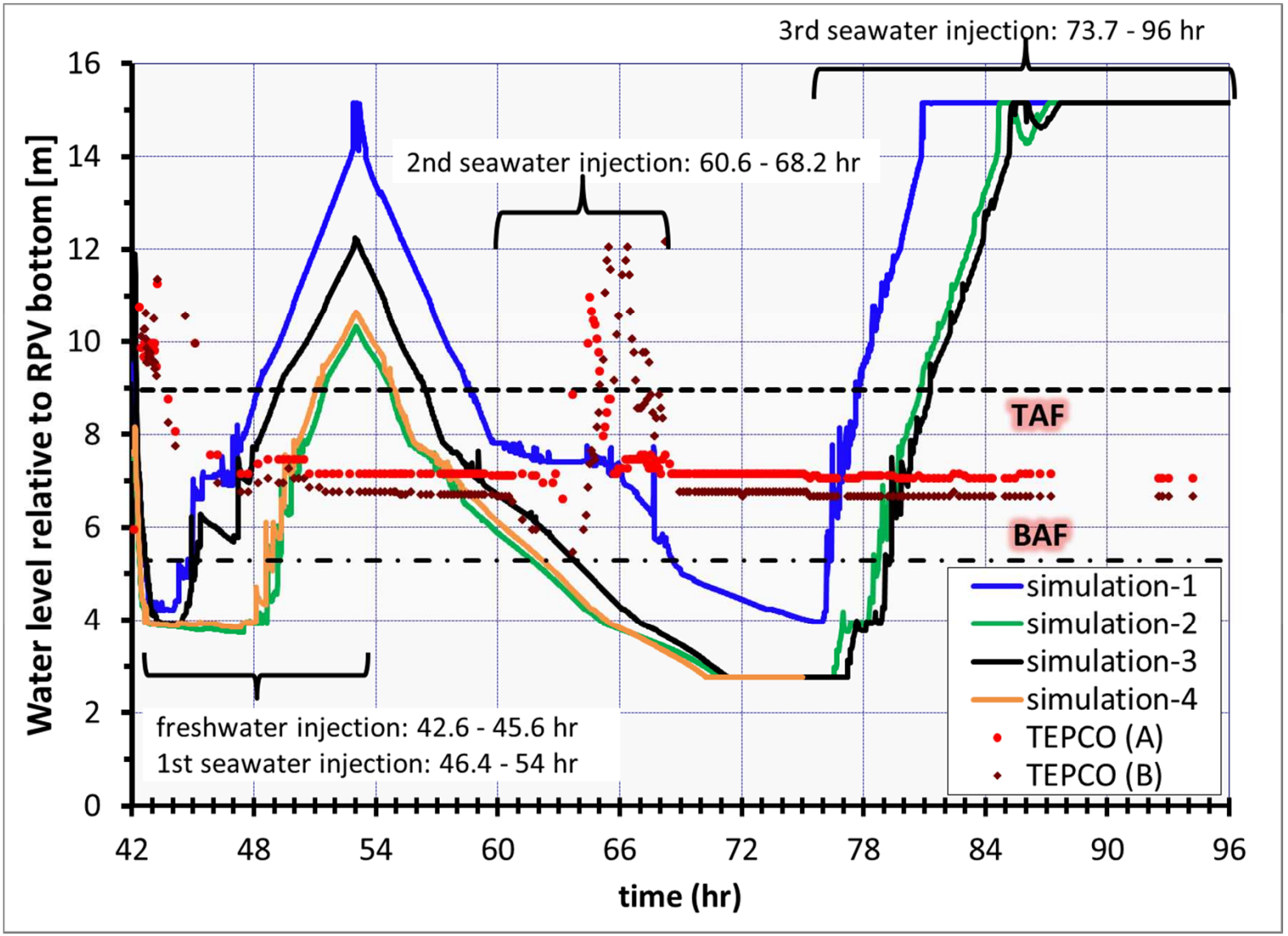
In conjunction with early void collapse, causes level to reach TAF momentarily (no oxidation or damage occurs)



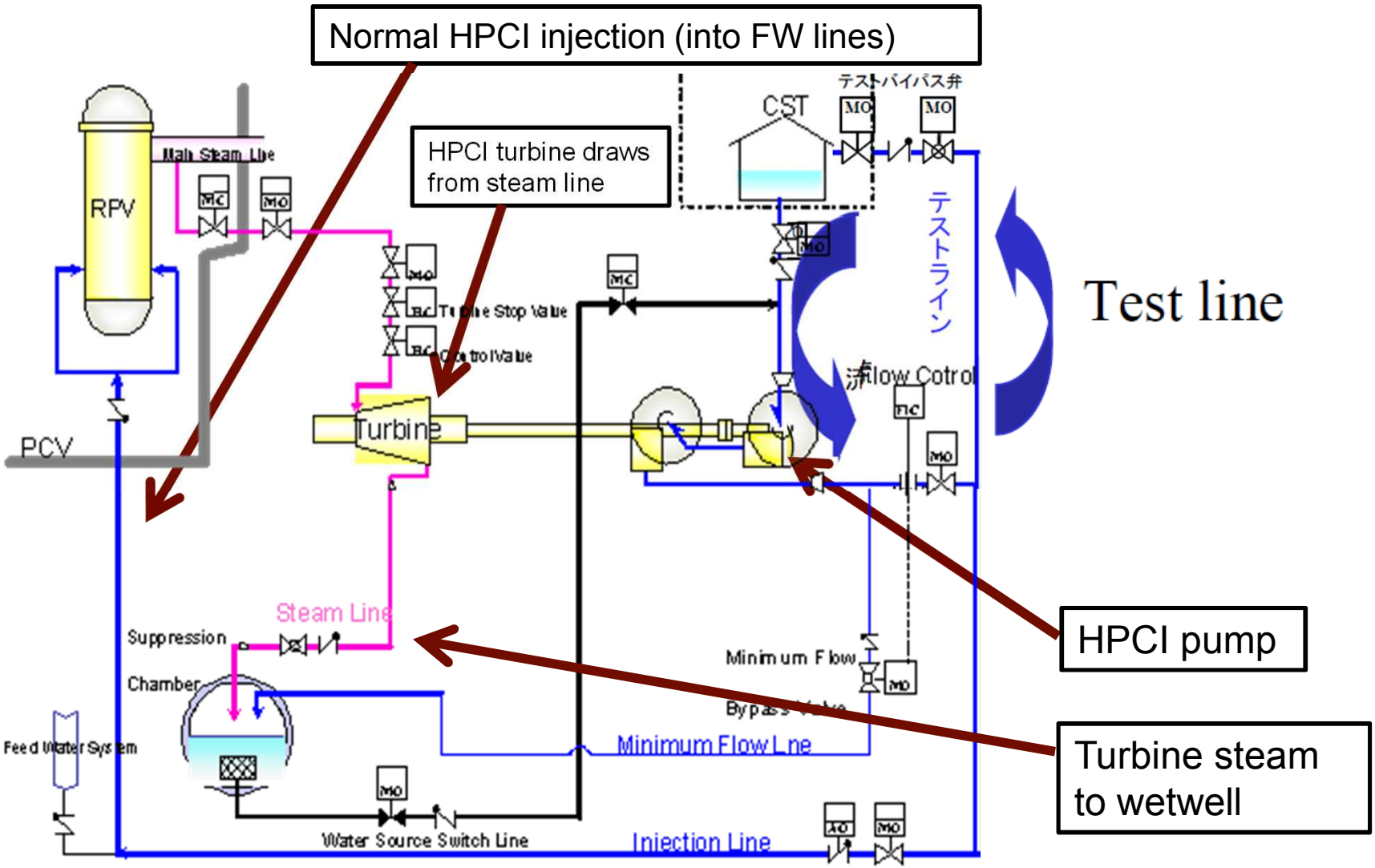
Unit 3 strip chart data for RPV pressure and water level



RPV water level, 42 – 96 hr

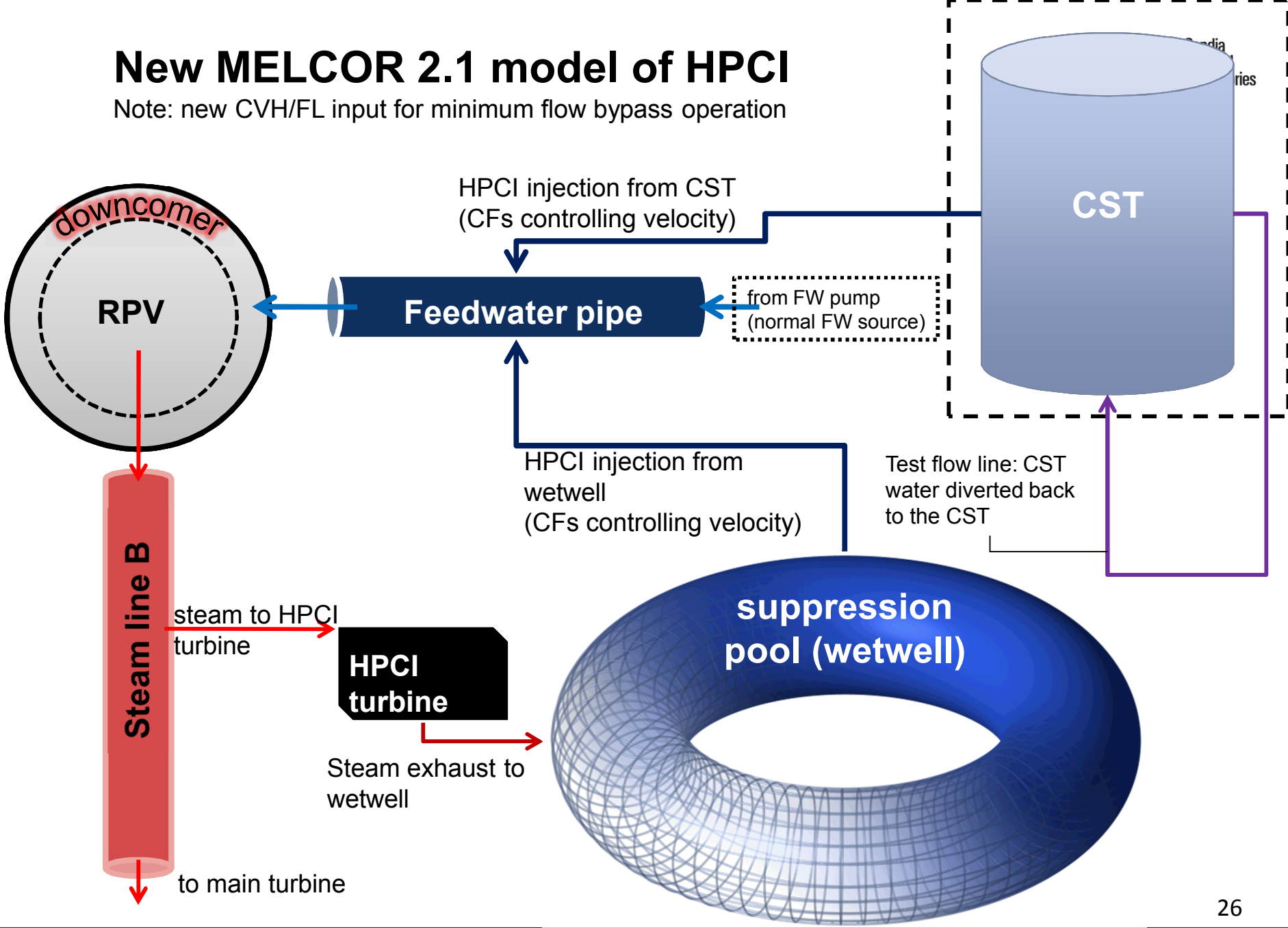


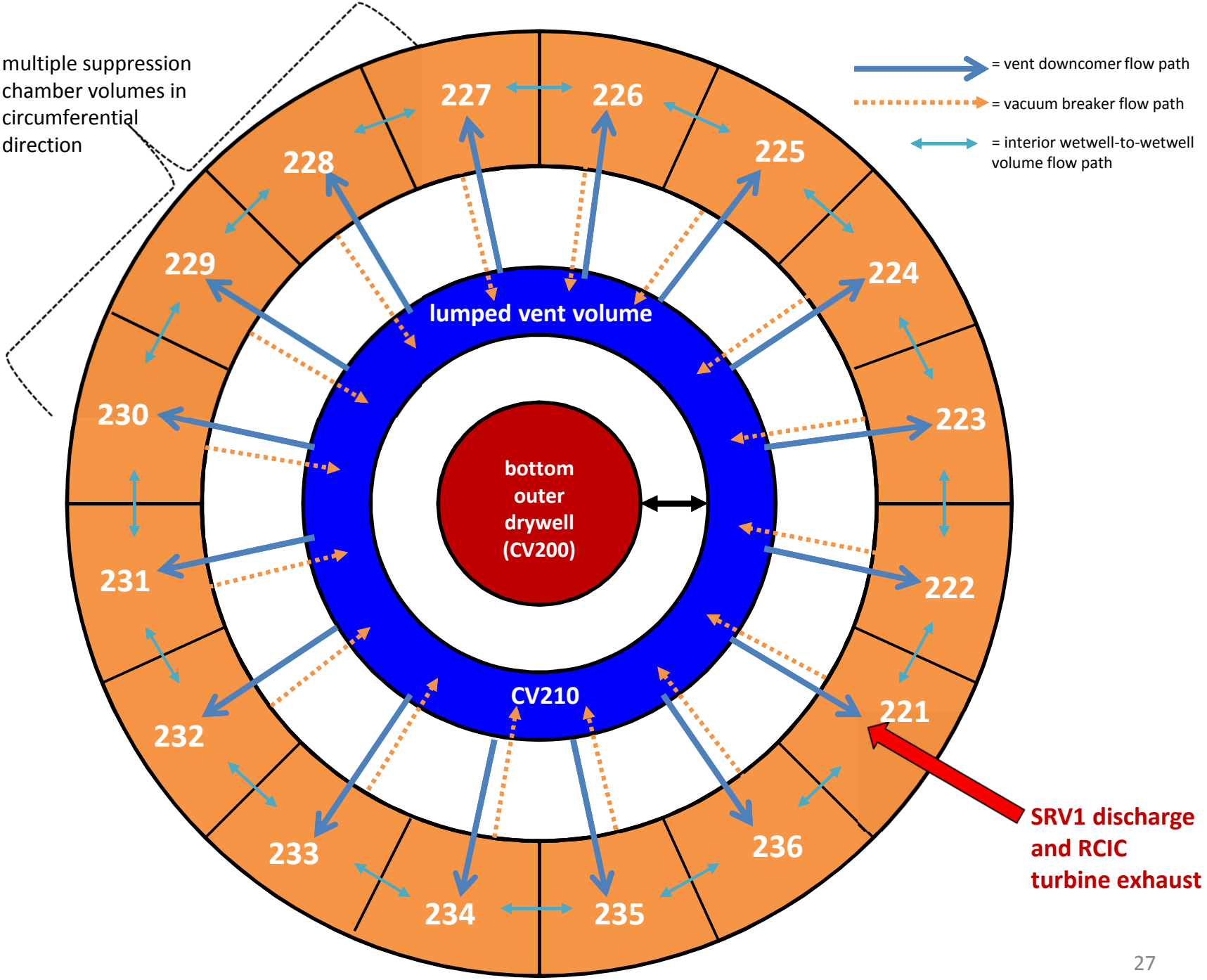
HPCI flow diagram



New MELCOR 2.1 model of HPCI

Note: new CVH/FL input for minimum flow bypass operation




multiple suppression chamber volumes in circumferential direction
= vent downcomer flow path
= vacuum breaker flow path
= interior wetwell-to-wetwell volume flow path
227
226
225
228
229
224
lumped vent volume
230
223
bottom outer drywell (CV200)
231
222
CV210
232
221
233
236
234
235
SRV1 discharge and RCIC turbine exhaust