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Evaluation of Strategies for Mitigating Radiological Releases in Severe Accidents:

Assumptions, Models, Input, and Data

BWR Mark I and Mark II Studies

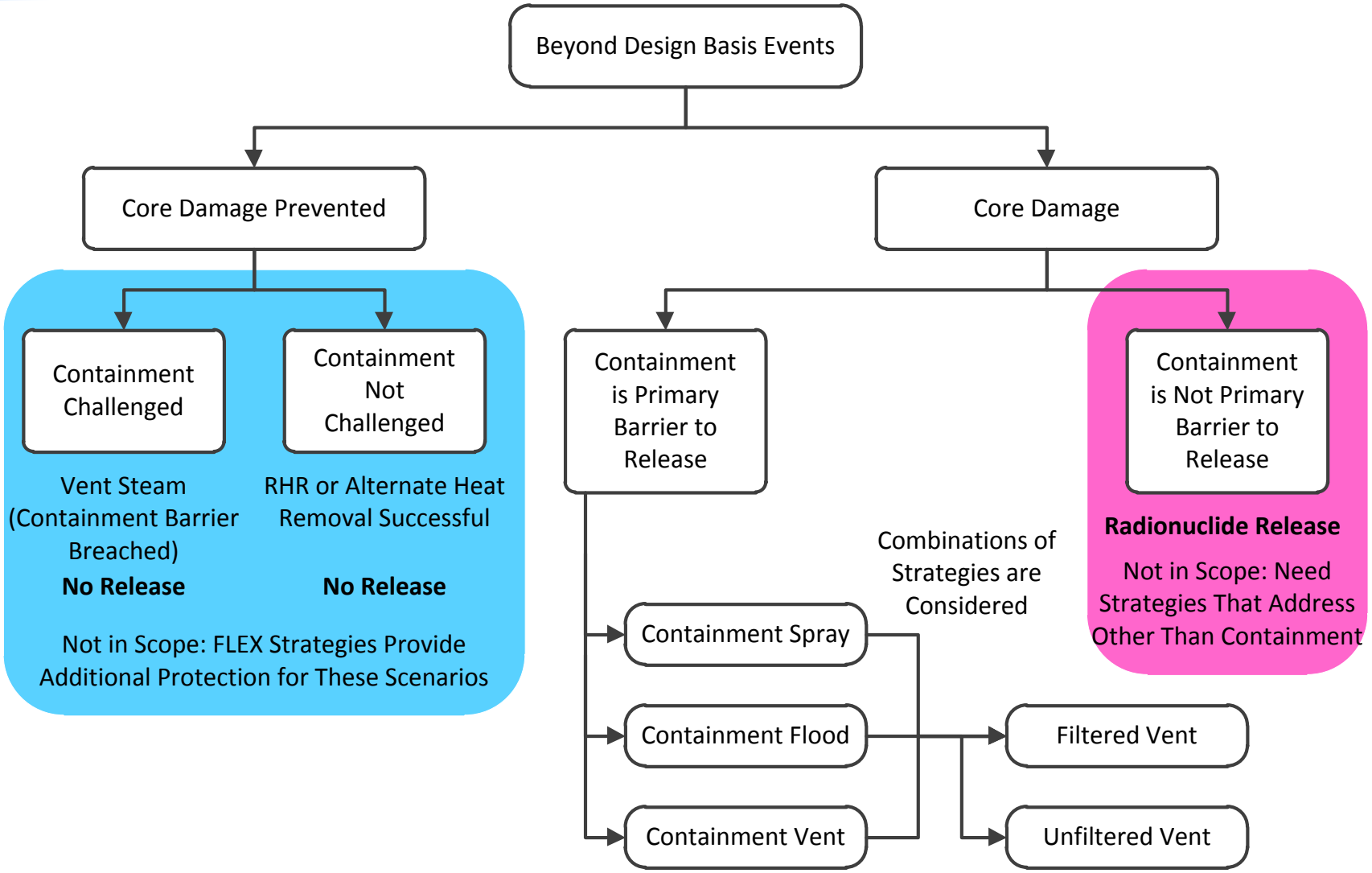
Topics

- EPRI's use of MAAP and MAACS2 to evaluate strategies to reduce radioactive release following a severe accident
  - Introduction
  - Selection of representative scenarios
  - Selection of viable strategies
  - MAAP models, input, and assumptions
  - MAAP output
  - Insights gained by performing the analyses
- The material will be presented for each case evaluated, rather than by topic group

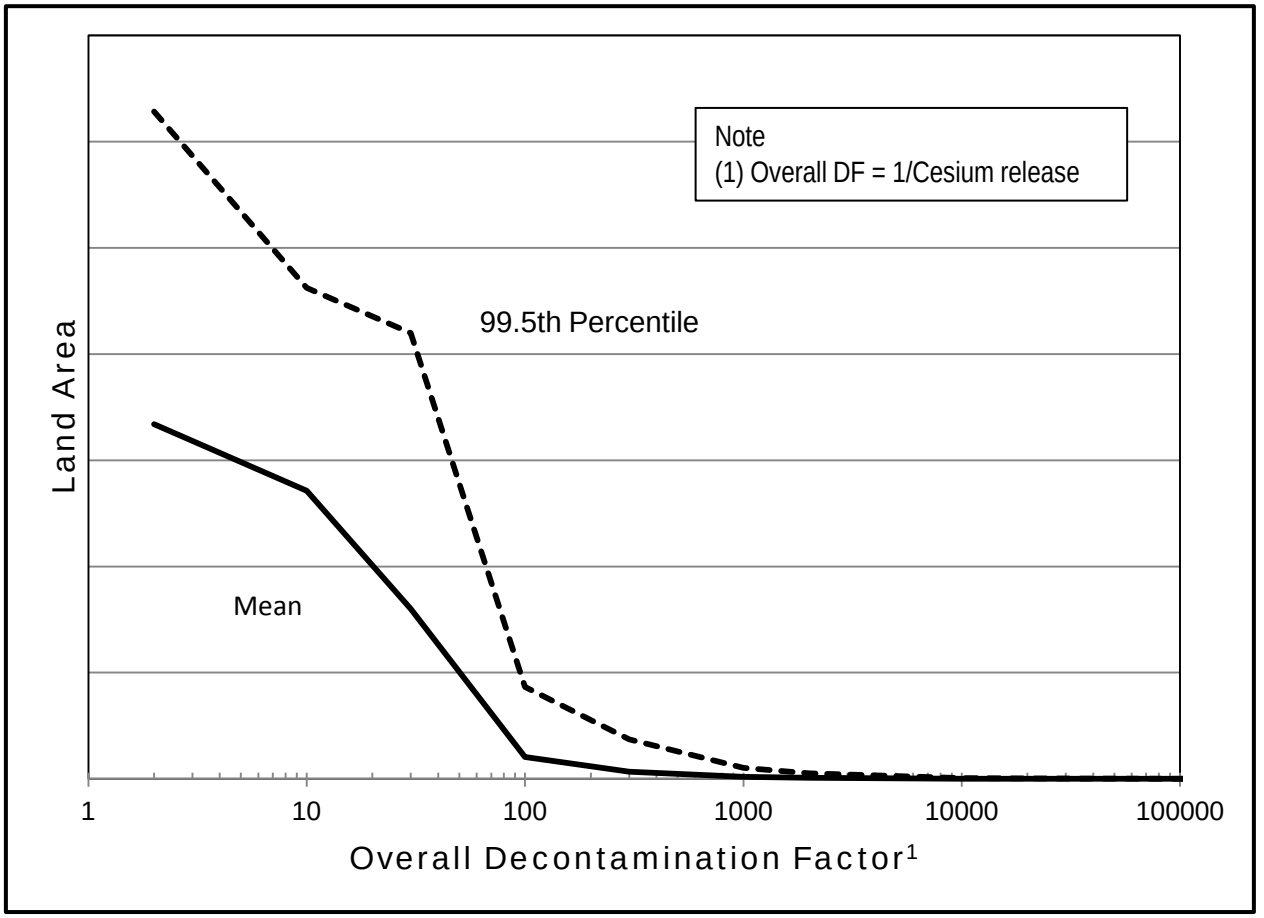
Introduction

- Best way to avoid radiological release is to prevent core damage
- Containment function is to retain fission products and the most effective strategies should maximize the retention within containment
- The goals of the EPRI work is to assess strategies for mitigating releases to the environment in a severe accident

Containment Enhancement Scenarios Evaluated

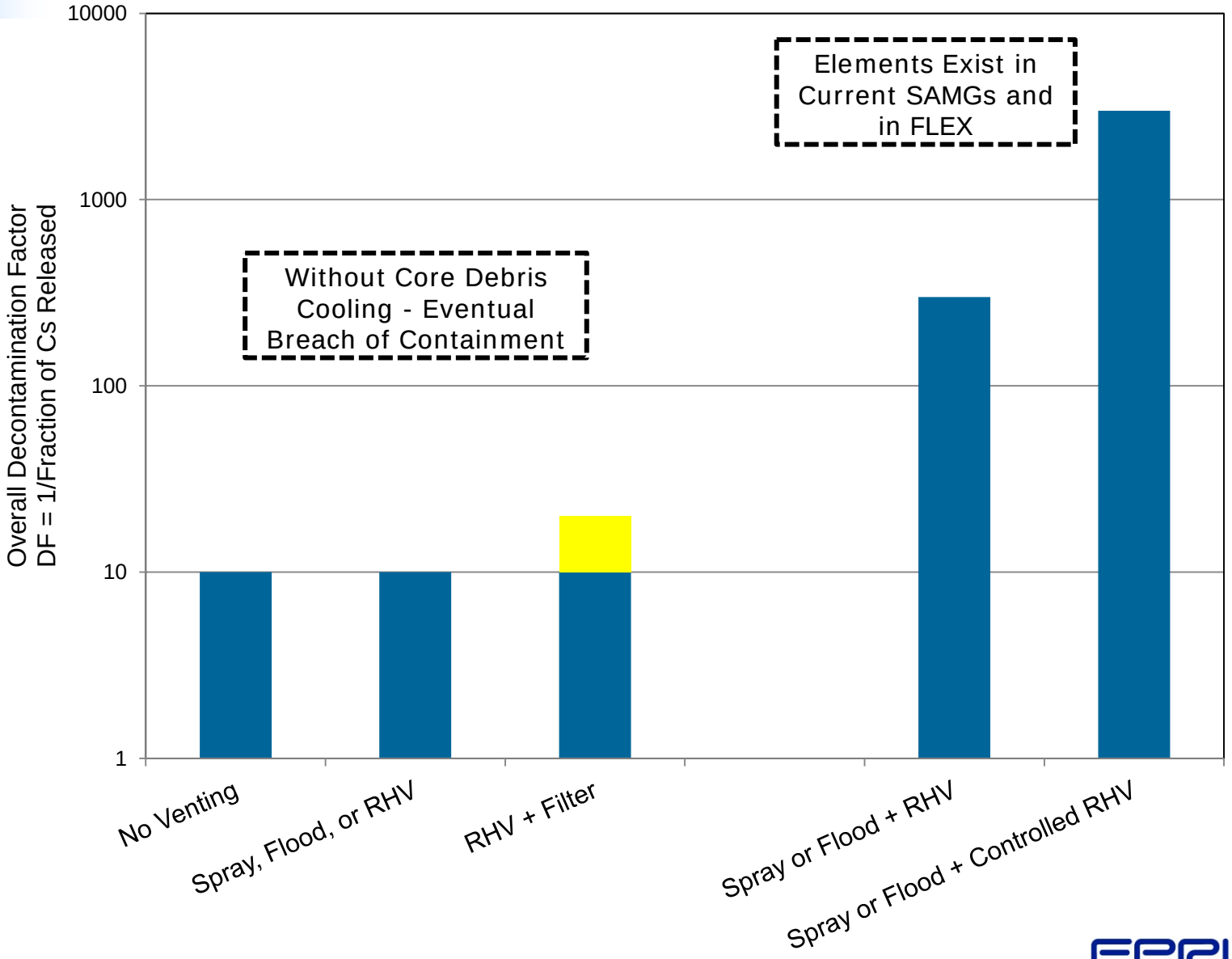


Land Contamination Figure of Merit

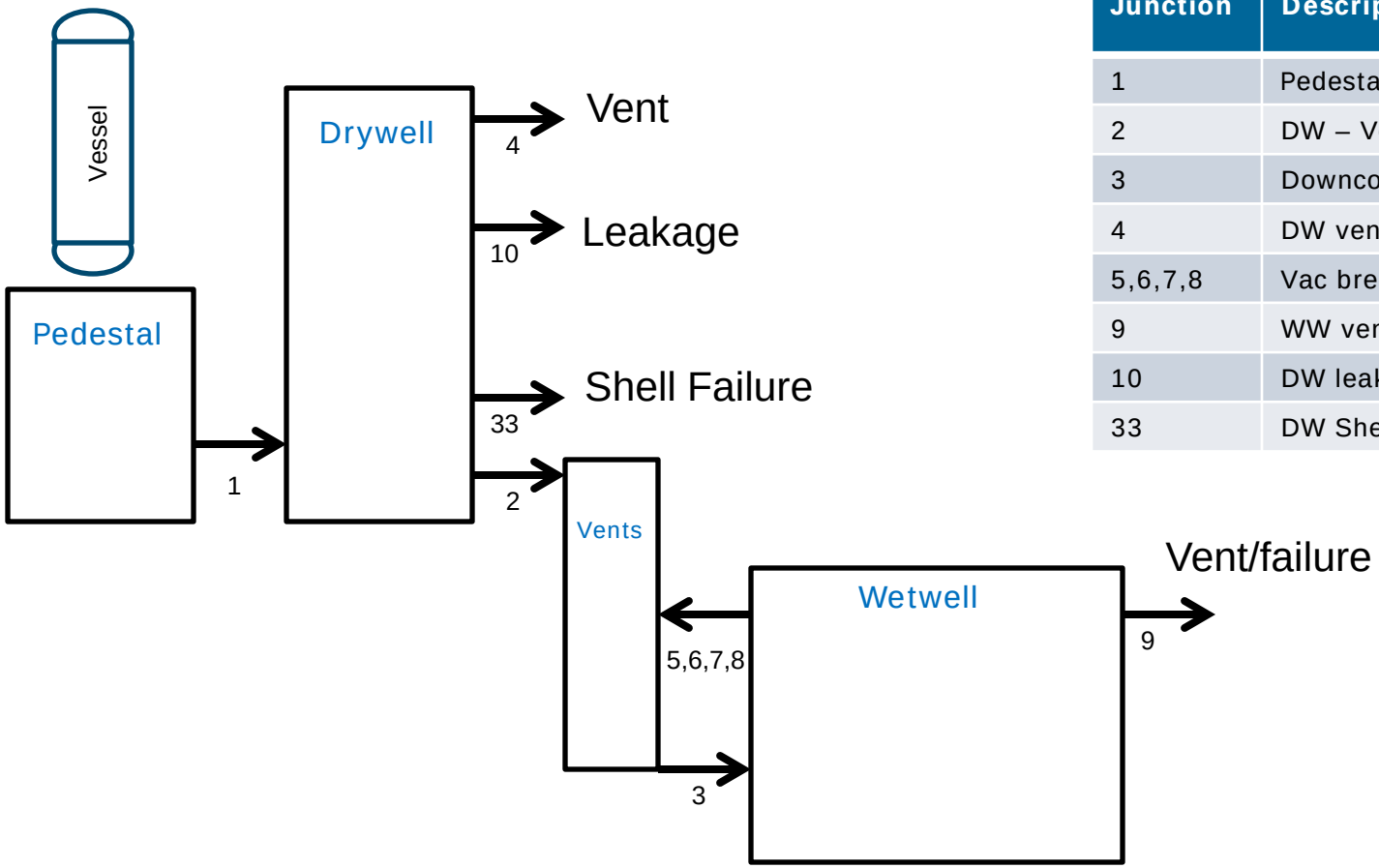


Diminishing Benefit as DF Approaches 1000

Representative Output for BWR Mark I Strategies



Mark I MAAP Nodalization

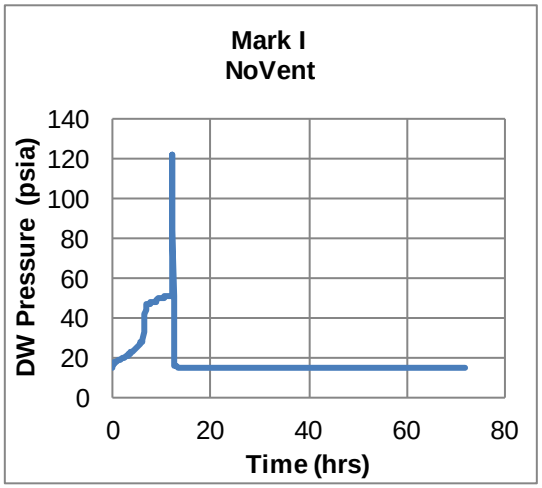


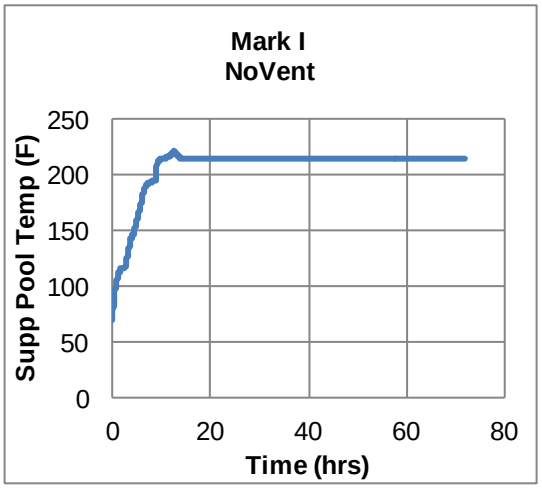
Junction	Description
1	Pedestal Door
2	DW – Vent Pipe
3	Downcomer
4	DW vent/failure
5,6,7,8	Vac breakers
9	WW vent/failure
10	DW leakage
33	DW Shell Failure

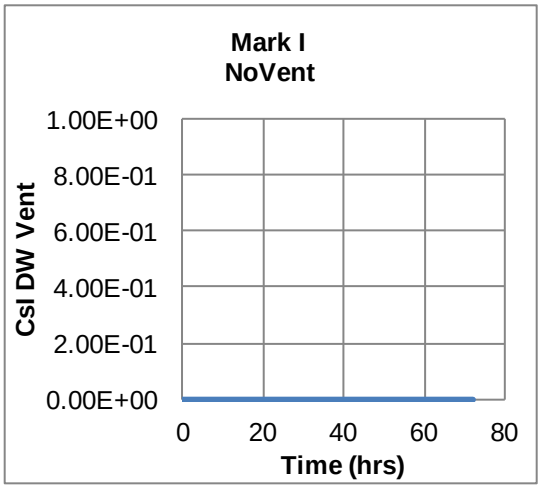
Mark I Output – No Vent

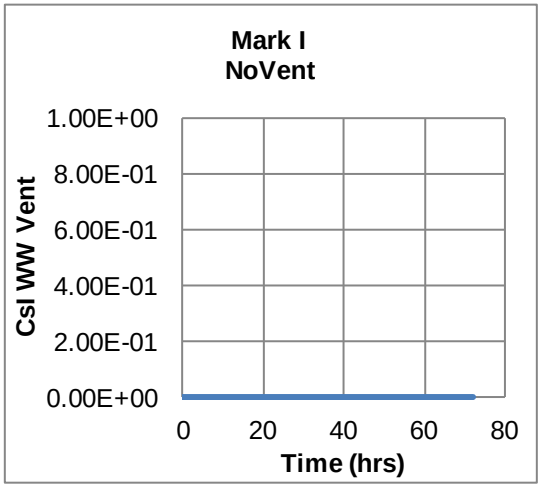
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.8
Reactor vessel breach	12.0
Drywell shell failure	12.3
Increased Drywell leakage	63.7

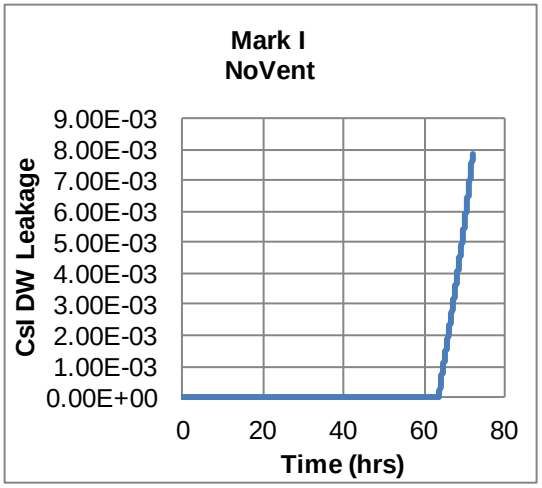
Mark I Output – No Vent

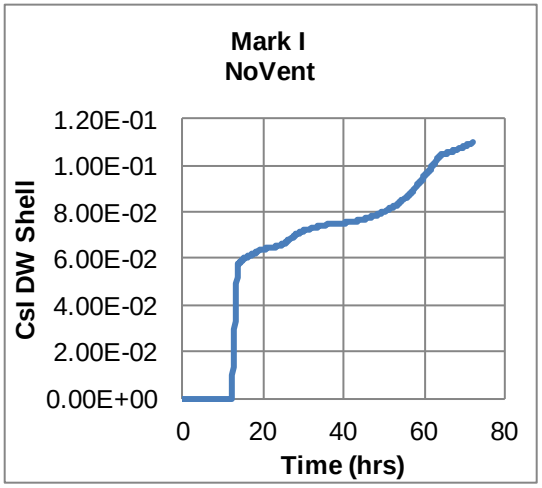












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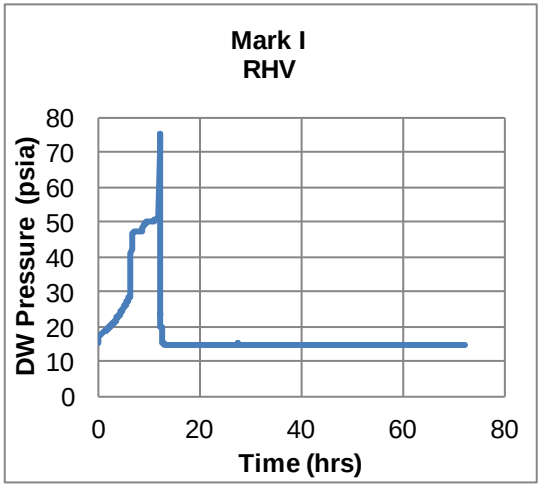
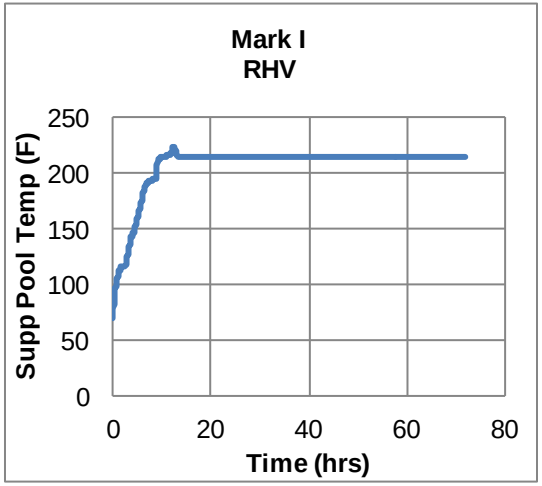
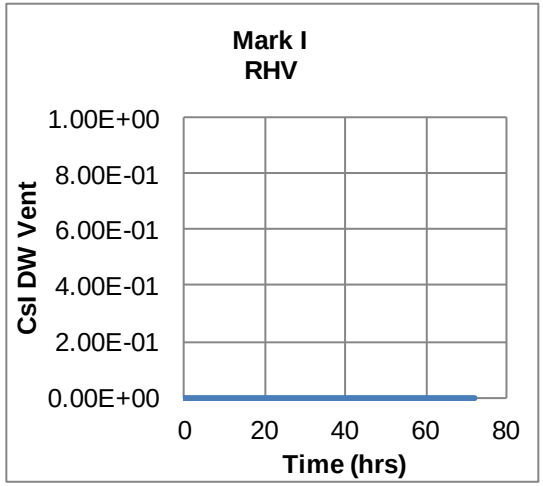
Mark I Output – RHV

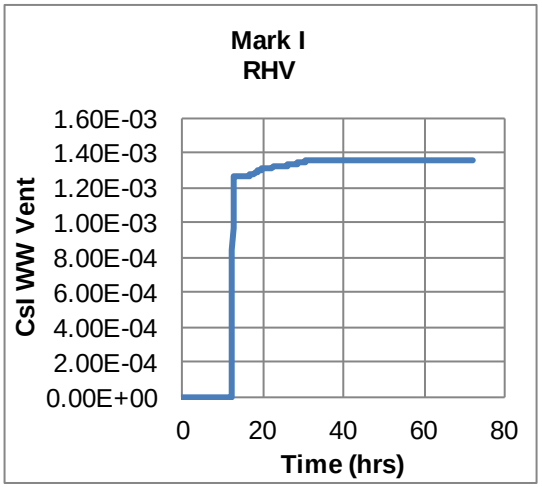
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.8
Reactor vessel breach	12.0
Wetwell Vent Open	12.1
Drywell shell failure	12.3
Increased Drywell leakage	50.5

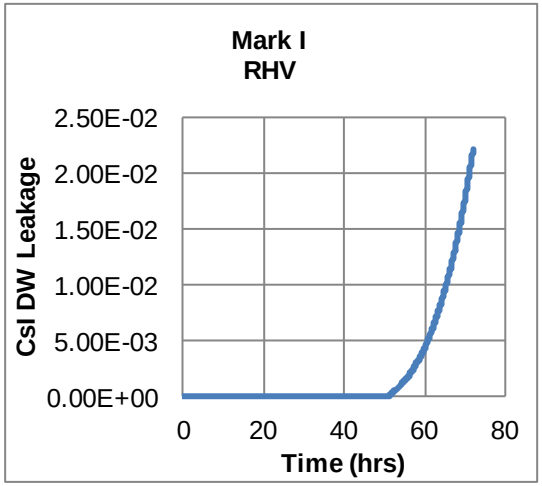
Mark I Output – RHV

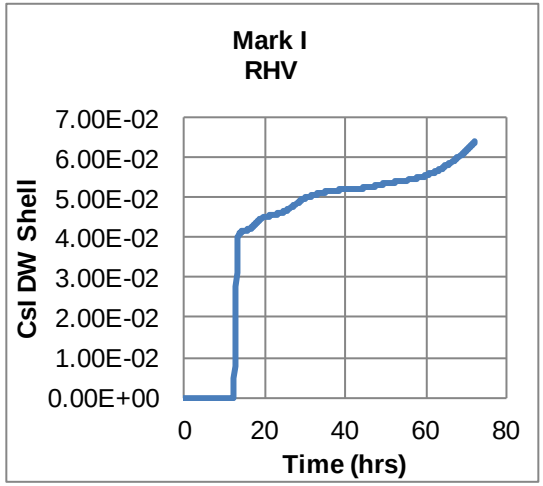












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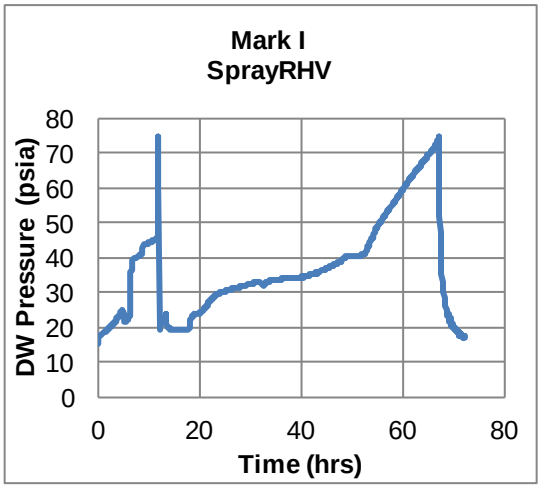
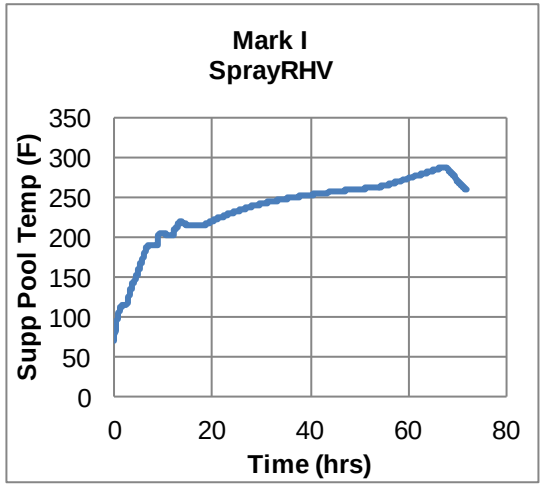
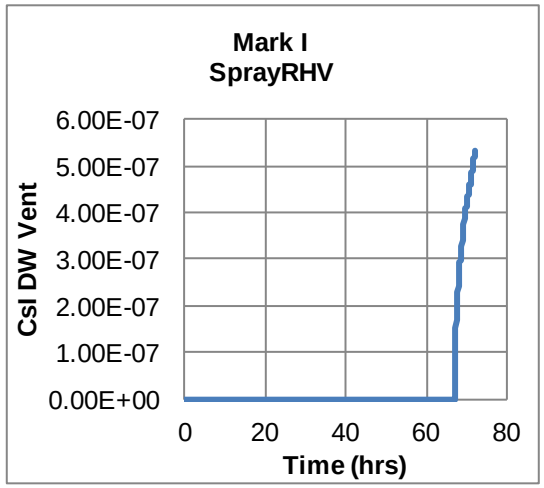
Mark I Output – Spray and RHV

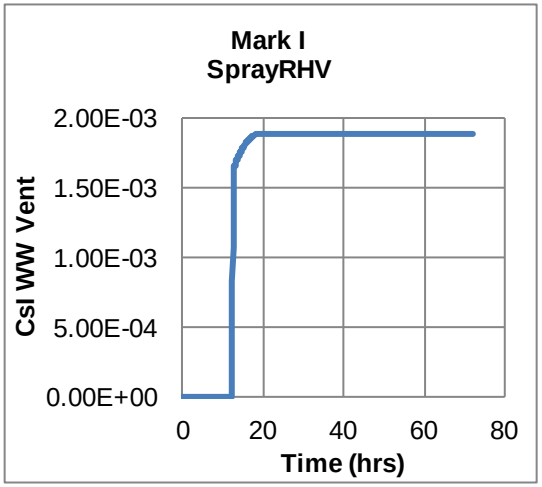
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.7
Reactor vessel breach	11.8
Wetwell Vent Open	11.9
Wetwell vent closed due to high pool level	17.9
Secure sprays due to high Drywell level	52.2
Open Drywell Vent	67.0

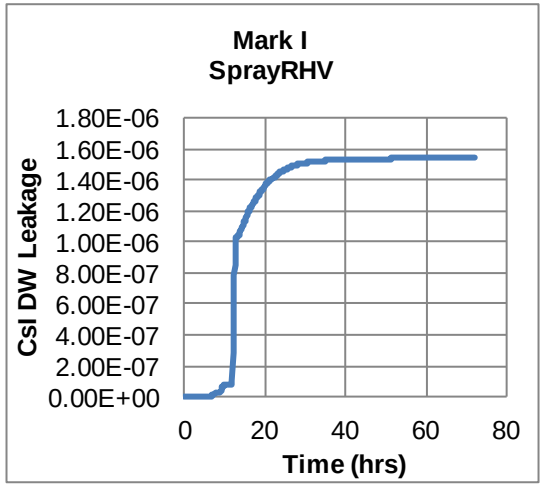
Mark I Output – Spray and RHV

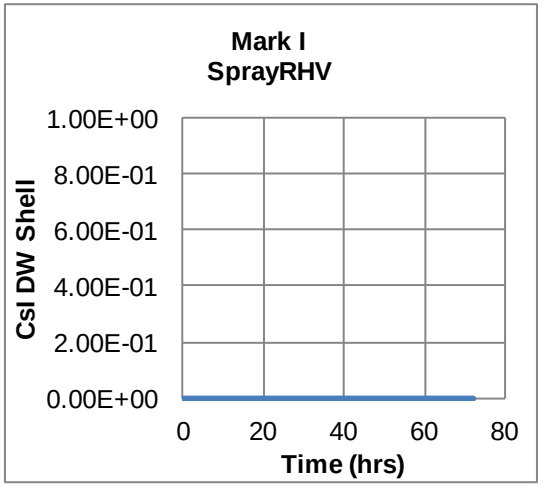












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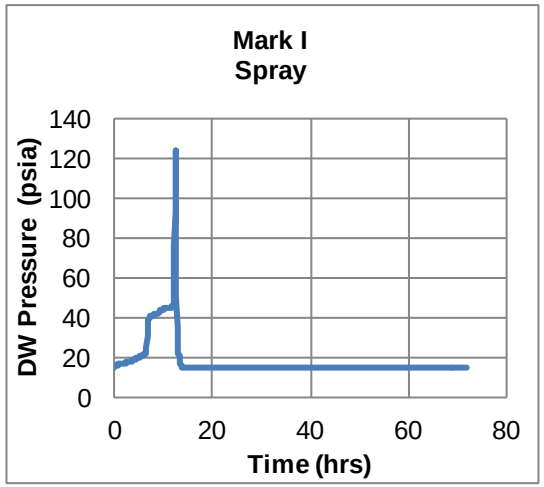
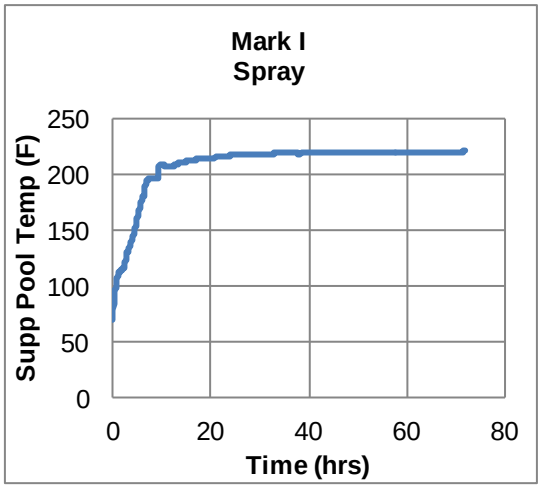
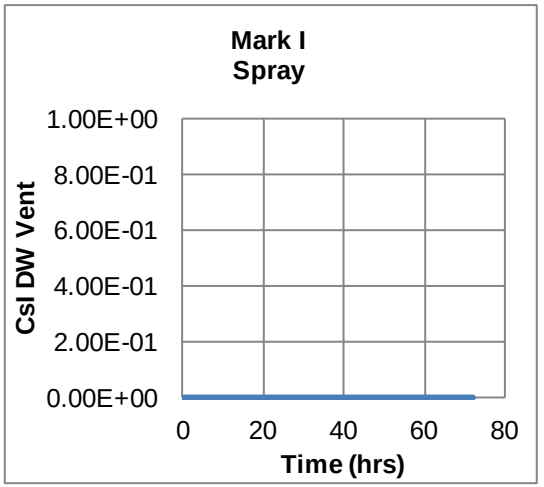
Mark I Output – Spray

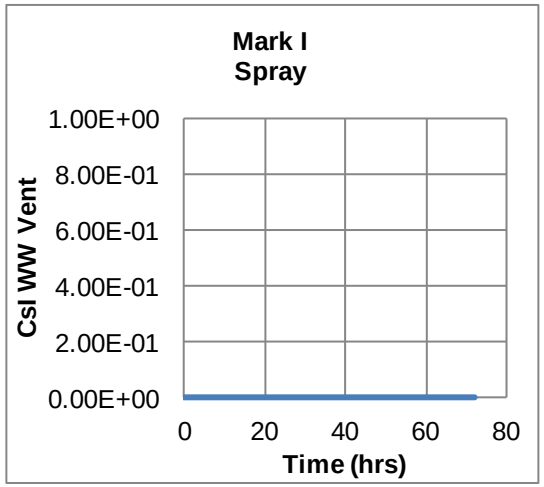
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	5.2
Onset of Core Damage	6.4
Single SRV assumed to seize open	6.4
Core material relocation to the lower plenum	9.0
Reactor vessel breach	12.1
Drywell failure due to overpressure	12.5
Secure sprays due to high Drywell level	58.3

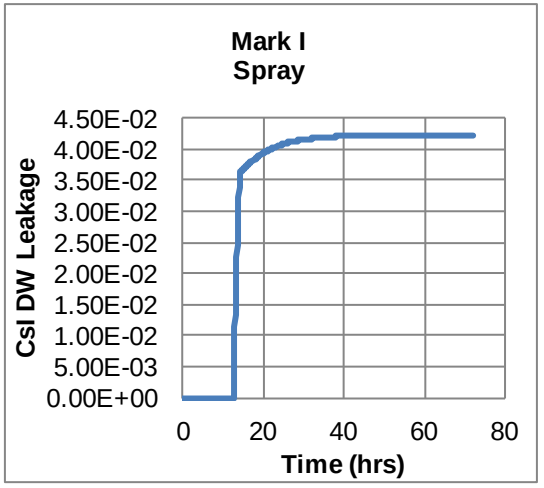
Mark I Output – Spray

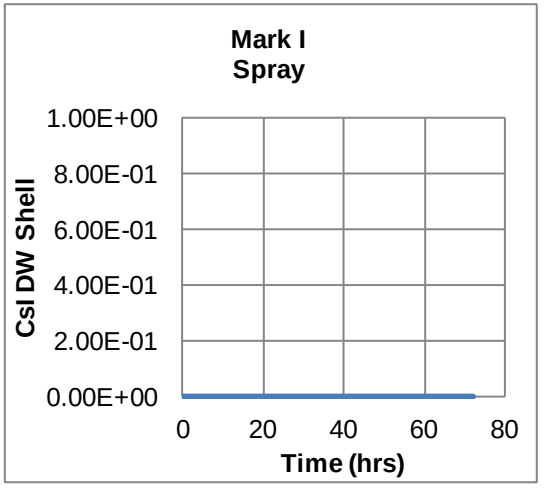








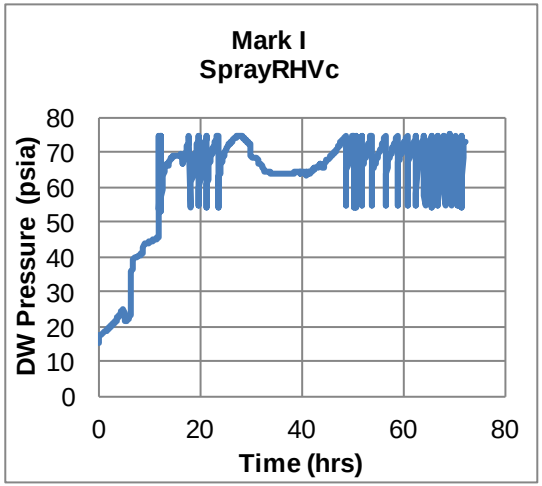


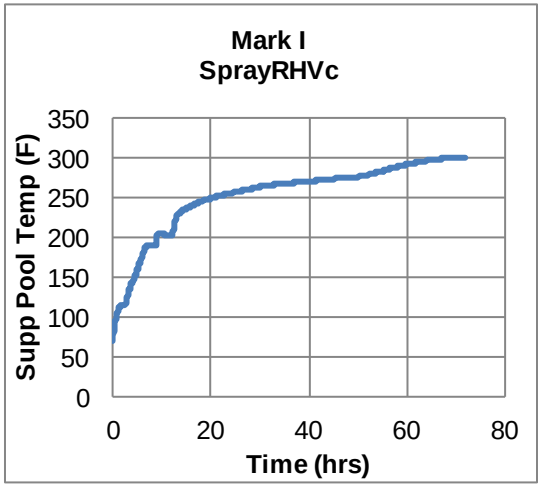


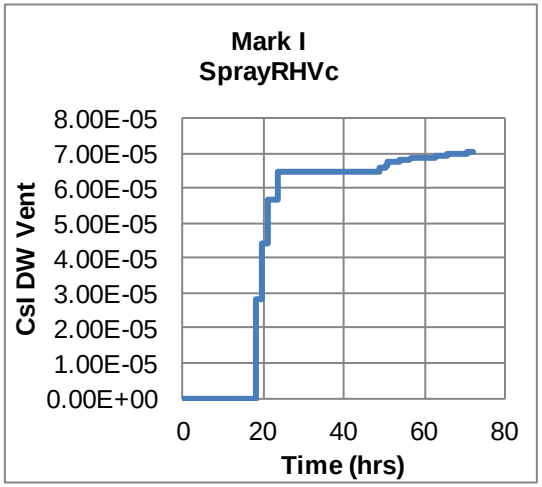
Mark I Output – Spray and Controlled RHV

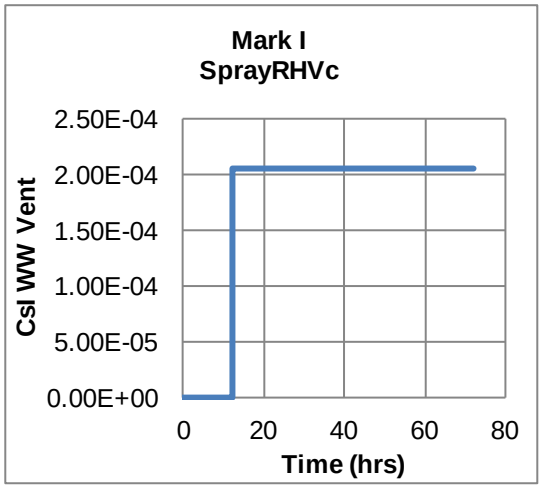
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.7
Reactor vessel breach	11.8
Wetwell Vent Initially Opened	11.9
Wetwell vent cycled open/close	11.9-17.9
Wetwell vent closed due to high pool level	17.9
Drywell Vent Initially Opened	19.7
Drywell Vent cycled open/close	19.7-72.0
Secure sprays due to high Drywell level	48.6

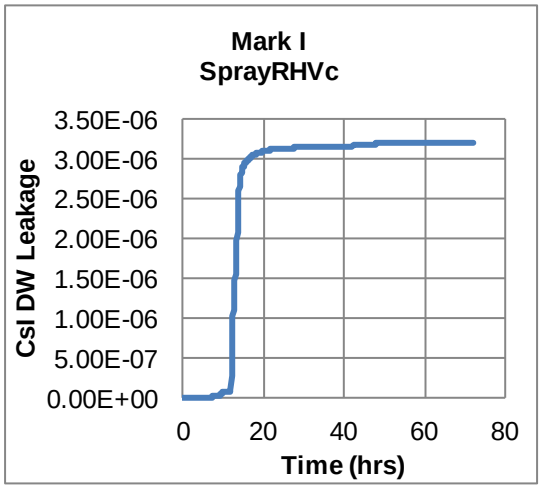
Mark I Output – Spray and Controlled RHV

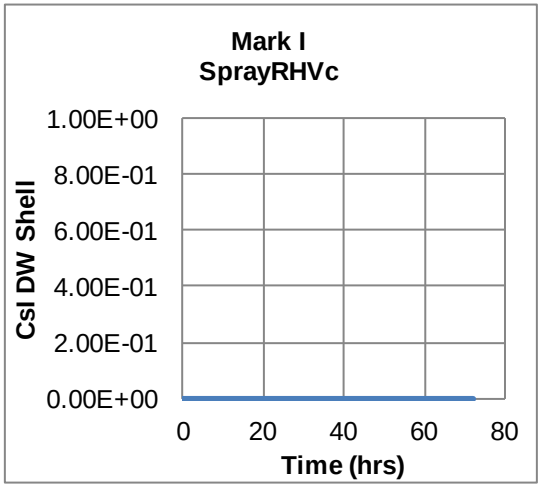












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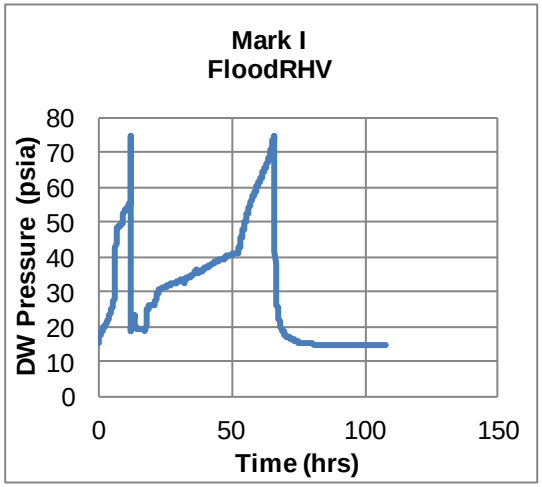
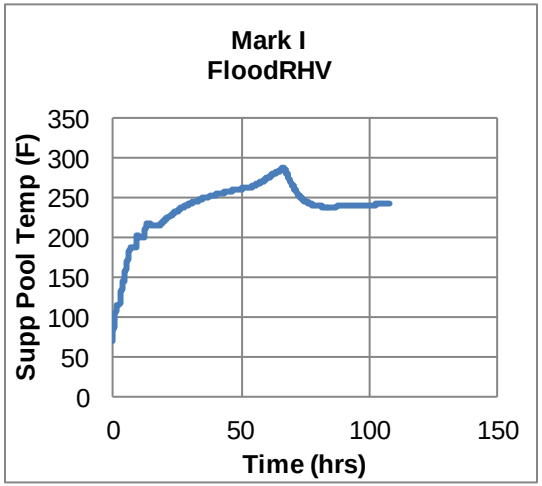
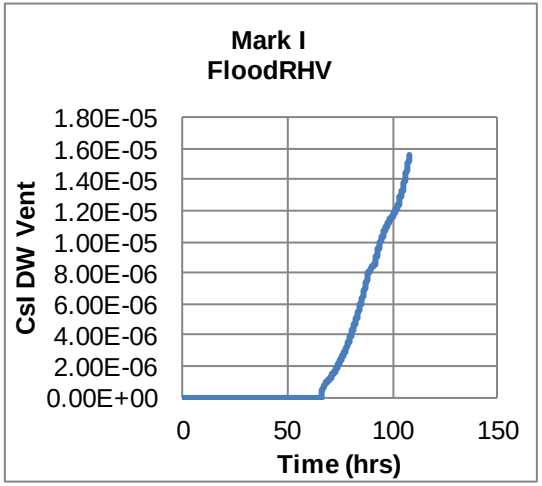
Mark I Output – Flood and RHV

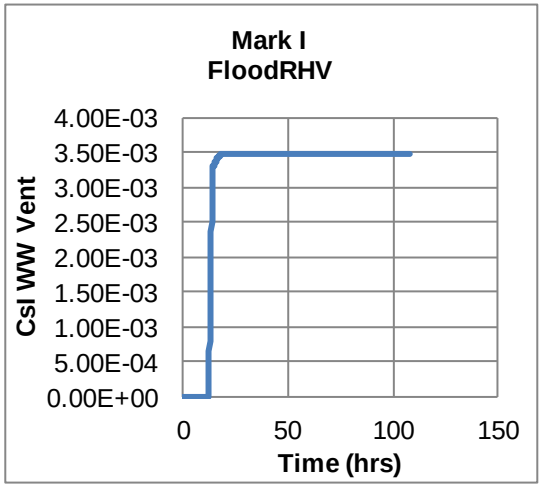
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell flooding	5.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.9
Reactor vessel breach	12.0
Wetwell Vent Open	12.1
Wetwell vent closed due to high pool level	17.7
Secure flood due to high Drywell level	52.1
Drywell Vent opened	66.0

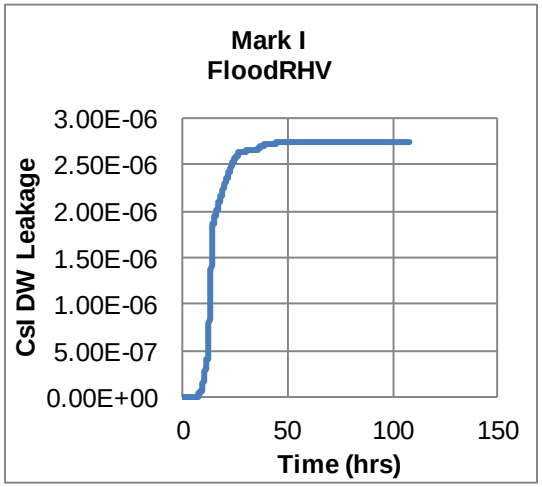
Mark I Output – Flood and RHV

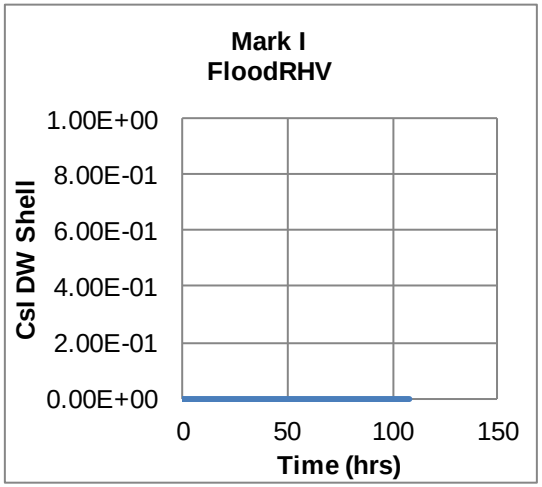












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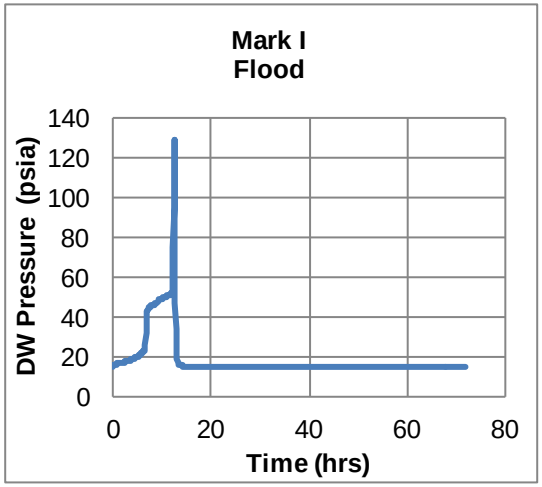
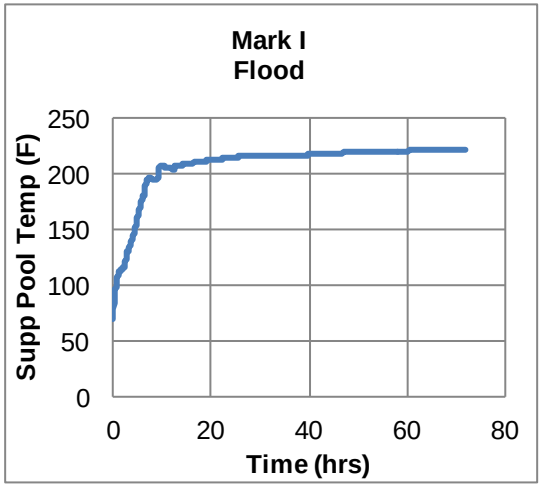
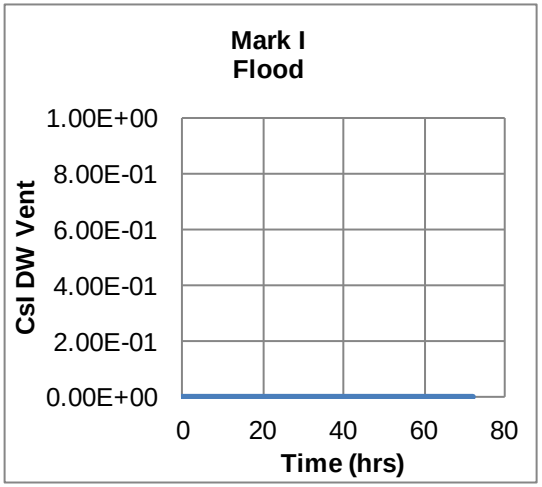
Mark I Output – Flood

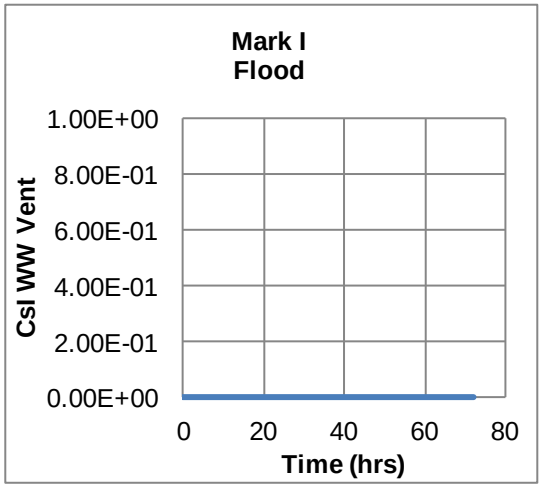
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell flooding	5.0
Core Uncovered	5.5
Onset of Core Damage	6.4
Single SRV assumed to seize open	6.4
Core material relocation to the lower plenum	9.1
Reactor vessel breach	12.1
Drywell failure due to overpressure	12.5

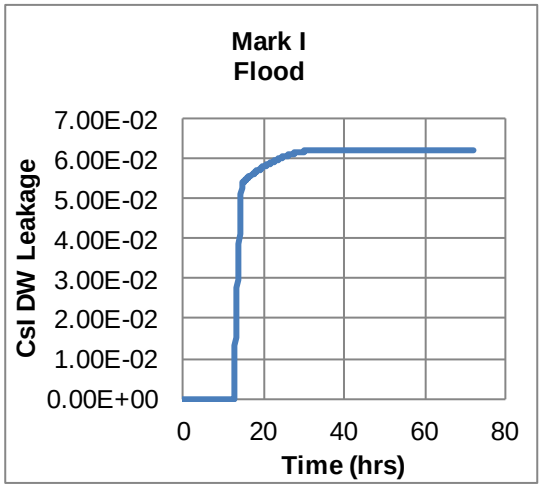
Mark I Output – Flood

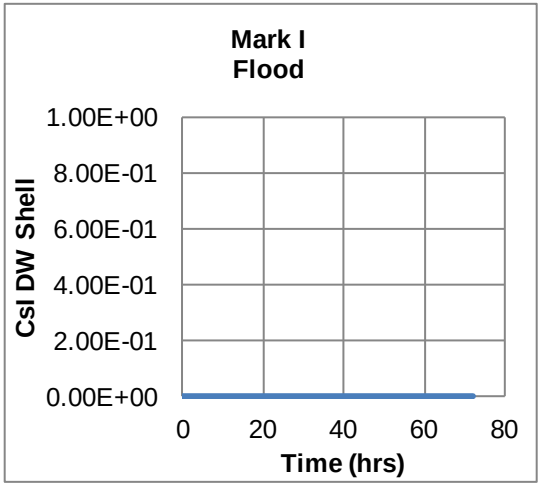












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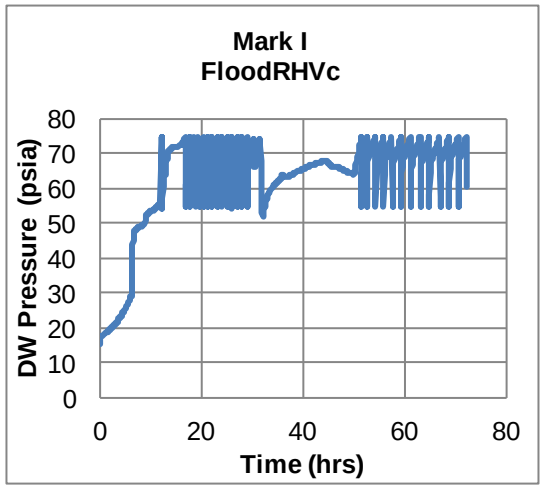
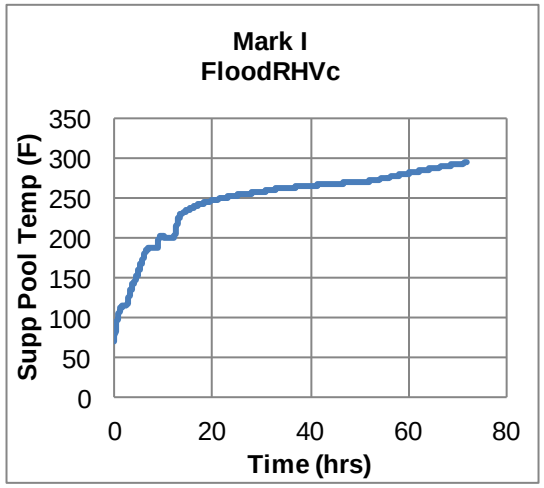
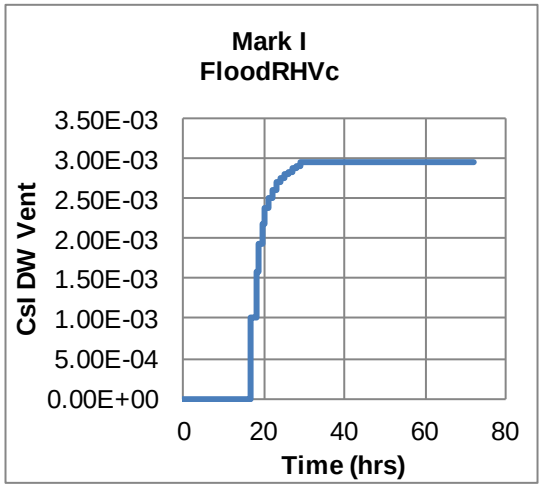
Mark I Output – Flood and Controlled RHV

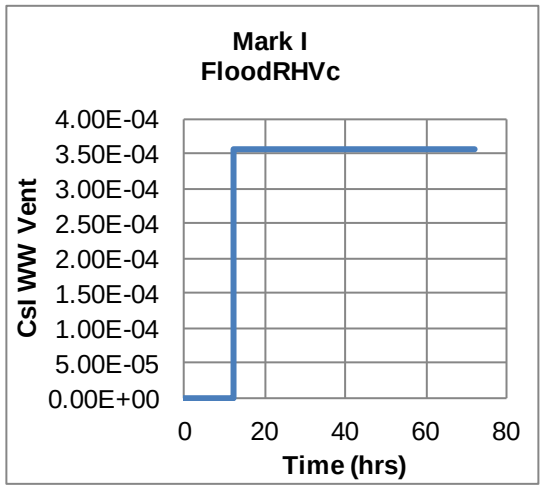
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell flooding	5.0
Core Uncovered	5.2
Onset of Core Damage	6.1
Single SRV assumed to seize open	6.1
Core material relocation to the lower plenum	8.9
Reactor vessel breach	12.0
Wetwell Vent Initially Opened	12.1
Wetwell vent cycled open/close	12.1-16.8
Wetwell vent closed due to high pool level	16.8
Drywell Vent Initially Opened	17.9
Drywell Vent cycled open/close	17.9-72.0
Secure sprays due to high Drywell level	49.7

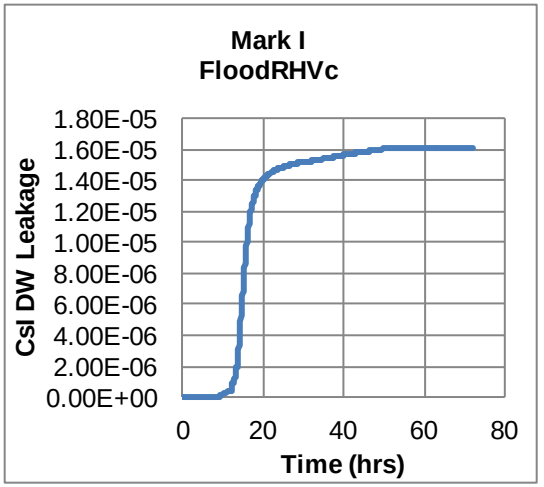
Mark I Output – Flood and Controlled RHV

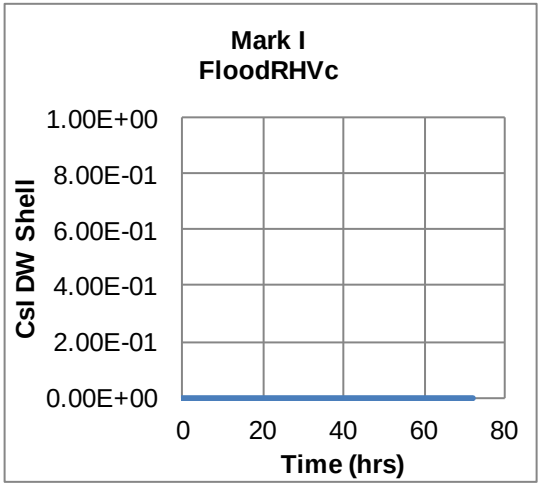












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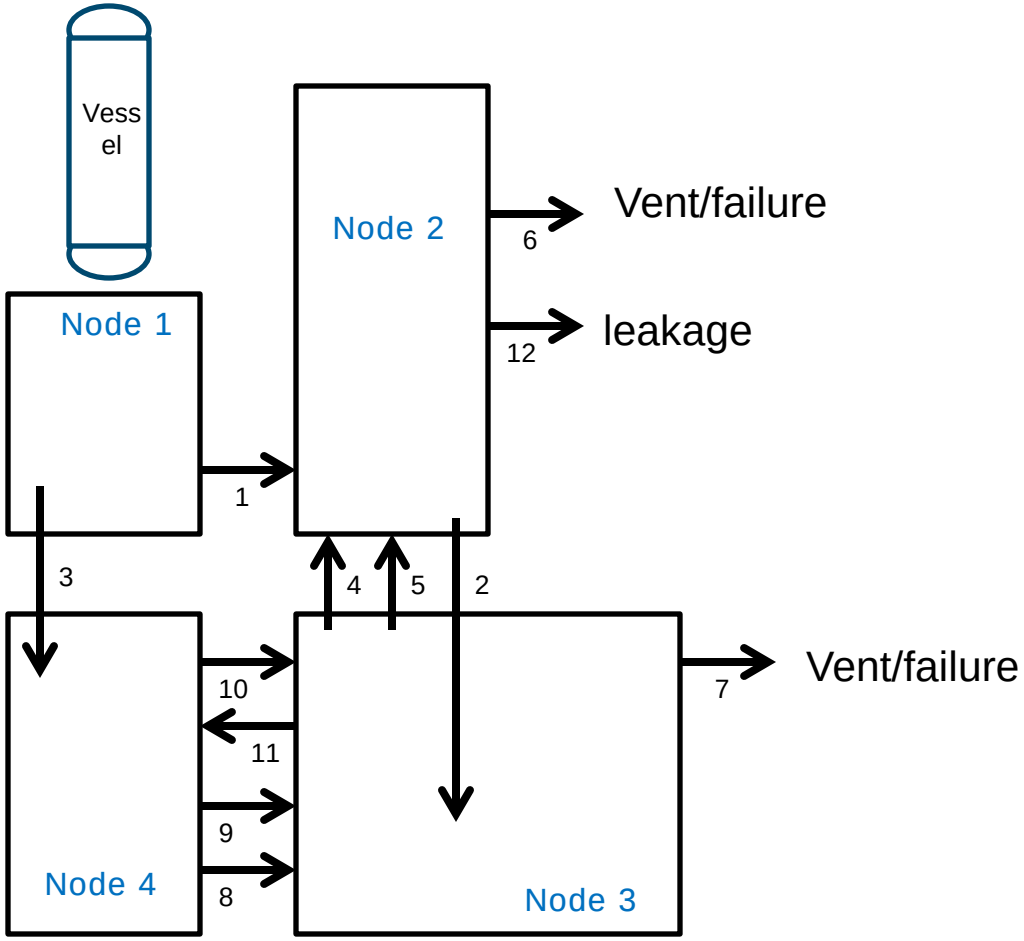
Mark II MAAP Nodalization – Cat 2

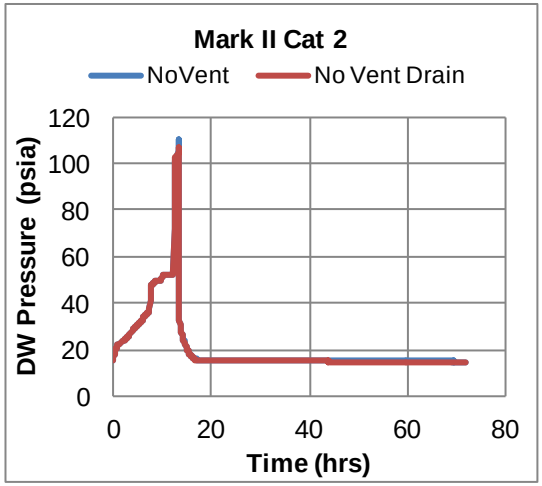


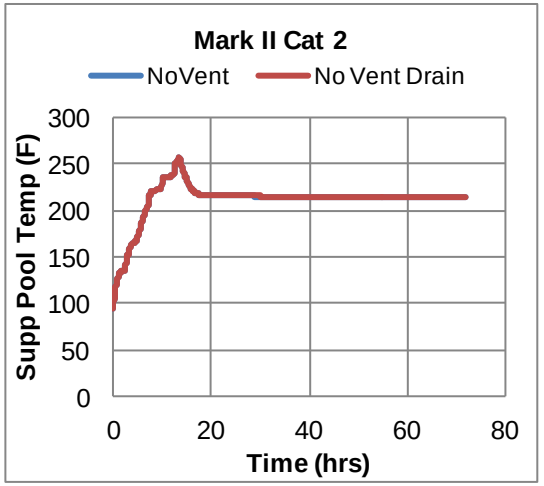
Junction	Description
1	Pedestal Door
2	Downcomers
3	Drain line
4	Vac breaker
5	Vac breaker
6	DW vent/failure
7	WW vent failure
8,9,10	Lower Ped - WW
11	Doorway
12	DW leakage

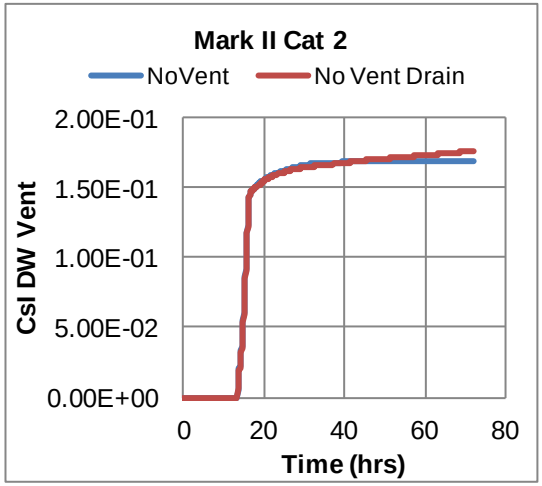
Mark II Output – Cat 2 No Vent

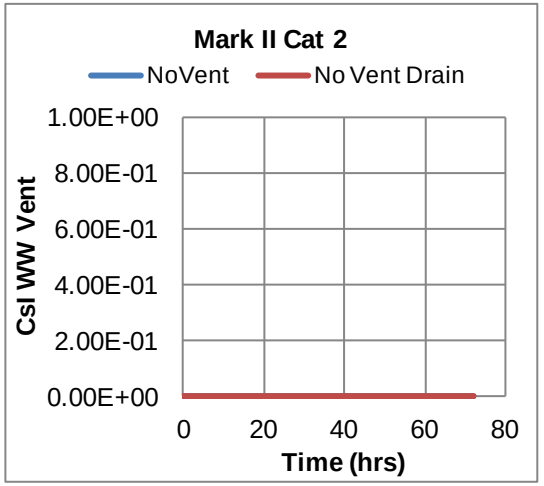
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Core Uncovered	6.2
Onset of Core Damage	7.2
Single SRV assumed to seize open	7.2
Core material relocation to the lower plenum	9.8
Reactor vessel breach	12.3
Pedestal drain line failure	12.4 (NA)
Drywell failure	13.4

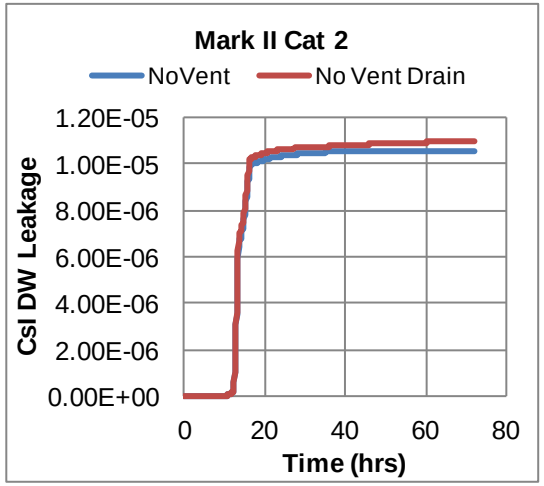
Mark II Output – Cat 2 No Vent











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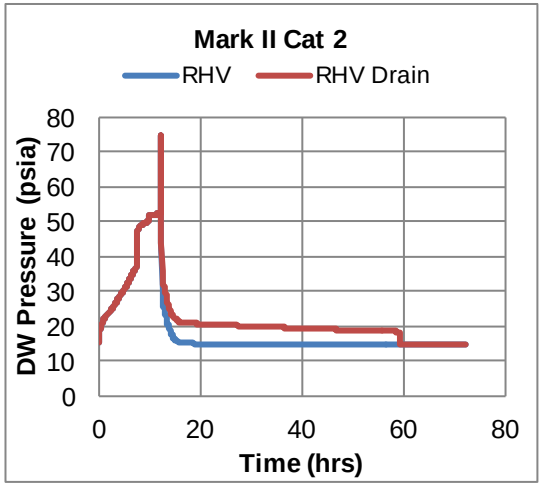
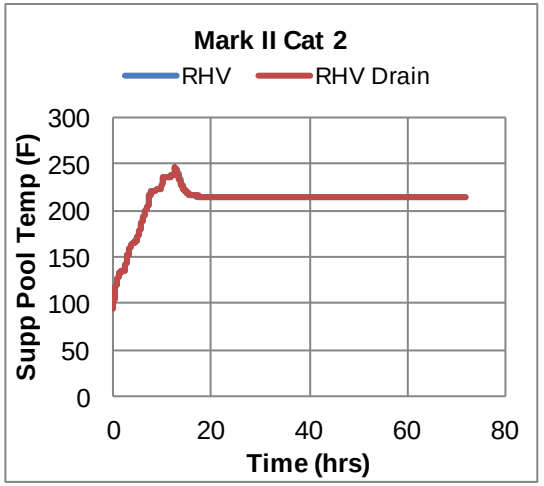
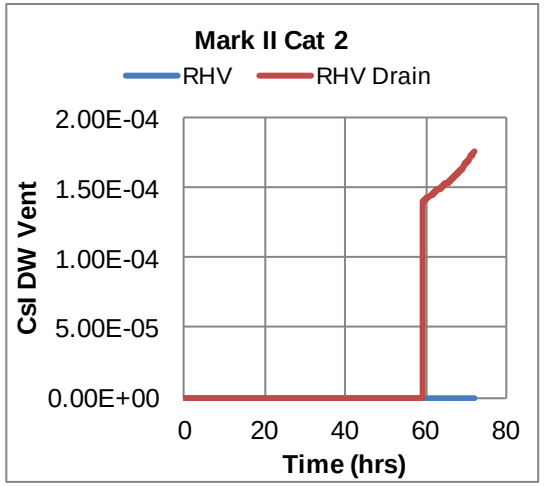
Mark II Output – Cat 2 RHV

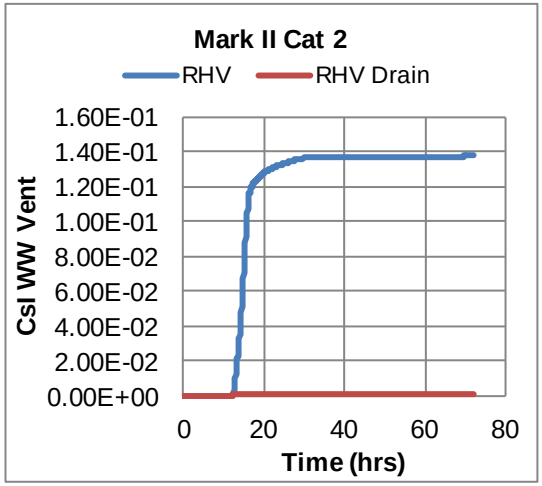
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Core Uncovered	6.2
Onset of Core Damage	7.2
Single SRV assumed to seize open	7.2
Core material relocation to the lower plenum	9.8
Reactor vessel breach	12.3
Wetwell Vent Open	12.3
Pedestal drain line failure	12.4 (NA)
Increased Drywell leakage	67.7 (59.3)

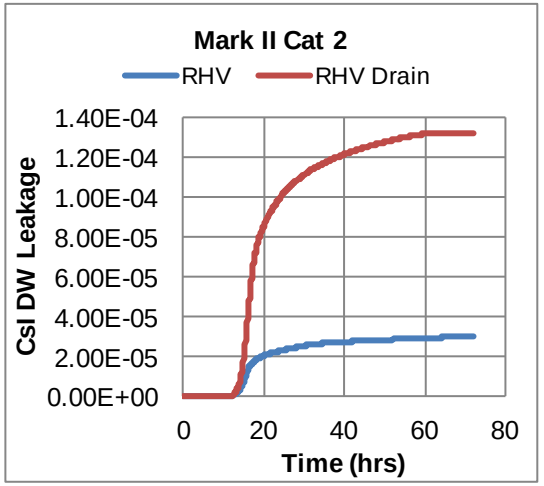
Mark II Output – Cat 2 RHV











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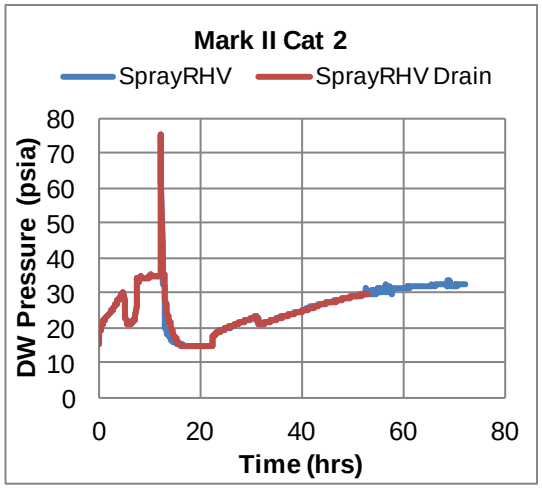
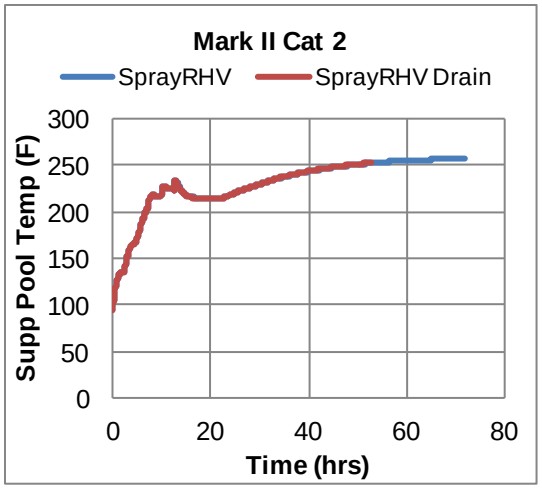
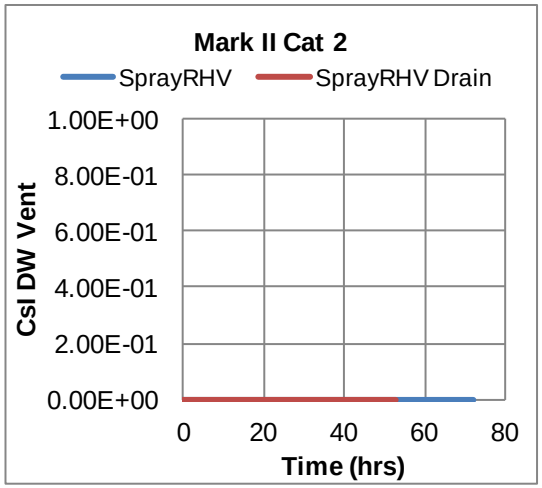
Mark II Output – Cat 2 Spray and RHV

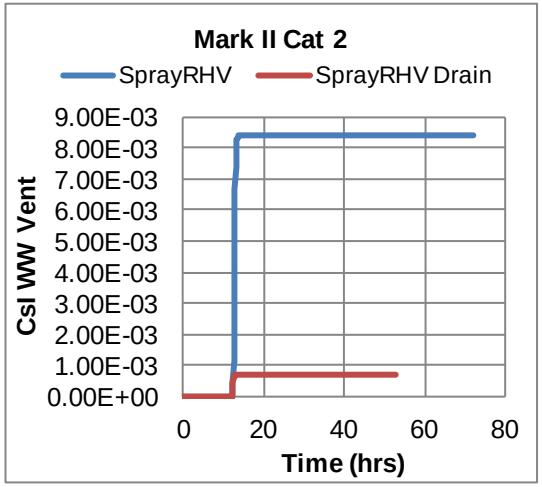
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	6.2
Onset of Core Damage	7.2
Single SRV assumed to seize open	7.2
Core material relocation to the lower plenum	9.8
Reactor vessel breach	12.3
Wetwell Vent Open	12.3
Pedestal drain line failure	12.4 (NA)
Wetwell vent closed due to high pool level	22.3
Drywell vent opened	22.3

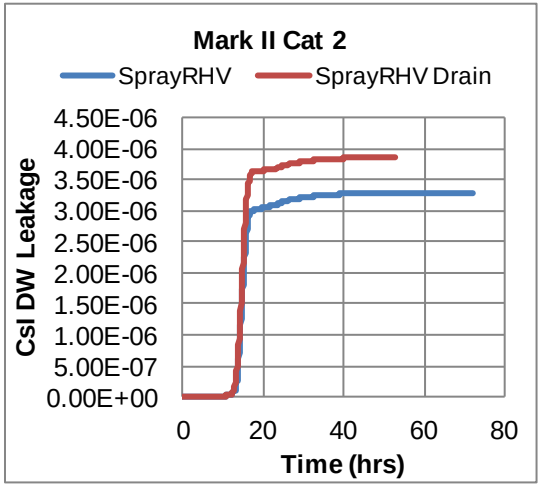
Mark II Output – Cat 2 Spray and RHV











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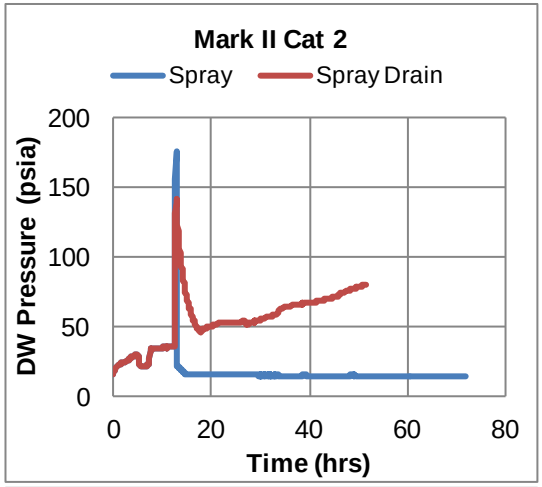
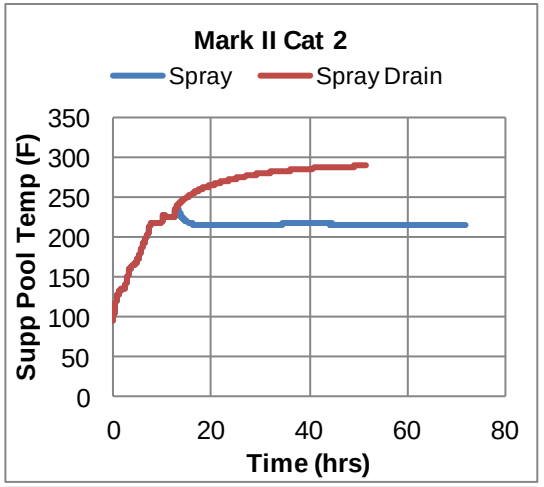
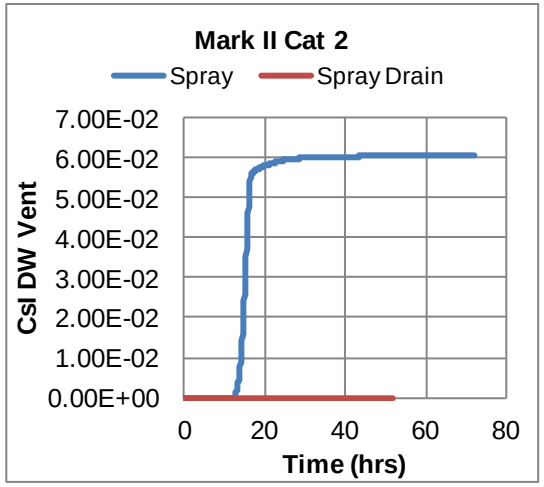
Mark II Output – Cat 2 Spray

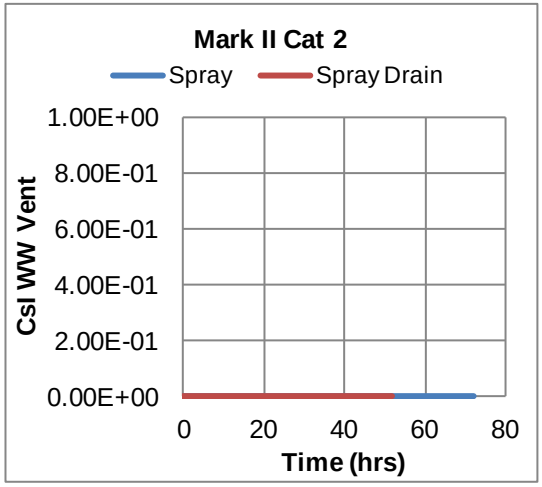
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	6.2
Onset of Core Damage	7.2
Single SRV assumed to seize open	7.2
Core material relocation to the lower plenum	9.8
Reactor vessel breach	12.3
Pedestal drain line failure	12.4 (NA)
Drywell failure	12.8 (NA)

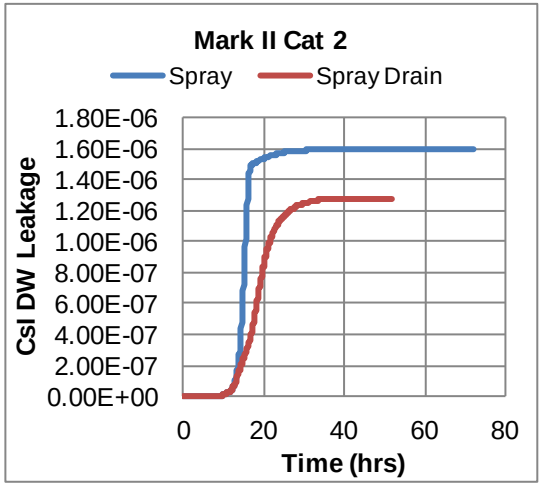
Mark II Output – Cat 2 Spray











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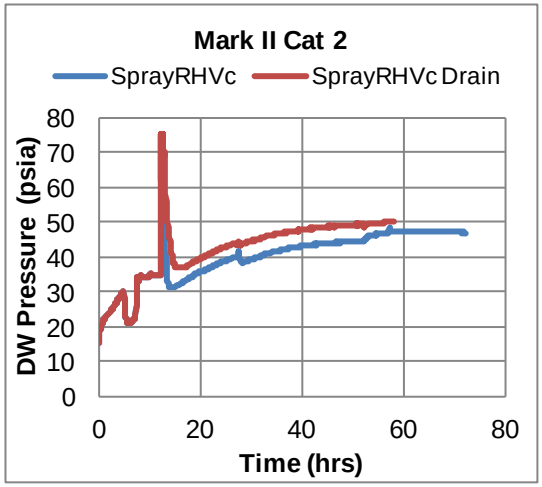
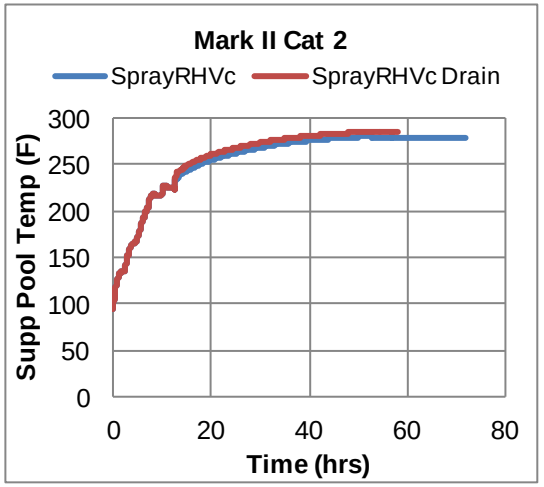
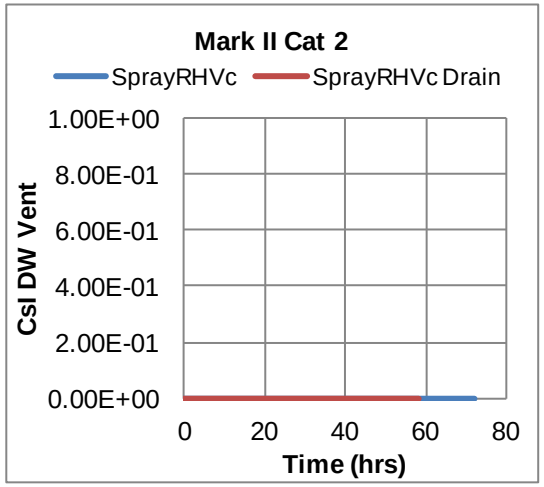
Mark II Output – Cat 2 Spray & Controlled RHV

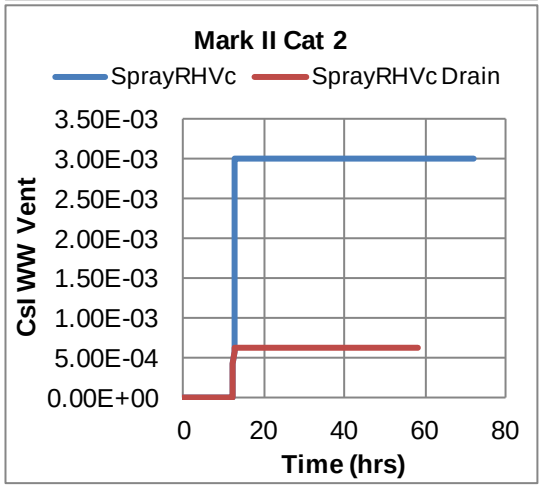
Phenomenon	Time (hr)
Reactor trip	0
RCIC lost due to loss of DC	4.0
Initiate Drywell sprays	5.0
Core Uncovered	6.2
Onset of Core Damage	7.2
Single SRV assumed to seize open	7.2
Core material relocation to the lower plenum	9.8
Reactor vessel breach	12.3
Wetwell Vent Initially Opened	12.4
Pedestal drain line failure	12.5 (NA)
Wetwell vent cycled open/close	12.4-12.9
Wetwell vent closed	12.9

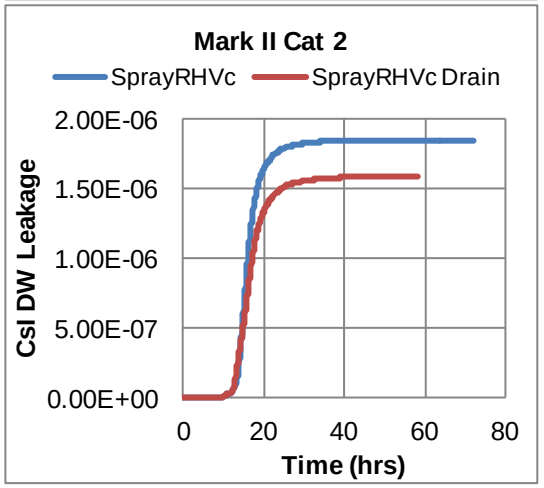
Mark II Output – Cat 2 Spray & Controlled RHV











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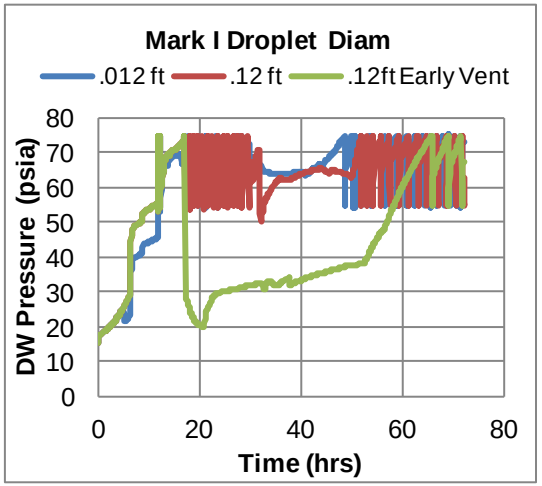
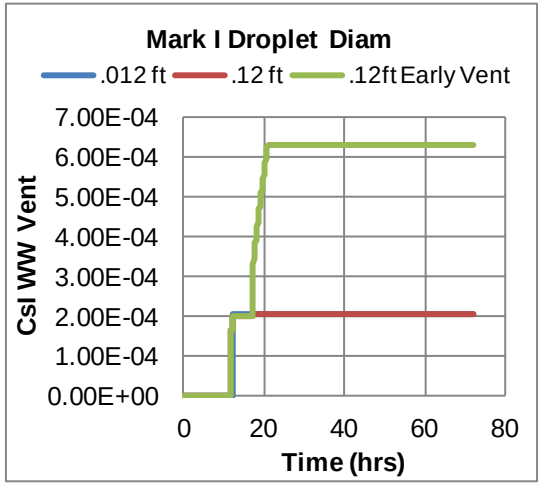
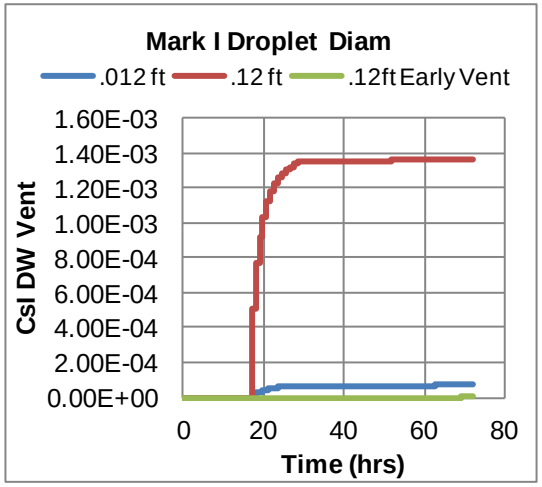
Sensitivity Analysis

- Drywell spray droplet diameter
  - Nominal value = 0.012 ft
  - Sensitivity value = 0.12 ft
  - Sensitivity value = 0.12 ft plus early wetwell venting
  - Performed for Spray and Controlled RHV case
- Drywell spray aerosol removal efficiency
  - Nominal value = 0.02
  - Sensitivity value = 0.002 and 0.0002
  - Performed for Spray and Controlled RHV case
- RCIC operation timing
  - 0,4,8, and 12 hours
  - Performed on Spray and RHV case
- Spray/Injection flow rate
  - 100, 500 gpm
  - Flood and spray
  - Performed on RHV case

Sensitivity Analysis – Spray Droplet Size







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Sensitivity Analysis – Aerosol Removal Efficiency

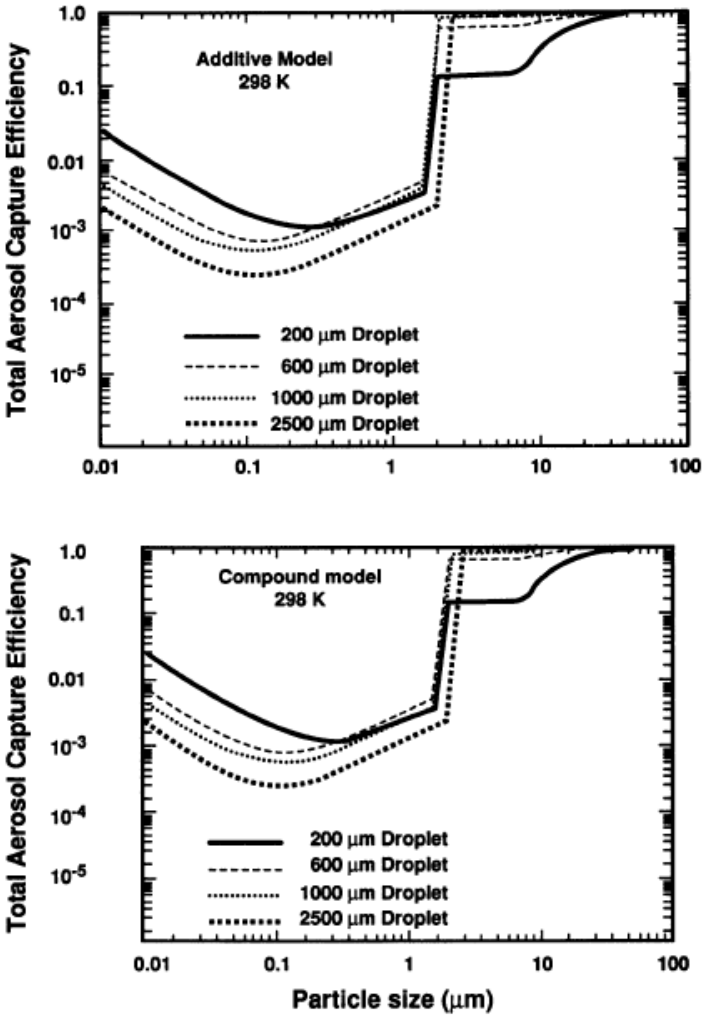
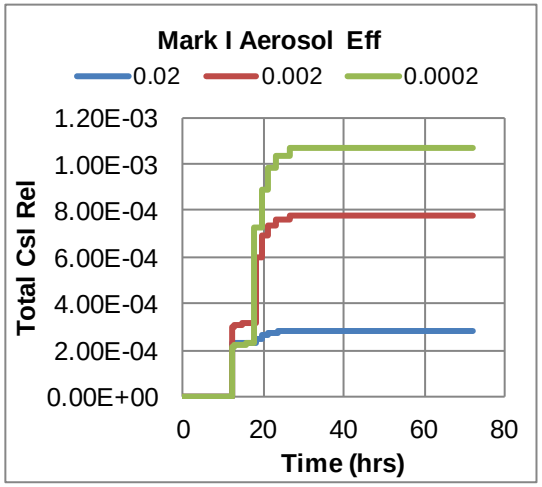
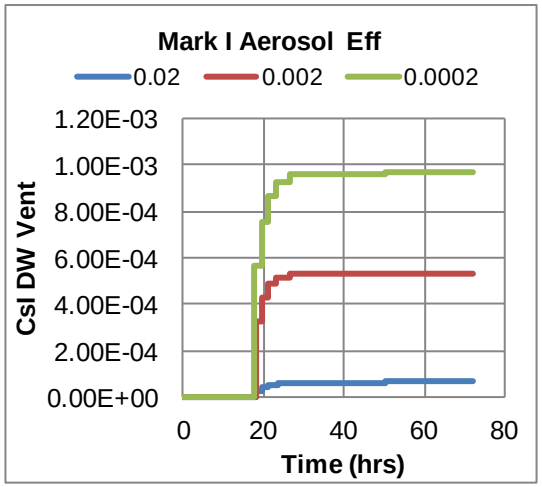
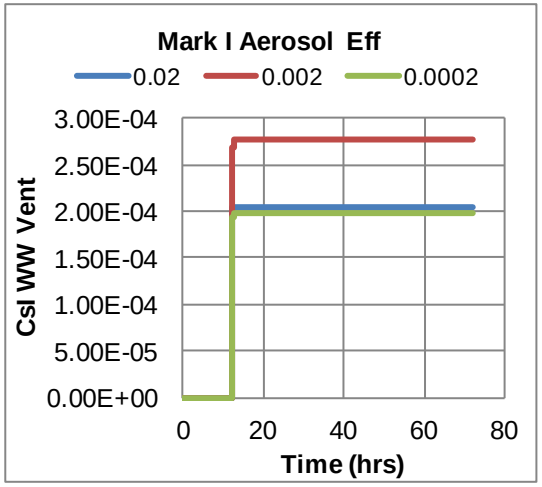


Figure 19 $\in'$(total), the compound model, and $\in$(total), the additive model, as functions of aerosol particle size and water drop size

Sensitivity Analysis – Aerosol Removal Efficiency







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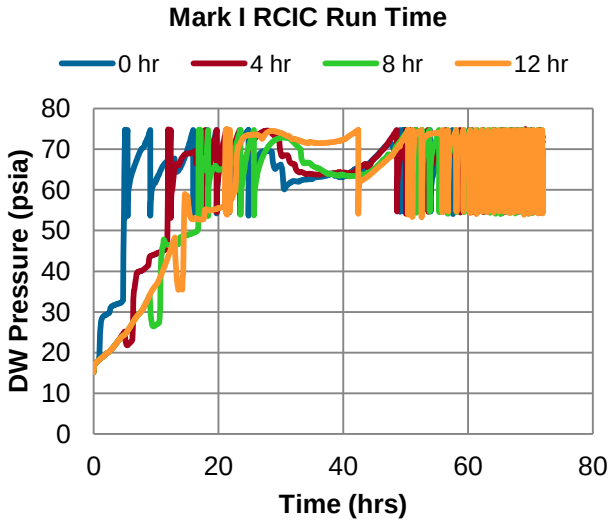
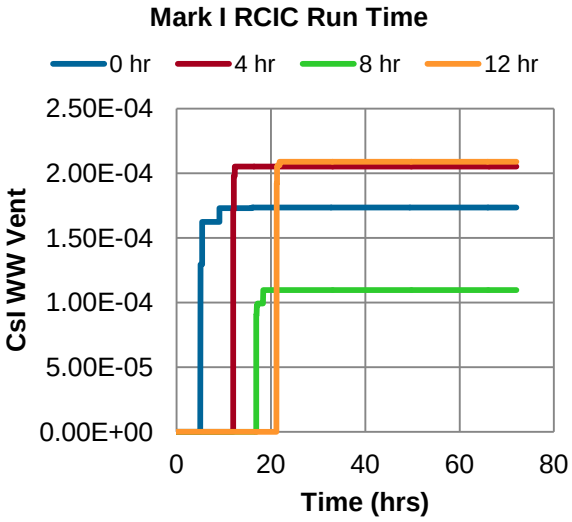
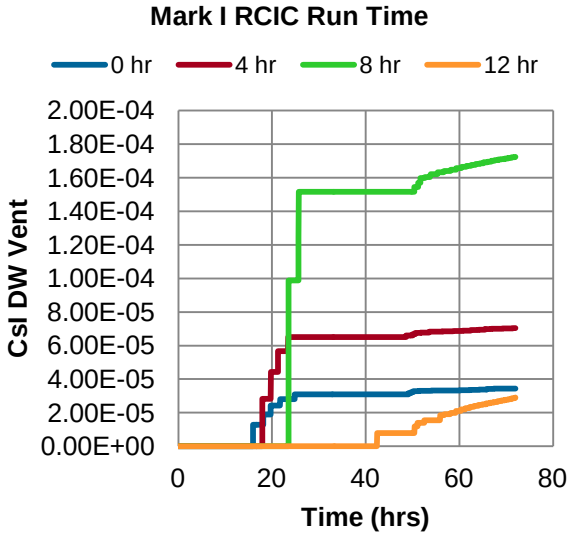
Sensitivity Analysis – RCIC Operating Time







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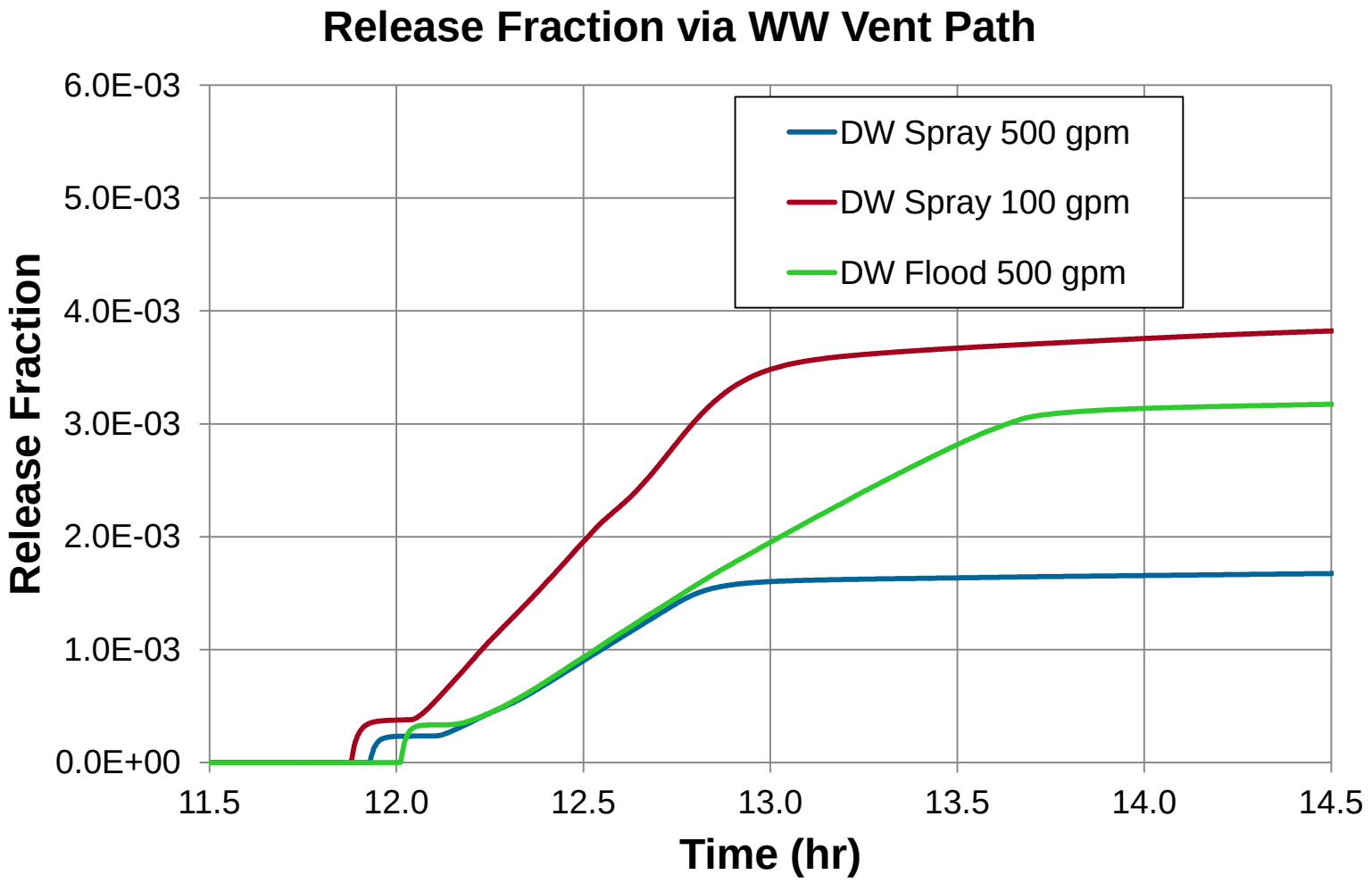
Sensitivity Analysis – Spray/Flood Flow Rate



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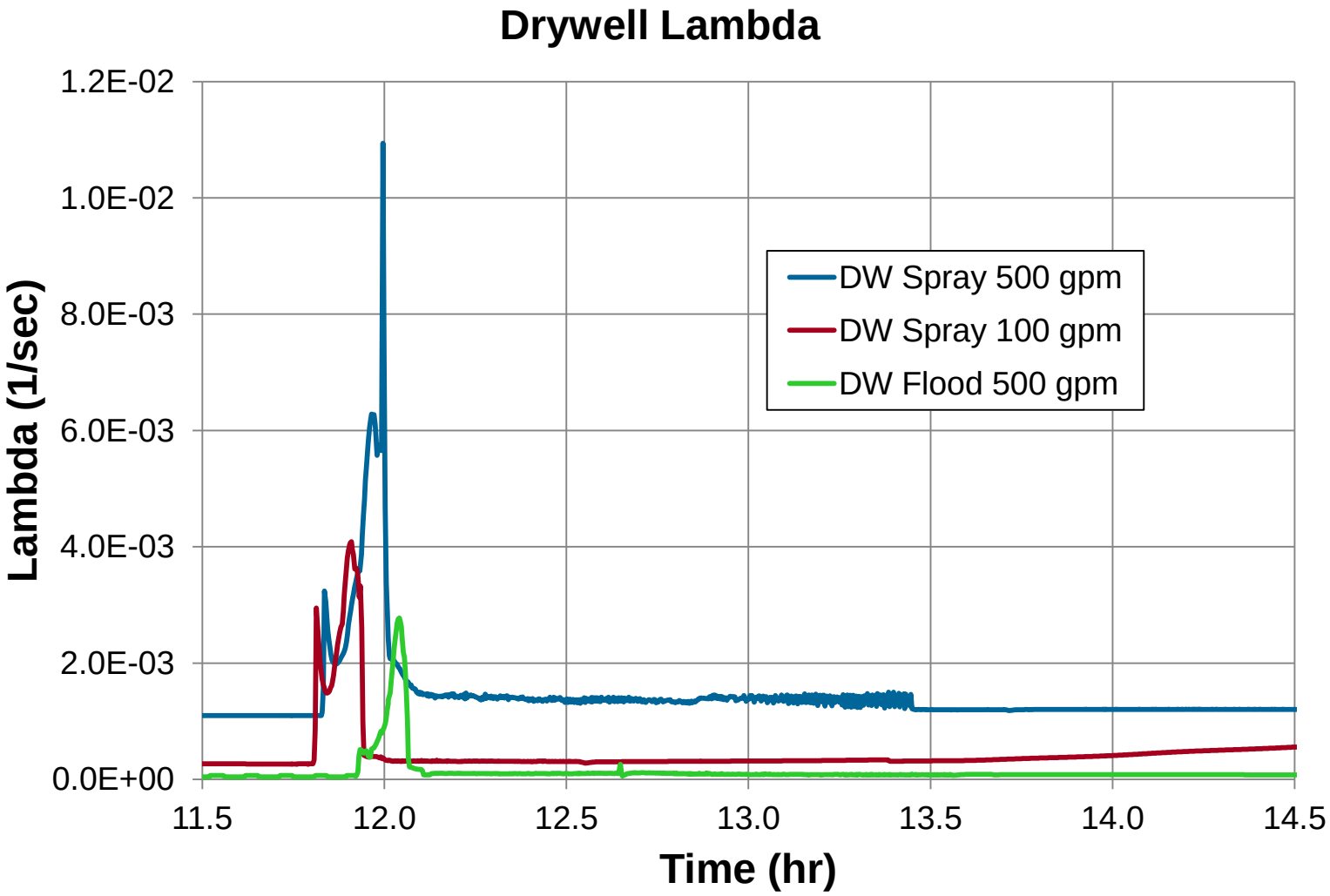
Sensitivity Analysis – Spray/Flood Flow Rate



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