

# **Analytical Tools used in Analyzing Severe Accident Conditions in Mark I and Mark II BWR Containments**

Revision to Order EA-12-050

April 4, 2013



# Agenda

- Introductions
- Opening remarks
- NRC staff presentation
  - MELCOR analysis of containment venting in BWR Mark I
  - Key differences between NRC and Industry analyses
- NEI/Industry presentation
- Public questions and comments

# **MELCOR ANALYSIS OF CONTAINMENT VENTING IN BWR MARK I**

Division of Systems Analysis  
Office of Nuclear Regulatory Research

April 4, 2013

# Discussion Topics

- Accident sequences
- Mitigation strategies
- MELCOR modeling
- Uncertainties

# Selection of Accident Sequences

- Focus on risk-significant sequences
  - Informed by Fukushima
  - Built on SOARCA and earlier PRA studies
  - Commission guidance
- Base case long-term SBO
  - Large number of variations of base cases featuring mitigation actions
- Additional cases of LPHC events
  - Include MSL rupture, seal failure, STSBO, etc.
  - Informed by Fukushima and SOARCA

# Selection of Mitigation Actions

- Mitigation actions
  - RCIC
  - Core and drywell spray (B.5.b and FLEX)
  - Containment venting
- Base cases: 16 hour RCIC, 300 gpm spray, wetwell venting
- Sensitivity analysis
  - Spray flow rate and timing, wetwell versus drywell venting, and RCIC duration

# MELCOR Phenomenological Modeling

Phenomena	Modeling Features	Implications
In-vessel Accident Progression	BWR-oriented models <ul style="list-style-type: none"><li>- Gradual core degradation and relocation</li><li>- Enhanced clad and structure oxidation</li><li>- Holdup of some fission products in core</li></ul>	<ul style="list-style-type: none"><li>- Gradual release of relatively cold core debris at vessel breach</li><li>- Significantly more in-vessel hydrogen production from enhanced clad and structure oxidation</li><li>- Late release of held-up fission products</li></ul>
Ex-vessel Core Debris Behavior	<ul style="list-style-type: none"><li>- slow spreading of relatively cold core debris</li><li>- Extended core-concrete interaction</li></ul>	<ul style="list-style-type: none"><li>- Liner failure physically unreasonable in presence of water on the drywell floor</li><li>- Coolable debris bed in the long-term</li><li>- Generation of non-condensable for longer duration</li></ul>
Fission Product Transport	Mechanistic modeling based on PHEBUS and other recent experiments	<ul style="list-style-type: none"><li>- More realistic assessment of in-containment retention mechanisms</li></ul>

# Modeling Uncertainties

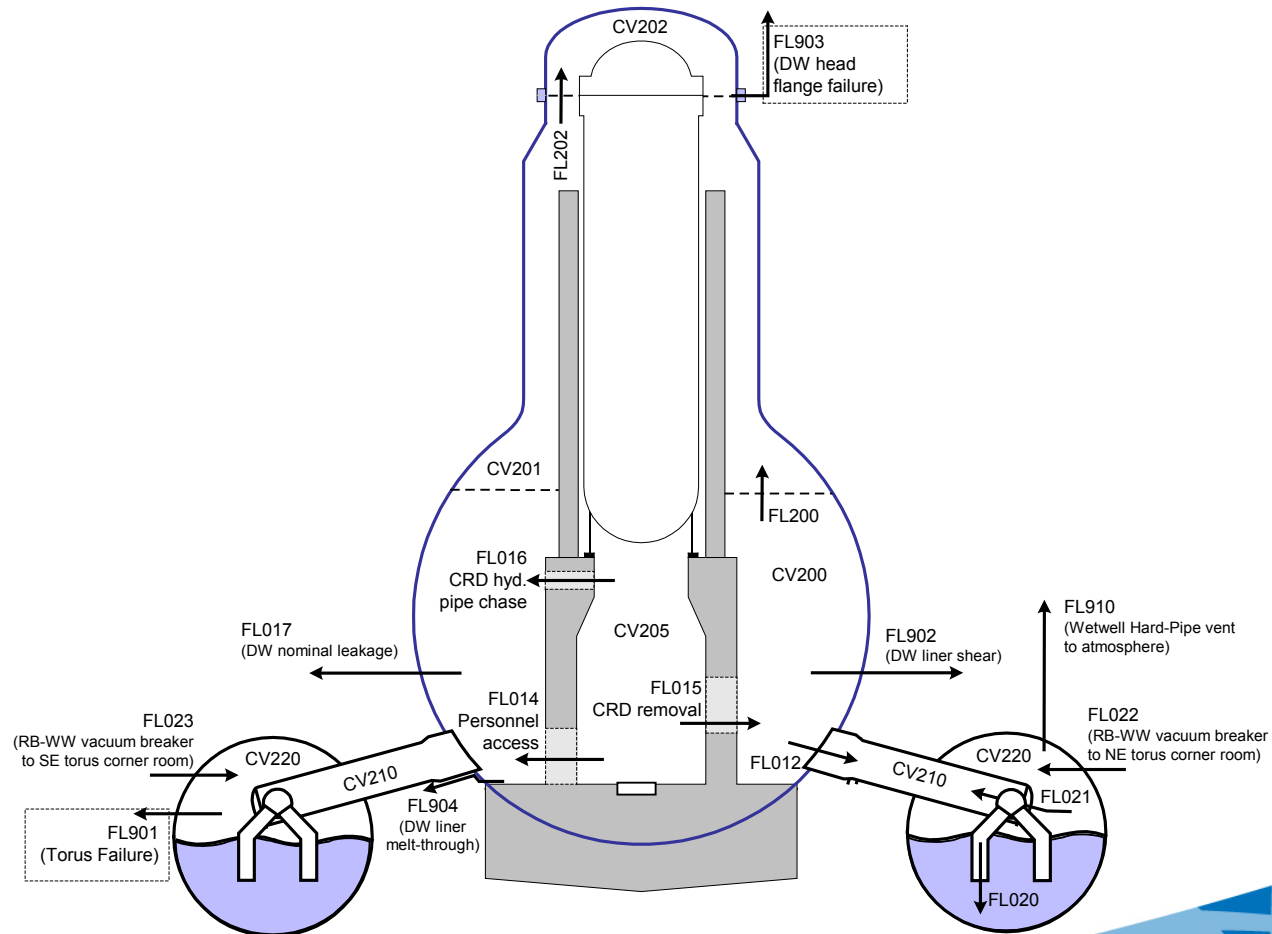
Phenomena	Uncertainties	Implications
In-vessel Accident Progression	<ul style="list-style-type: none"> <li>- Mass and composition of relocated core debris</li> <li>- Location and timing of vessel breach</li> <li>- Oxidation kinetics</li> <li>- Reflood of degraded core</li> </ul>	<ul style="list-style-type: none"> <li>- Initial and boundary conditions for ex-vessel phenomena (e.g., temperature of core debris ejected from vessel)</li> <li>- Uncertainties in the amount of hydrogen production</li> </ul>
Ex-vessel Core Debris Behavior	<ul style="list-style-type: none"> <li>- Debris coolability with an overlying water pool</li> <li>- Meltspread modeling</li> </ul>	<ul style="list-style-type: none"> <li>- Uncertainties in drywell temperature</li> <li>- Uncertainties in non-condensable production including hydrogen</li> <li>- Likelihood of drywell liner melt-through</li> </ul>
Fission Product Transport	<ul style="list-style-type: none"> <li>- Late revaporization of fission products</li> <li>- Suppression pool decontamination</li> </ul>	<ul style="list-style-type: none"> <li>- Uncertainties in release estimates</li> <li>- Uncertainties in decontamination factor</li> </ul>

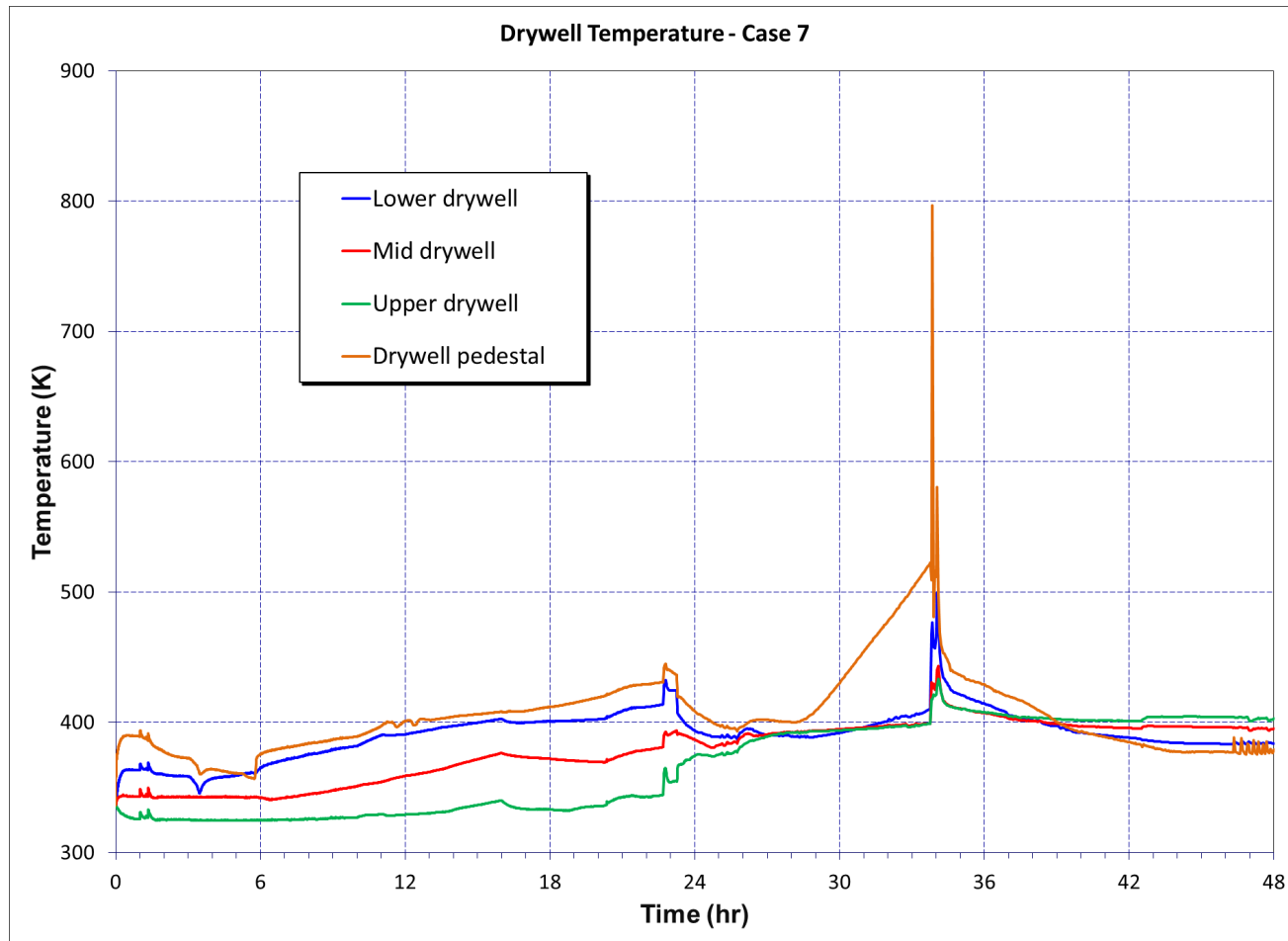


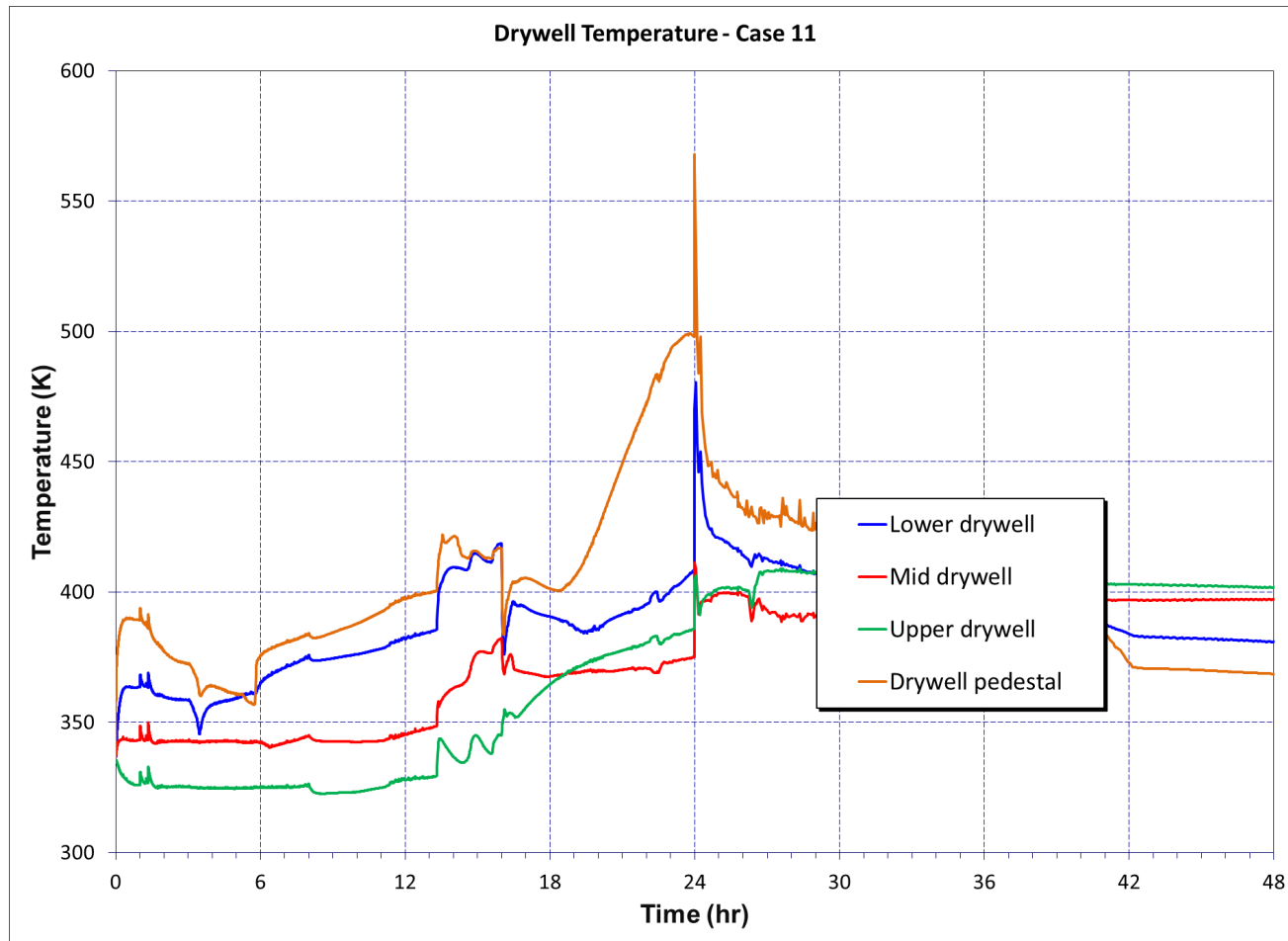


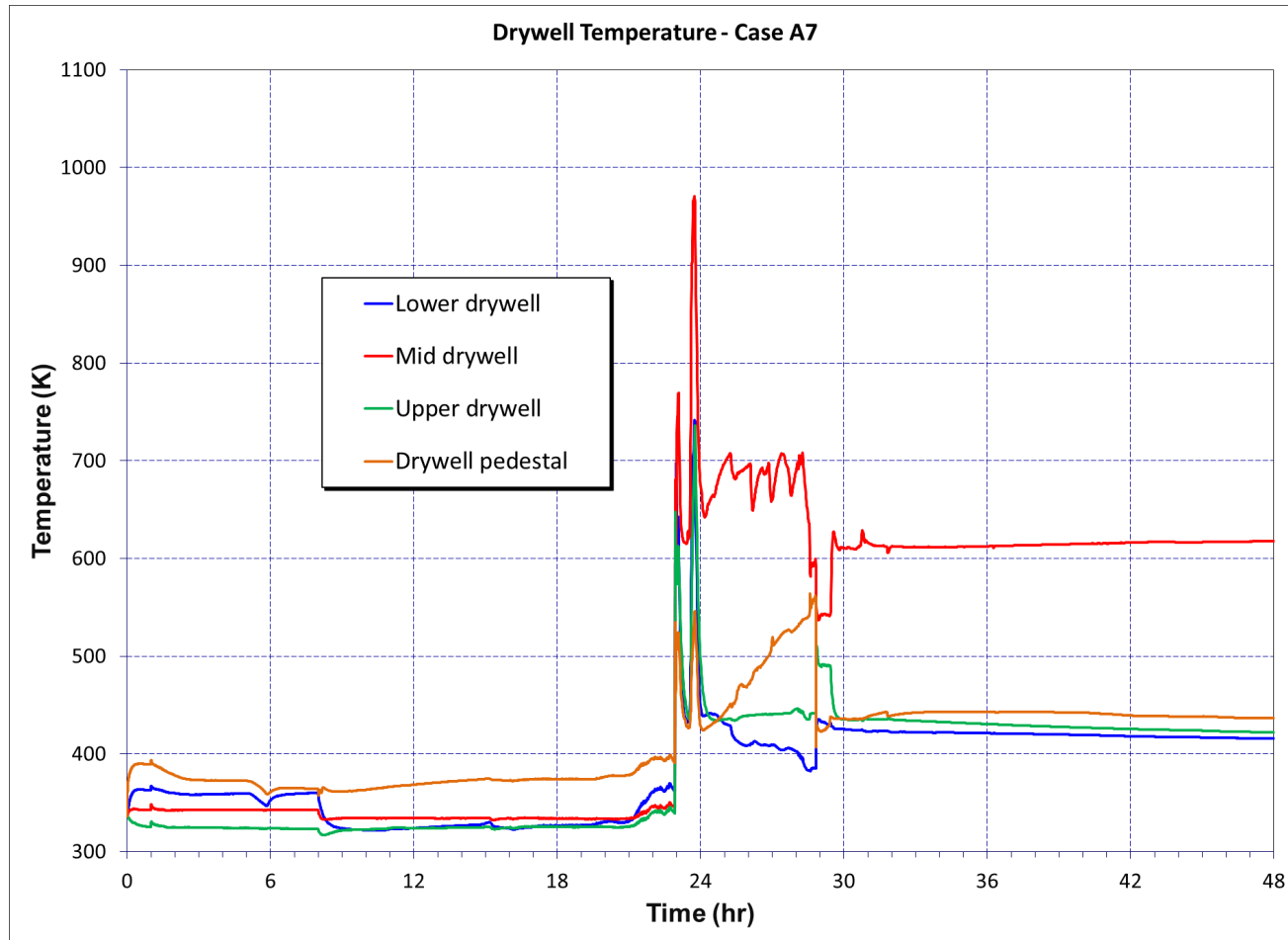
## Selected MELCOR Calculations

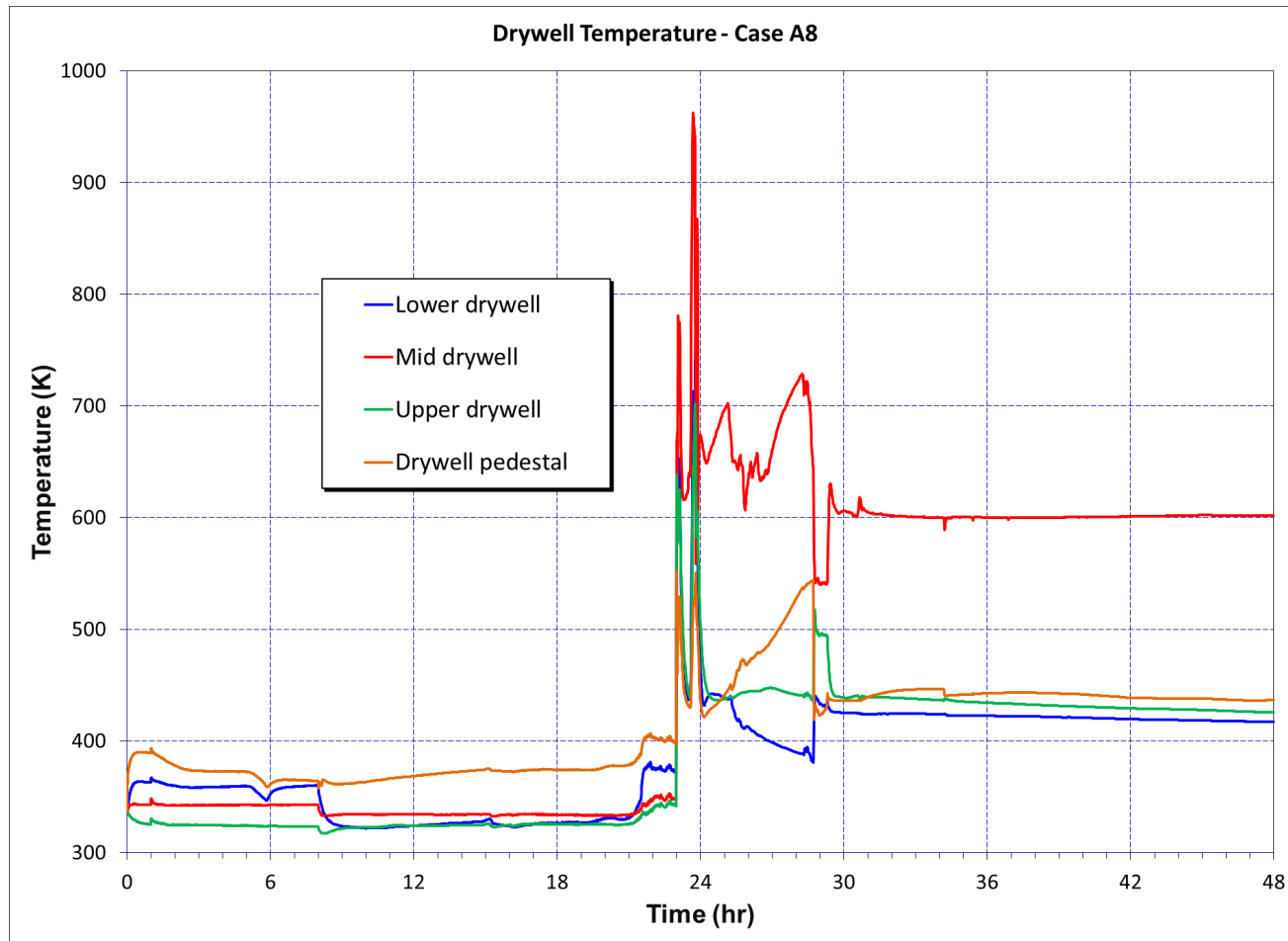
Case Description	Case 7	Case 11	Case 22	Case 23	Case 24	Case 25
8-hour RCIC		X				
16-hour RCIC	X		X	X	X	
Wetwell venting at 60 psig	X	X	X	X	X	X
Core spray after RPV failure	X	X				
Drywell spray at 8 hours			X	X	X	X
MSL creep rupture			X			
TIP leakage to containment				X		
SRV seal leakage					X	
Short term SBO with no RCIC						X

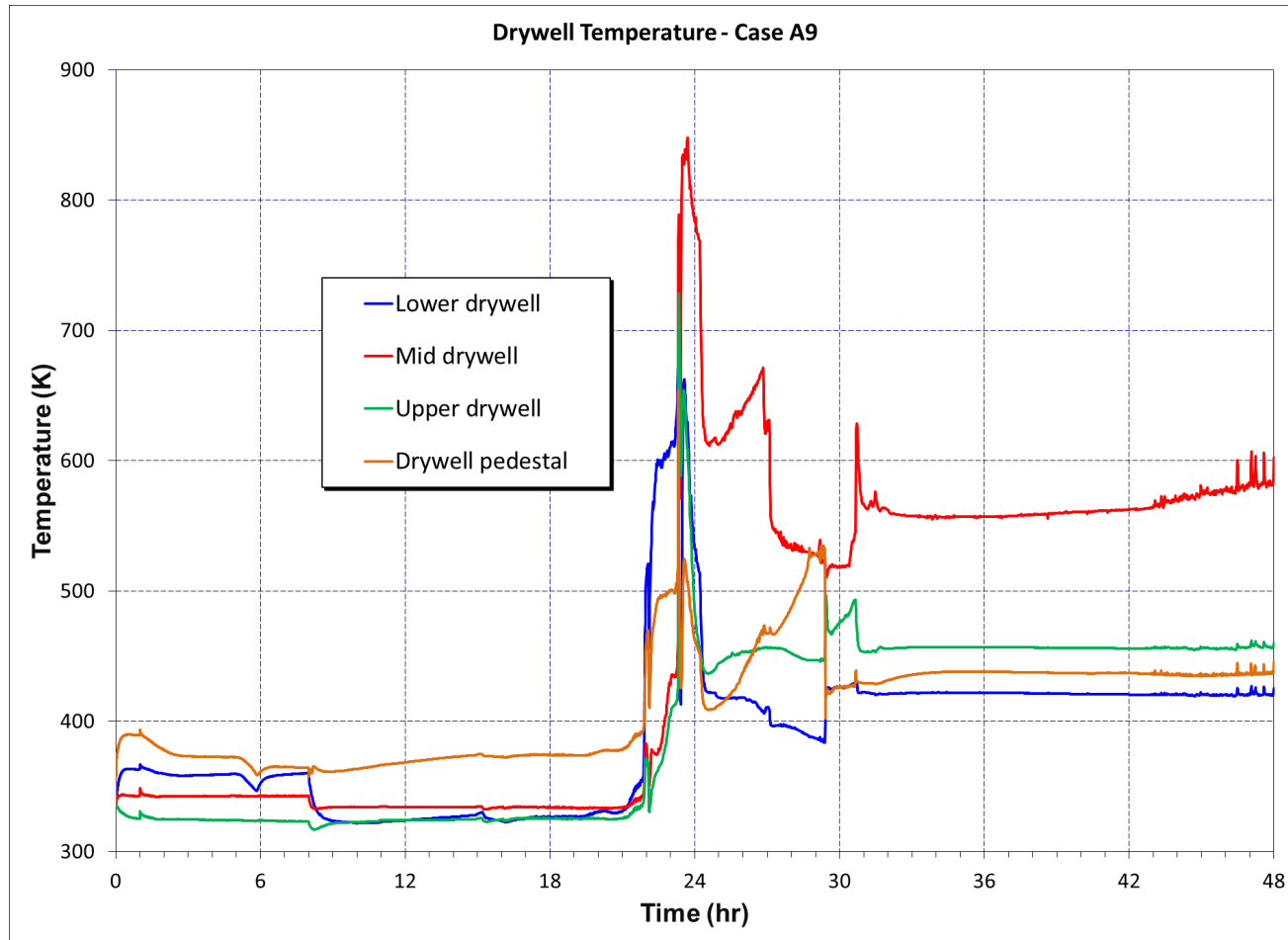




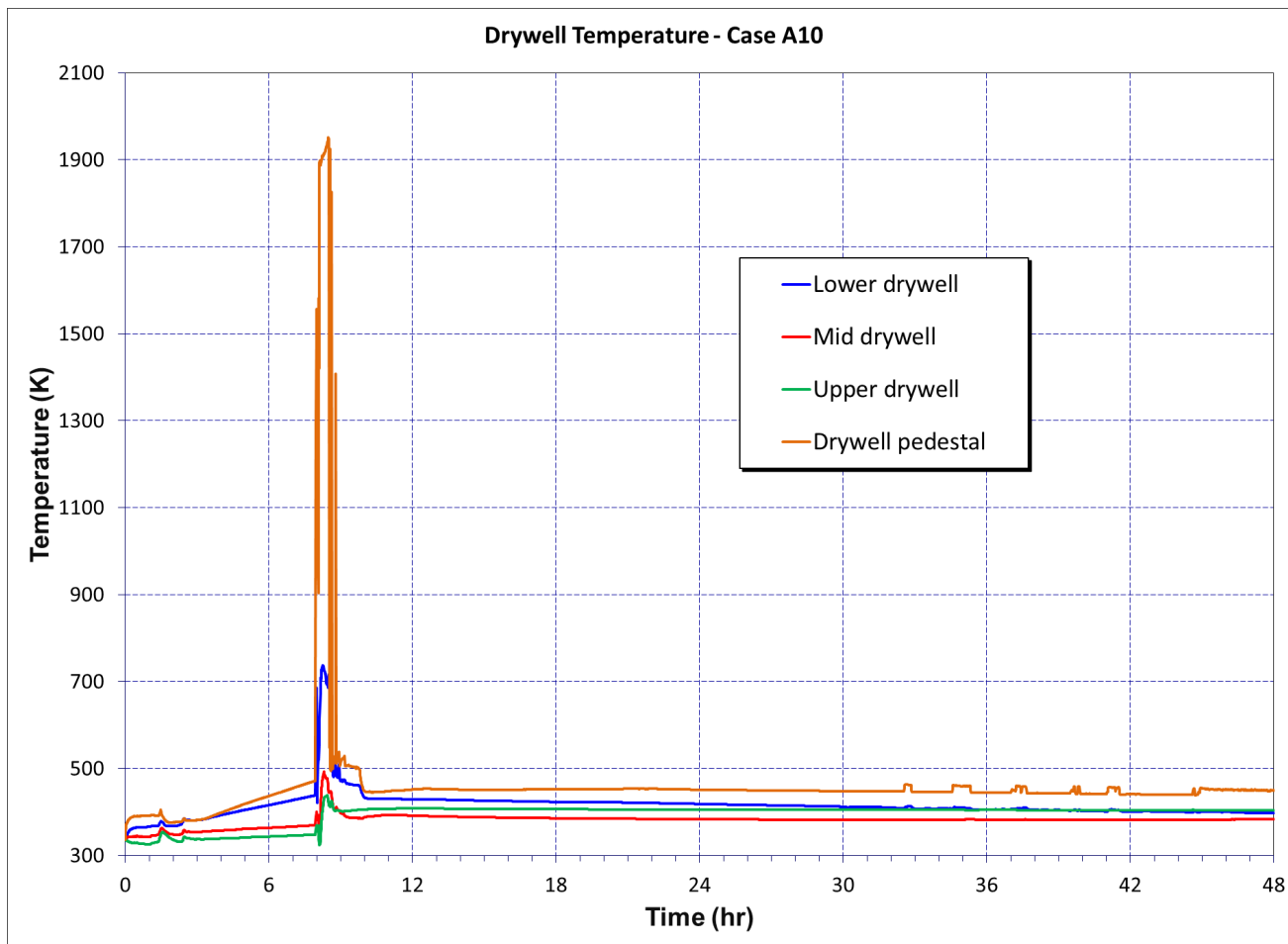


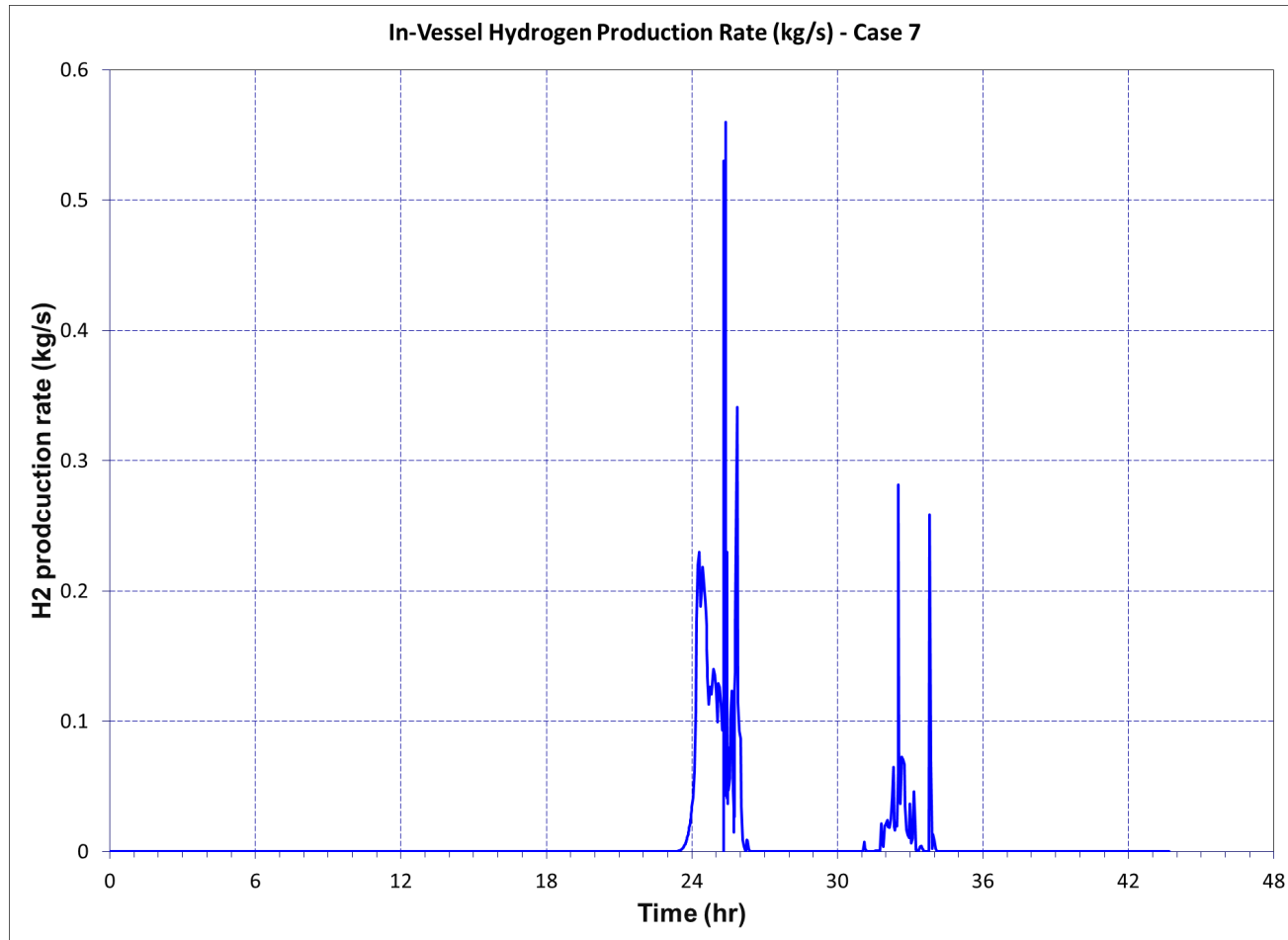


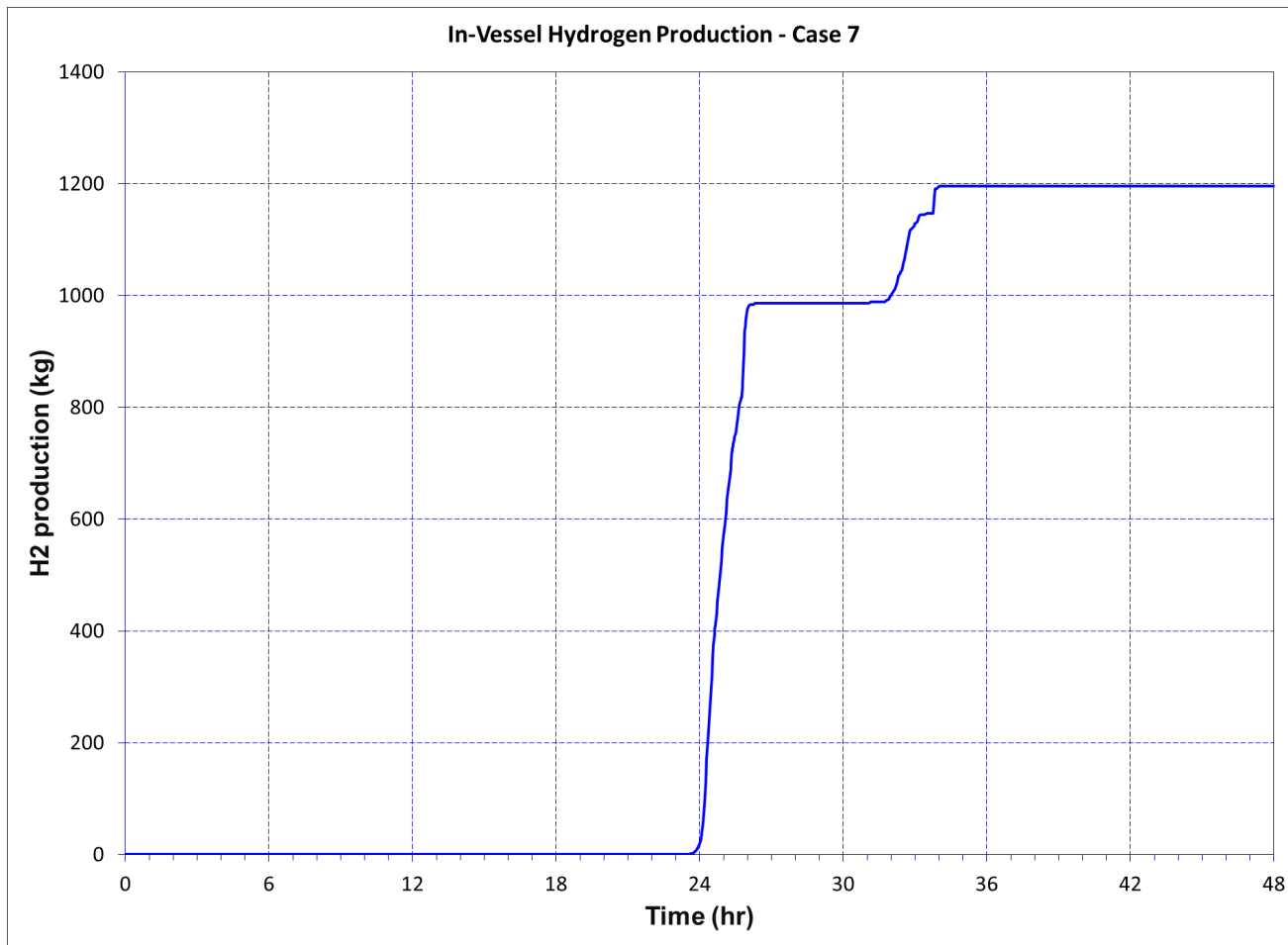


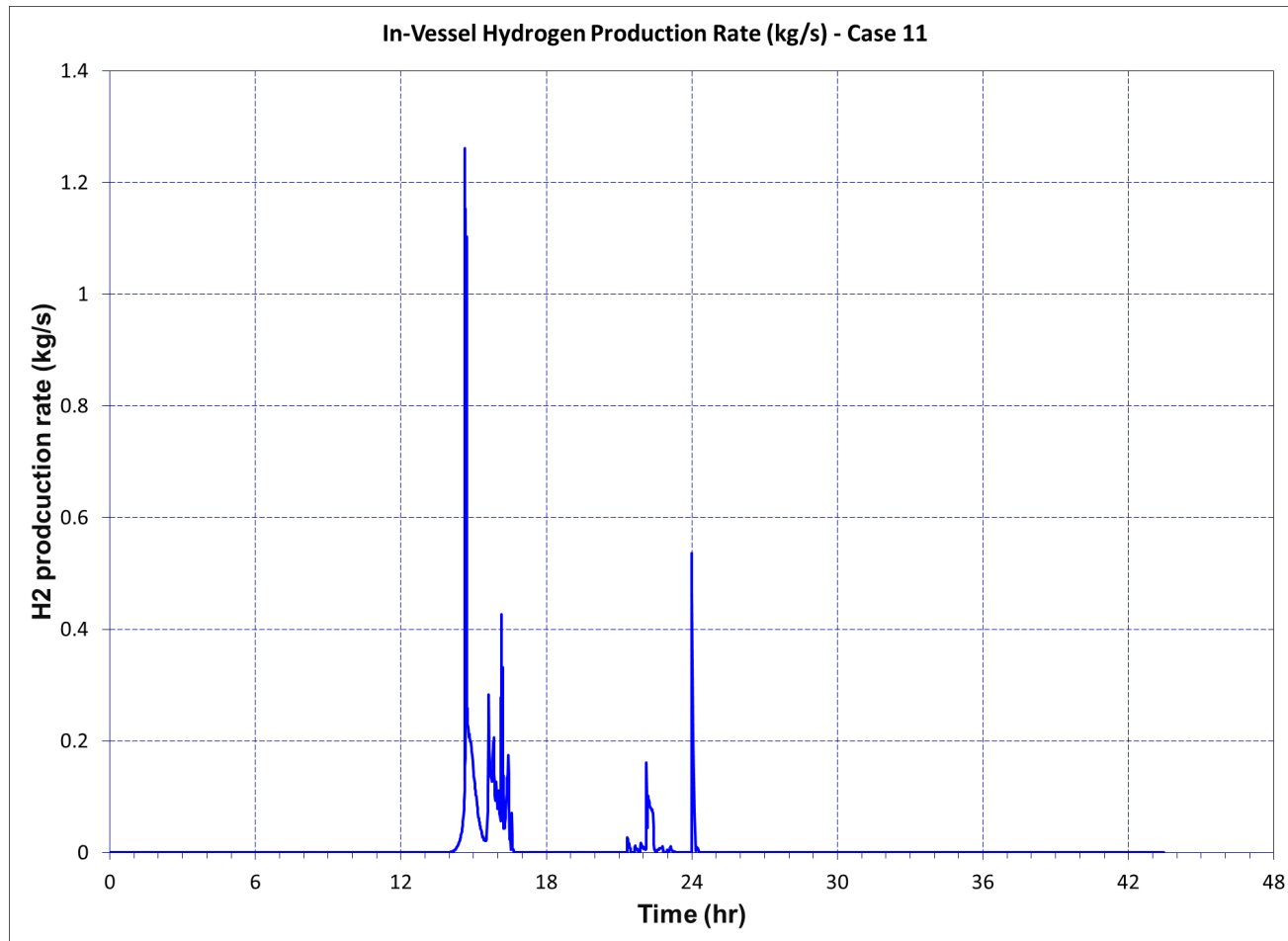


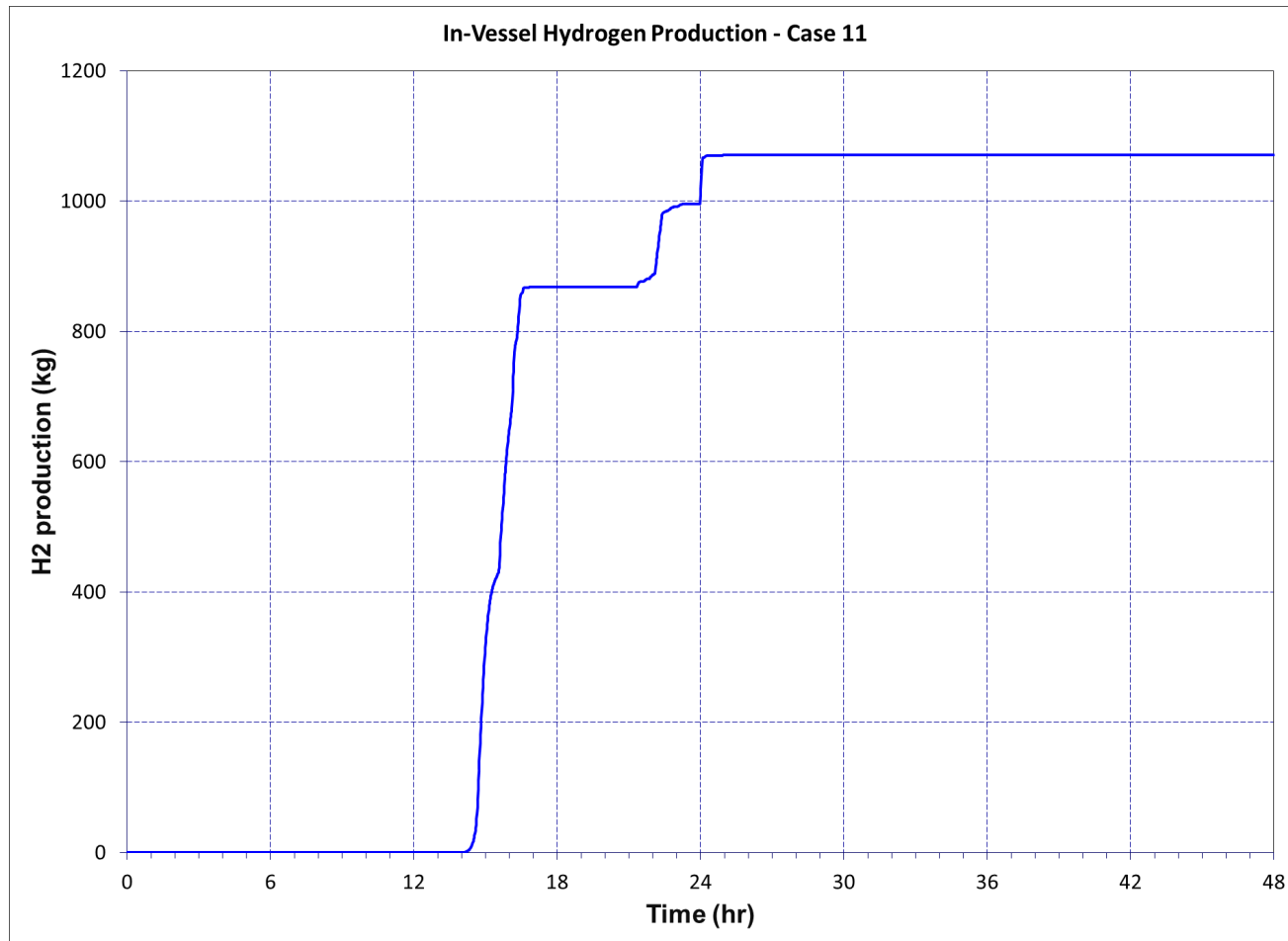


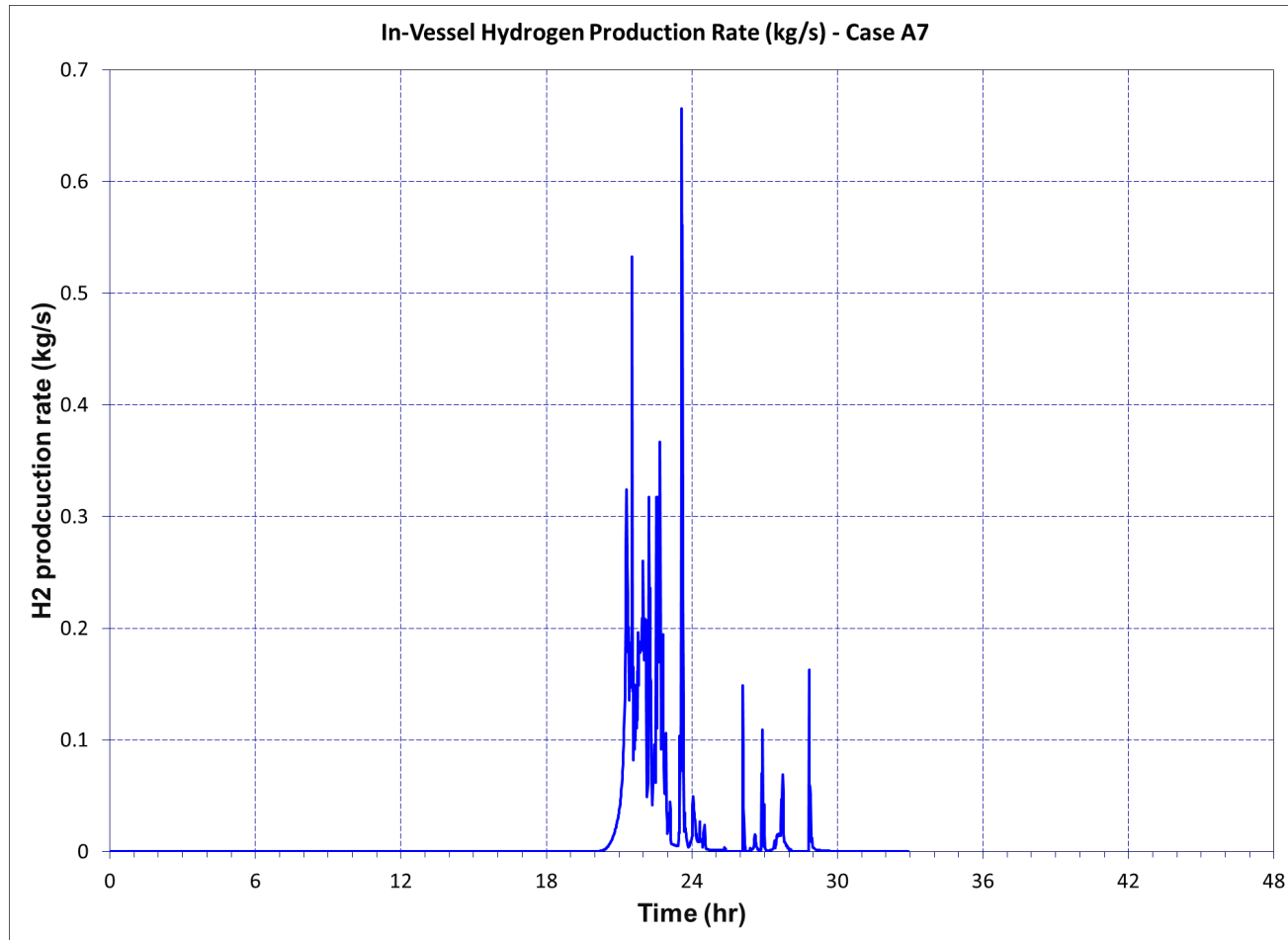


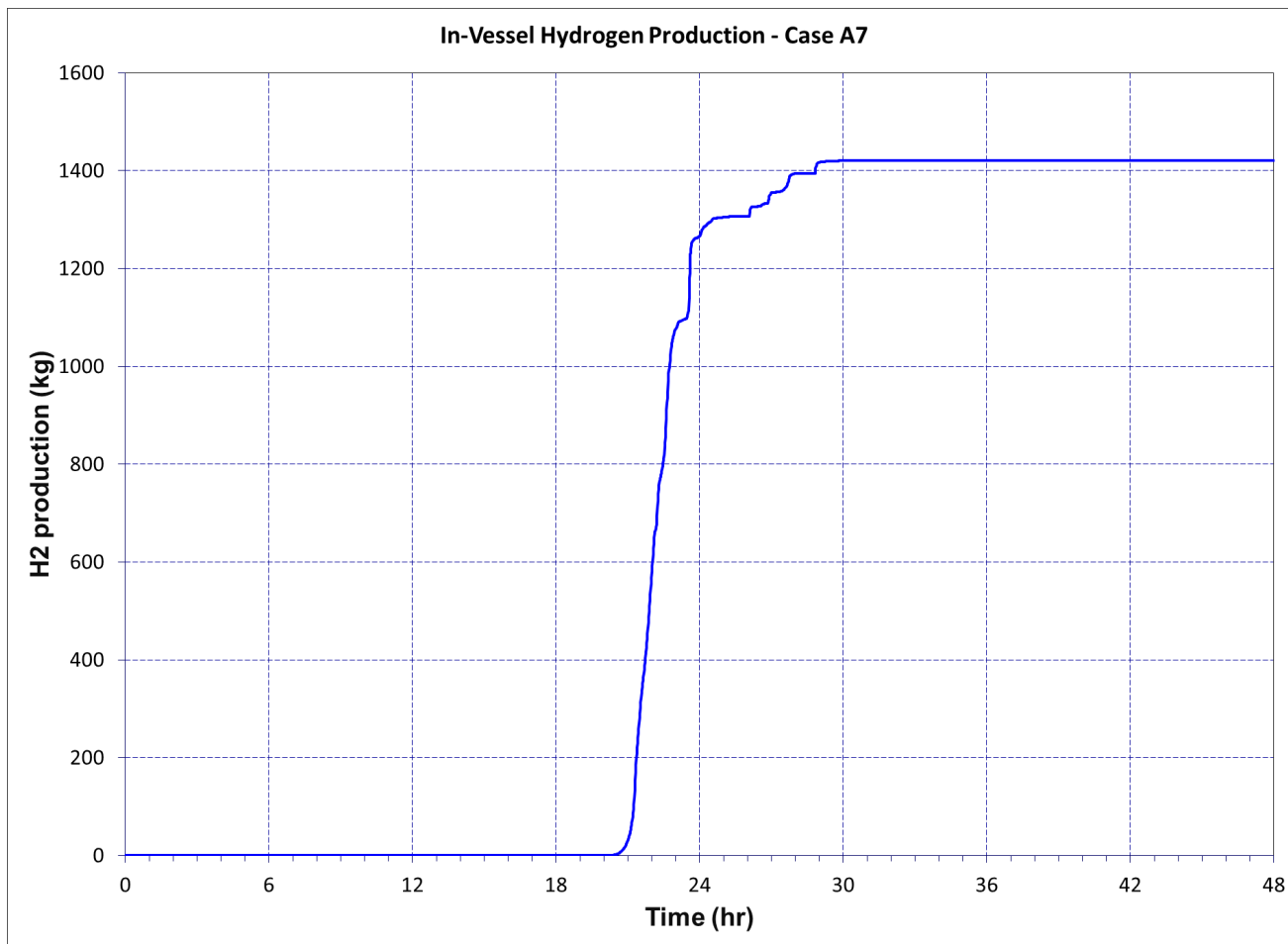


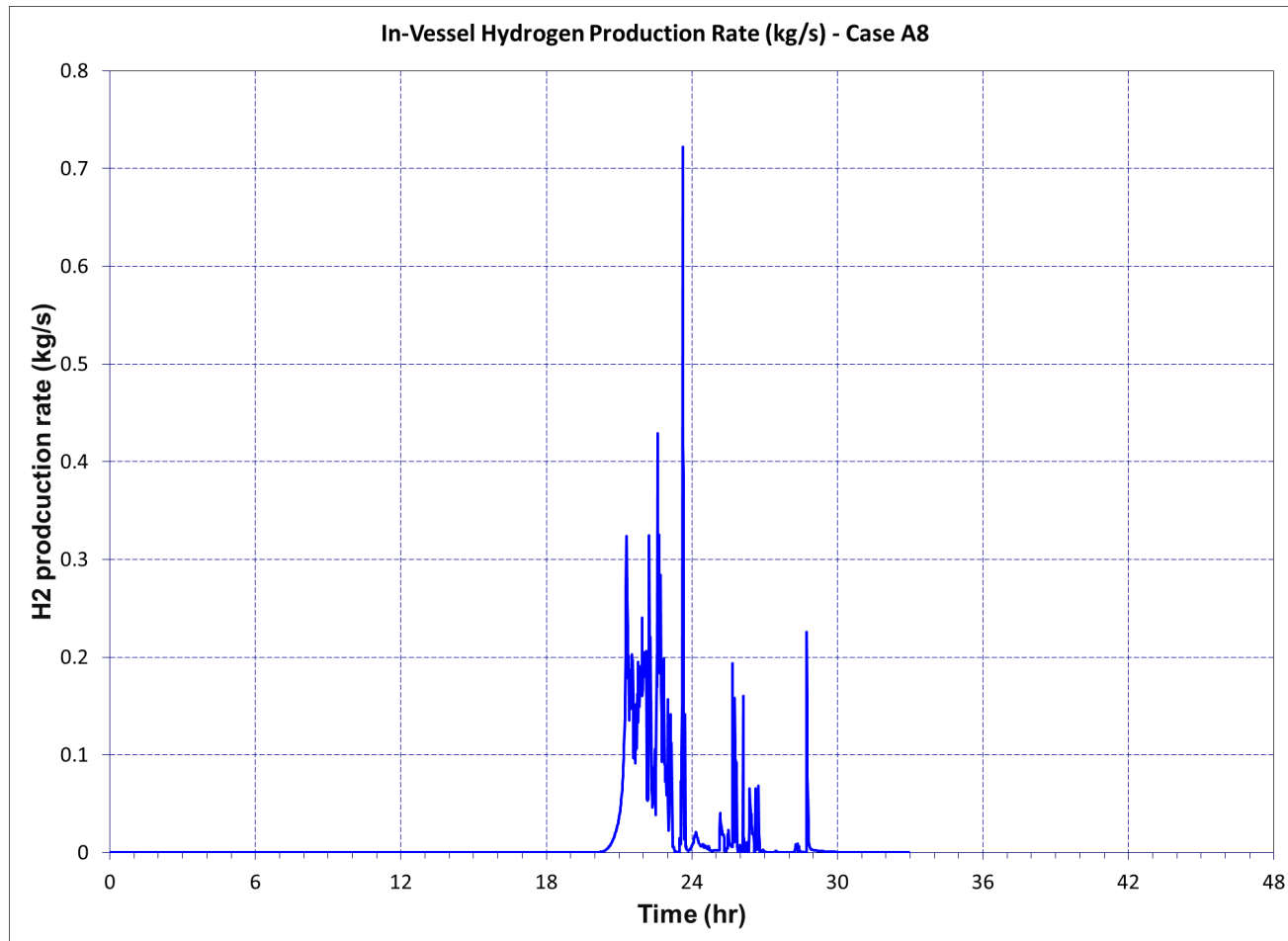




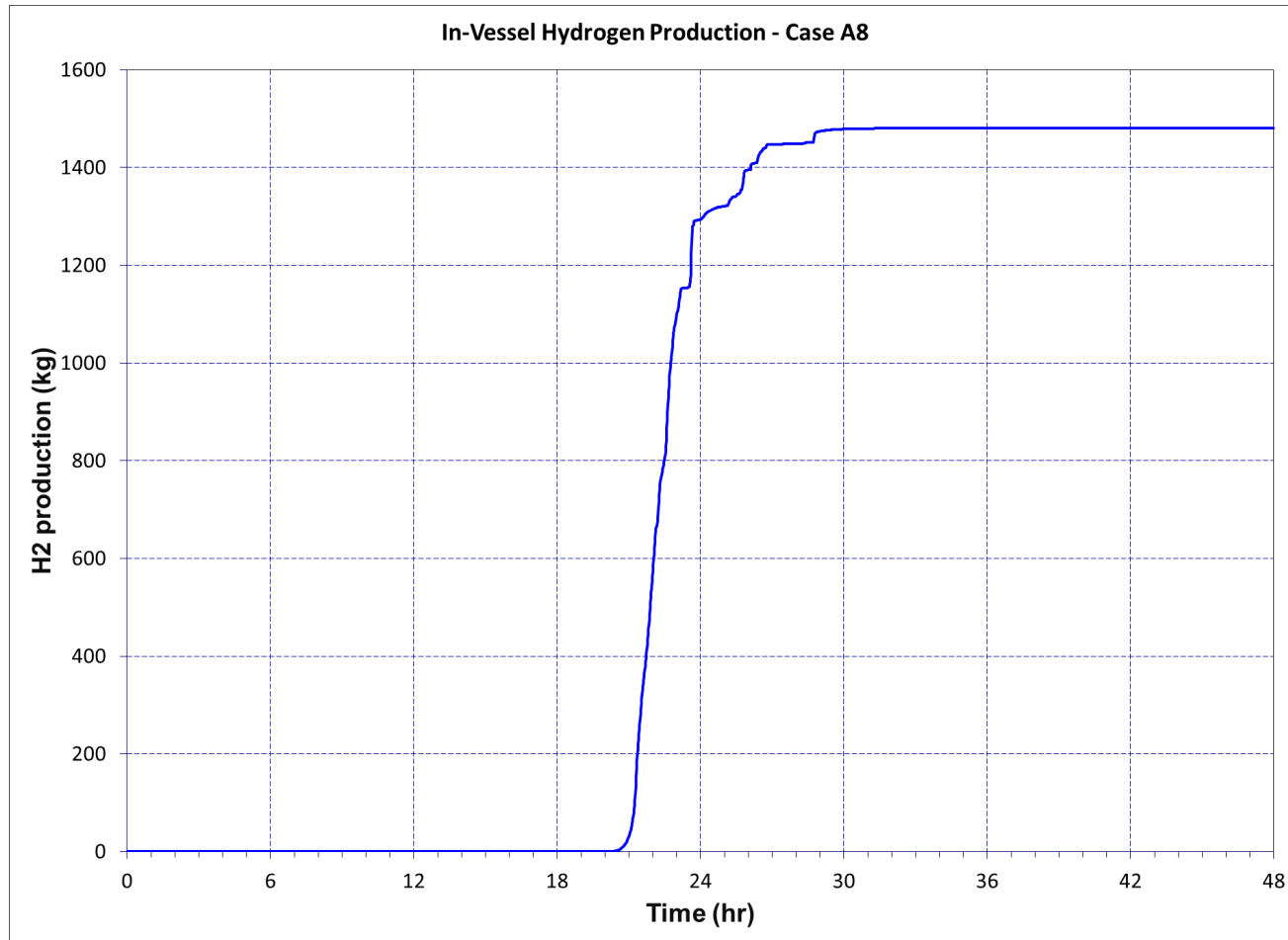


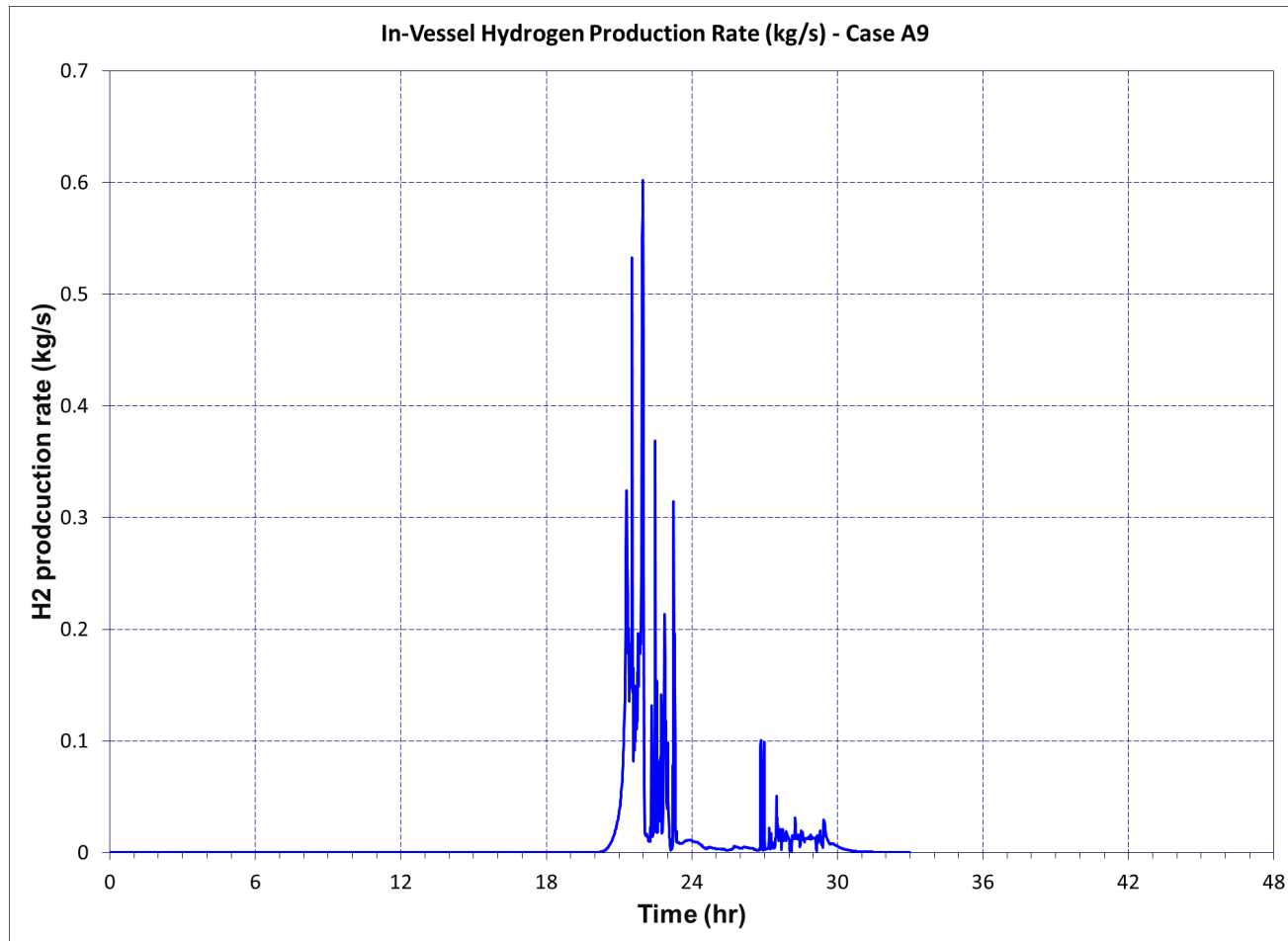


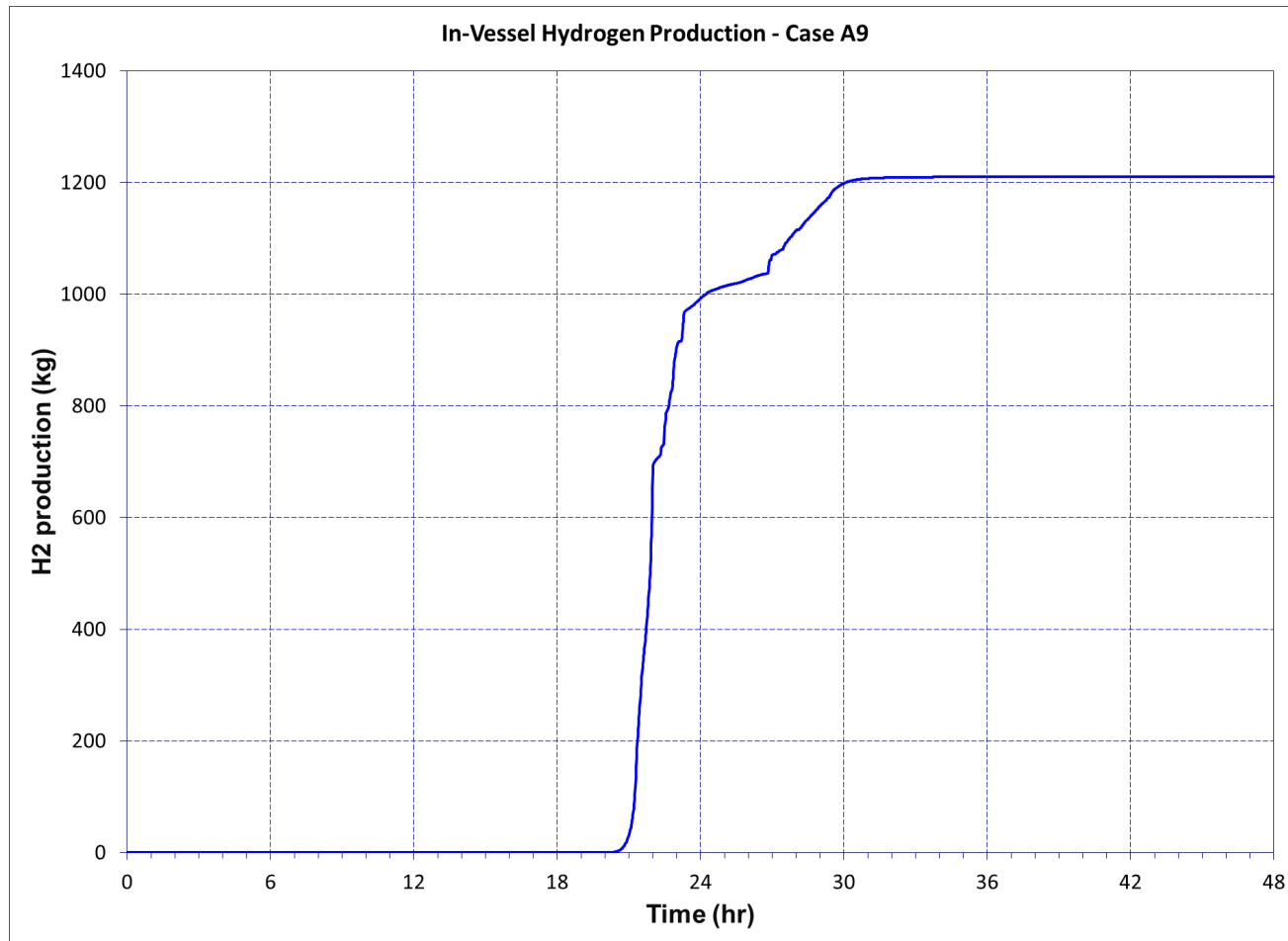


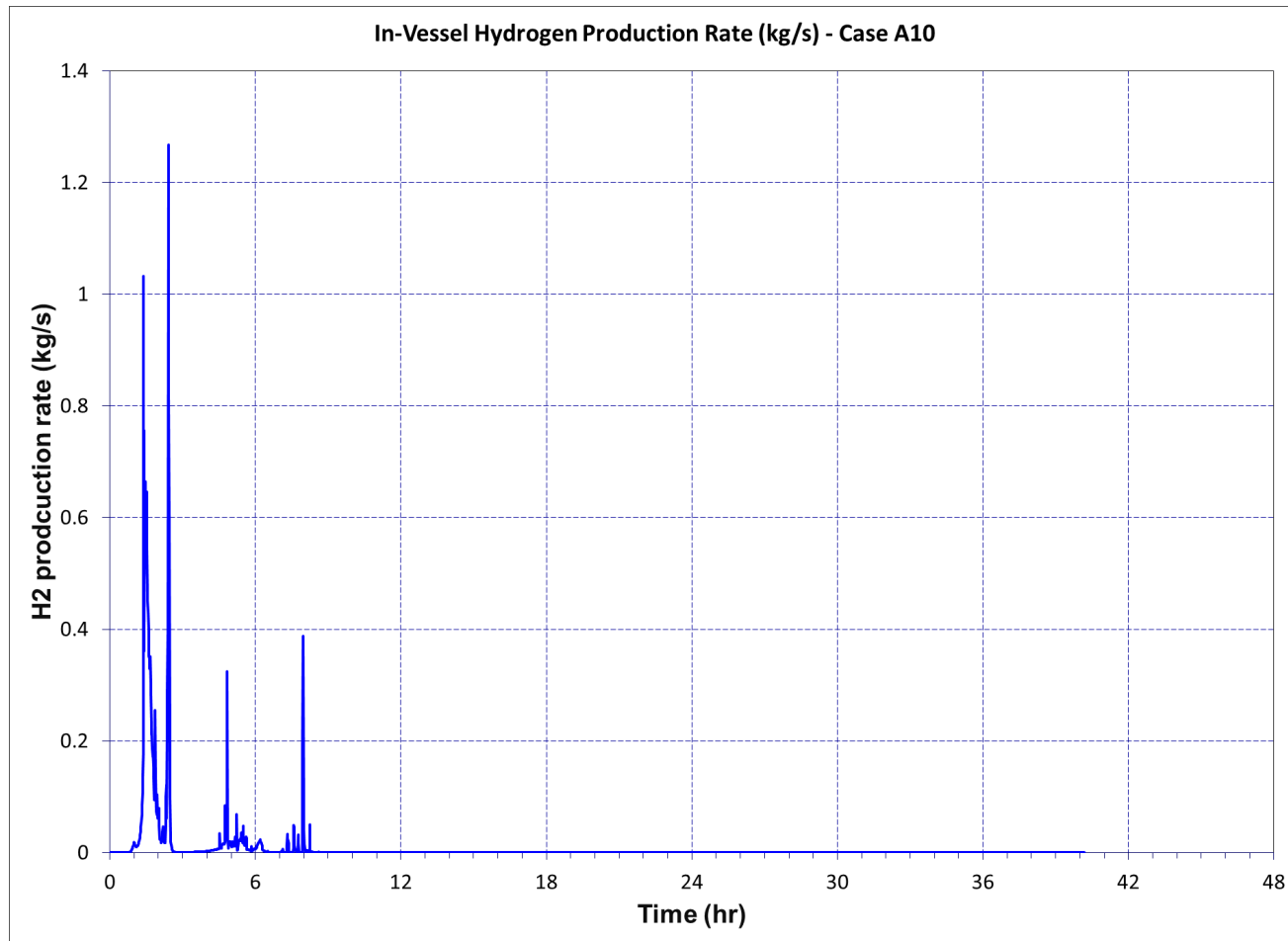


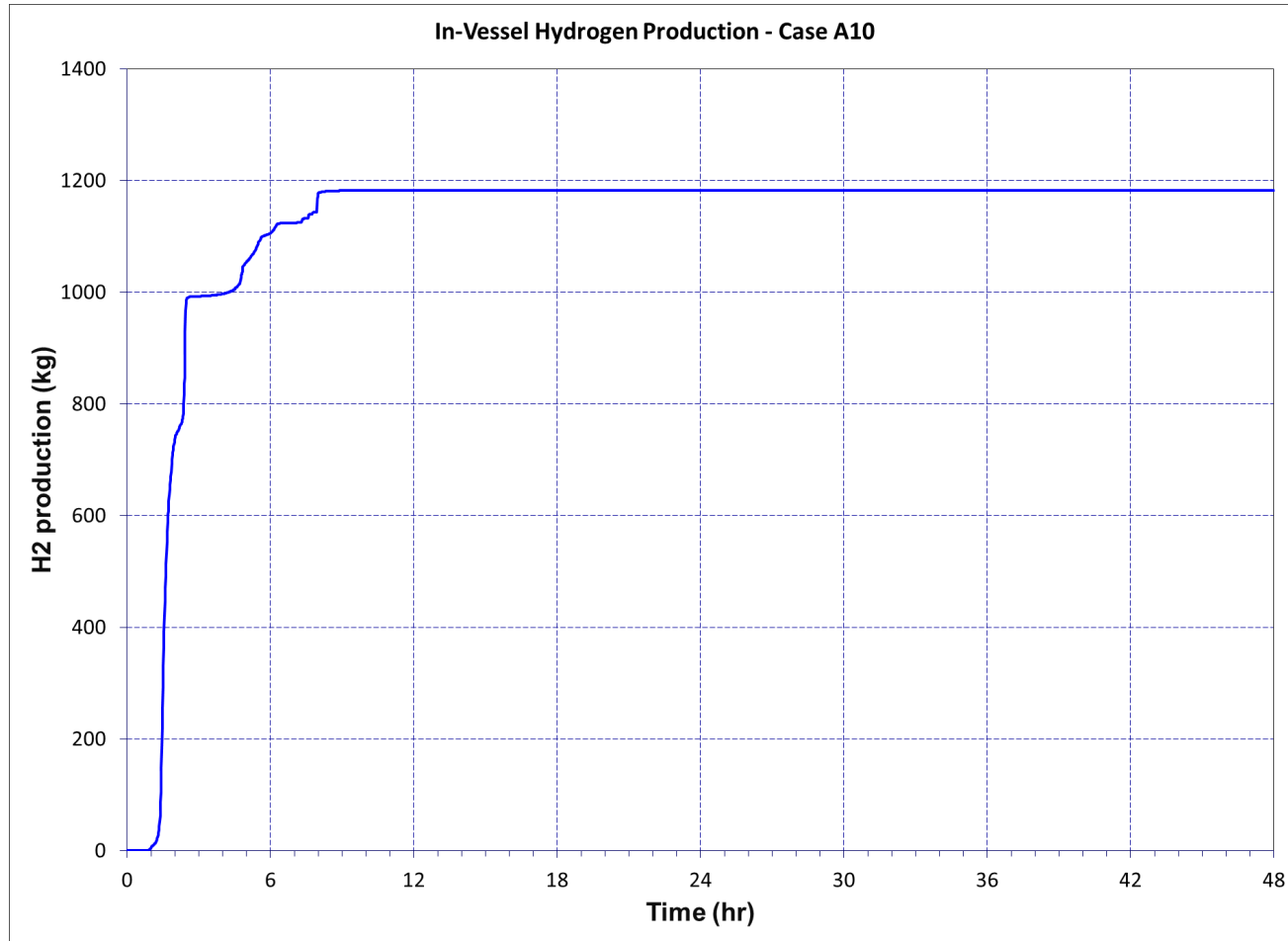














# Insights from Reviewing Relevant MELCOR and MAAP Results

- RCIC operation and suppression pool temperature
- Core melt progression
- Cesium release, transport, and revaporization
  - MELCOR has mostly Cesium Molybdate, with some Cesium Iodide; very little if any Cesium Hydroxide
  - Default MAAP assumes 9% CsI, and 45.5% each of CsOH and Cs<sub>2</sub>MoO<sub>4</sub>

# Sources for Observations

- Peach Bottom SOARCA report
- Attachment 5A of SECY-12-0157
- EPRI Technical Report 1026539 and related MAAP 5 analyses



# LTSSBO Cases Considered

- SOARCA unmitigated LTSSBO – 4 hour battery
- Case B.1 of EPRI report – 4 hour battery
- Case B.8 of EPRI report
  - 4 hour battery
  - 500 gpm flow to drywell spray
  - Vent cycling and switchover

# Event Summaries for LTSBO Cases (time in hours)

Event	SOARCA Unmitigated	EPRI Unmitigated	EPRI Mitigated	MAAP 5.0.1 Unmitigated	MAAP 5.0.1 Mitigated
RPV Depressurization	1.0	None	none	1.0	1.0
Battery Depletion	4.0	4.0	4.0	4.0	4.0
SRV Sticks Open	8.2	6.1	6.1	5.9	5.9
Core Uncovers	8.4	5.2	5.2	6.3	6.3
Core Relocates	10.5	8.8	8.9	9.5	9.6
Vessel Fails	19.7	12.0	12.0	12.1	12.0
Sprays On	none	none	5.0	none	6.3
Containment Fails	19.9	12.3	none	12.1	none
Wetwell Venting	none	none	12.1	none	12.3
Drywell Venting	none	none	17.9	none	26.9
Drywell Sprays Off	N/A	N/A	49.7	N/A	43.6

# Cesium Releases

Release Fraction	SOARCA Unmitigated	EPRI Unmitigated	EPRI Mitigated	MAAP 5.0.1 Unmitigated	MAAP 5.0.1 Mitigated
<b>CsI</b>	NR	0.11	0.00032	0.15	0.00039
<b>CsOH</b>	NR	NR	NR	0.20	0.00032
<b>Cs<sub>2</sub>MoO<sub>4</sub></b>	NR	NR	NR	0.00033	7.49E-05
<b>Cs</b>	0.005	NR	NR	0.10	2.15E-04
<b>Cs DF</b>	200	9	3000	10	4656

# SOARCA LTSBO RPV Pressure

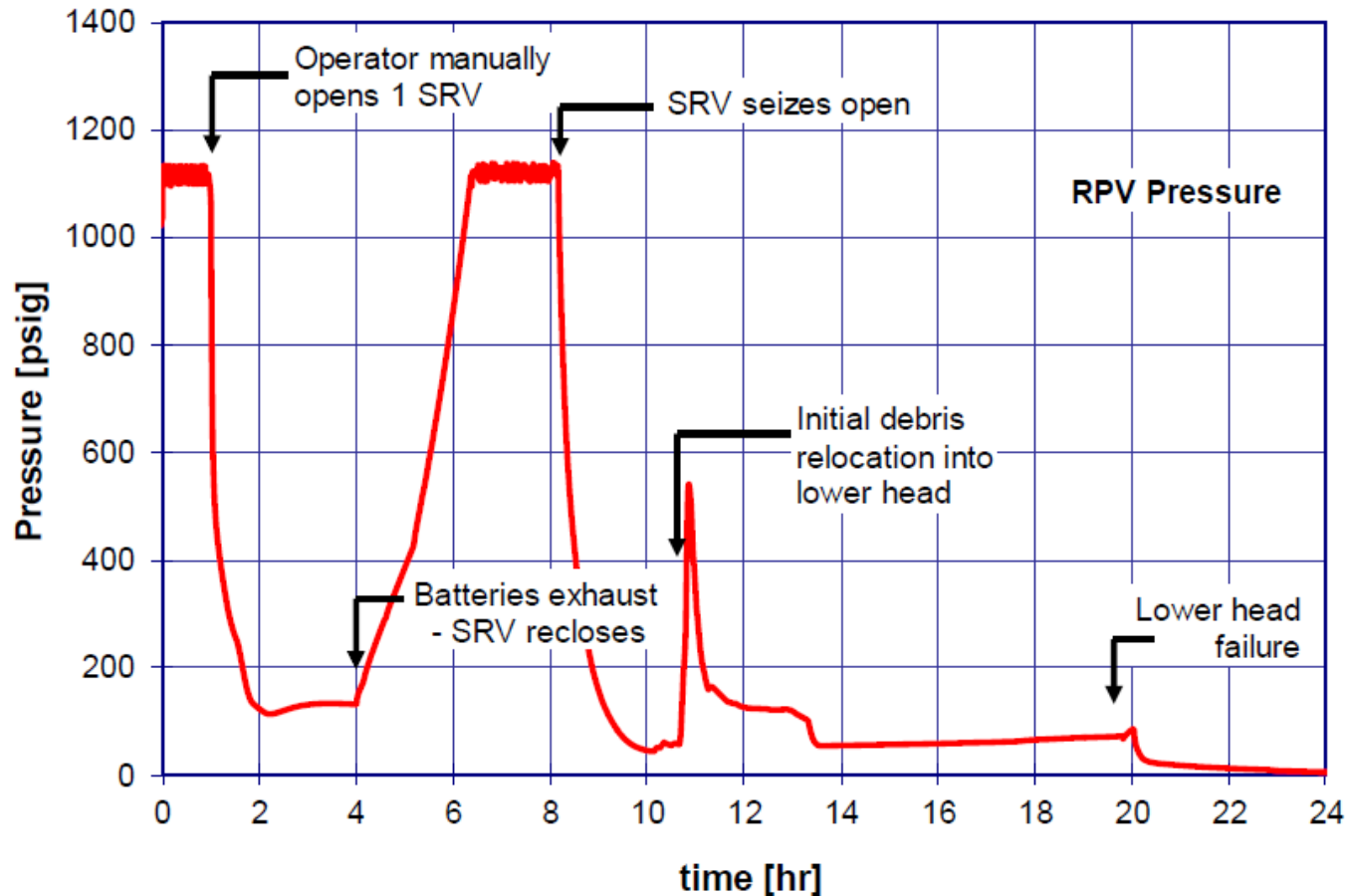


Figure 5-1 LTSBO vessel pressure

# SOARCA LTSBO RPV Level

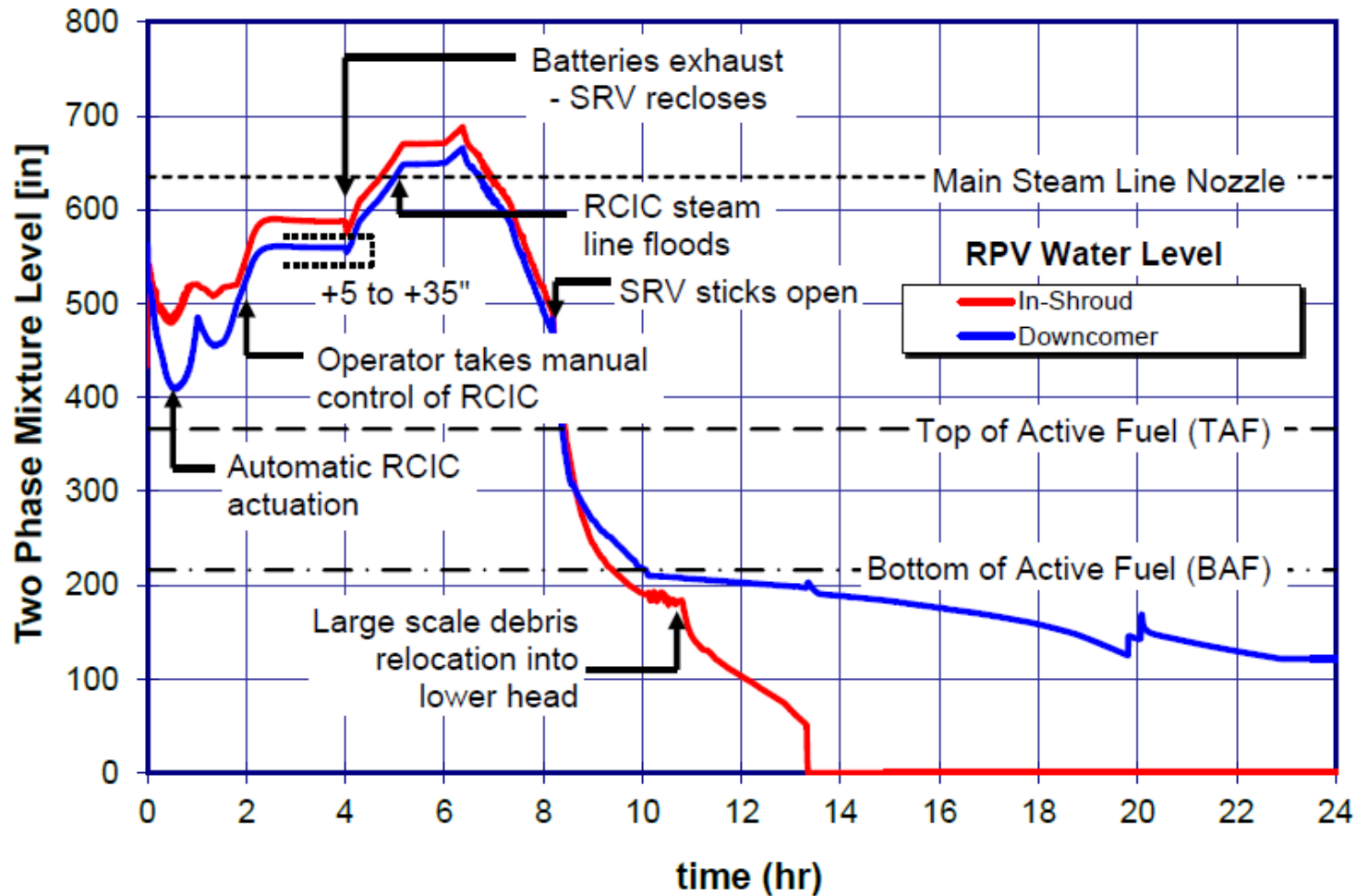


Figure 5-2 LTSBO reactor pressure vessel water level

# SOARCA LTSBO Drywell Pressure

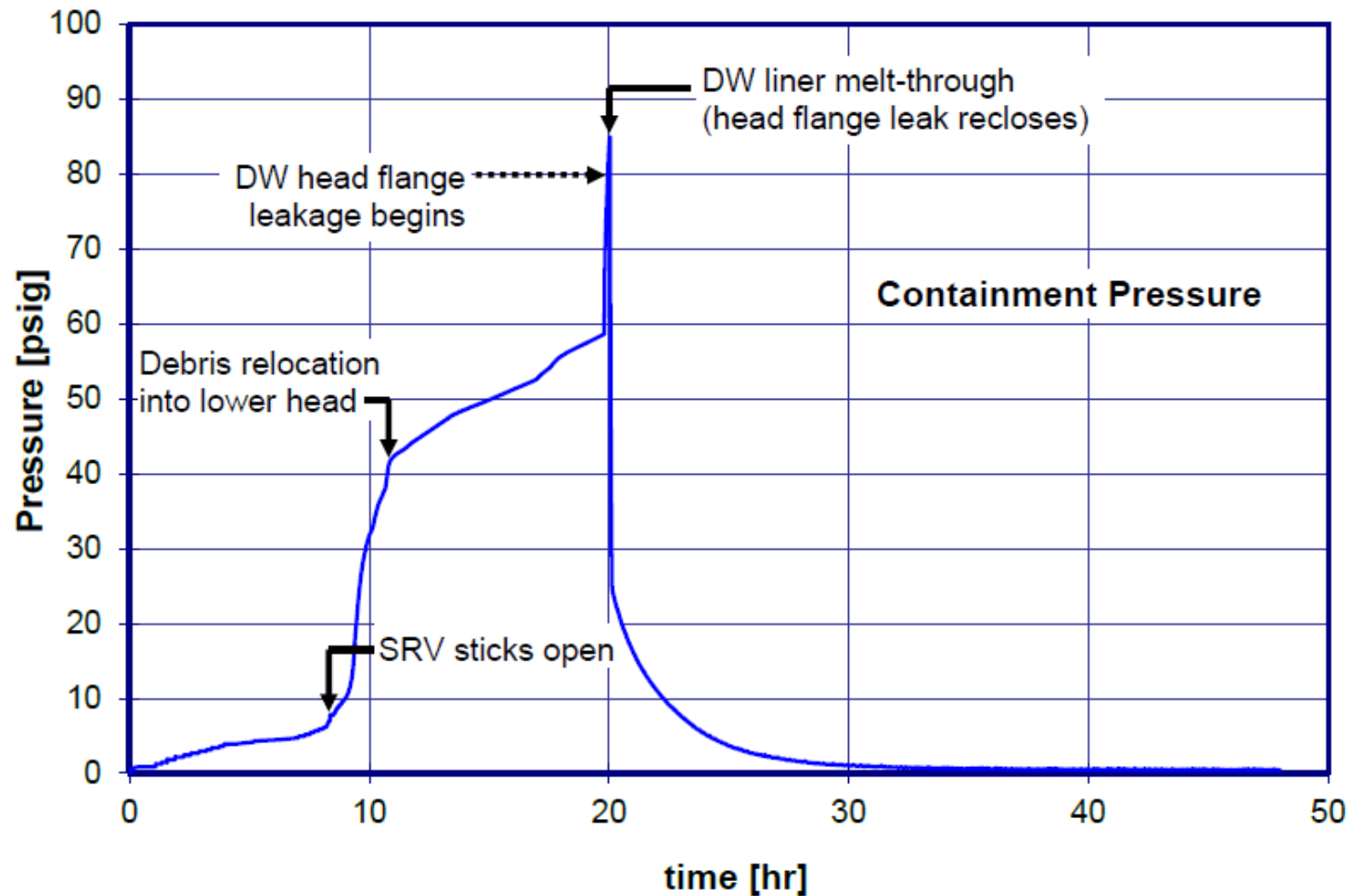


Figure 5-8 LTSBO containment pressure

# SOARCA LTSBO

## Suppression Pool Temperature

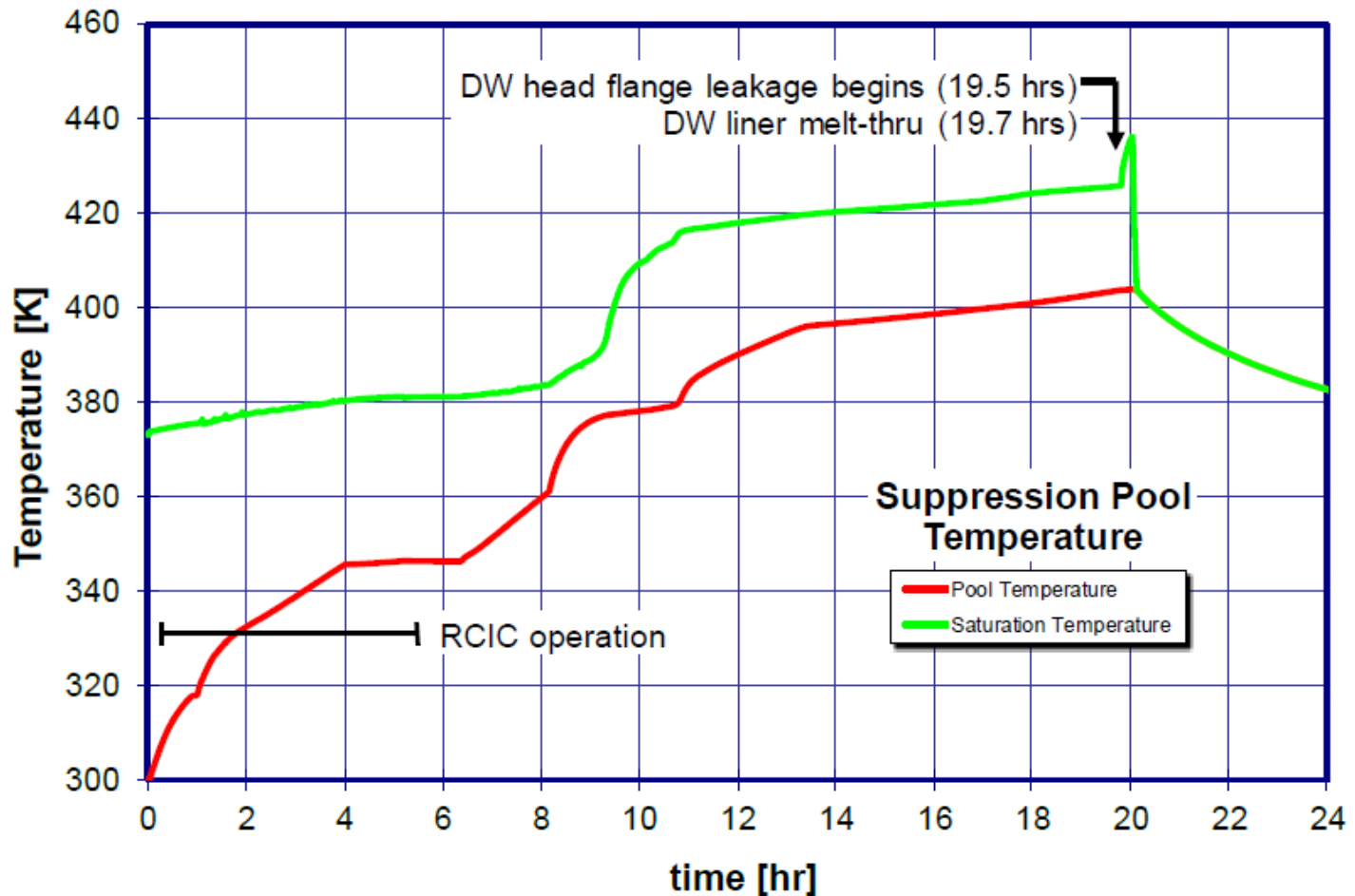
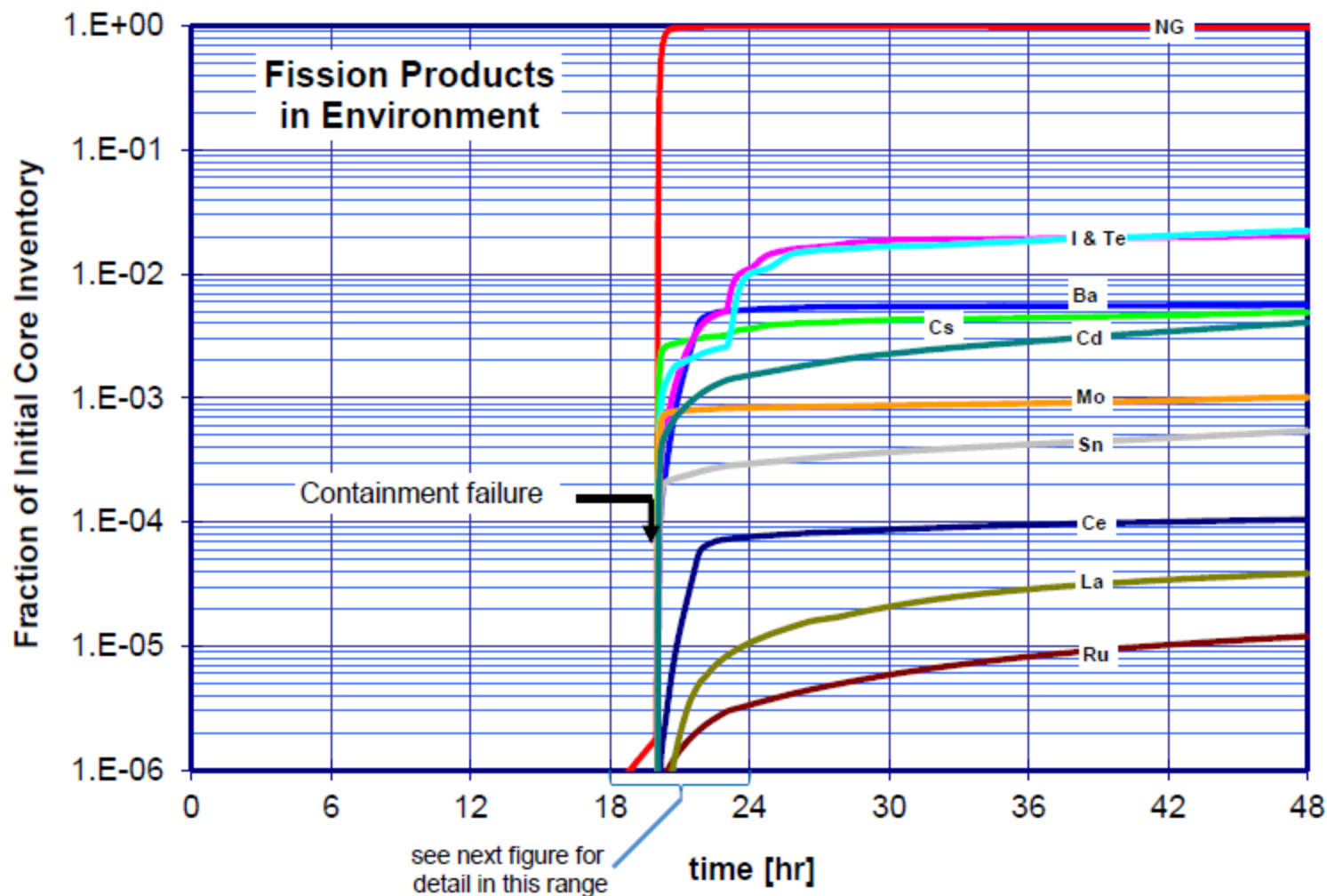


Figure 5-9 LTSBO suppression pool temperature

# SOARCA LTSBO

## Fission Product Releases



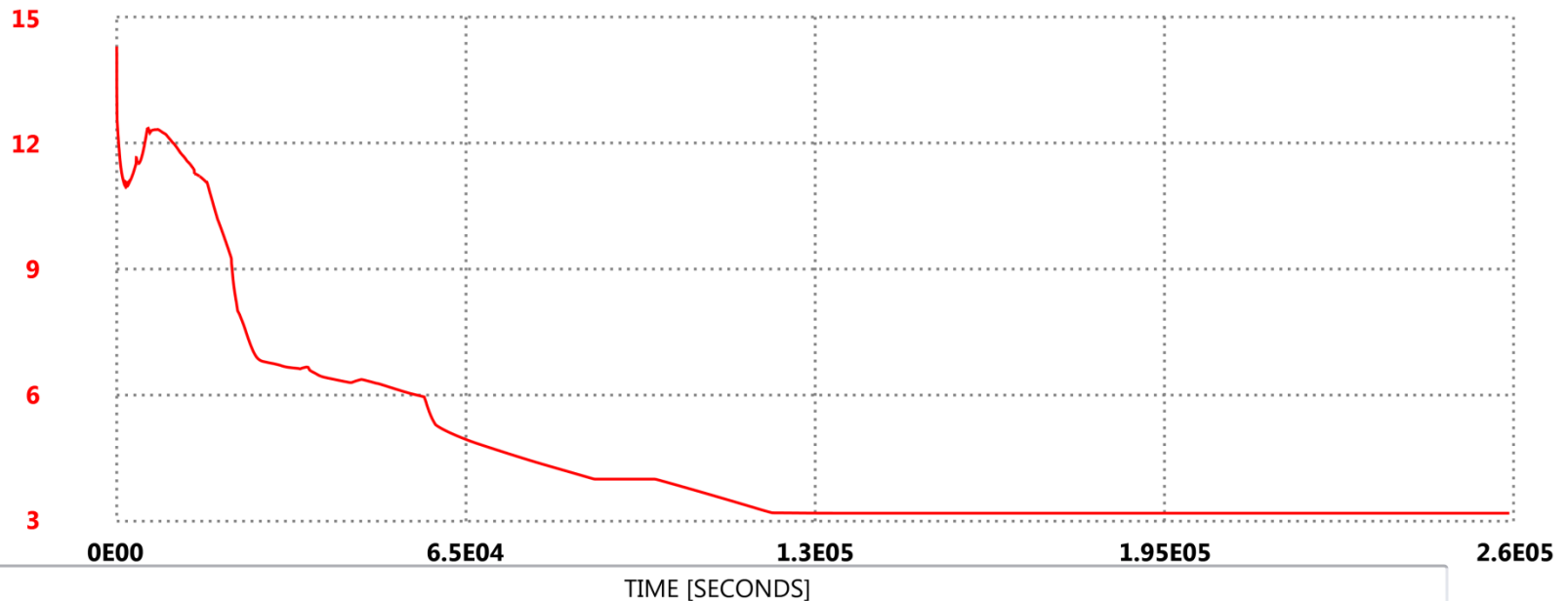


# MAAP 5.0.1

## Water Level in Shroud

SOARCA LTSBO TDBATT = 4 HR

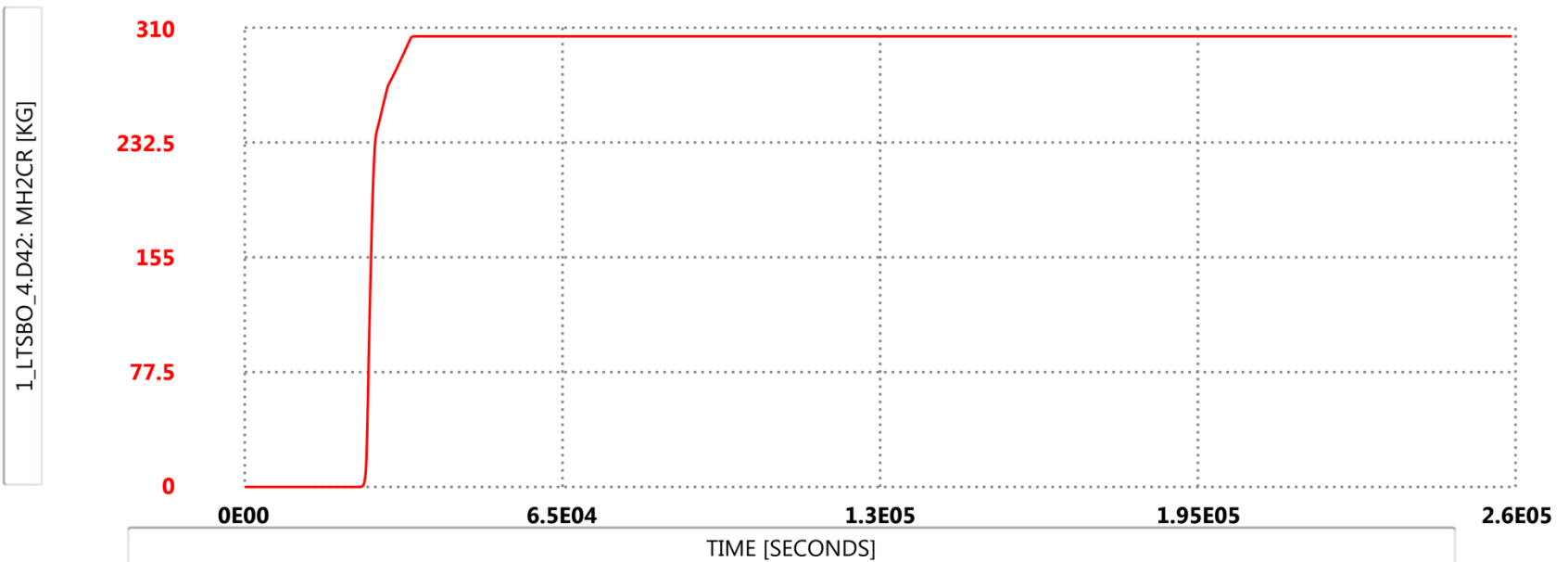
1\_LTSBO\_4.D41: XWSH [M]



# MAAP 5.0.1

## Hydrogen Produced In-vessel

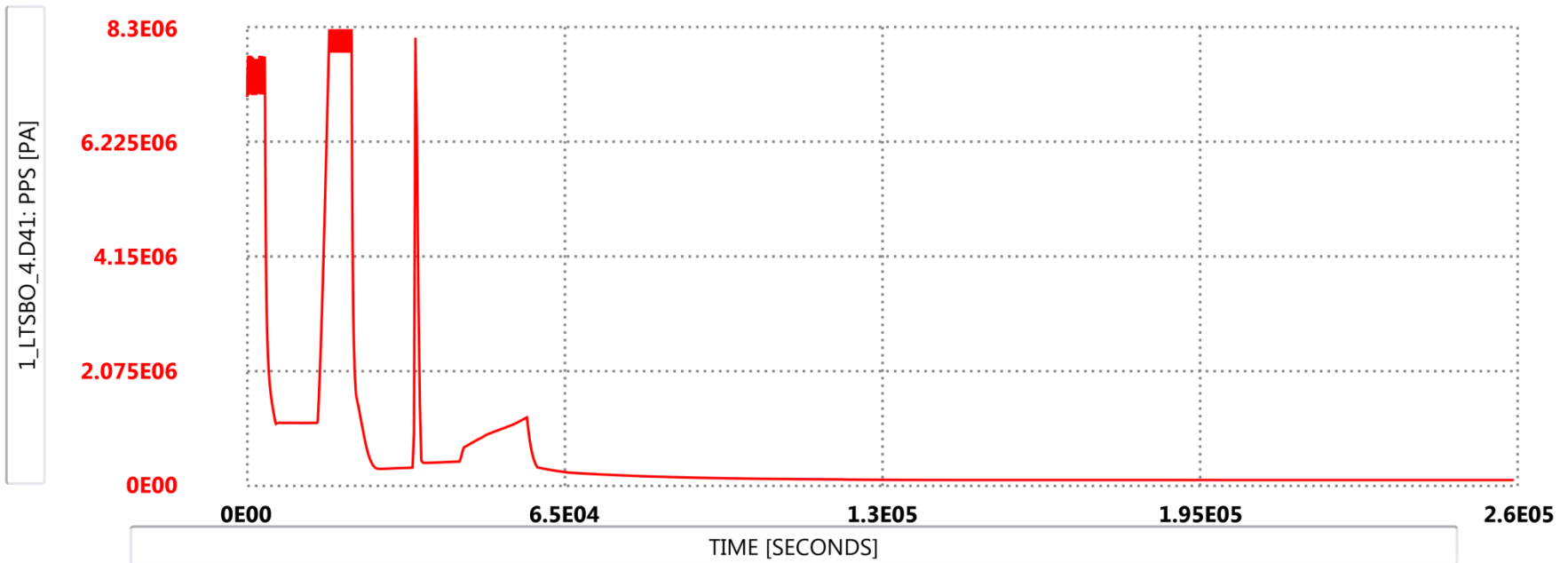
SOARCA LTSBO TDBATT = 4 HR



# MAAP 5.0.1

## Pressure in RPV

SOARCA LTSBO TDBATT = 4 HR

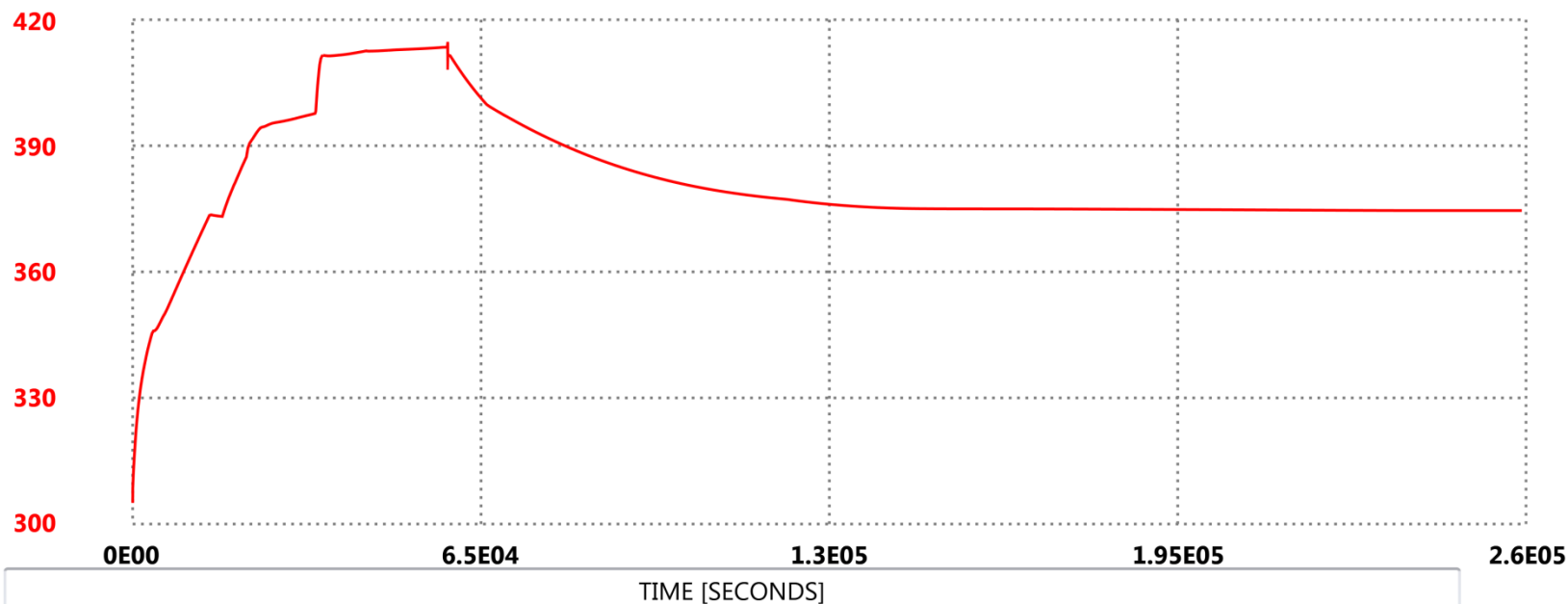


# MAAP 5.0.1

## Suppression Pool Temperature

SOARCA LTSBO TDBATT = 4 HR

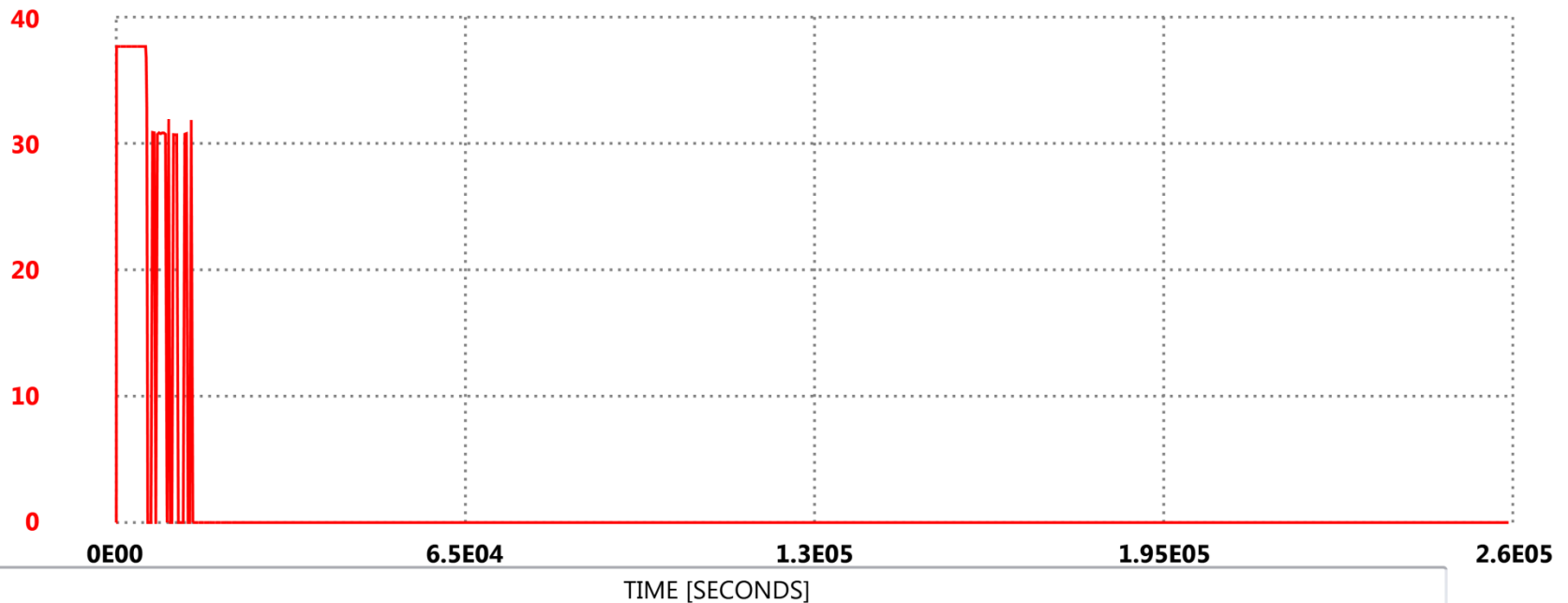
1\_LTSBO\_4.D43: TWRB(4) [K]



# MAAP 5.01 RCIC Flow

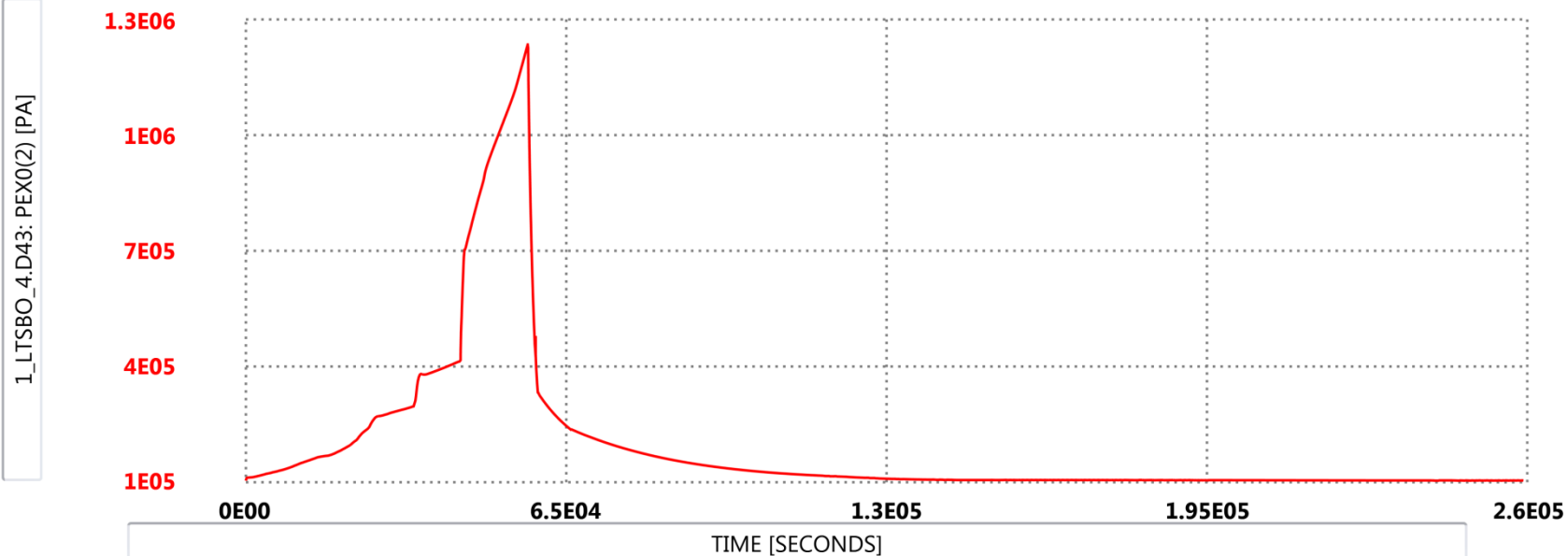
SOARCA LTSBO TDBATT = 4 HR

1\_LTSBO\_4.D41: WWRCIC [KG/S]



# MAAP 5.01 Drywell Pressure

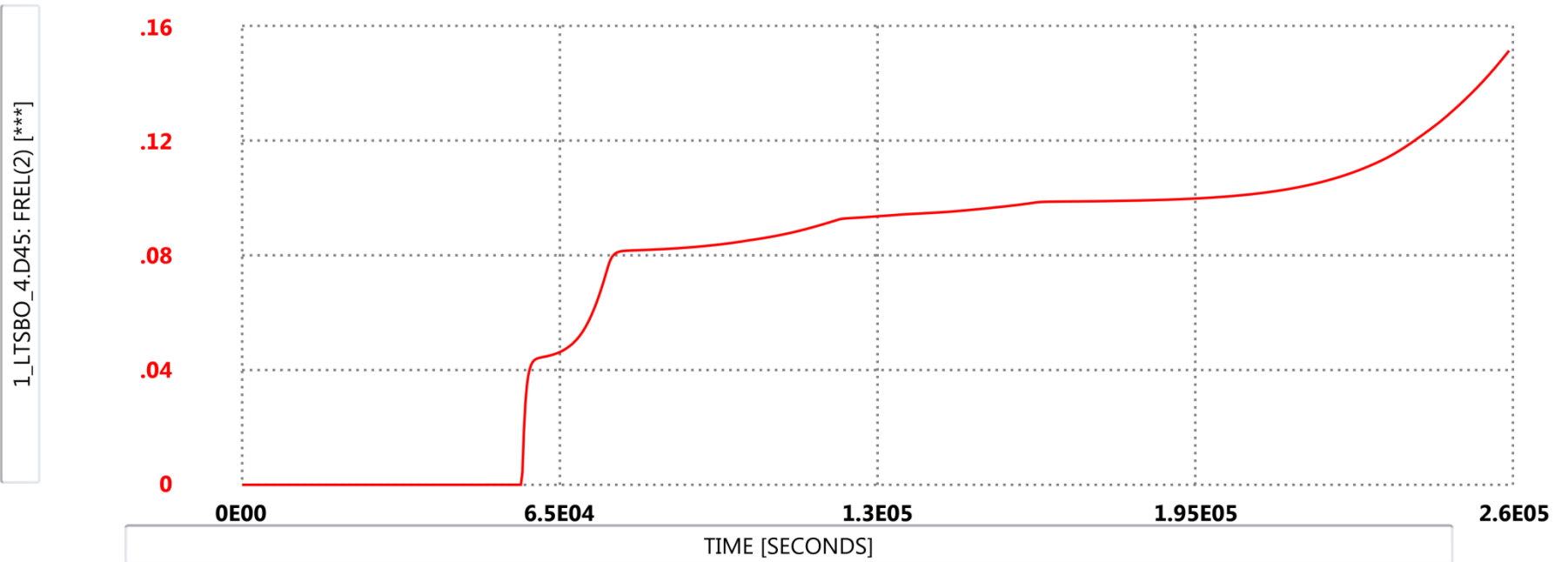
SOARCA LTSBO TDBATT = 4 HR



# MAAP 5.01

## Cesium Iodide Release Fraction

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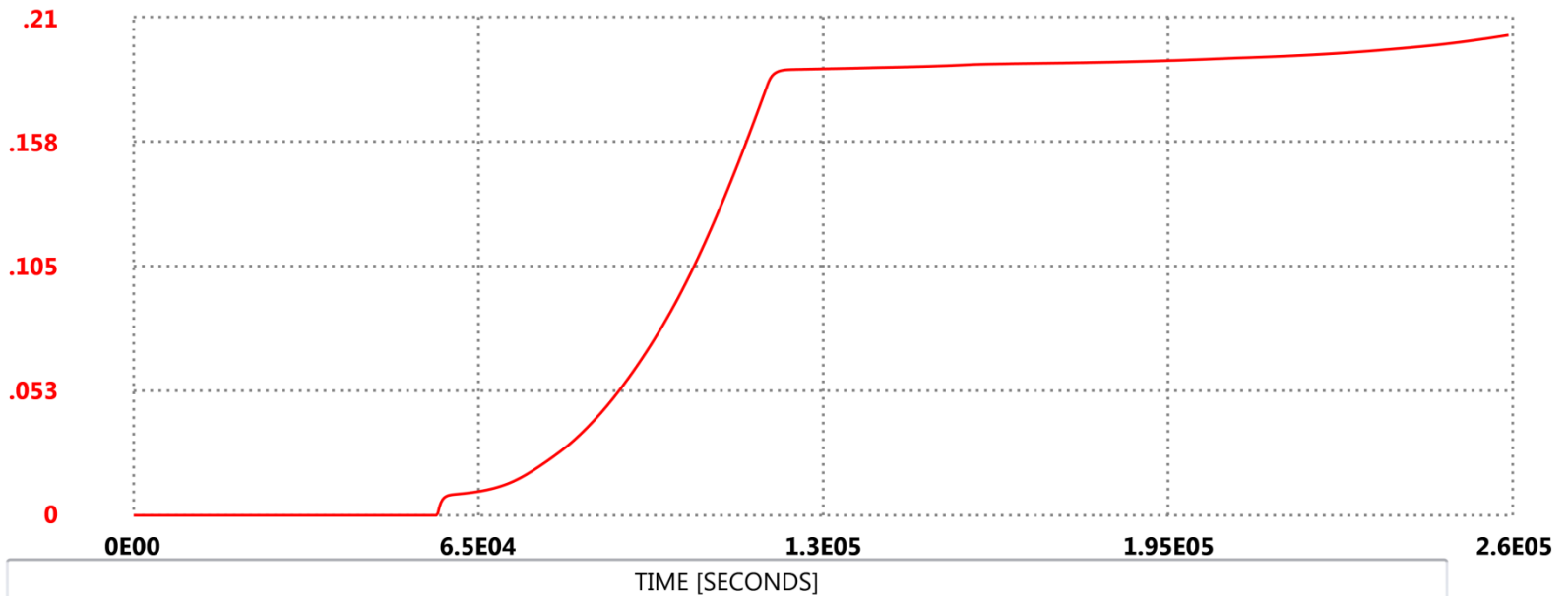


# MAAP 5.01

## Cesium Hydroxide Release Fraction

SOARCA LTSBO TDBATT = 4 HR

1\_LTSBO\_4.D45: FREL(6) [\*\*\*]





# MAAP 5.01

## Cesium Molybdate Release Fraction

SOARCA LTSBO TDBATT = 4 HR

