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# 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

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- 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

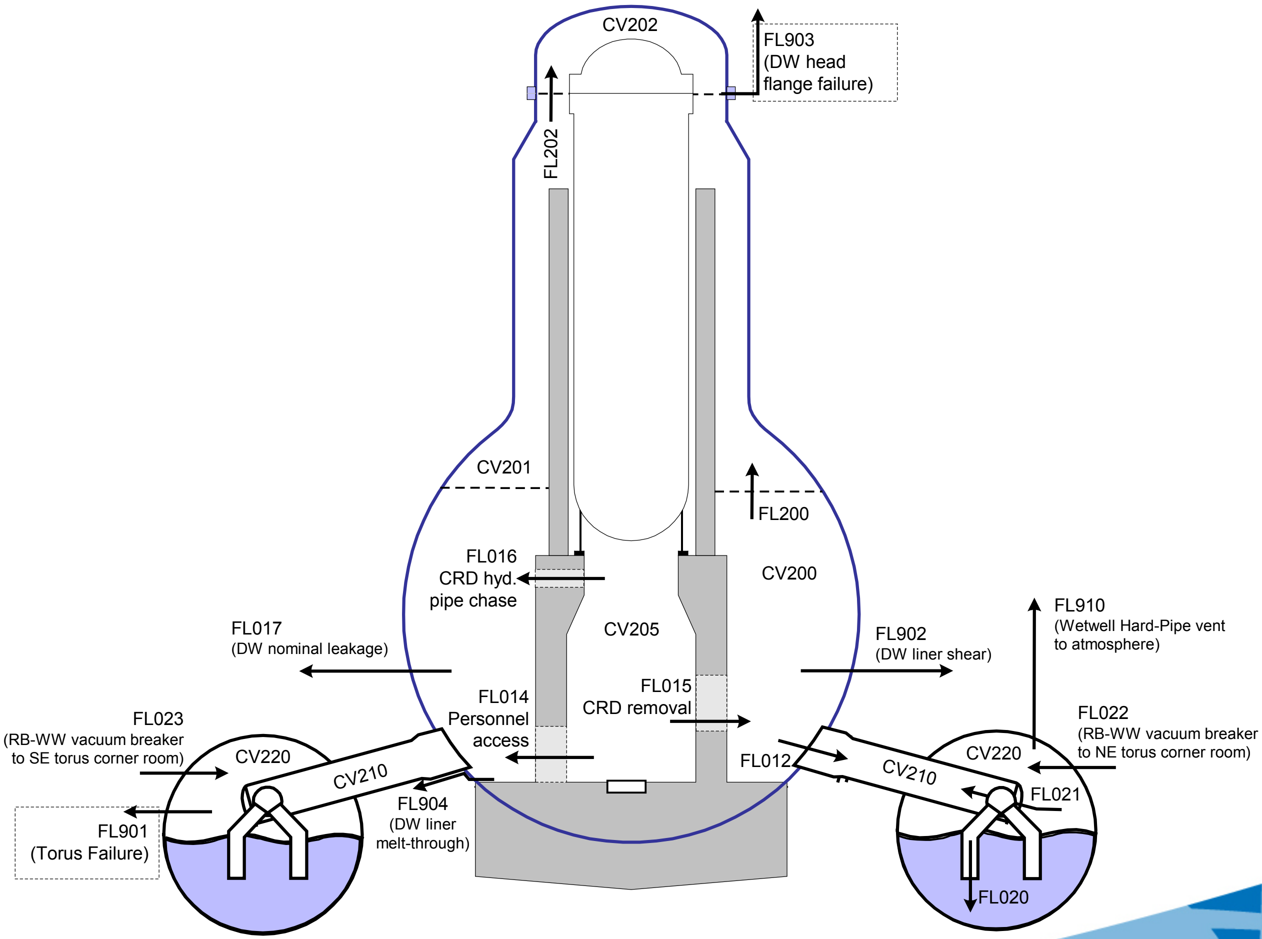
| Phenomena | Modeling Features | Implications |
|---|---|---|
| In-vessel Accident Progression | BWR-oriented models<br>- Gradual core degradation and relocation<br>- Enhanced clad and structure oxidation<br>- Holdup of some fission products in core | - Gradual release of relatively cold core debris at vessel breach<br>- Significantly more in-vessel hydrogen production from enhanced clad and structure oxidation<br>- Late release of held-up fission products |
| Ex-vessel Core Debris Behavior | - slow spreading of relatively cold core debris<br>- Extended core-concrete interaction | - Liner failure physically unreasonable in presence of water on the drywell floor<br>- Coolable debris bed in the long-term<br>- Generation of non-condensable for longer duration |
| Fission Product Transport | Mechanistic modeling based on PHEBUS and other recent experiments | - More realistic assessment of in-containment retention mechanisms |

# Modeling Uncertainties

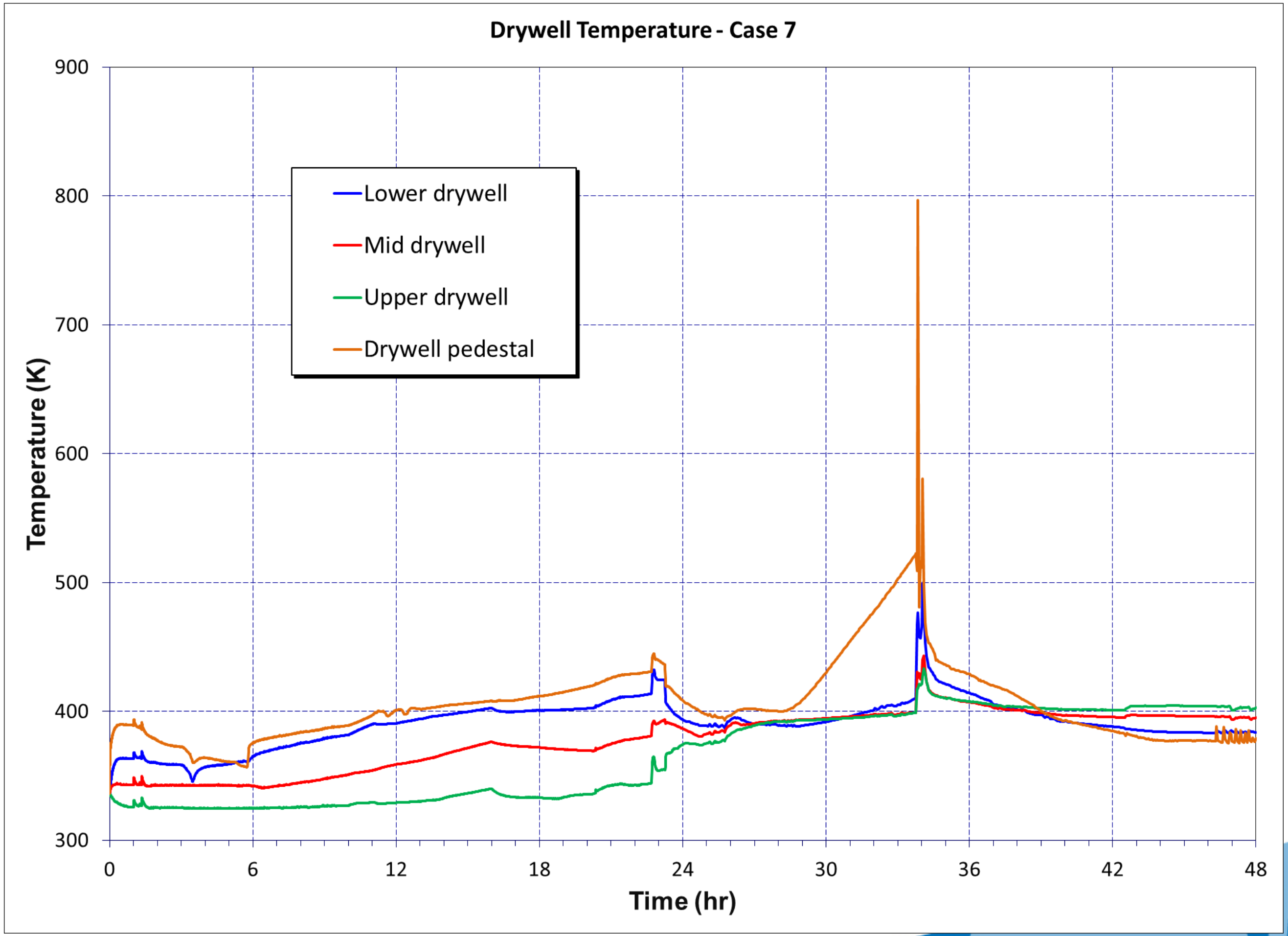
| Phenomena | Uncertainties | Implications |
|---|---|---|
| In-vessel Accident Progression | - Mass and composition of relocated core debris<br>- Location and timing of vessel breach<br>- Oxidation kinetics<br>- Reflood of degraded core | - Initial and boundary conditions for ex-vessel phenomena (e.g., temperature of core debris ejected from vessel)<br>- Uncertainties in the amount of hydrogen production |
| Ex-vessel Core Debris Behavior | - Debris coolability with an overlying water pool<br>- Meltspread modeling | - Uncertainties in drywell temperature<br>- Uncertainties in non-condensable production including hydrogen<br>- Likelihood of drywell liner melt-through |
| Fission Product Transport | - Late revaporization of fission products<br>- Suppression pool decontamination | - Uncertainties in release estimates<br>- Uncertainties in decontamination factor |

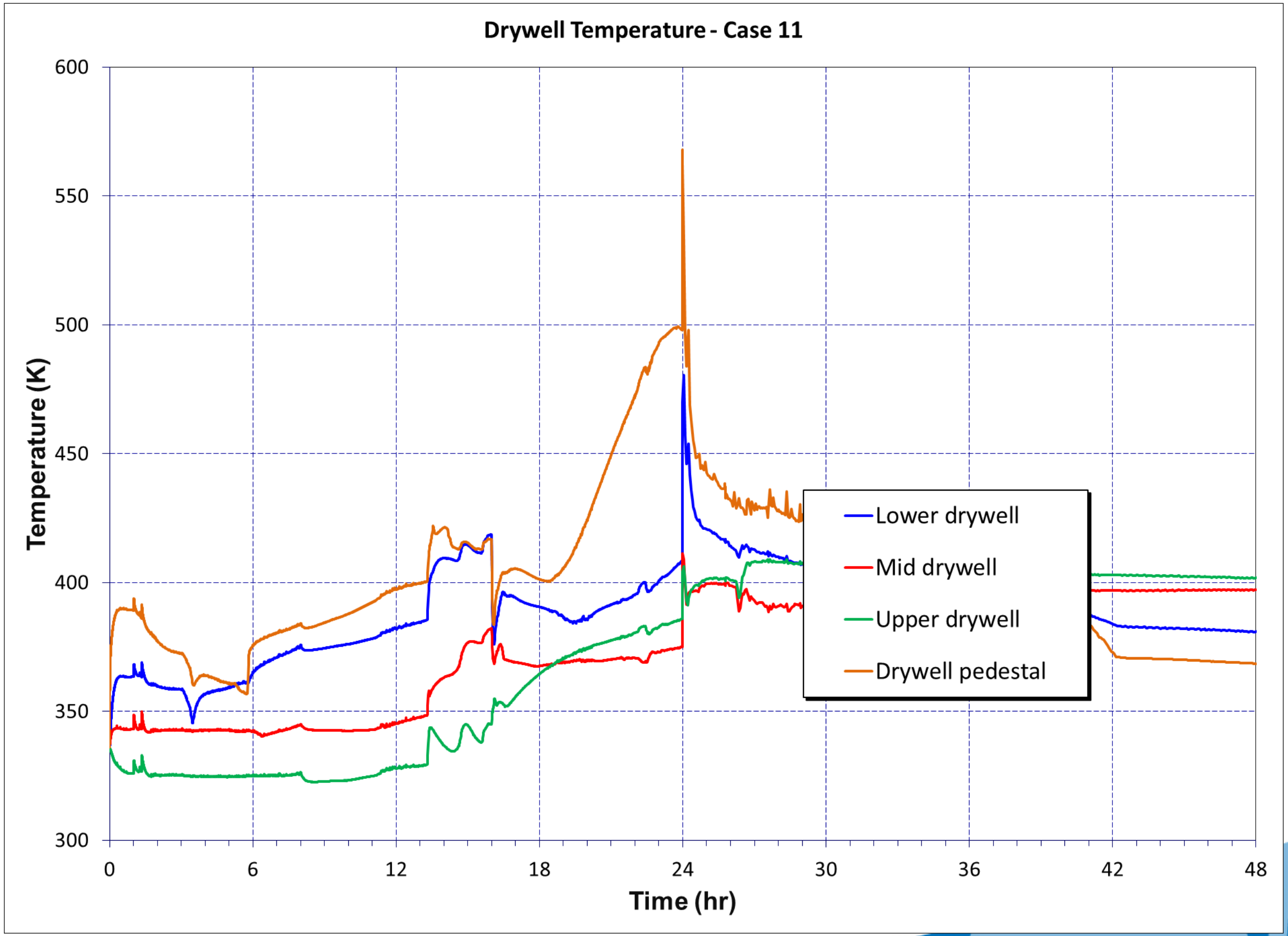
# Selected MELCOR Calculations

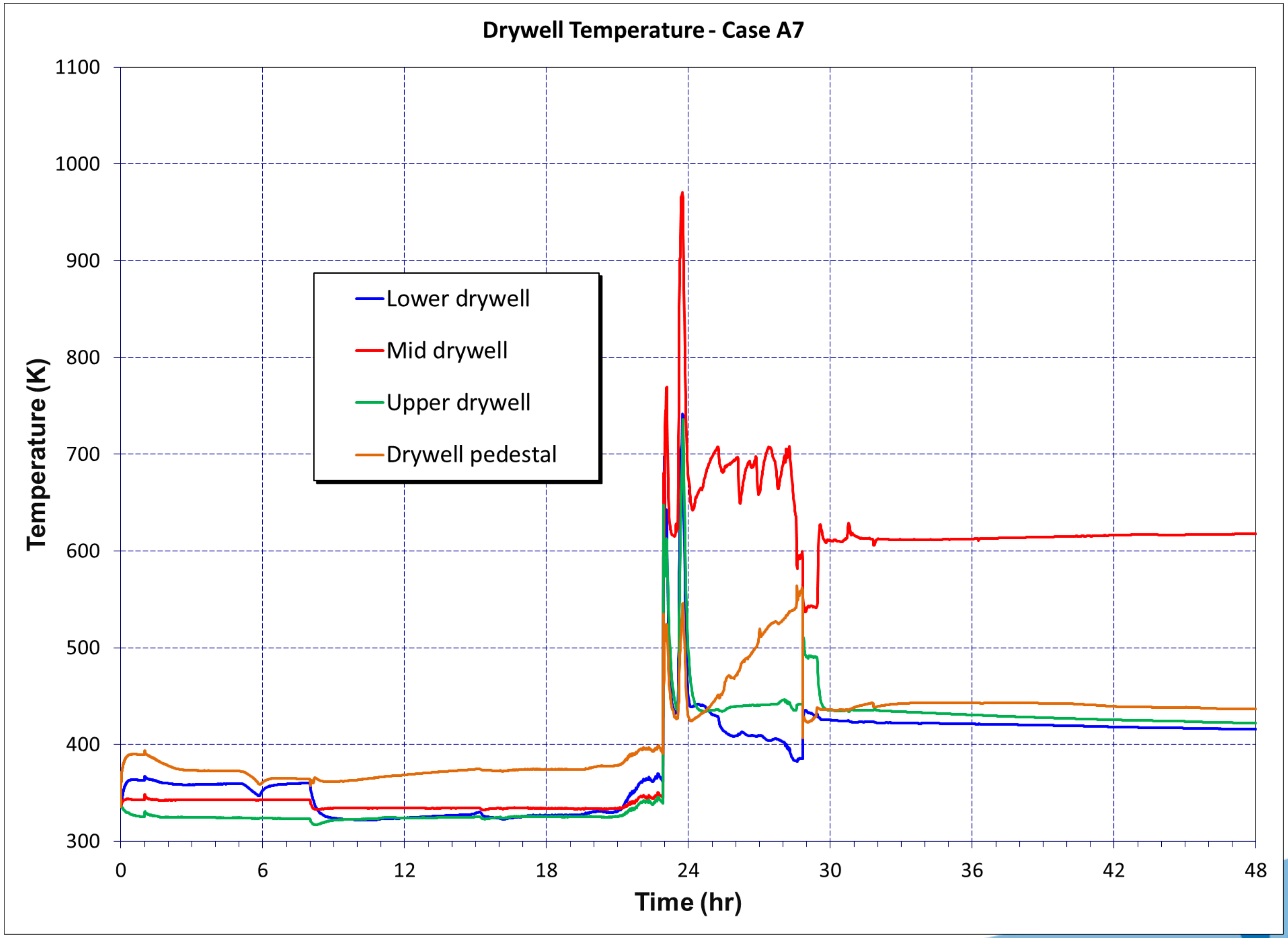
| Case Description | Case 7 | Case 11 | Case 22 | Case 23 | Case 24 | Case 25 |
|---|---|---|---|---|---|---|
| 8-hour RCIC | | X | | | | |
| 16-hour RCIC | X | | X | X | X | |
| Wetwell venting at 60 psig | X | X | X | X | X | X |
| Core spray after RPV failure | X | X | | | | |
| Drywell spray at 8 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 |



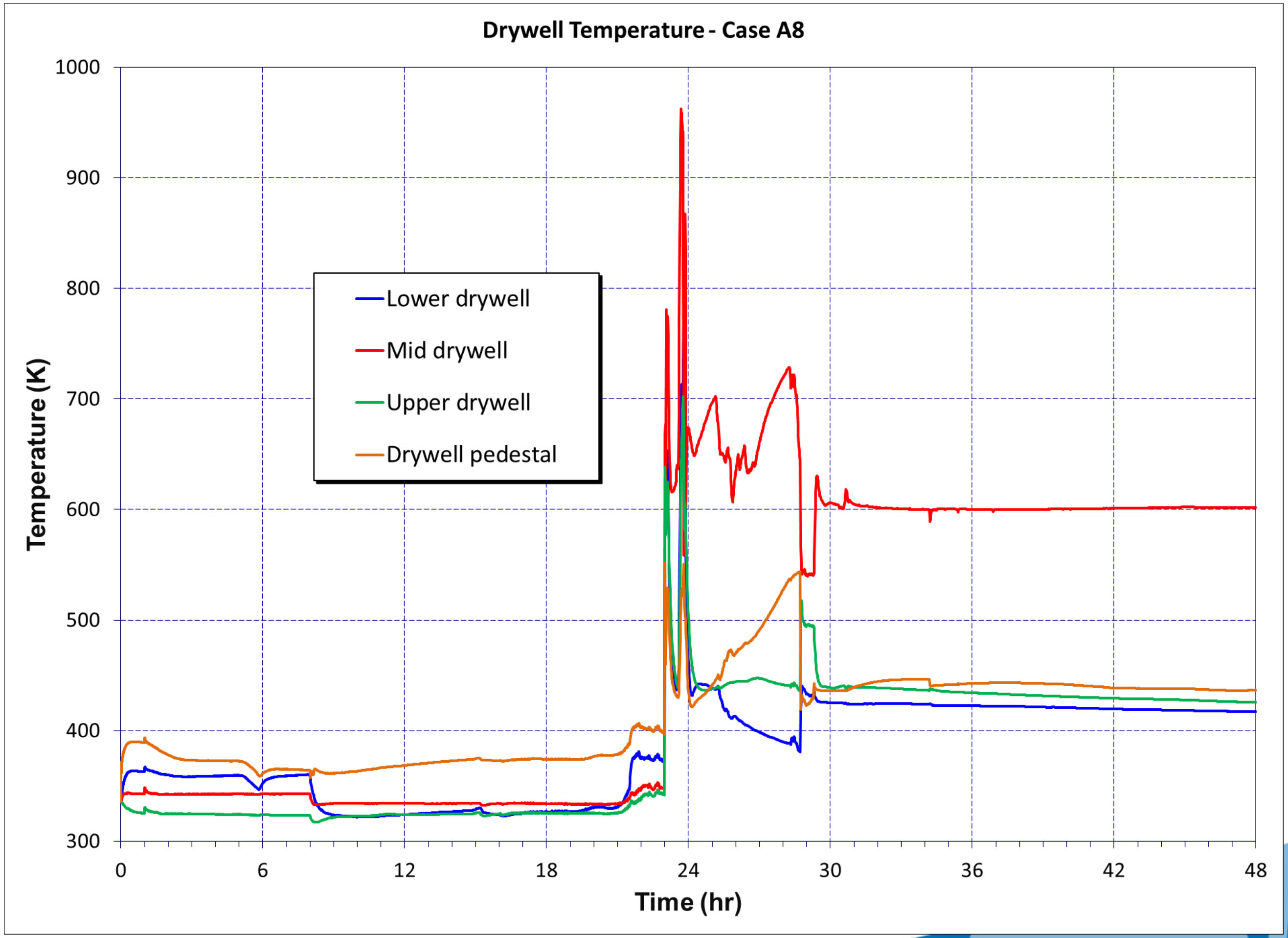
CV202
FL903
(DW head
flange failure)
FL202
CV201
FL200
FL016
CRD hyd.
pipe chase
CV200
CV205
FL910
(Wetwell Hard-Pipe vent
to atmosphere)
FL017
(DW nominal leakage)
FL902
(DW liner shear)
FL015
CRD removal
FL014
Personnel
access
FL022
(RB-WW vacuum breaker
to NE torus corner room)
FL023
(RB-WW vacuum breaker
to SE torus corner room)
CV220
CV210
FL012
CV210
CV220
FL021
FL904
(DW liner
melt-through)
FL901
(Torus Failure)
FL020

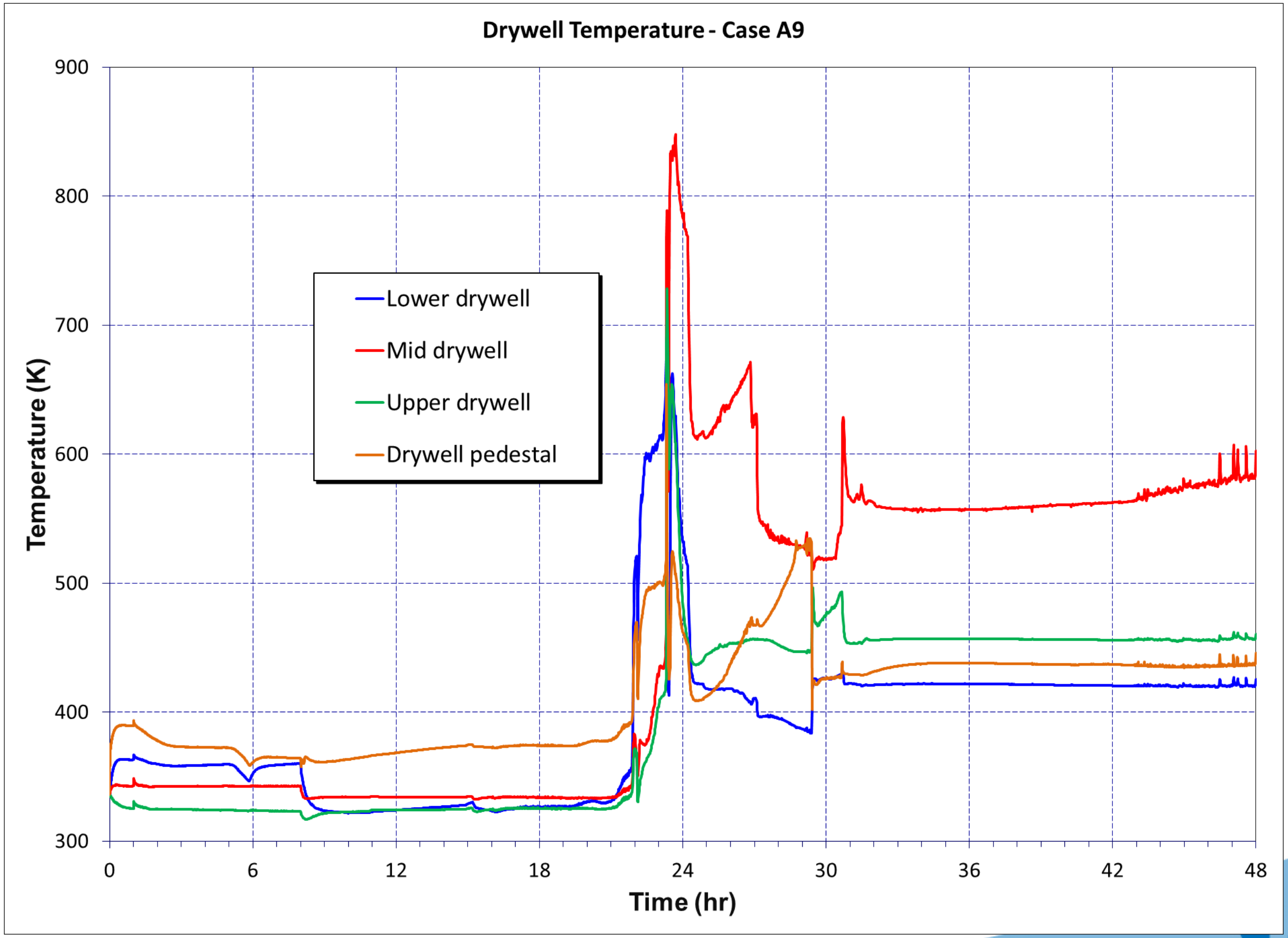

Drywell Temperature - Case 7
Temperature (K)
900
800
700
600
500
400
300
0
6
12
18
24
30
36
42
48
Time (hr)
Lower drywell
Mid drywell
Upper drywell
Drywell pedestal

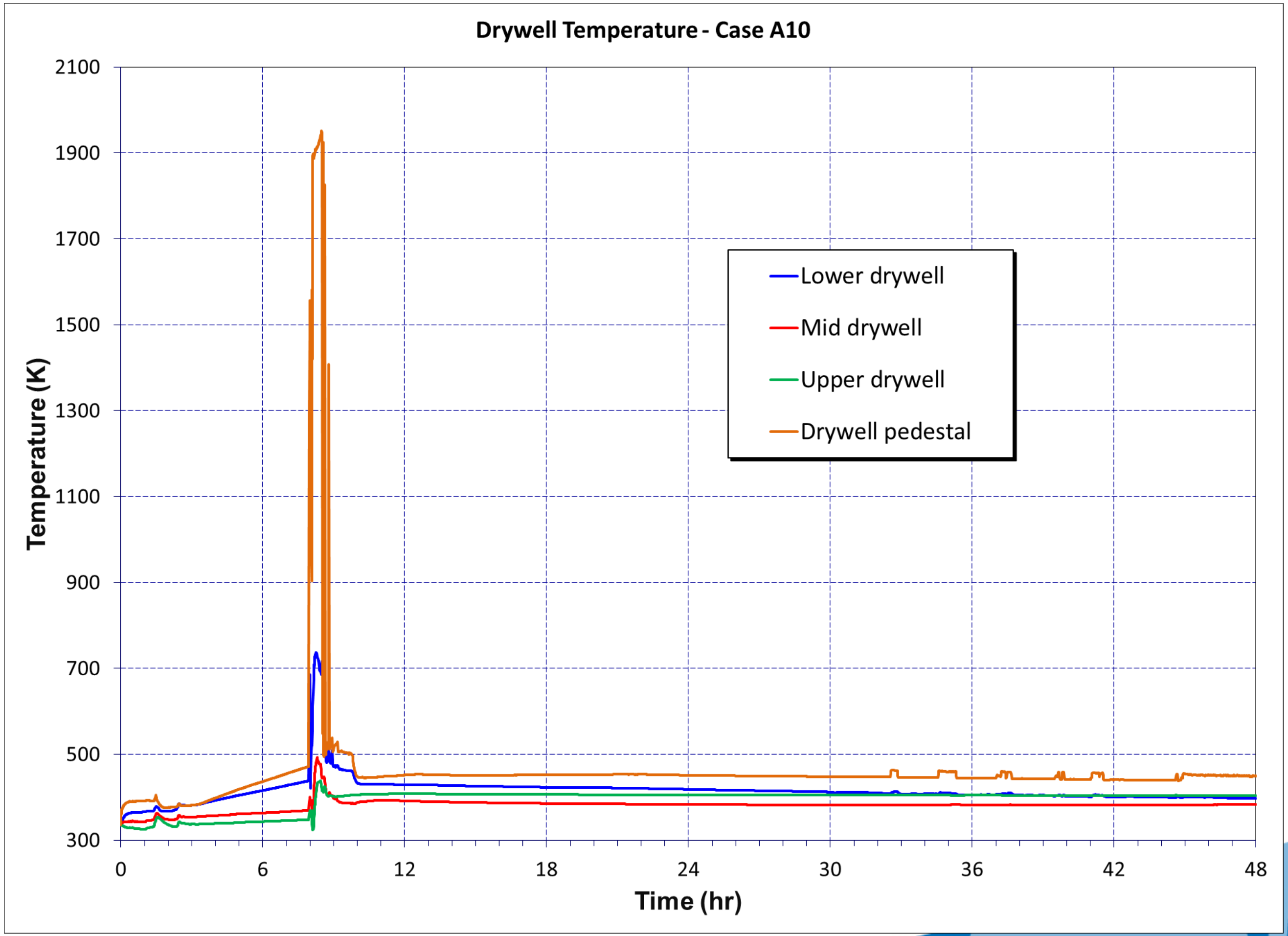

Drywell Temperature - Case 11
Temperature (K)
600
550
500
450
400
350
300
0
6
12
18
24
30
36
42
48
Time (hr)
Lower drywell
Mid drywell
Upper drywell
Drywell pedestal



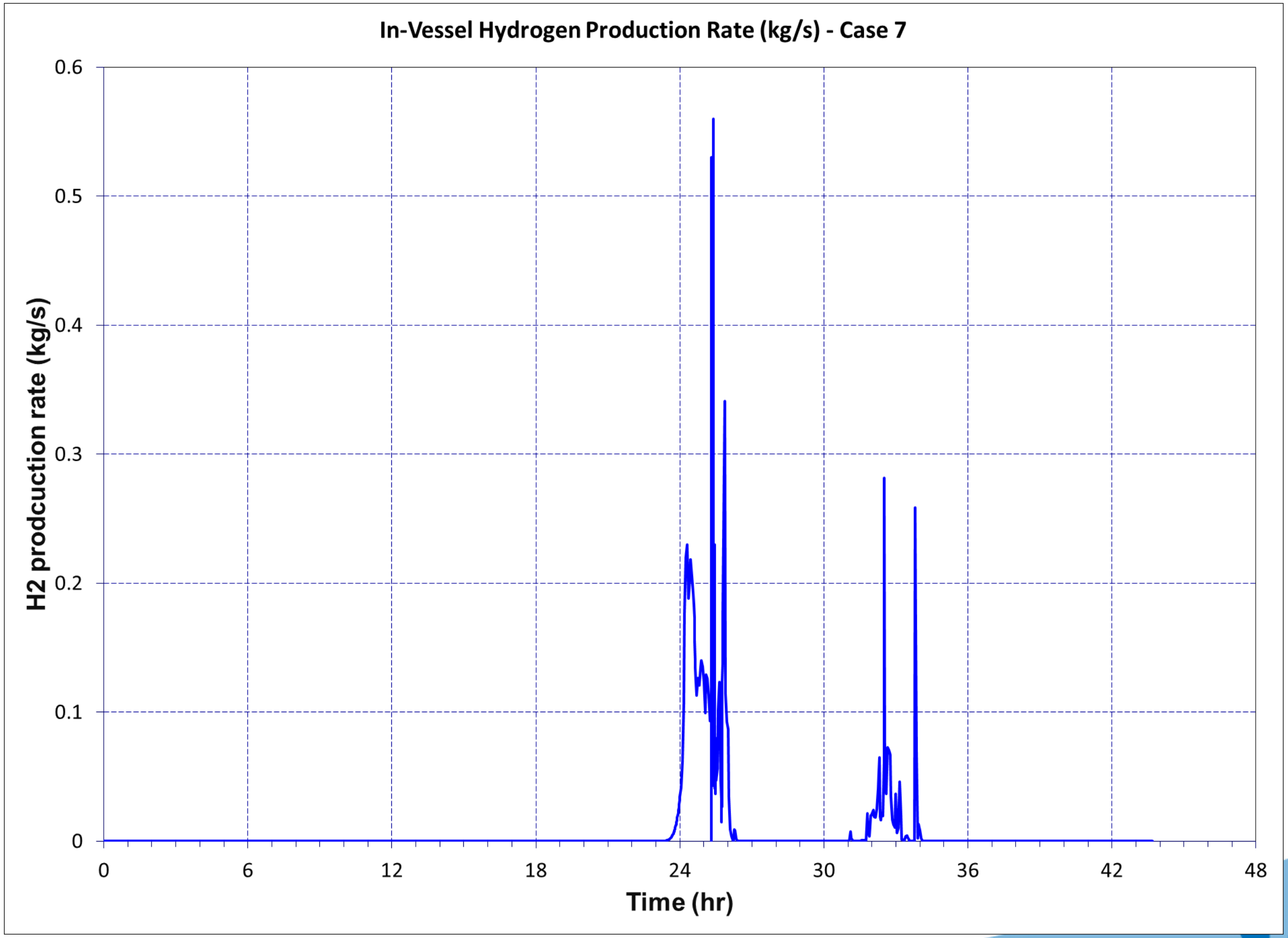
Drywell Temperature - Case A7
Temperature (K)
1100
1000
900
800
700
600
500
400
300
0
6
12
18
24
30
36
42
48
Time (hr)
Lower drywell
Mid drywell
Upper drywell
Drywell pedestal


Drywell Temperature - Case A8
Temperature (K)
1000
900
800
700
600
500
400
300
0
6
12
18
24
30
36
42
48
Time (hr)
Lower drywell
Mid drywell
Upper drywell
Drywell pedestal


Drywell Temperature - Case A9
Temperature (K)
900
800
700
600
500
400
300
0
6
12
18
24
30
36
42
48
Time (hr)
Lower drywell
Mid drywell
Upper drywell
Drywell pedestal



Drywell Temperature - Case A10
Temperature (K)
2100
1900
1700
1500
1300
1100
900
700
500
300
0
6
12
18
24
30
36
42
48
Time (hr)
Lower drywell
Mid drywell
Upper drywell
Drywell pedestal



In-Vessel Hydrogen Production Rate (kg/s) - Case 7
H2 prodcuction rate (kg/s)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
30
36
42
48
Time (hr)

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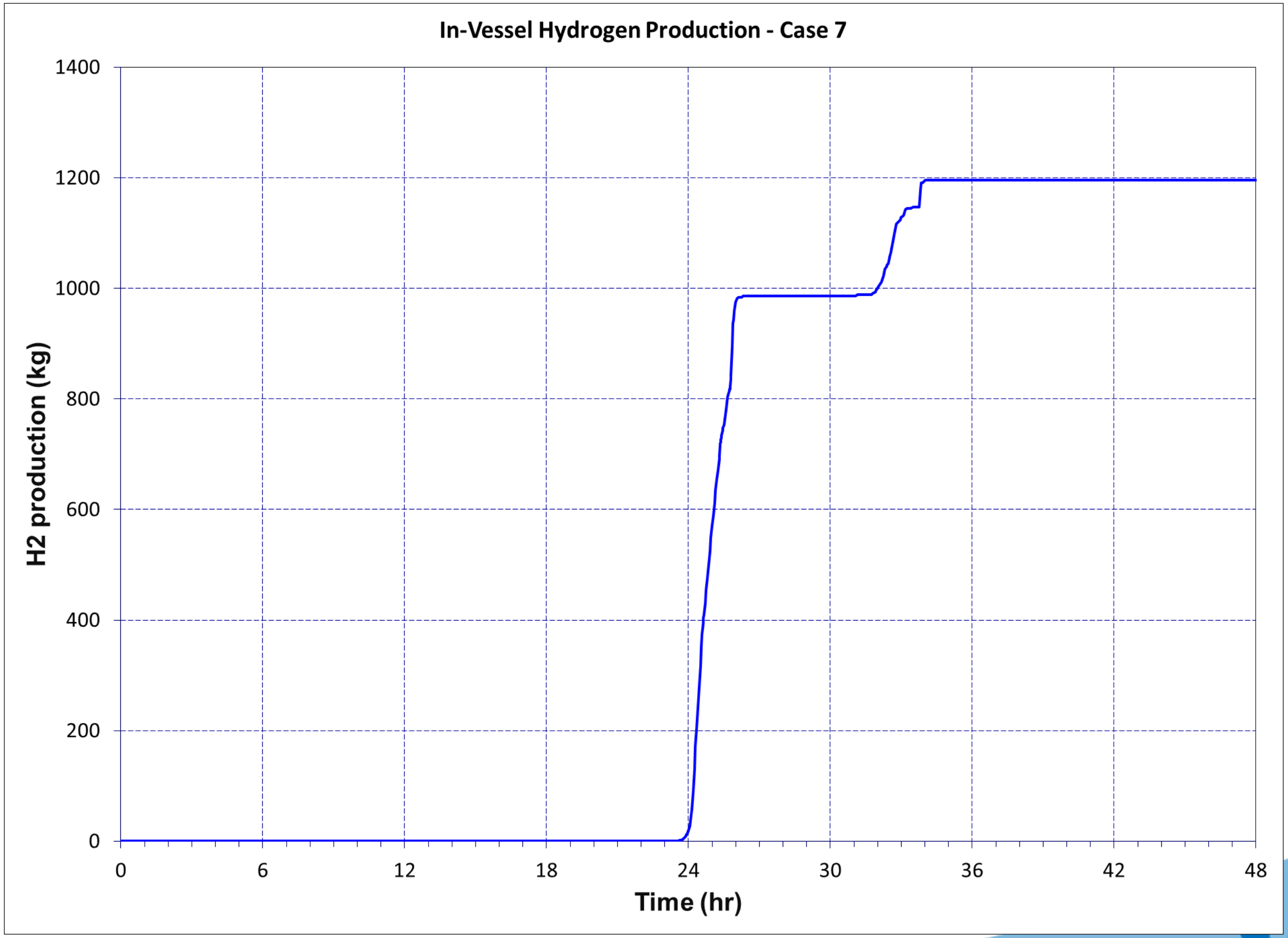
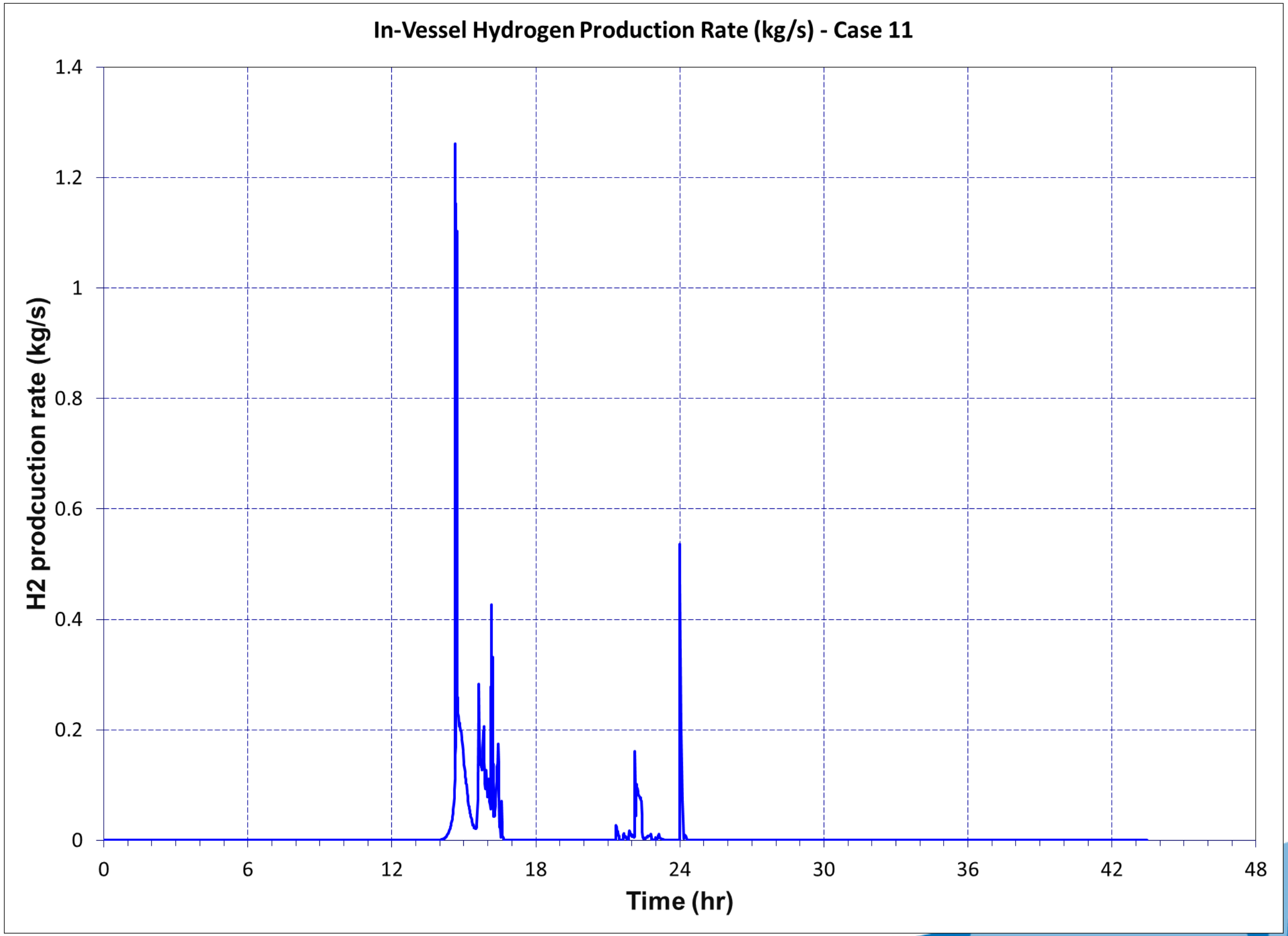
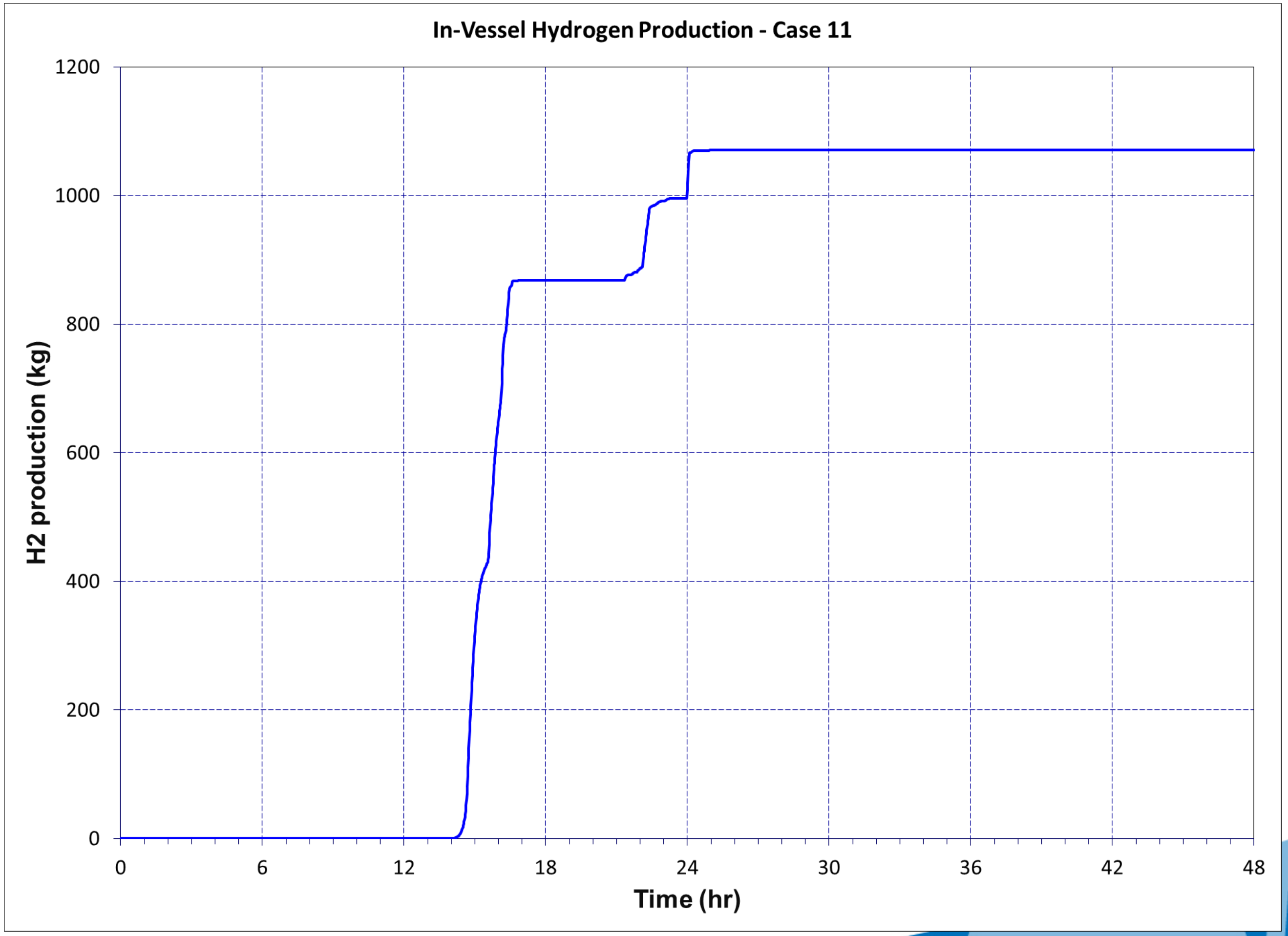
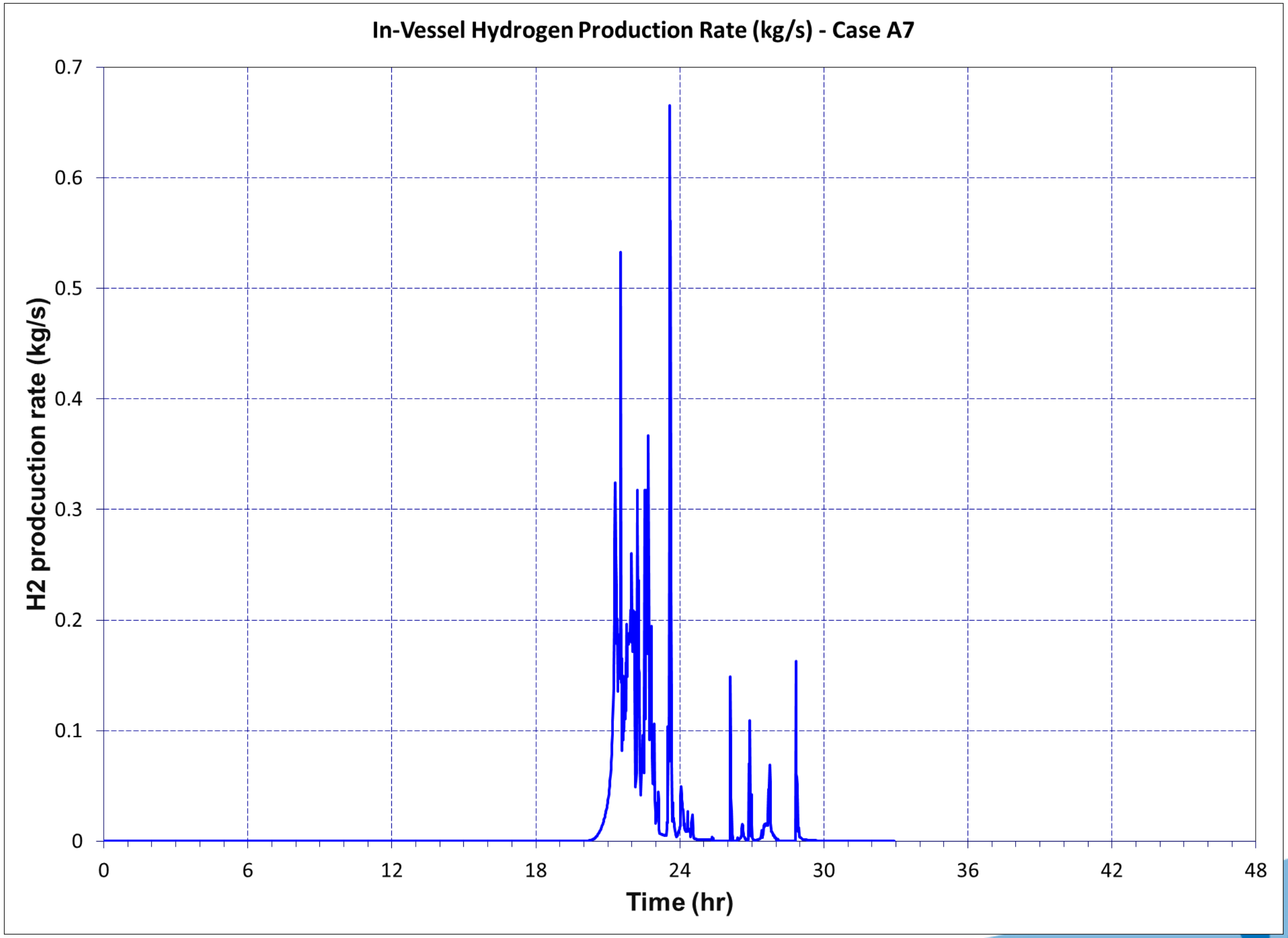
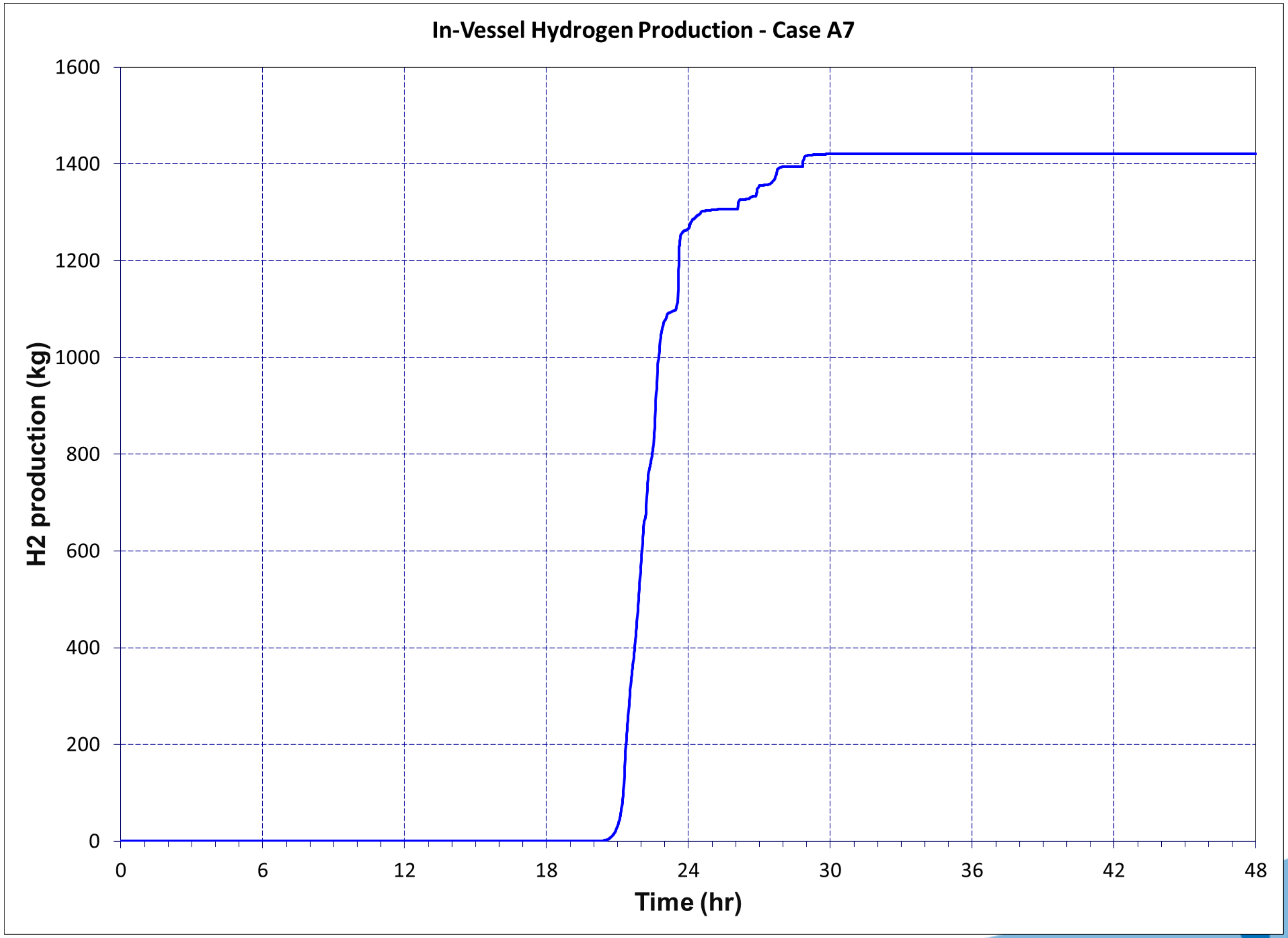



In-Vessel Hydrogen Production Rate (kg/s) - Case 11
H2 prodcuction rate (kg/s)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
6
12
18
24
30
36
42
48
Time (hr)


In-Vessel Hydrogen Production - Case 11
H2 production (kg)
1200
1000
800
600
400
200
0
0
6
12
18
24
30
36
42
48
Time (hr)


In-Vessel Hydrogen Production Rate (kg/s) - Case A7
H2 prodcuction rate (kg/s)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
30
36
42
48
Time (hr)


In-Vessel Hydrogen Production - Case A7
H2 production (kg)
0
200
400
600
800
1000
1200
1400
1600
Time (hr)
0
6
12
18
24
30
36
42
48

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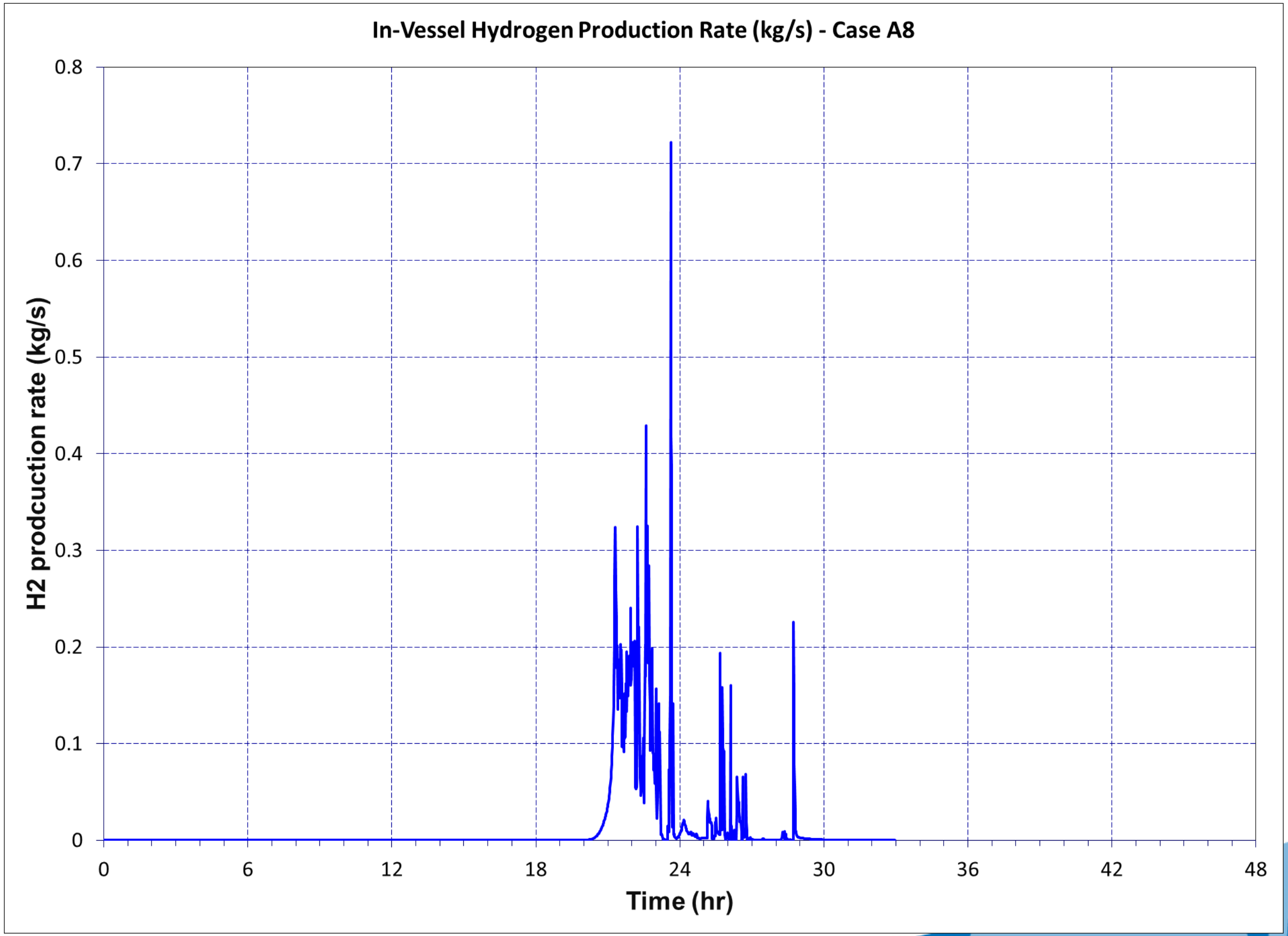
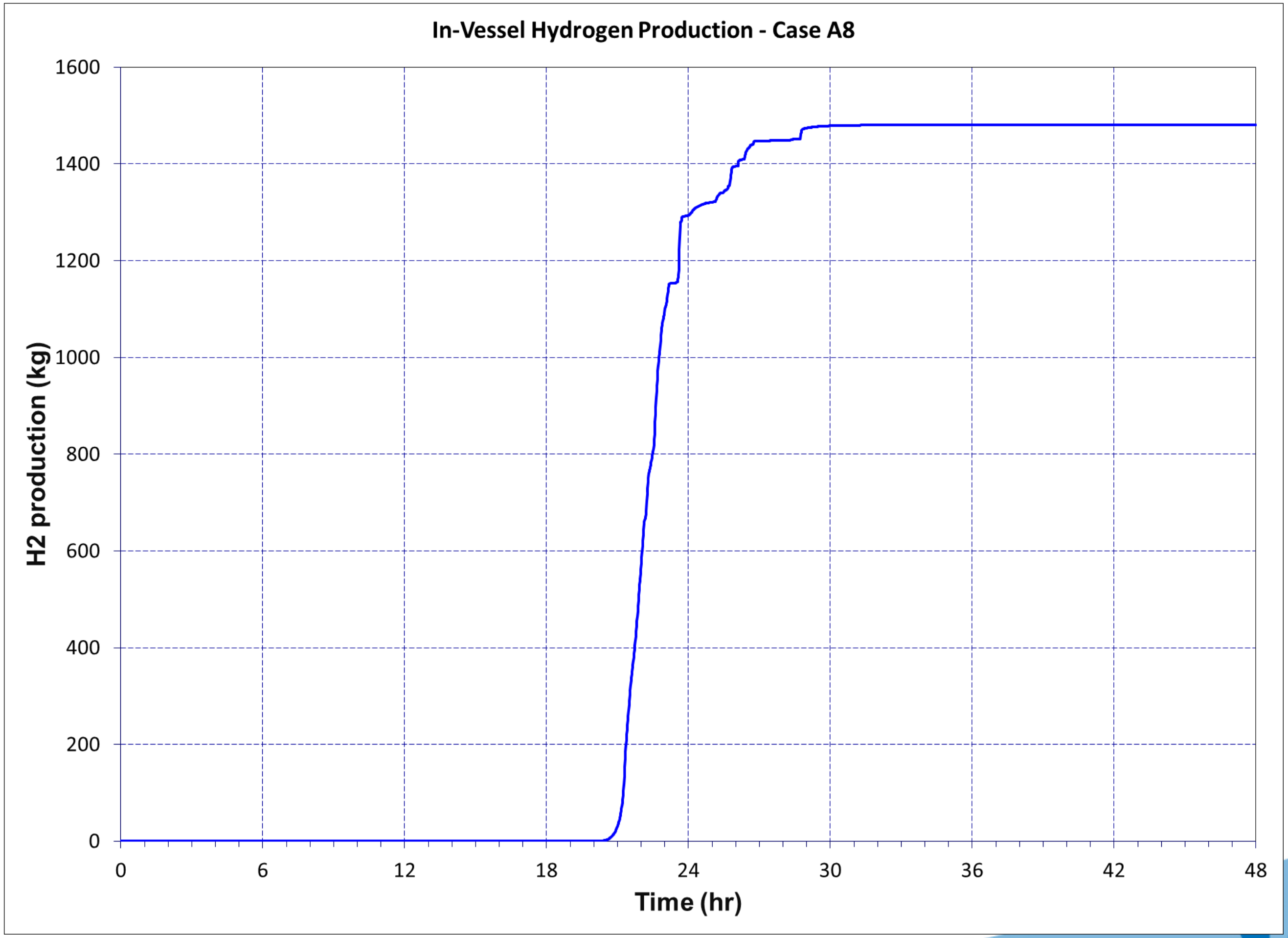
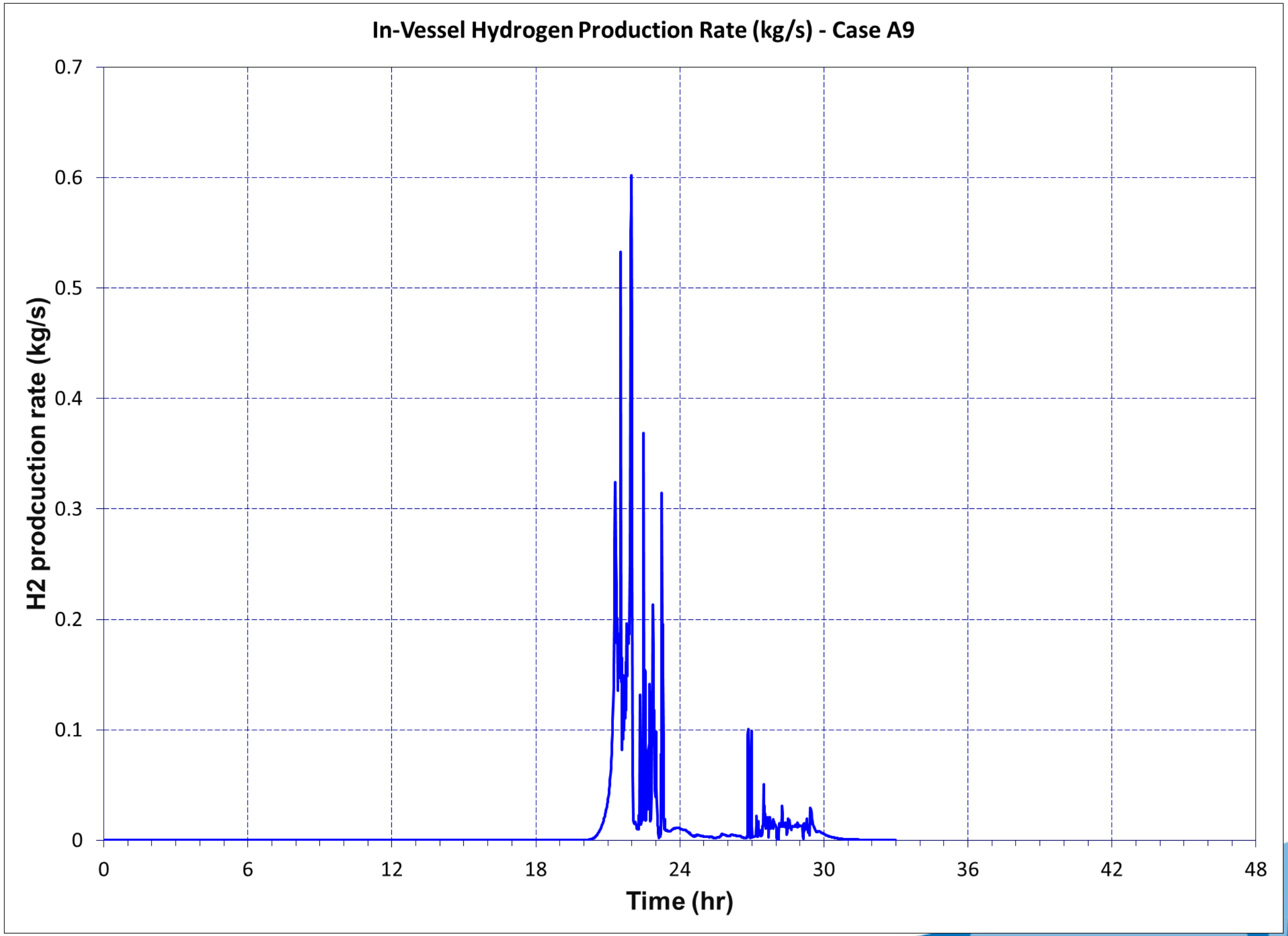
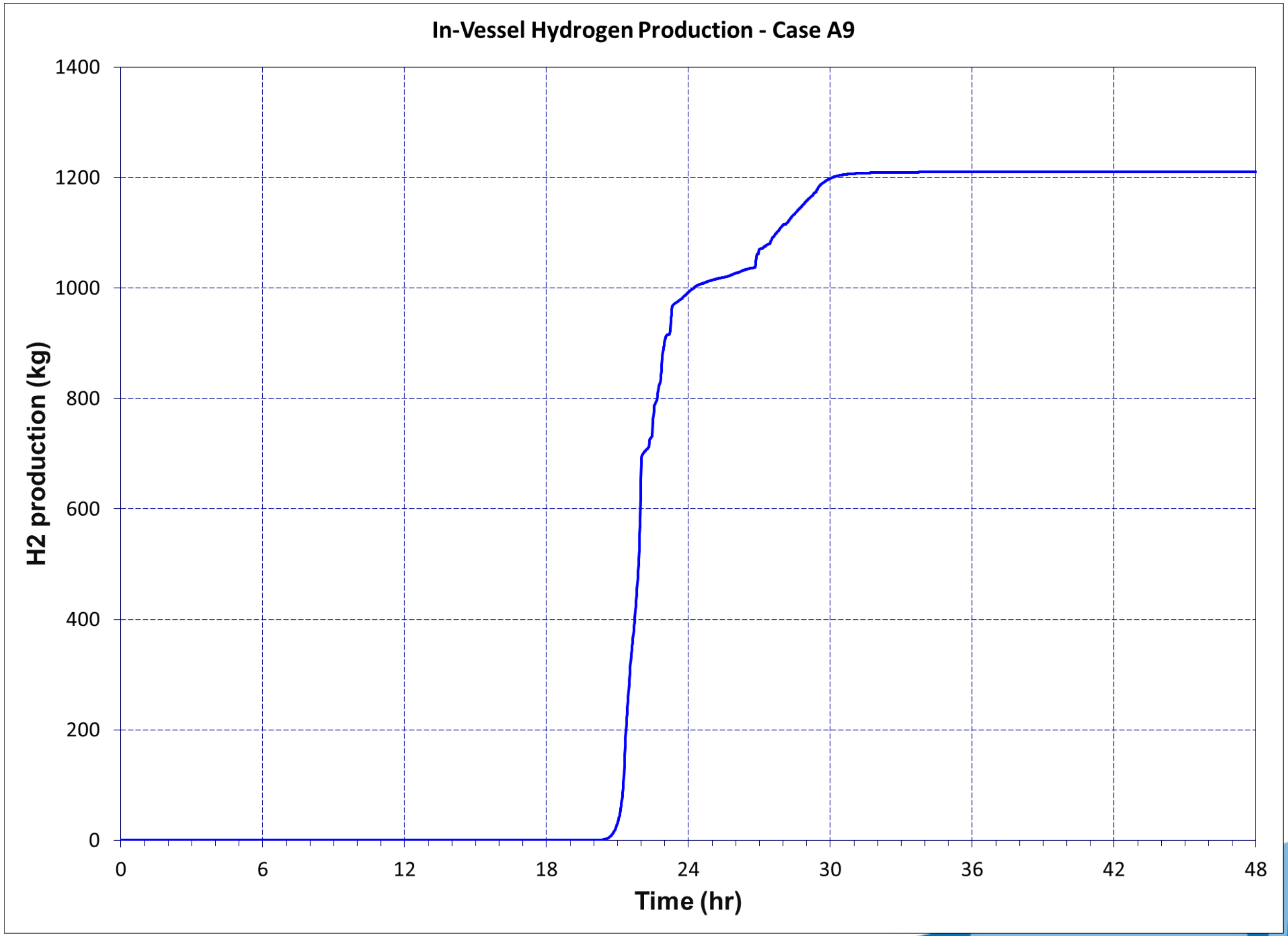
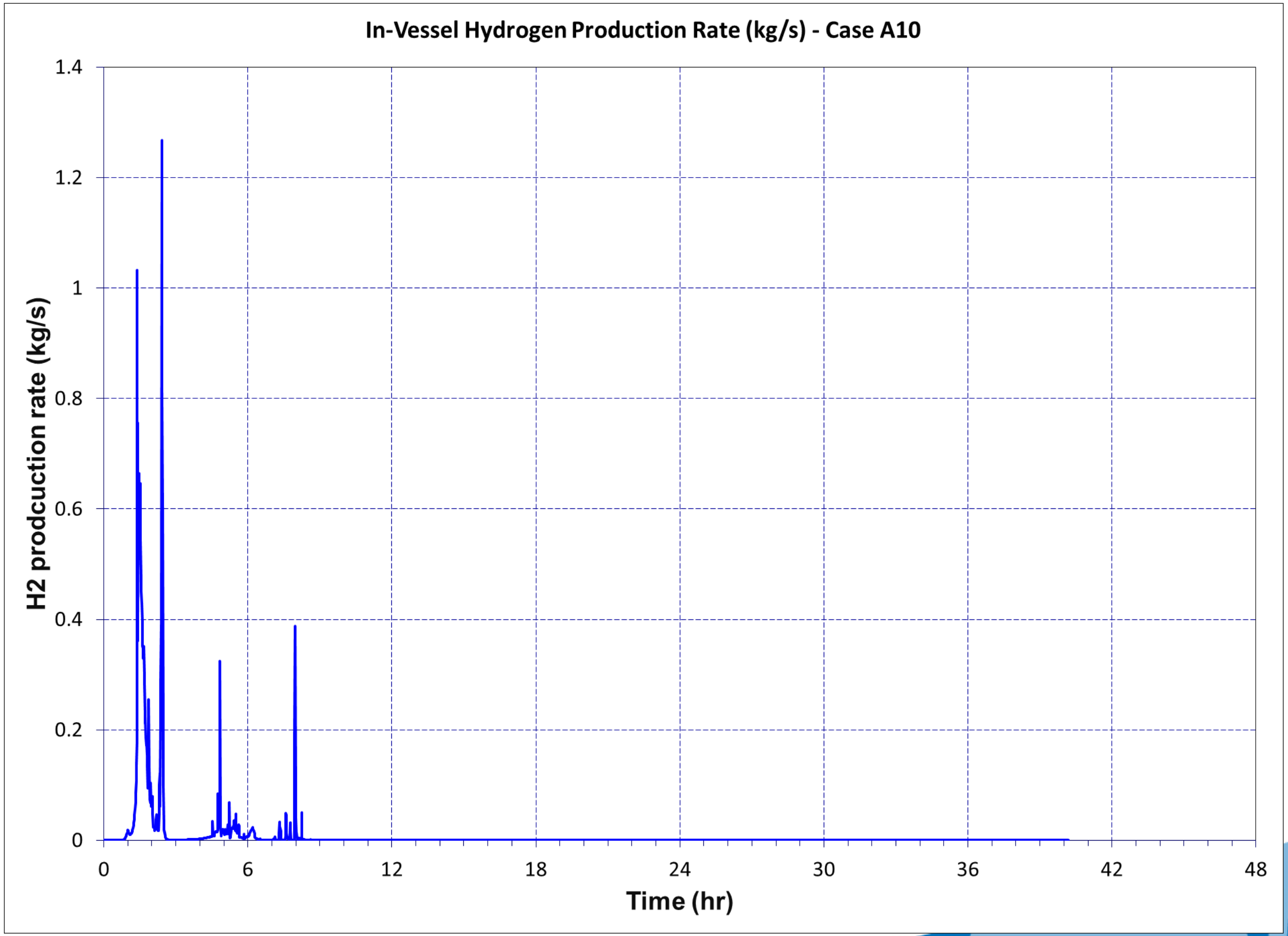


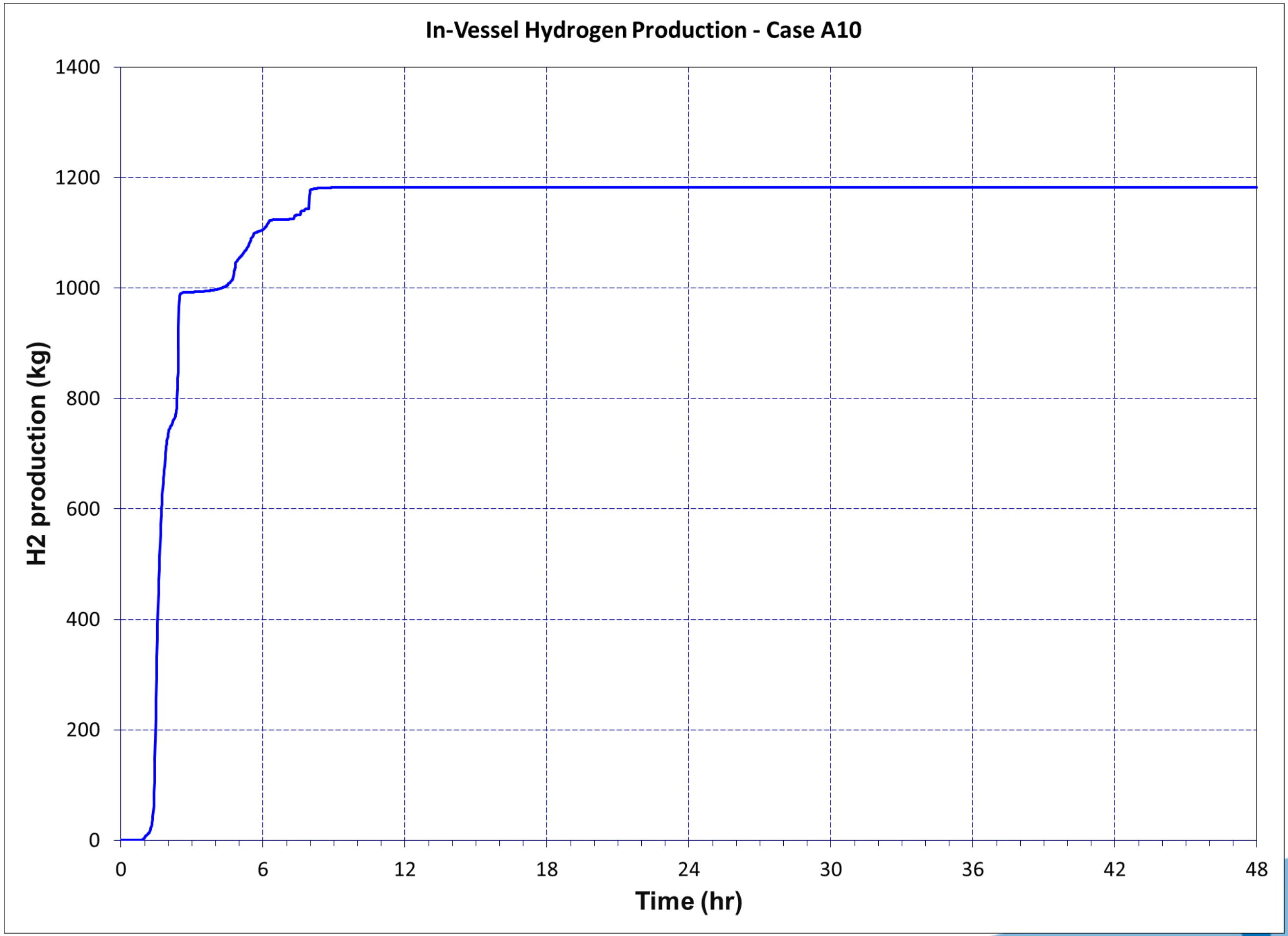

In-Vessel Hydrogen Production - Case A8
H2 production (kg)
0
200
400
600
800
1000
1200
1400
1600
Time (hr)
0
6
12
18
24
30
36
42
48


In-Vessel Hydrogen Production Rate (kg/s) - Case A9
H2 prodcuction rate (kg/s)
Time (hr)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
6
12
18
24
30
36
42
48



In-Vessel Hydrogen Production - Case A9
H2 production (kg)
Time (hr)
0
200
400
600
800
1000
1200
1400
0
6
12
18
24
30
36
42
48


In-Vessel Hydrogen Production Rate (kg/s) - Case A10
H2 prodcuction rate (kg/s)
Time (hr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
6
12
18
24
30
36
42
48



In-Vessel Hydrogen Production - Case A10
H2 production (kg)
1400
1200
1000
800
600
400
200
0
0
6
12
18
24
30
36
42
48
Time (hr)

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# 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 Cs2MoO4

# Sources for Observations

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

# LTSBO Cases Considered

- SOARCA unmitigated LTSBO – 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)

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| 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 |
|---|---|---|---|---|---|
| CsI | NR | 0.11 | 0.00032 | 0.15 | 0.00039 |
| CsOH | NR | NR | NR | 0.20 | 0.00032 |
| Cs2MoO4 | NR | NR | NR | 0.00033 | 7.49E-05 |
| Cs | 0.005 | NR | NR | 0.10 | 2.15E-04 |
| Cs DF | 200 | 9 | 3000 | 10 | 4656 |

# SOARCA LTSBO RPV Pressure

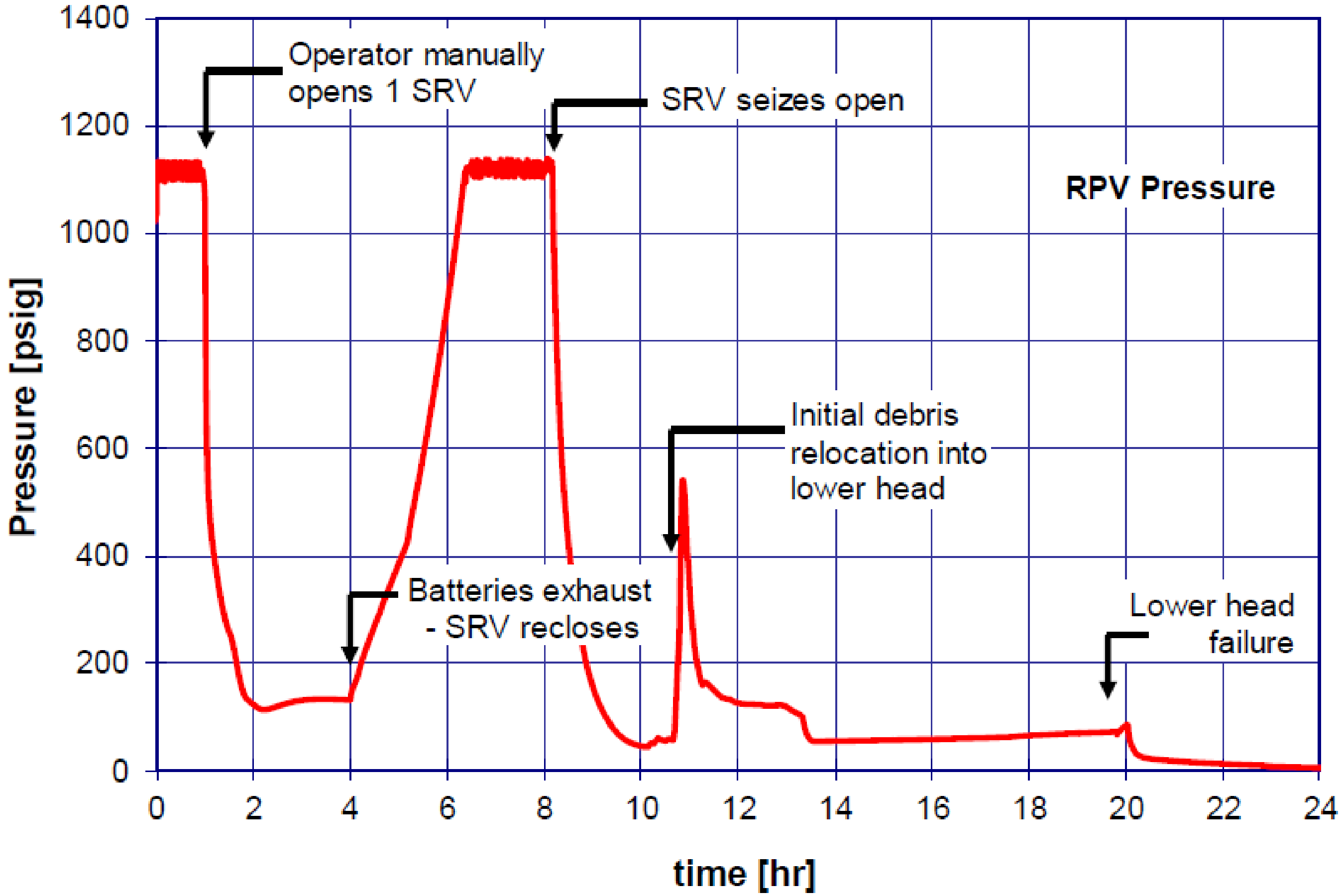



Figure 5-1 LTSBO vessel pressure

# SOARCA LTSBO RPV Level

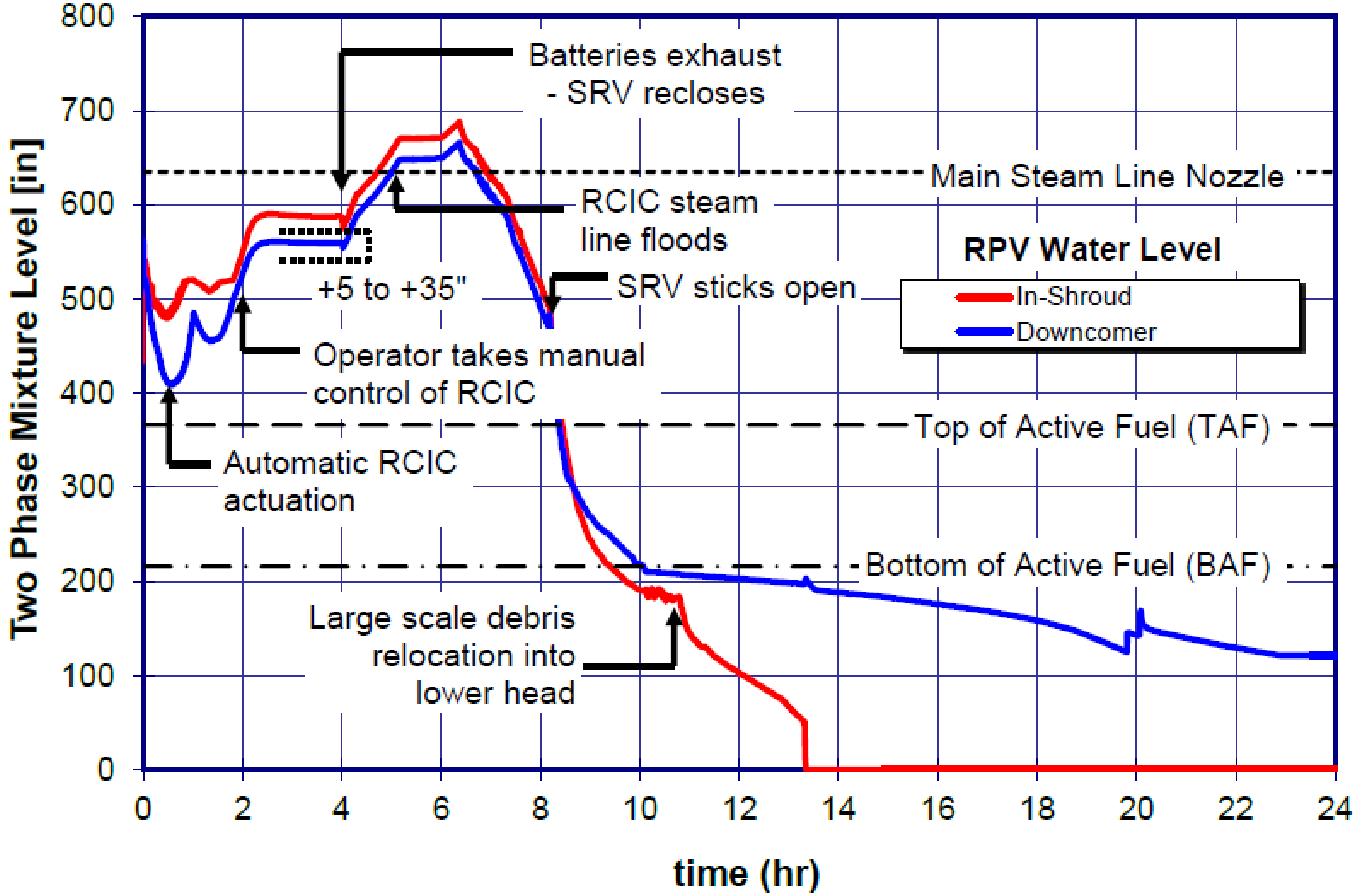



Figure 5-2 LTSBO reactor pressure vessel water level

# SOARCA LTSBO Drywell Pressure

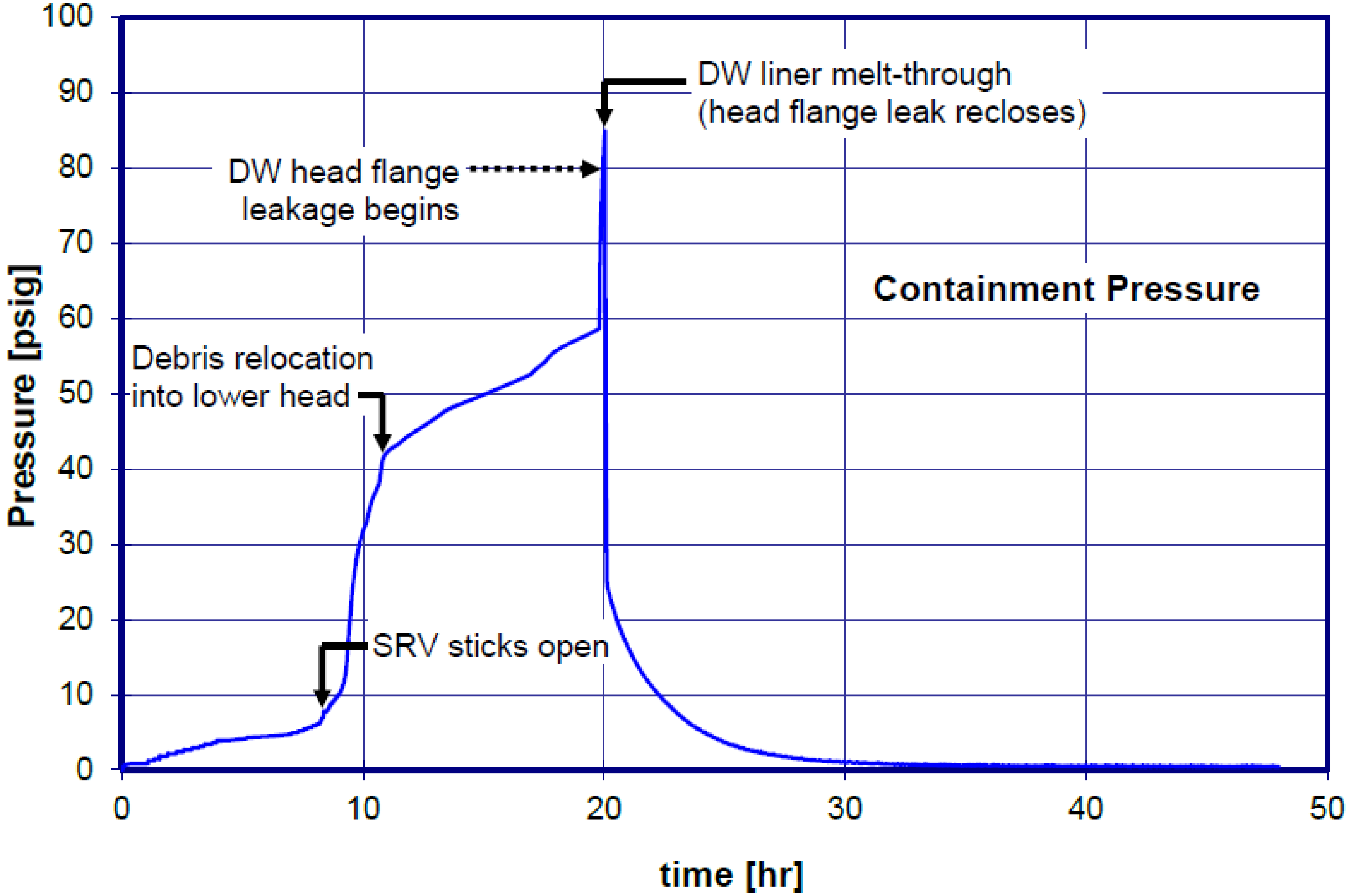



Figure 5-8 LTSBO containment pressure

# SOARCA LTSBO Suppression Pool Temperature



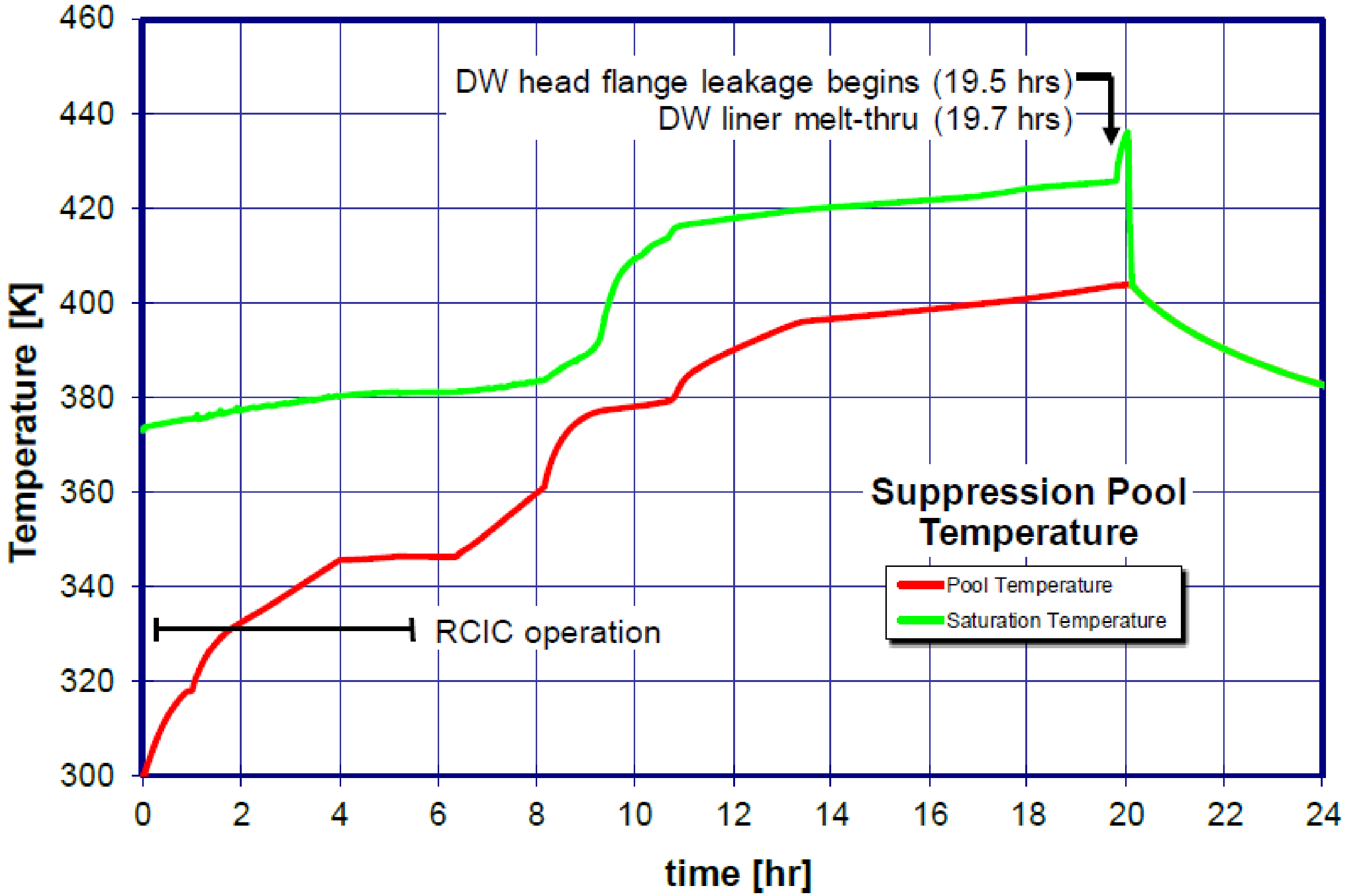
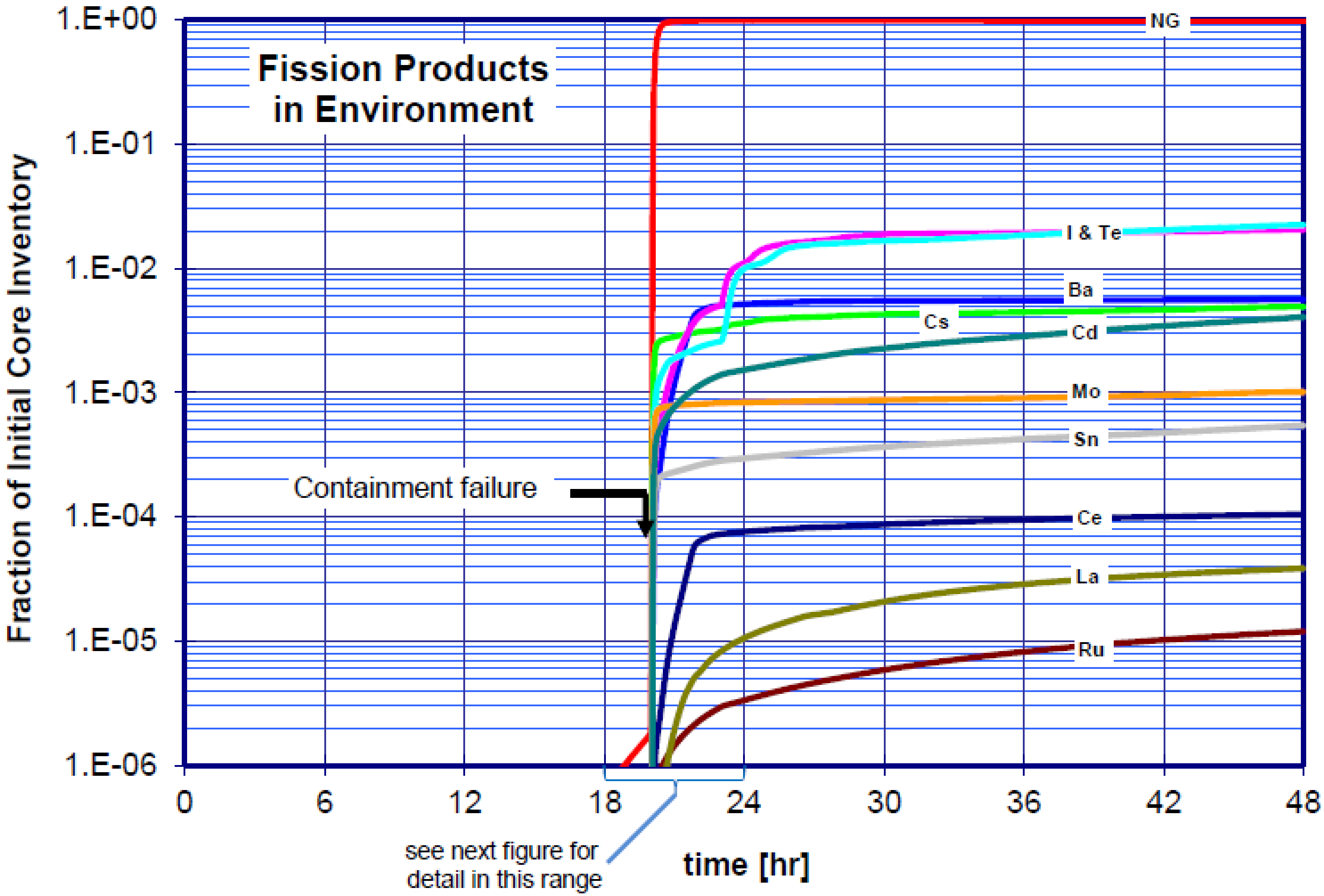
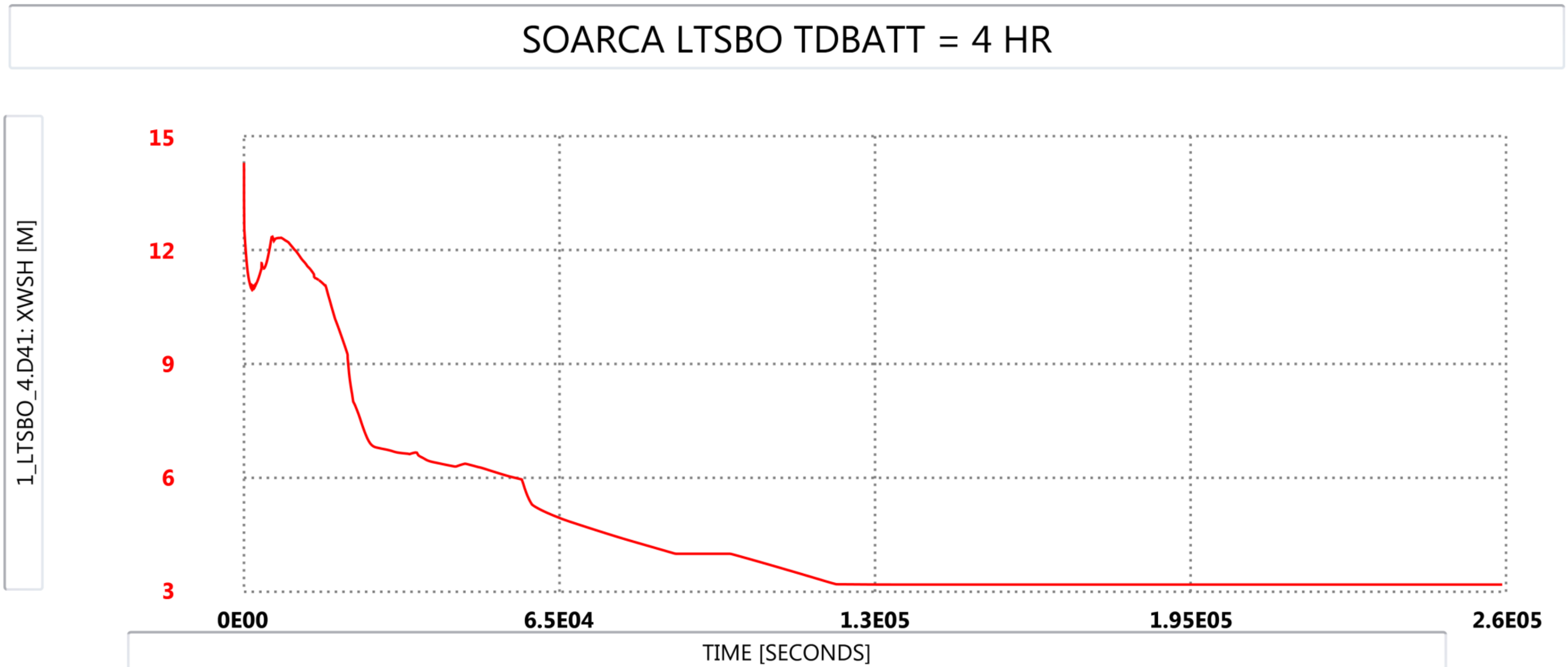



Figure 5-9 LTSBO suppression pool temperature

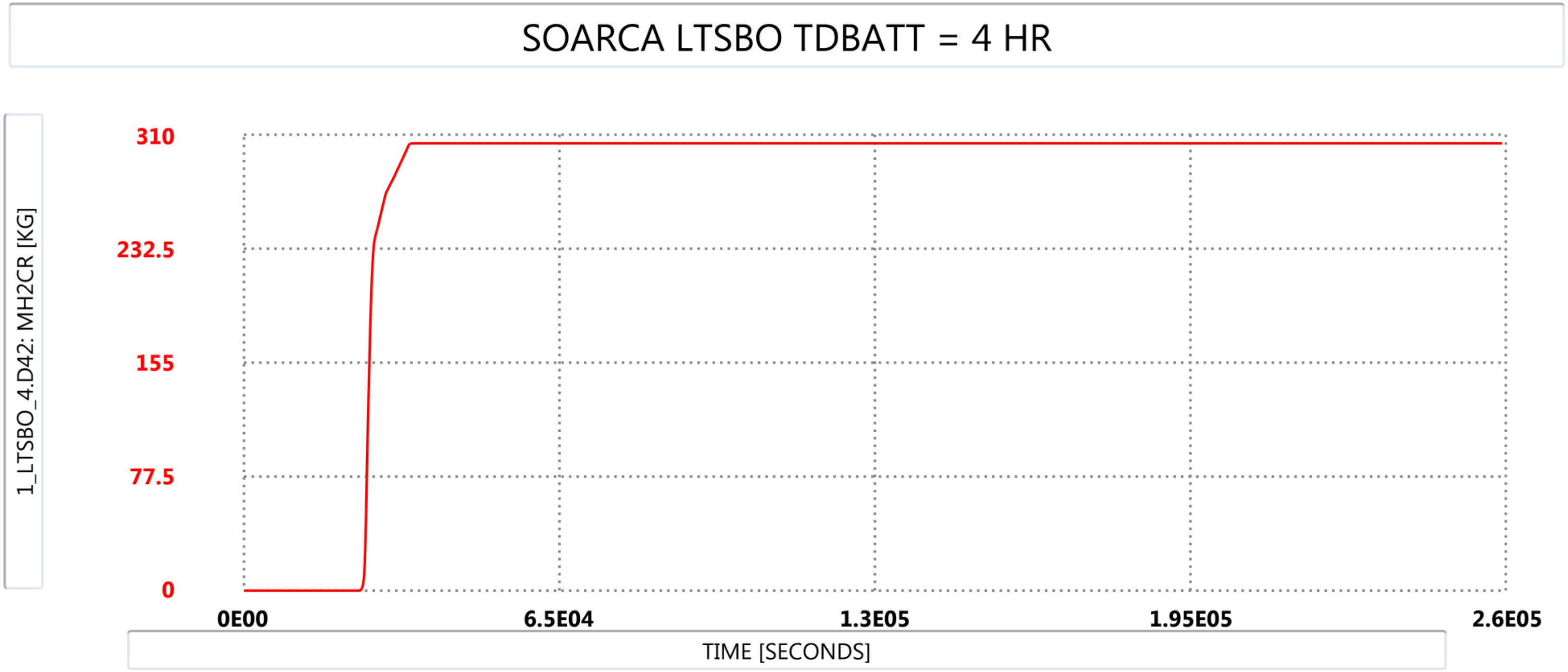
# SOARCA LTSBO Fission Product Releases



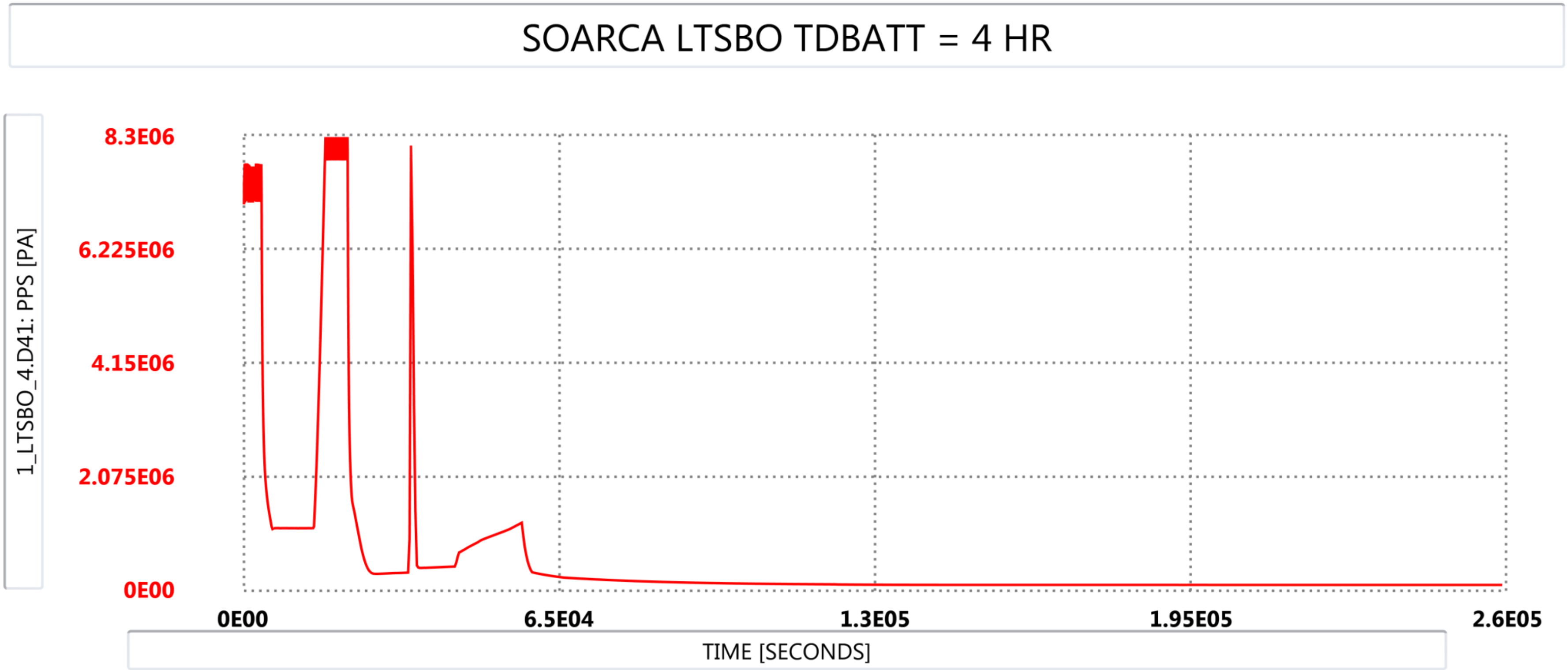
# MAAP 5.0.1
# Water Level in Shroud



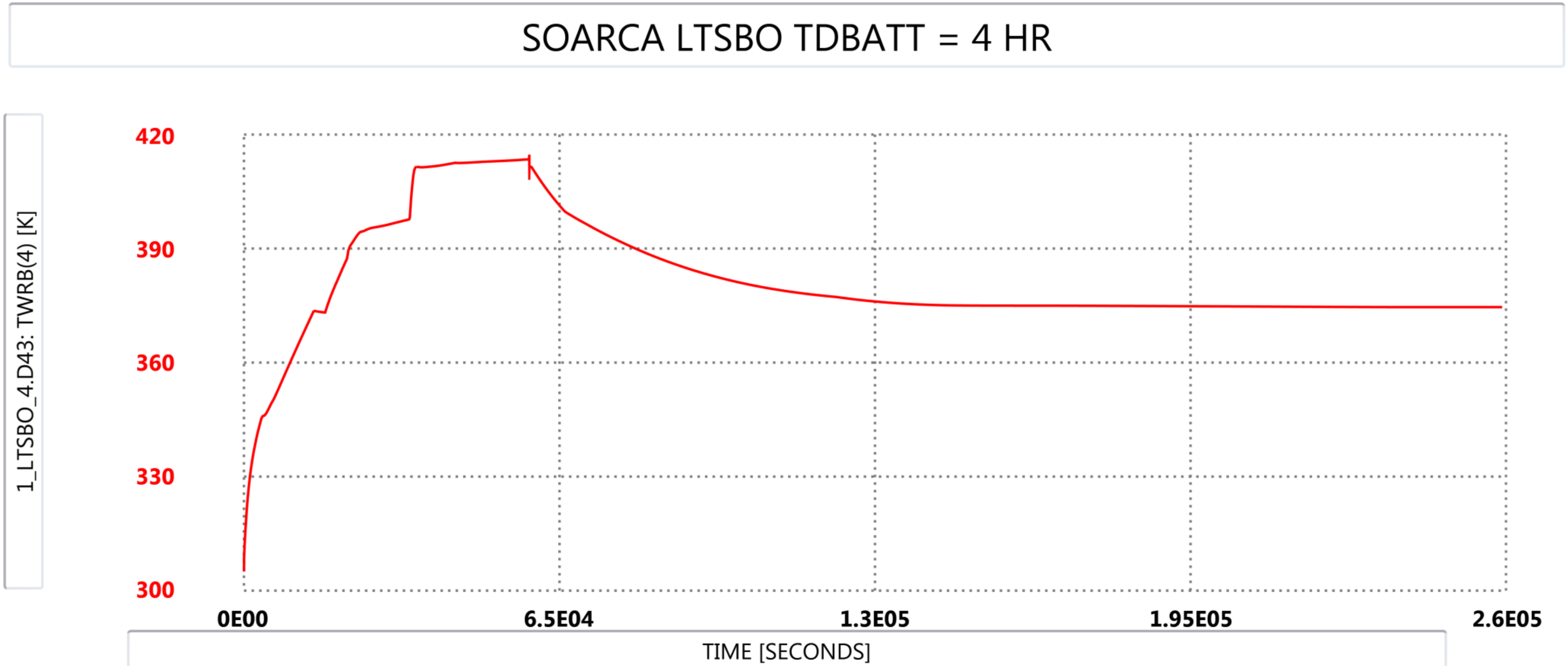
# MAAP 5.0.1
# Hydrogen Produced In-vessel



# MAAP 5.0.1
# Pressure in RPV



# MAAP 5.0.1
# Suppression Pool Temperature



# MAAP 5.01 RCIC Flow

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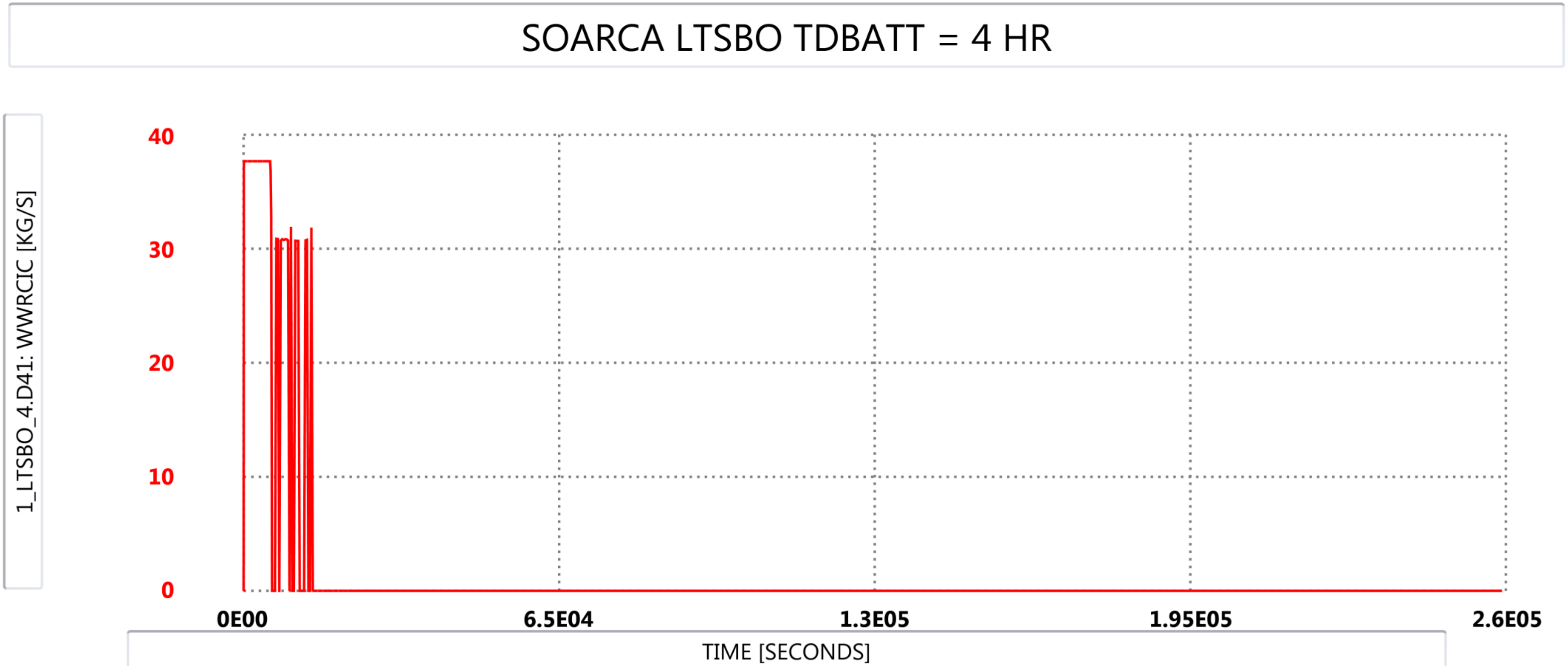
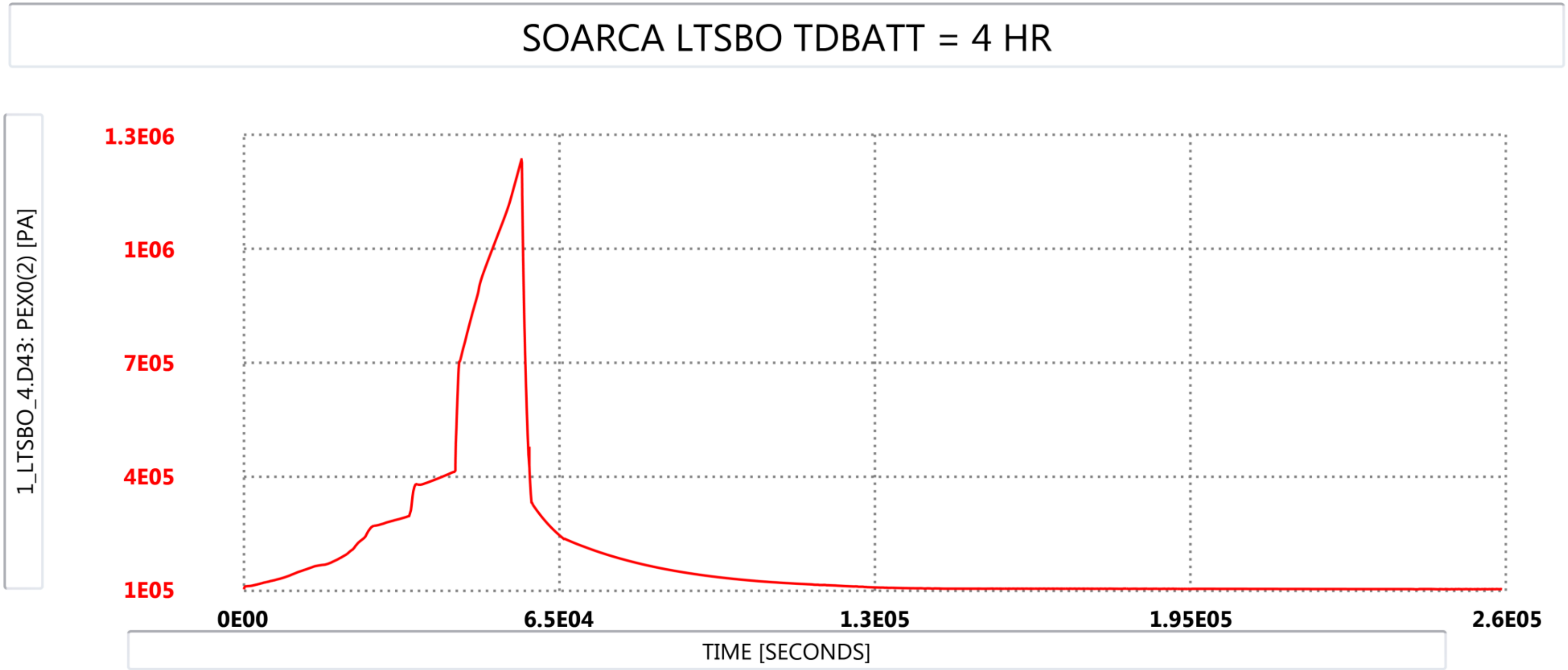
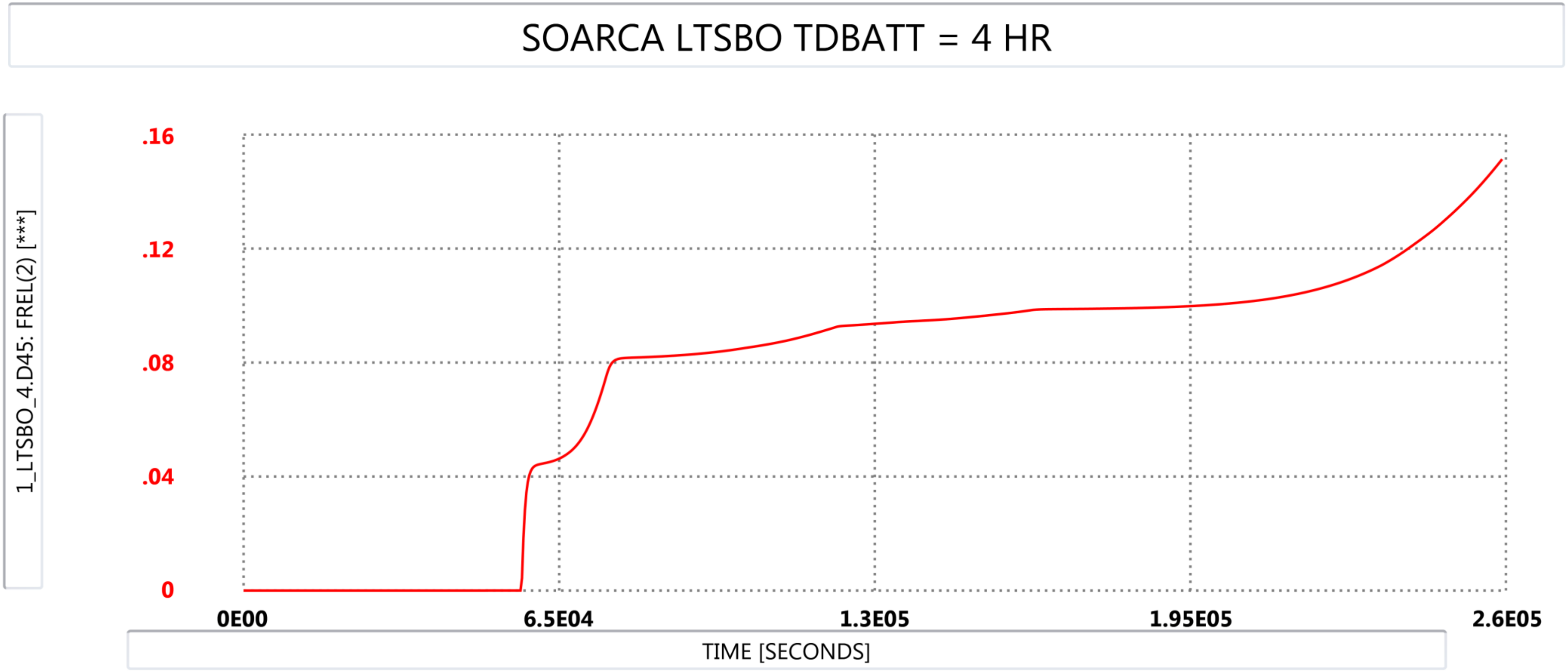


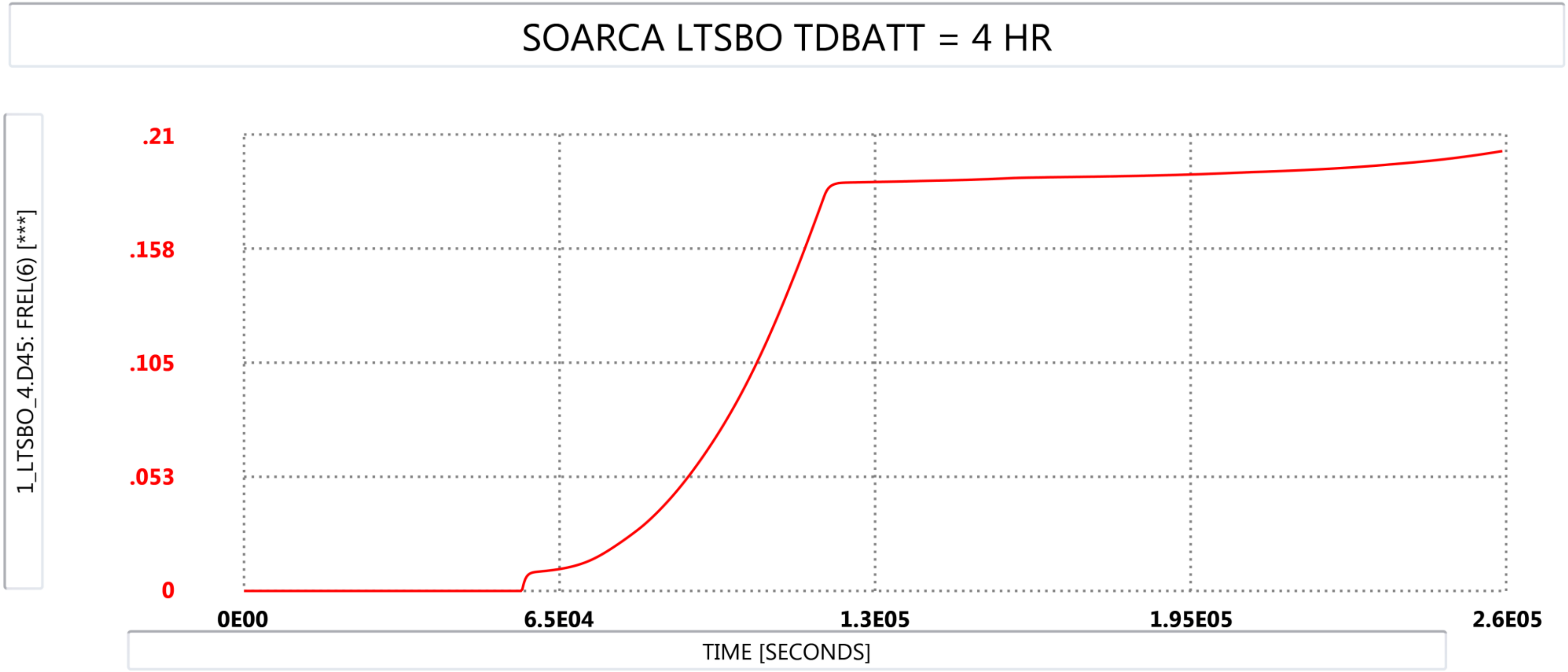
# MAAP 5.01 Drywell Pressure



# MAAP 5.01
# Cesium Iodide Release Fraction



# MAAP 5.01
# Cesium Hydroxide Release Fraction



# MAAP 5.01
# Cesium Molybdate Release Fraction