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Protecting People and the Environment

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MELCOR ANALYSIS IN SUPPORT OF CPRR RULEMAKING

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OVERVIEW

- Background
  - In SECY-12-0157, staff recommended the requirement of severe accident capable hardened vents and external filters for BWRs with Mark I and II containments
  - Commission directed staff to prepare and issue Order EA-13-109 for severe accident capable vents and prepare a regulatory basis for rulemaking
- Technical Approach
  - Development of accident progression event trees and core damage states
  - MELCOR accident progression analysis for representative BWR Mark I and Mark II plants
    - o fission product release characteristics
    - o effectiveness of mitigation (RPV pressure control, containment venting, and core/containment water injection strategies including severe accident water addition [SAWA] and severe accident water management [SAWM]).
  - SOARCA Mark I model converted to MELCOR 2.1
  - MACCS2 offsite consequence analysis (land contamination and health effects)
  - Risk integration and regulatory analysis

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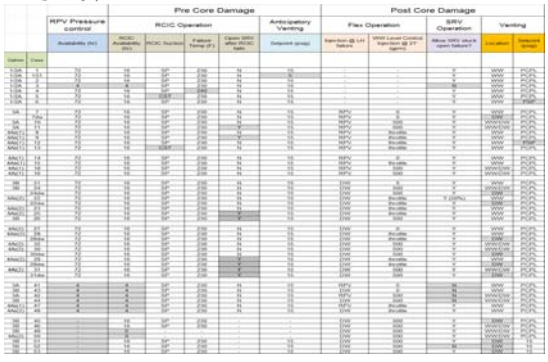
MELCOR Run Matrix for Mark I



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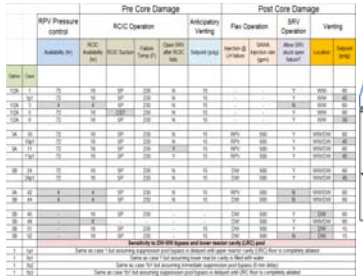
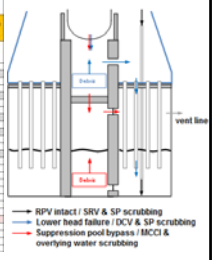
MELCOR Run Matrix for Mark II



		Pre Core Damage						Post Core Damage					
		RPV Pressure control	RCIC Operation				Anticipatory Venting	Flex Operation		SRV Operation	Venting		
			RCIC Availability (hr)	RCIC Availability (%)	RCIC Suction	Failure Temp (F)	Open SRV after RCIC fails	Setpoint (psig)	Injection @ LH failure	Unlimit injection rate (gpm)	Allow SRV stuck open failure?	Location	Setpoint (psig)
Option	Case												
TQN	1	72	16	SP	235	N	15	-	-	-	Y	WW	60
	1qv	72	16	SP	235	N	15	-	-	-	Y	WW	60
TQN	5	8	16	SP	235	N	15	-	-	-	N	WW	60
TQN	6	72	16	SP	235	N	15	-	-	-	Y	WW	60
TQN	9	72	16	SP	235	N	15	-	-	-	Y	WW	60
SA	10	72	16	SP	235	N	15	MPa	500	Y	WW/DW	60
	10qv	72	16	SP	235	N	15	MPa	500	Y	WW/DW	60
SA	11	72	16	SP	235	N	15	MPa	500	Y	WW/DW	60
	11qv	72	16	SP	235	N	15	MPa	500	Y	WW/DW	60
SB	24	72	16	SP	235	N	15	CM	500	Y	WW/DW	60
	24qv	72	16	SP	235	N	15	CM	500	Y	WW/DW	60
SA	42	8	16	SP	235	N	15	MPa	500	N	WW/DW	60
SB	44	8	16	SP	235	N	15	CM	500	N	WW/DW	60
SB	43	-	16	SP	235	-	-	CM	500	Y	DW	60
SB	48	-	8	-	-	-	-	CM	500	Y	WW/DW	60
SB	72	-	16	SP	235	-	15	CM	500	Y	DW	60
SB	72	-	16	SP	235	-	15	CM	500	N	DW	60
Sensitivity to DW-RPV bypass and lower reactor cavity (LRC) pool													
1	1qv	Same as case 1 but assuming suppression pool bypass is delayed until upper reactor cavity (LRC) floor is completely ablated											
1	1qv	Same as case 1 but assuming lower mix for cavity is filled with water											
1	1qv	Same as case 1qv but assuming immediate suppression pool bypass (0 min delay)											
1	1qv	Same as case 1qv but assuming suppression pool bypass is delayed until LRC floor is completely ablated											



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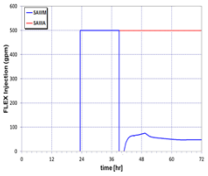
MELCOR Results for Mark I

(Timing of key events for selected scenarios)

Event Timing (hr)	Case 1 (no water)	Case 9 (SAWM)	Case 10 (SAWA)
Start of ELAP	0.0	0.0	0.0
Operators first open SRV to control pressure	0.17	0.17	0.17
Low-level 2 and RCIC actuation signal	0.18	0.18	0.18
Operators open SRV to control pressure (200-400 psig)	1.0	1.0	1.0
RCIC flow terminates	9.6	9.6	9.6
SRV sticks open or operators open SRV after RCIC fails	16.0	9.6	16.0
Water level reaches TAF	12.4	11.9	11.9
First hydrogen production	13.7	13.2	13.7
First fuel cladding gap release	13.7	13.2	13.7
Start of containment venting at 60 psig	14.9	14.4	16.3
Relocation of core debris to lower plenum	15.6	15.5	15.5
RPV lower head dries out	18.1	18.2	18.9
RPV lower head fails	23.0	23.4	23.1
Drywell head flange leakage	27.1	-	-
Hydrogen burn in reactor building refueling bay	28.8	-	-
Drywell liner melt-through	31.4	-	-
Calculation terminated	72	72	72
Selected MELCOR Results	**Case 1**	**Case 9**	**Case 10**
Debris mass ejected (kg)	292,000	280,000	287,000
In-vessel hydrogen generated (kg)	1,195	1,032	1,232
Iodine release fraction at 72 hr	2.28E-01	7.86E-02	8.10E-02
Cesium release fraction at 72 hr	1.94E-02	6.12E-03	7.26E-03



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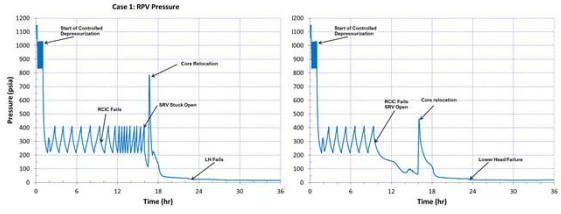
MELCOR Results for Mark I

(RPV pressure response)

Case 1: No injection

Case 9: SAWM



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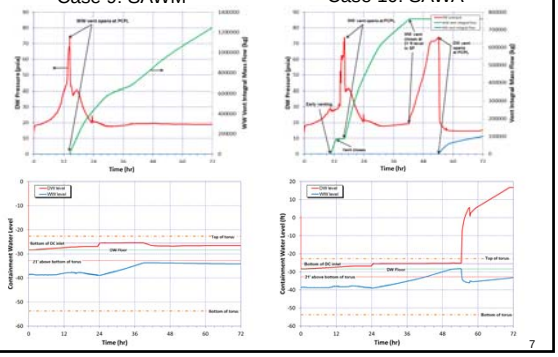
MELCOR Results for Mark I

(containment pressure & water level)

Case 9: SAWM

Case 10: SAWA



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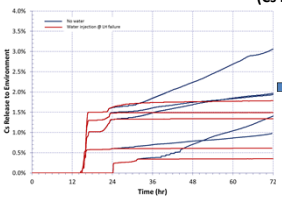
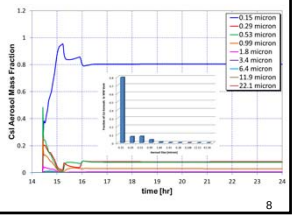
MELCOR Results for Mark I

(Cs release fraction to environment)



Water addition at lower head failure has the benefit of mitigating further release, but does not affect the release at the time of venting

Particle size distribution dominated by very small aerosols at the time of venting



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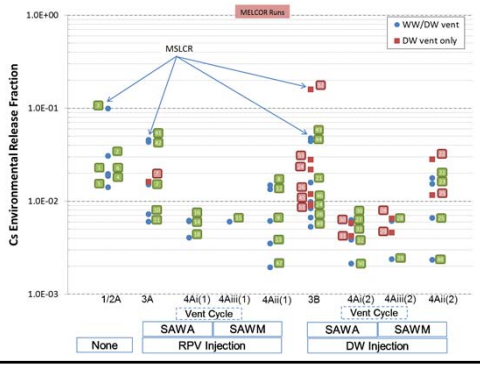
MELCOR Results for Mark I

(Cs release fraction to environment)



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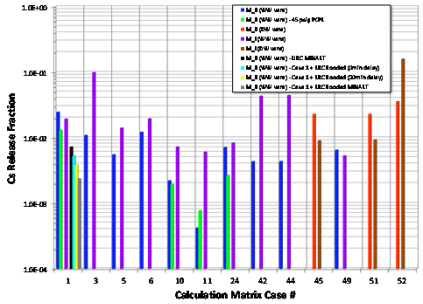
MELCOR Results for Mark II

(Cs release fraction to environment)



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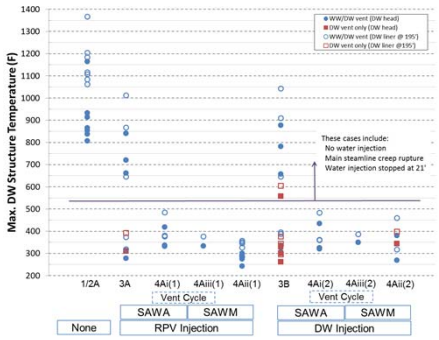
MELCOR Results for Mark I

(containment structure temperature)



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Conclusions

- A combination of venting and water addition is required to prevent containment failure and is a beneficial strategy for mitigating radiological releases. Containment venting generally results in a puff release to the environment which can occur shortly after core damage and before water addition.
- Anticipatory venting (before core damage) is beneficial to reduce the containment pressure and delay the radionuclide release to the environment.
- Containment venting is efficient in purging hydrogen and non-condensables. Water injection is also helpful in maintaining a steam-inerted atmosphere which can preclude an energetic hydrogen combustion.
- The highest calculated releases to the environment result from a main steam line creep rupture scenario, which is one of the least likely variations.
- The releases to the environment for the Mark II analysis are generally comparable to or lower than those in the Mark I analysis.
- For the Mark II analysis, scoping analyses were performed to investigate different lower cavity configurations. The environmental releases are within the range of source terms predicted based on the variations in the scenario boundary conditions.

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Acronyms

- BWR — Boiling water reactor
- DCV — Downcomer vent
- DW — Drywell
- MCCI — Molten core concrete interaction
- MSLCR — Main steam line creep rupture
- PCPL — Primary containment pressure limit
- PSP — Pressure suppression pressure
- RCIC — Reactor core isolation cooling
- RPV — Reactor pressure vessel
- SAWA — Severe accident water addition
- SAWM — Severe accident water management
- SOARCA — State-of-the-art reactor consequence analysis
- SP — Suppression pool
- SRV — Safety/Relief valve
- WW — Wetwell

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