Risk and Operational Insights of St. Lucie Flooding Event

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Topics Covered

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- Description of the event, especially how rainwater infiltrated the Reactor Auxiliary Building (RAB)
- Performance Deficiency and associated violation assessed by the NRC
- Detailed risk evaluation performed
  - Plant operating states evaluated
  - Initiating Event frequencies used
  - Submergence of in-plant components
  - Remaining mitigation
- Operational Insights

January 9, 2014 Event

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- Extreme localized rainfall at the St. Lucie site
  - 5"+ (2 hours), 6.5"+ (4 hours), 7.3" (24 hours)
- Blocked pipes in storm drain basin caused backup into Component Cooling Water (CCW) open pit
- Flood waters entered non safety-related electrical conduits in a pipe tunnel
- Missing flood seals in conduits allowed water to enter Reactor Auxiliary Building (RAB)
- Total of 50,000 gallons (190,000 liters) entered RAB
- Both units remained at 100% power and no safety-related equipment was affected during the event

Root Cause – Storm Drain

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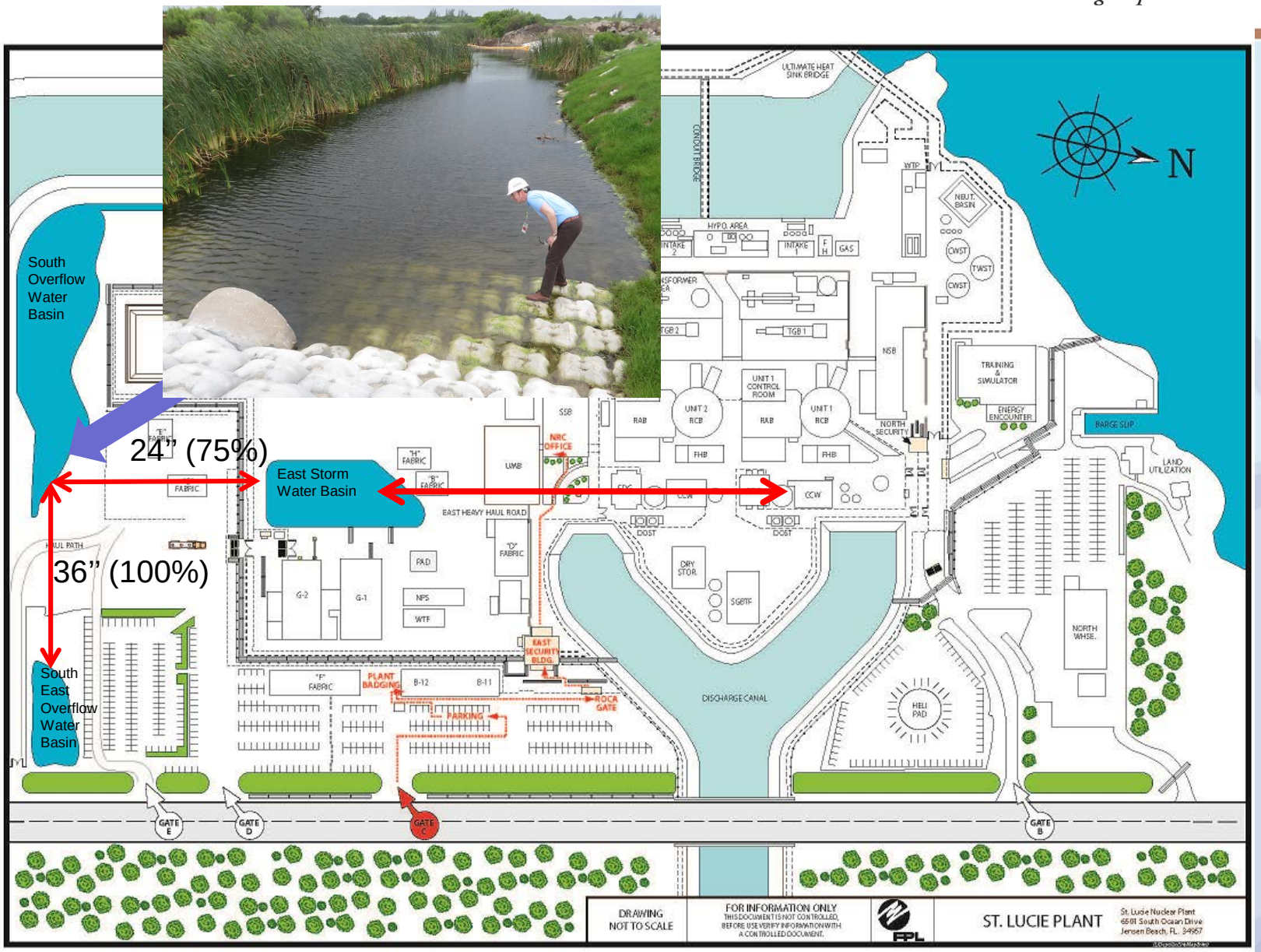

Root Cause – Storm Drain

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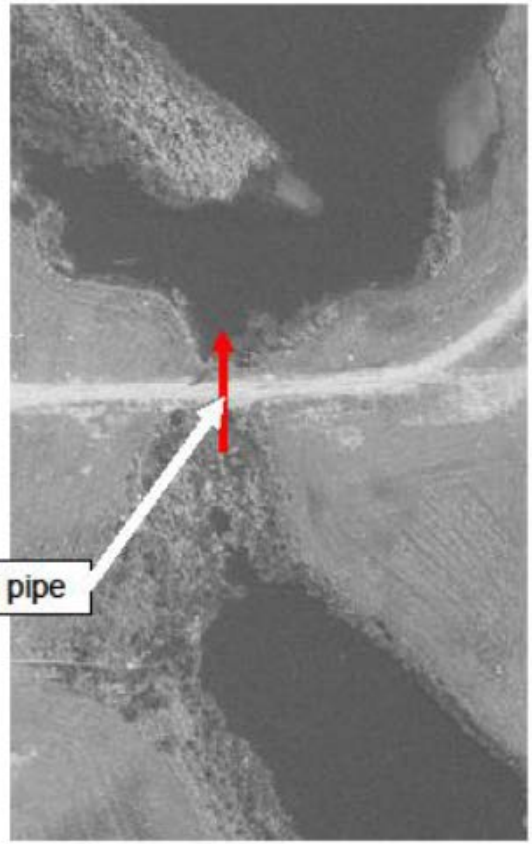
Cause of Site Drainage System Blockage
Vegetation Growth

Location Plan

Large increase in vegetation growth between 2005 and 2013 at the 36" pipe that flows into "Lake Bouska". Major contributor to blockage of drainage system.

July 2013



March 2005

Root Cause – CCW Pit

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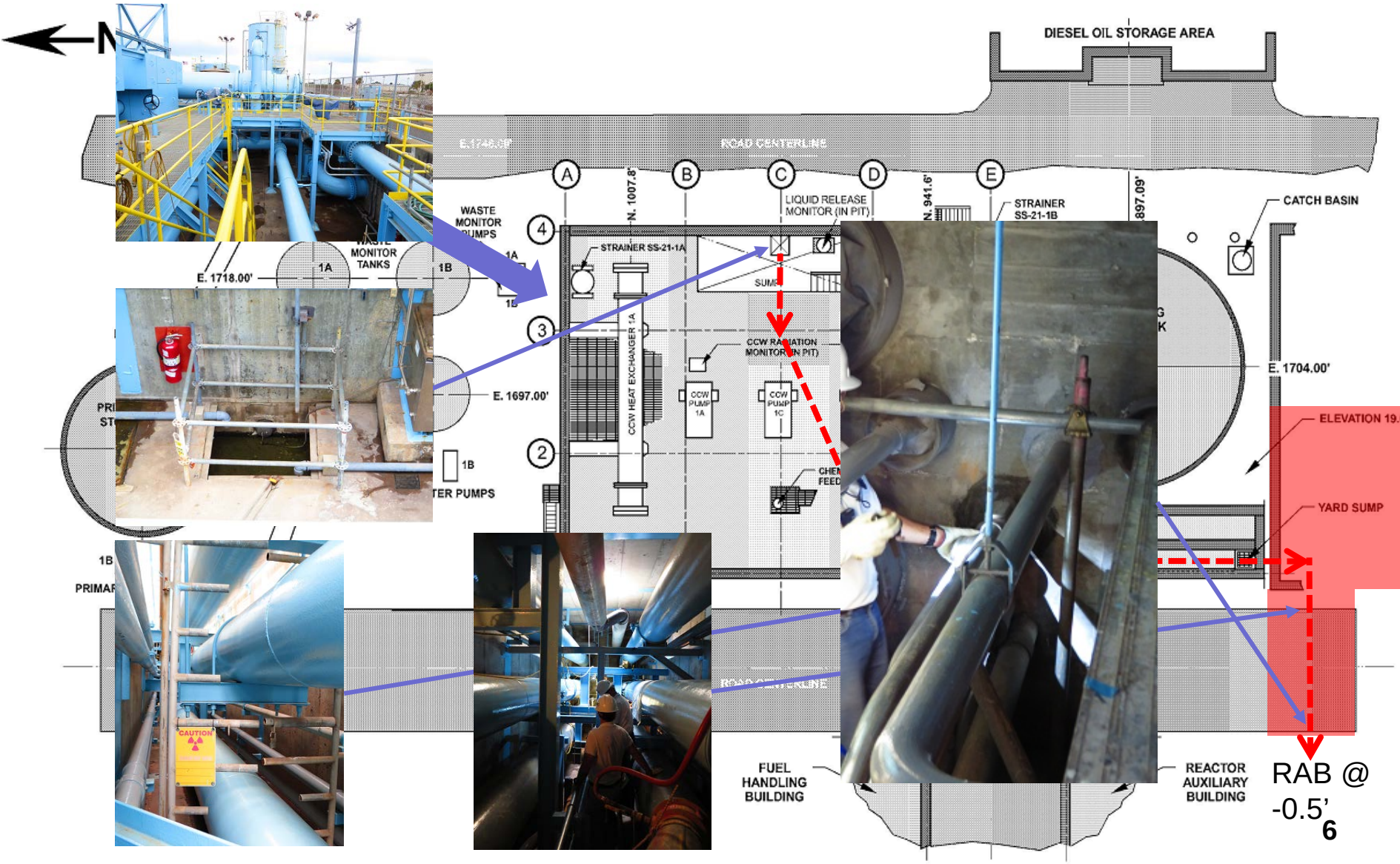

Root Cause – RAB U1

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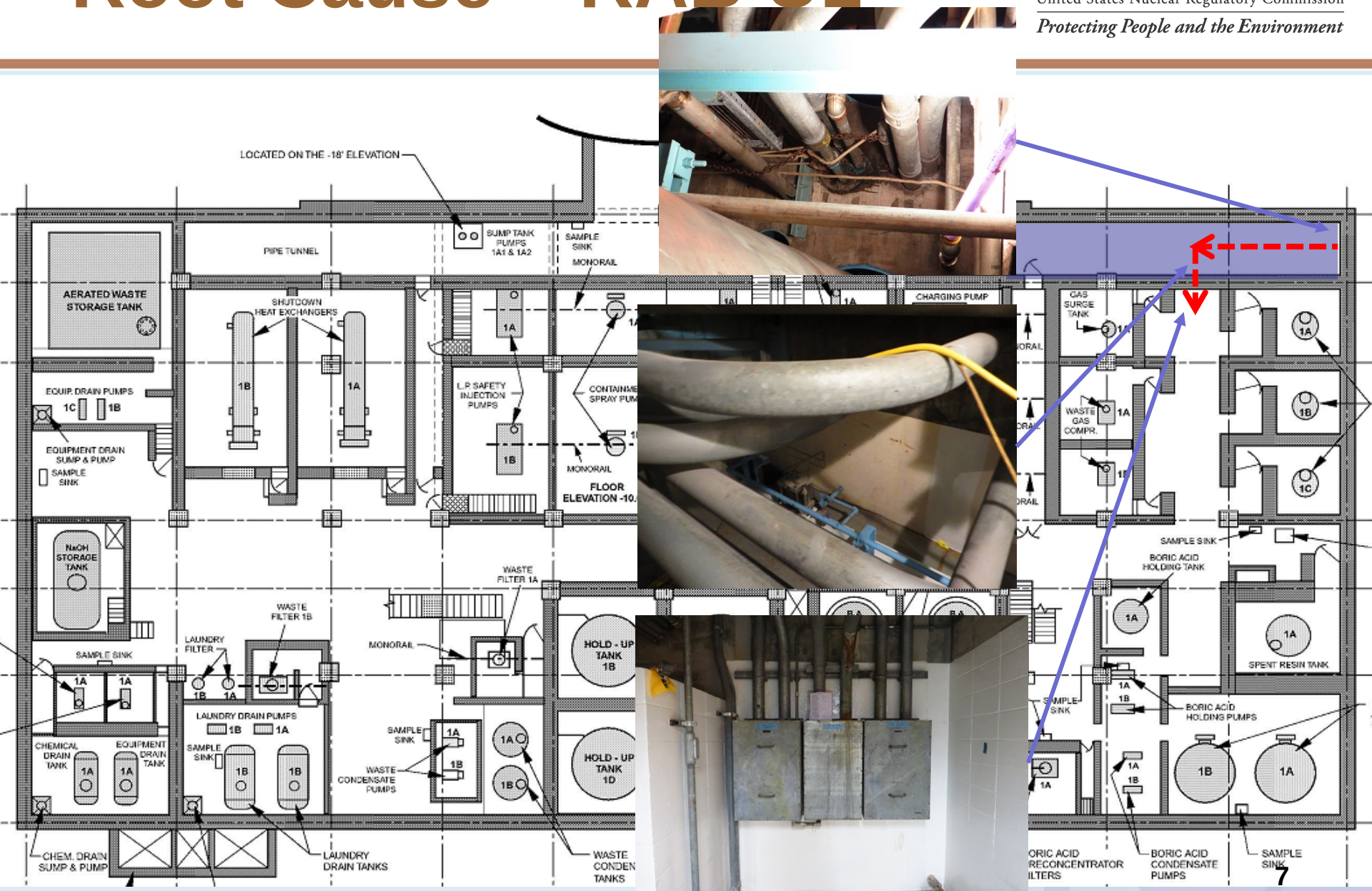

RAB (-0.5’) on Jan 9, 2014

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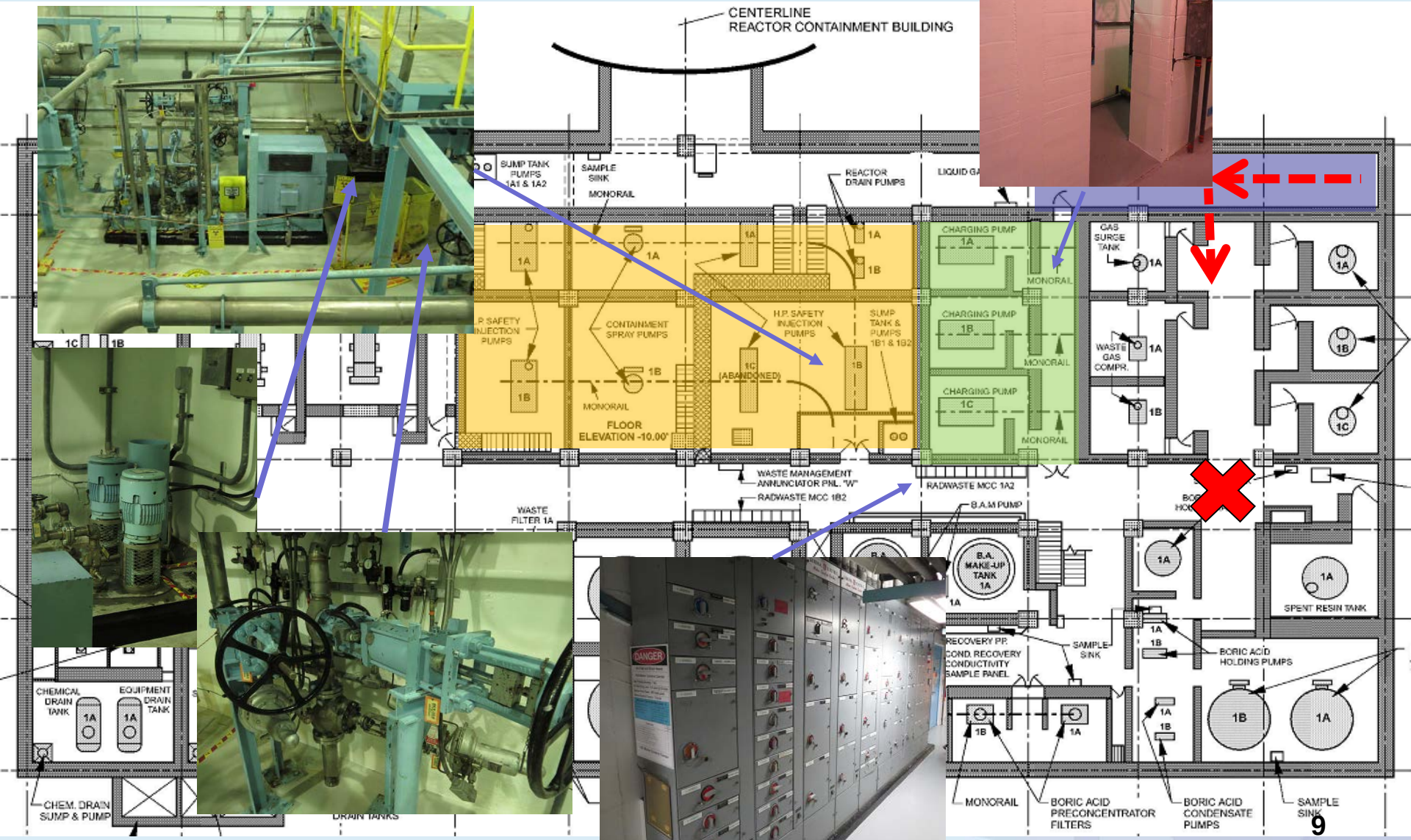
Root Cause – RAB U1



Hydraulic Paths – RAB U1

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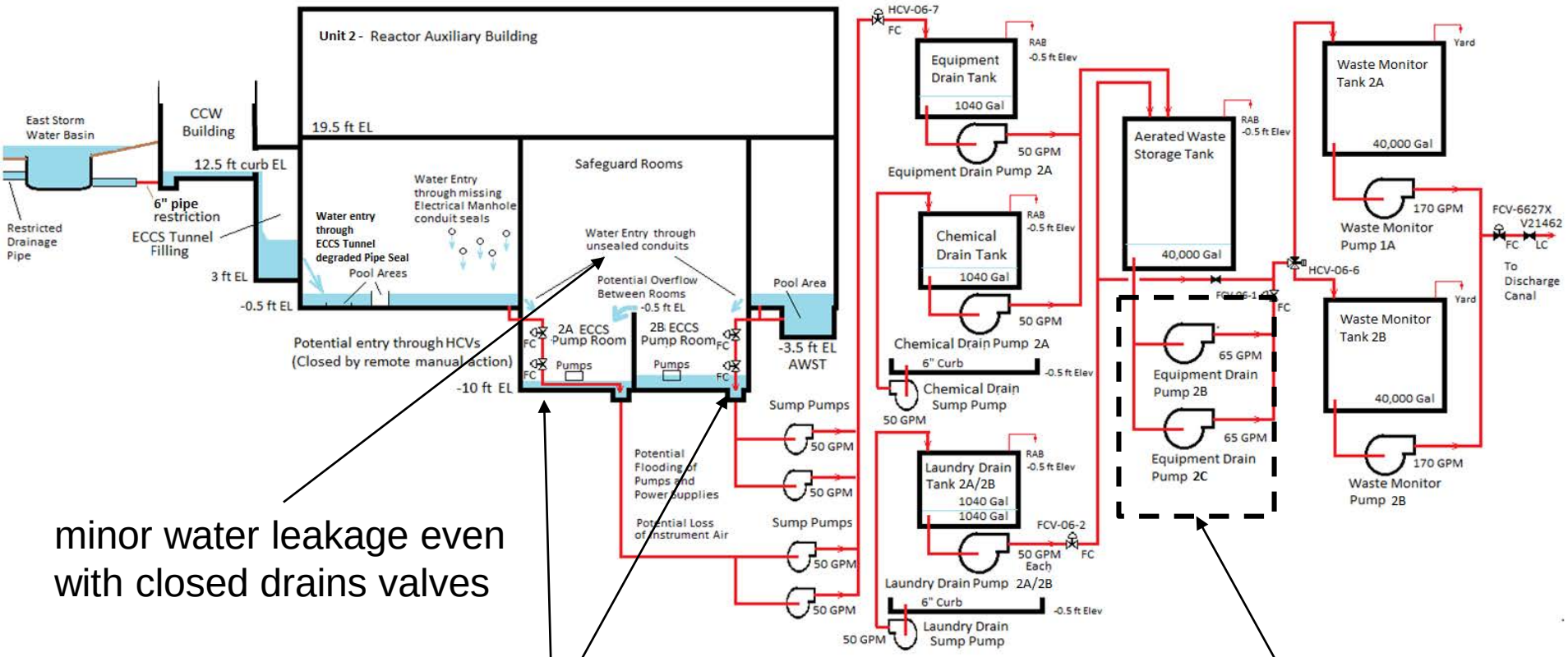

minor water leakage even with closed drains valves

HCVs 4x drain lines (parallel) into ECCS room sumps (2x in series)

1B/1C Drain Tank Pumps impacted early during flood

Performance Deficiency

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- Licensing bases states RAB protected against flooding at +19.5’ above mean low water (MLW), PMP = 47.1”
- Units 1 & 2 Near Term Task Force flooding walkdowns stated RAB is protected against external flood
  - RAB U1 had significant flood via degraded conduits
  - RAB U2 had minor leakage at piping boots
- Failure to ensure that all below grade conduits that enter U1 and U2 RABs were sealed to prevent water ingress
- Self-revealing violation of Title 10 Code of Federal Regulations Part 50, App. B, Criterion III, “Design Control”
- Degraded flood protection existed since original plant construction (i.e., SDP full exposure time of 1 year)

Risk Analysis – operating states

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- Initiating Events considered
  - At-power, localized rain event
  - At-power (initially), hurricane coastal surge (Cat 1-3)
  - At-power (initially), hurricane coastal surge (Cat 4-5)
  - Refueling Outage, localized rain event
  - Refueling Outage, hurricane-induced coastal surge
  - Pipe rupture in ECCS Tunnel (internal flooding)

- Event/Scenarios considered
  - Drain valves Open/Closed, TRANS
  - Drain valves Open/Closed, LOOP

Precipitation Data

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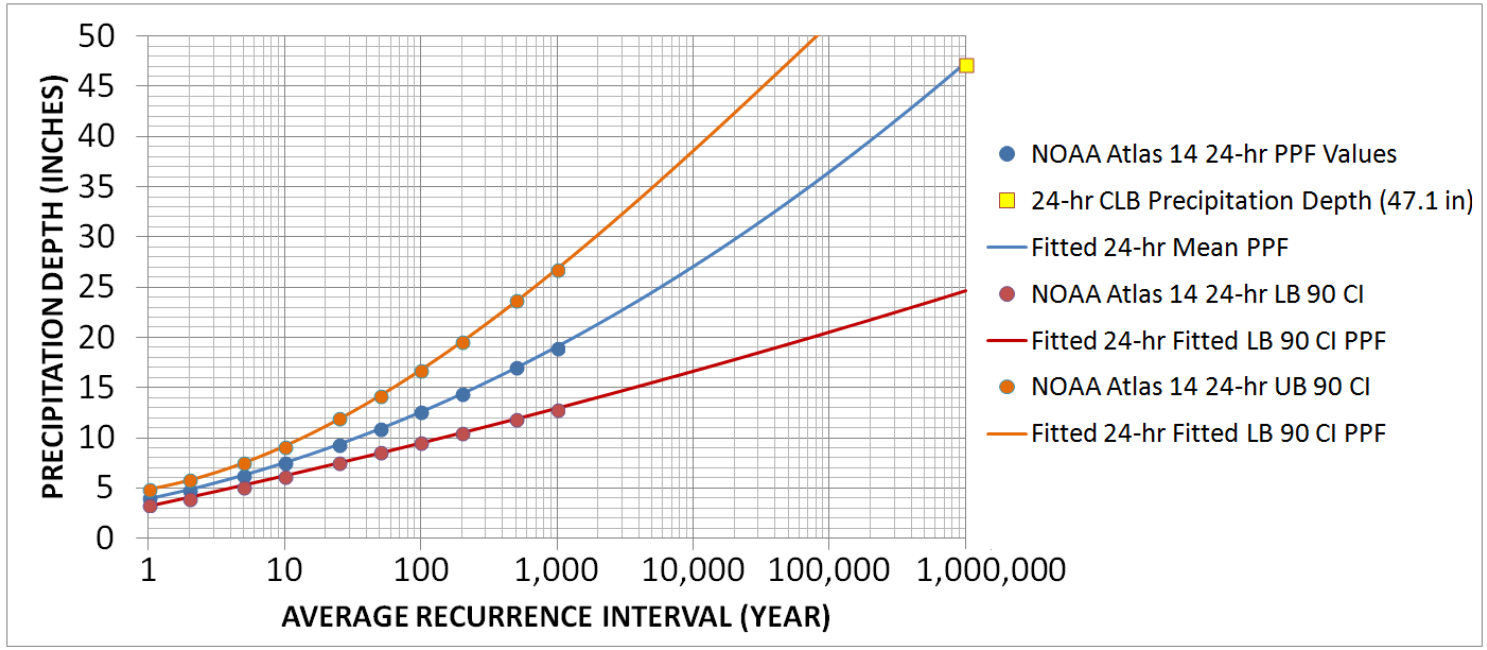
- Precipitation frequency from NOAA Atlas 14 @ St. Lucie based on a 24-hour duration storm

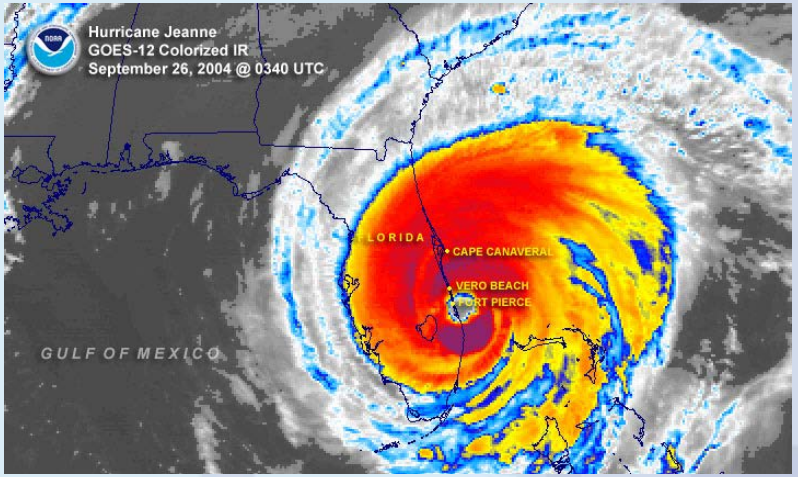
Precipitation frequency estimates (in inches) at St. Lucie

Duration	Average recurrence interval(years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.557	0.634	0.763	0.873	1.03	1.15	1.28	1.41	1.59	1.73
10-min	0.815	0.928	1.12	1.28	1.51	1.69	1.88	2.07	2.33	2.54
15-min	0.994	1.13	1.36	1.56	1.84	2.06	2.29	2.53	2.85	3.1
30-min	1.51	1.72	2.08	2.38	2.81	3.15	3.49	3.85	4.34	4.72
60-min	2.01	2.29	2.76	3.15	3.69	4.12	4.55	4.99	5.57	6.02
2-hr	2.5	2.86	3.44	3.92	4.58	5.09	5.6	6.12	6.8	7.31
3-hr	2.76	3.17	3.82	4.36	5.11	5.68	6.25	6.83	7.59	8.17
6-hr	3.18	3.68	4.51	5.22	6.23	7.03	7.85	8.7	9.85	10.7
12-hr	3.57	4.19	5.29	6.27	7.72	8.92	10.2	11.5	13.4	15
24-hr	4.01	4.81	6.21	7.48	9.37	10.9	12.6	14.4	17	19
2-day	4.67	5.63	7.28	8.74	10.9	12.6	14.4	16.4	19.1	21.2
3-day	5.25	6.22	7.9	9.37	11.5	13.3	15.1	17.1	19.8	21.9

Frequency – Rain/Hurricane



- Based on available historical hurricane data from NOAA
  - All Categories ~ 0.125/yr
  - Above Cat 3 ~ 0.053/yr



Frequency – Int. Flooding

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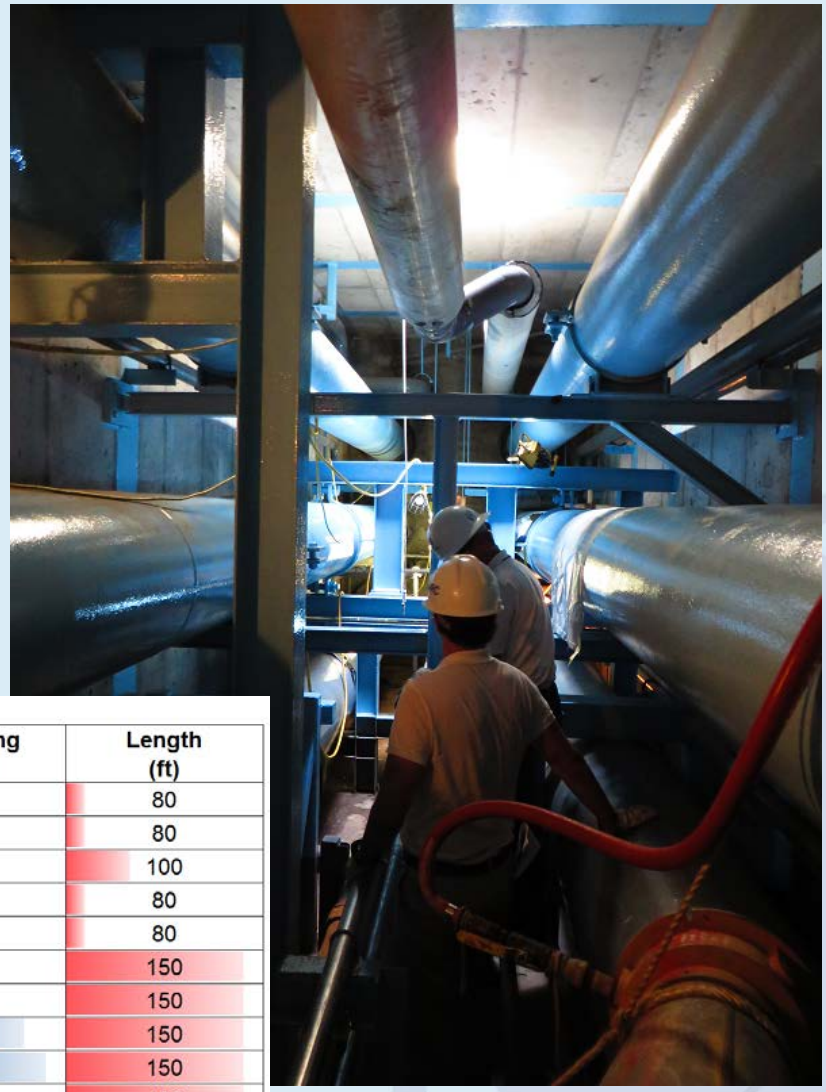
- Licensee provided list of piping in ECCS Pipe Tunnel Area
- Available pipe rupture frequencies in the range of 6E-6/year to less than 1E-6/year
- Additional mitigation expected to be at least 0.1
- Not a significant ΔCDF contributor



List of Piping in ECCS Pipe Tunnel Area

Piping	Line	Water Source	Operating (psi)	Length (ft)
A Train Containment Spray	I-24"-CS-3	RWT (500 Kgal)[1]	45	80
B Train Containment Spray	I-24"-CS-2	RWT (500 Kgal)[1]	45	80
Safeguard Pumps Return	6"-CS-500	RWT (0 Kgal)[2]	60	100
Charging System Return	3"-CH-938	RWT (360 Kgal)[2]	60	80
Fuel Pool Return	3"-FS-555	RWT, SFP (9 Kgal)[2]	60	80
Primary Water Supply	4"-PMW-6	PWT (150 Kgal)[1]	60	150
Primary Water Supply	3"-PMW-16	PWT (150 Kgal)[1]	95	150
Waste Management Discharge	3"-WM-48	WMT (0 Kgal)[2]	130	150
Demineralized Water Supply	3"-DWS-11	DWST (10 Kgal)[1]	150	150
SG Blowdown	8"-B-5	Discharge Canal (0 Kgal)[2]	5	150

1. Nominal Tank Volume 2. Volume reflects line elevation/configuration/isolation

Affected Components- Rain

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- Based on licensee's site hydraulic model coupled with a plant flooding model (precipitation→ elevation→ SSCs)

Correlation of Precipitation and Impacted SSCs (HCVs Open)					
BIN	**IMPACTED SSCs**	**PrecipRange (in) (Non- LOOP)**	**PrecipFreq (/yr) (Non- LOOP)**	**PrecipRange (in) (LOOP)**	**PrecipFreq (/yr) (LOOP)**
1	B HPSI	9.36 - 9.55	3.40E-03	9.55 - 9.75	3.24E-03
2	B HPSI/LPSI	9.55 - 11.16	1.87E-02	9.75 - 10.73	1.19E-02
3	A/B HPSI + B LPSI			10.73 - 10.93	1.79E-03
4	A/B HPSI/LPSI	11.16 - 11.72	3.76E-03	10.93 - 11.72	5.62E-03
5	A/B HPSI/LPSI + BAM	11.72 - 11.99	1.49E-03	11.72 - 12.02	1.65E-03
6	A/B HPSI/LPSI + BAM + CHG	11.99 - 12.92	3.95E-03	12.02 - 14.68	8.05E-03
7	A/B HPSI/LPSI + BAM + CHG + SDC Valves	>=12.92	8.75E-03	>=14.68	4.49E-03

Correlation of Precipitation and Impacted SSCs (HCVs Closed)					
BIN	**IMPACTED SSCs**	**PrecipRange (in) (Non-LOOP)**	**PrecipFreq (/yr) (Non-LOOP)**	**PrecipRange (in) (LOOP)**	**PrecipFreq (/yr) (LOOP)**
1	BAM	11.44 - 11.72	1.76E-03	11.47 - 11.56	5.82E-04
2	BAM + B HPSI			11.56 - 11.66	6.19E-04
3	BAM + B HPSI + CHG	11.72 - 11.75	1.75E-04		
4	BAM + B HPSI/LPSI			11.66 - 11.75	5.32E-04
5	BAM + B HPSI/LPSI + CHG	11.75 - 13.32	6.53E-03	11.75 - 13.32	6.53E-03
6	BAM + B HPSI/LPSI + CHG + SDC Valves	>=13.32	7.48E-03	>=13.32	7.48E-03
7	BAM + CHG + B HPSI/LPSI + SDC + A HPSI	'A' train HPSI/LPSI pumps not affected during 24-hour mission time with valves closed.			
8	BAM + CHG + B HPSI/LPSI + SDC + A HPSI/LPSI				

Risk Assessment

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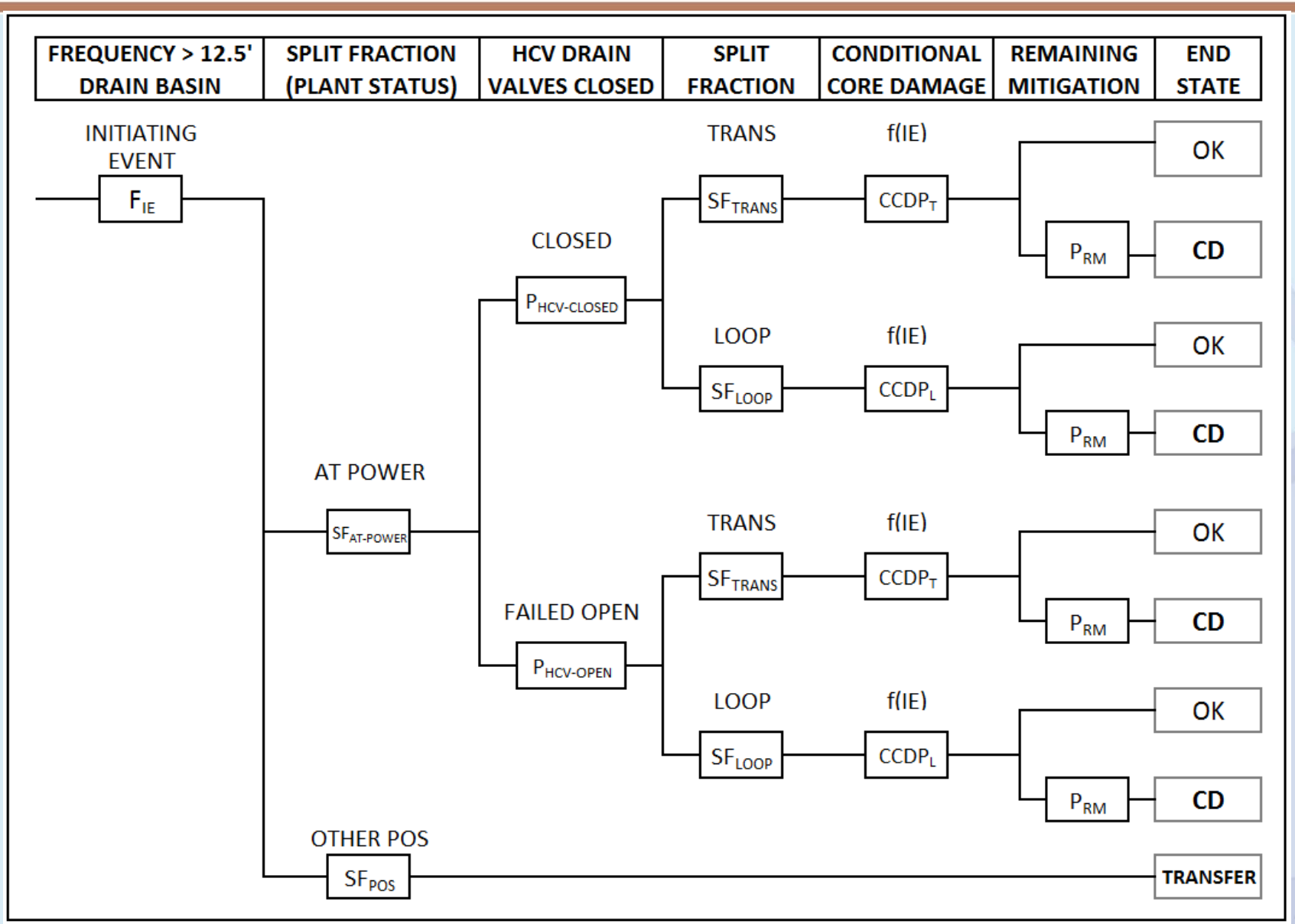

Risk Analysis Approach

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- Split fraction for plant operational states from available data
- Failure to close drain valves treated in NRC, licensee analyses
  - Includes HEP screening value of 1E-2 in licensee analysis
  - Similar value obtained using generic data, estimating CCF
  - Success/failure due to cycling of valves not considered
- Split fraction of LOOP/non-LOOP obtained from available data
  - Mostly insensitive to various splits (e.g., 99/1, 95/5, 90/10)
  - LOOP assumed for Category 4 and 5 hurricanes
- Calculated CCDP values for TRANS/LOOP depend on SSCs
  - Results from SPAR model in the range of E-4/year to E-6/year
  - Licensee values lower (e.g., additional CST refill credit)
- Credit for additional mitigation in NRC analysis
  - Significant change from full credit (low white) to no credit for specific sequences (yellow/red threshold)

Risk Insights

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- CDF was the dominant “item of merit”; risk was initially above 1E-5/year, but lowered due to qualitative/quantitative factors
- Exposure time was “capped” at 1 year per our process, however the perform. deficiency had elevated risk for > 1yr. historically
- Initiating event frequency was quite high for an external flooding (and particularly a FLEX-related) finding/violation, e.g., E-2/year
- Simplistic modeling of drain valves either open or shut, but not intermediate/indeterminate states
- Assumption of core damage when “safe and stable” not achieved at 24 hours was a driver (Aux Feedwater for decay heat removal important)

Operational Insights

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- Maintenance of non-safety related structures, systems & components (in this case storm drains, removal of vegetation) can have risk significant impacts
- Operators may need to “go outside” of existing procedures/guidance in order to mitigate a flood (HCV valves)
- Location of Control Power Transformers in AC breakers can be very physically low … and if submerged Loss of DC may result
- During refueling outage flood barriers may be impaired
- Low leakage reactor coolant pump seals important for station blackout (Extended Loss of AC Power scenarios)

Questions/Comments

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Any comments or questions?

Backup Slides

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BACKUP SLIDES

Additional Info. Resources

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- NRC Inspection Report 05000335/389/2014-009, "Preliminary White Finding and Apparent Violations"
- Licensee Event Report 50-335/2014-001, "Internal RAB Flooding During Heavy Rain Due to Degraded Conduits Lacking Internal Flood Barriers"
- NUREG/CR-5820 "Consequences of the Loss of the Residual Heat Removal Systems in Pressurized Water Reactors"
- WCAP -17601-P, "Reactor Coolant System Response to the Extended Loss of AC Power Event for Westinghouse, Combustion Engineering and Babcock & Wilcox NSSS Designs"

Drainage Detail

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Penetration Details

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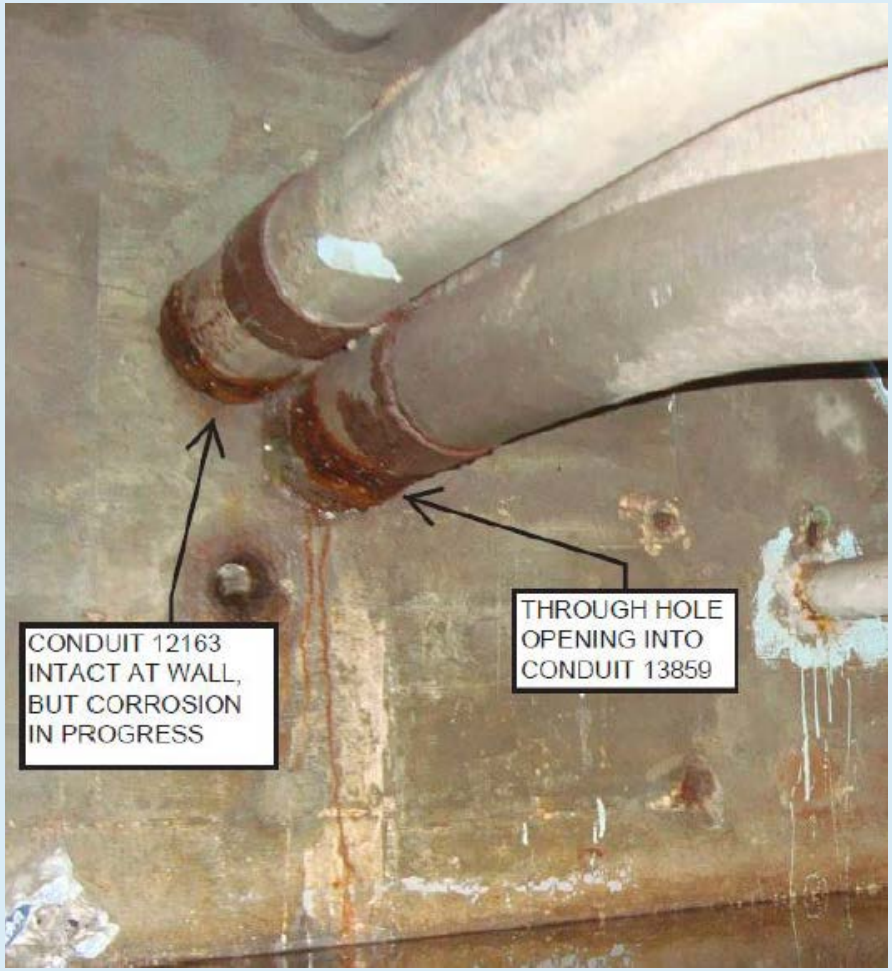

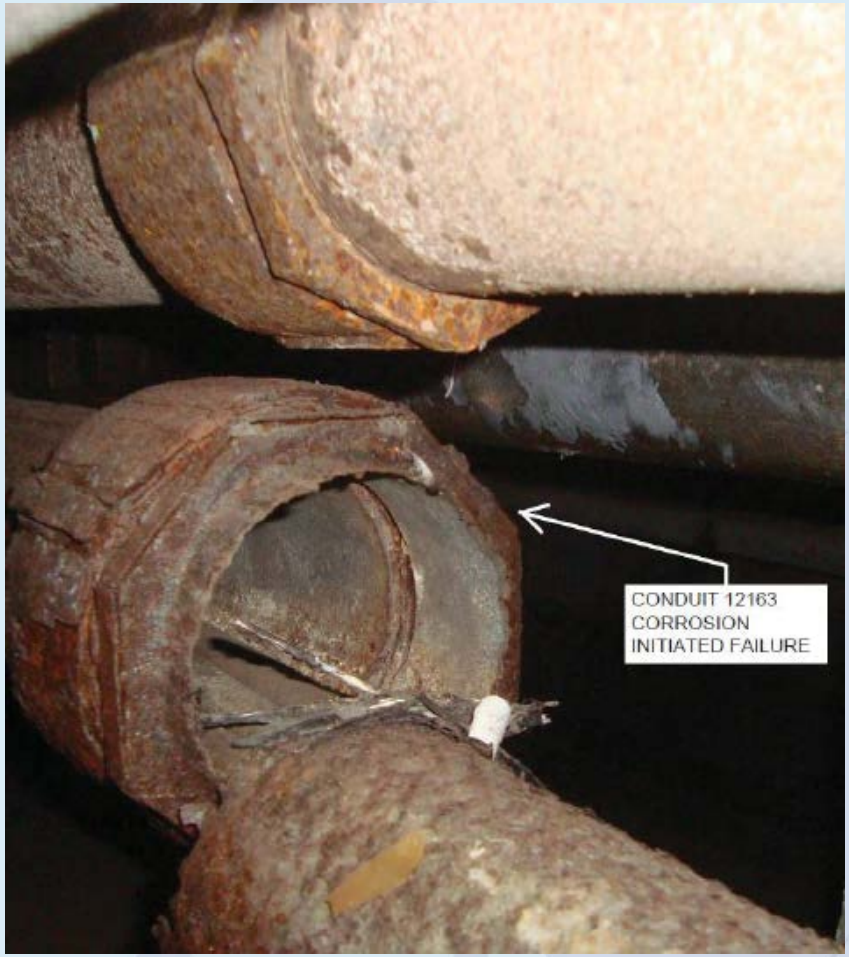

Fault Tree Modeling HCV

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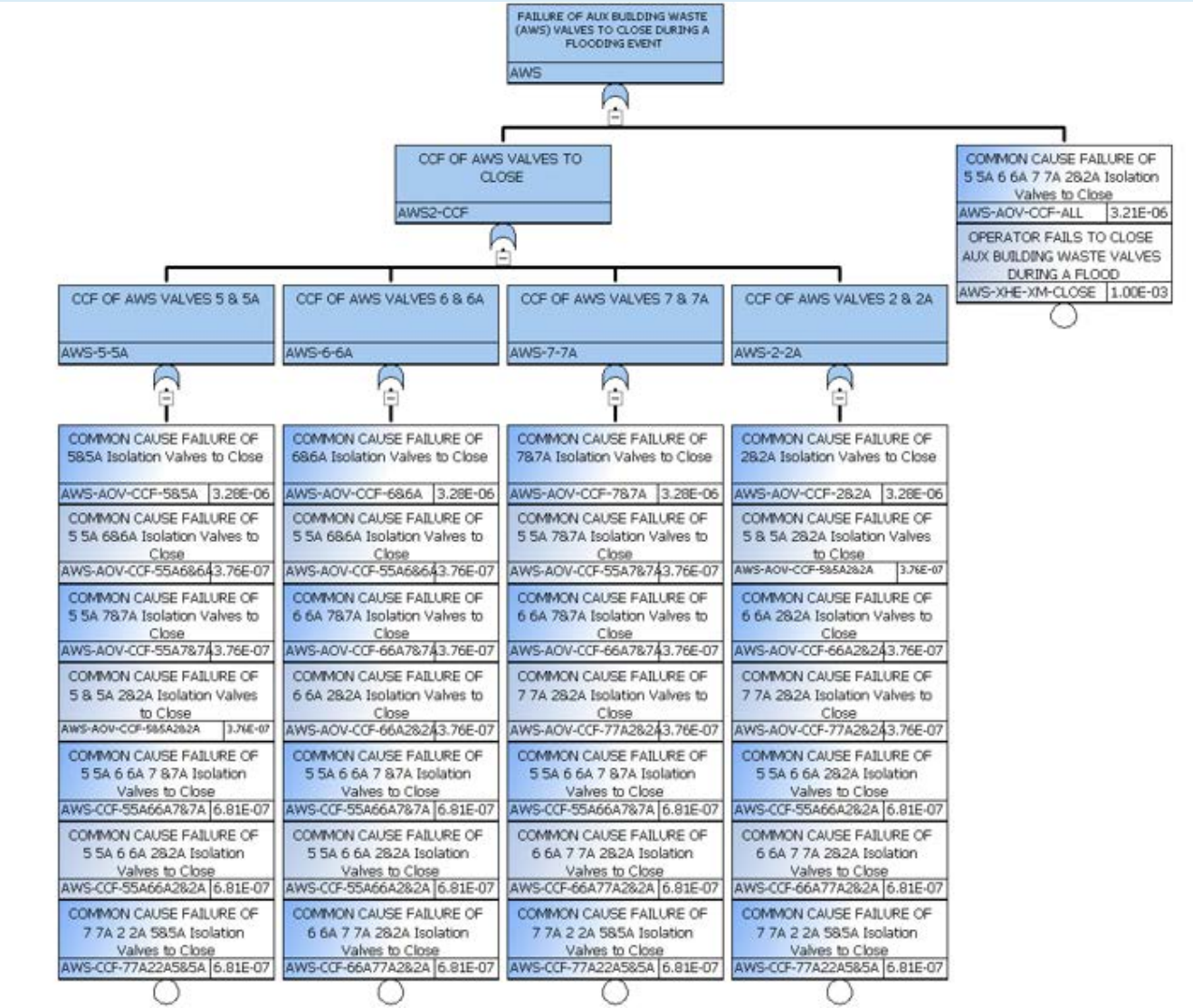

Rain, At-power (NRC)

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PLANT-CONDITION	STORM-SURGE	HCV-DRAIN-VLVS	TRANS-LOOP	SEVERITY	REMAINING-MITIG	End State	Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CD Assumed?
				9.71E-01 0		OK	1			
			9.40E-01							
			TRANS	1.43E-02 3.64E-06						
						CD	2	4.36E-08	Yes	
		9.90E-01								
		shut		1.43E-02 4.57E-06						
						CD	3	5.47E-08	Yes	
				9.65E-01 0		OK	4			
9.00E-01			6.00E-02							
operating @ 100% power			LOOP							
				1.57E-02 6.73E-06						
						CD	5	5.64E-09	Yes	
				1.43E-02 9.89E-06						
						CD	6	7.56E-09	Yes	
				9.65E-01 0		OK	7			
			9.40E-01							
			TRANS	1.70E-02 1.04E-06						
						CD	8	1.49E-10	Yes	
		1.00E-02								
		failed open		4.71E-03 1.40E-04						
						CD	9	5.58E-09	Yes	
				1.30E-02 1.41E-04						
						CD	10	1.55E-08	No	1.10E-04
				9.68E-01 0		OK	11			
				1.07E-02 7.46E-06						
			6.00E-02			CD	12	4.33E-11	Yes	
			LOOP	7.98E-03 2.12E-04						
						CD	13	9.15E-10	Yes	
				1.30E-02 2.15E-04						
						CD	14	1.50E-09	No	7.00E-06

Rain, Other POS (NRC)

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PLANT-CONDITION	STORM-SURGE	HCV-DRAIN-VLVS	TRANS-LOOP	SEVERITY	REMAINING-MITIG	End State	Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CD Assumed?
2.50E-02						OK	15			
POS-1				9.92E-01 0		OK	16			
		9.90E-01								
		shut	LORHR							
				8.22E-03 1.00E-02						
						CD	17	1.87214E-06	Yes	
2.30E-02				9.78E-01 0		OK	18			
POS-2										
				1.70E-02 1.00E-02						
		1.00E-02				CD	19	3.91E-08	Yes	
		failed open								
				4.71E-03 1						
						CD	20	1.08E-06	No	1.08E-06
5.20E-02						OK	21			
POS-3										

Hurricane, Mode 3 (NRC)

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UPT	PLANT-CONDITION	STORM-SURGE	HCV-DRAIN-VLVS	TRANS-LOOP	SEVERITY	REMAINING-MITIG	End State	Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CD Assumed?
		0.9					OK	22			
		less than 12.5'			3.30E-01 0		OK	23			
					3.30E-01 3.64E-06						
				5.00E-01			CD	24	2.68E-10	Yes	
				already shutdown	3.30E-01 4.57E-06						
			9.90E-01				CD	25	3.36E-10	Yes	
			shut		3.30E-01 0		OK	26			
				5.00E-01							
				LOOP	3.30E-01 6.73E-06						
							CD	27	4.94E-10	Yes	
	7.50E-01				3.30E-01 9.89E-06						
	Mode 3						CD	28	7.27E-10	Yes	
					2.50E-01 0						
		0.1					OK	29			
		greater than 12.5'			2.50E-01 1.04E-06						
				5.00E-01			CD	30	5.85E-13	Yes	
				already shutdown	2.50E-01 1.40E-04						
							CD	31	7.88E-11	Yes	
					2.50E-01 1.41E-04						
			1.00E-02				CD	32	7.93E-11	No	5.63E-07
			failed open		2.50E-01 0		OK	33			
					2.50E-01 7.46E-06						
				5.00E-01			CD	34	4.20E-12	Yes	
				LOOP	2.50E-01 2.12E-04						
							CD	35	1.19E-10	Yes	
					2.50E-01 2.15E-04						
							CD	36	1.21E-10	No	5.63E-07

Hurricane, Other POS (NRC)

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PLANT-CONDITION	STORM-SURGE	HCV-DRAIN-VLVS	TRANS-LOOP	SEVERITY	REMAINING-MITIG	End State	Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CD Assumed?
1.80E-01						OK	37			
POS-1	0.67					OK	38			
	less than 12.5'			0.5 0		OK	39			
2.30E-02		9.90E-01								
POS-2		shut	LORHR							
				5.00E-01 1.00E-02						
						CD	40	2.25E-07	Yes	
	0.33			2 TRAINS						
	greater than 12.5'			0.33		OK	41			
		1.00E-02	RISK WORTH OF 1 TRAIN OF RHR							
		failed open	LORHR	3.30E-01 1.00E-02						
						CD	42	1.50E-09	Yes	
				BOTH TRAINS						
				3.30E-01 1						
						CD	43	1.50E-07	No	1.50E-07
5.20E-02						OK	44			

ICCW Pipe Break (NRC)

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TYPE-OF-RUPT	PLANT-CONDITION	STORM-SURGE	HCV-DRAIN-VLVS	TRANS-LOOP	SEVERITY	REMAINING-MITIG	End State	Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CD Assumed?
					9.00E-01 0		OK	45			
			9.90E-01								
			shut		9.00E-02 3.64E-06						
							CD	46	8.46E-12	Yes	
					1.00E-02 4.57E-06						
	9.00E-01						CD	47	1.18E-12	Yes	
	operating										
					9.00E-01 0		OK	48			
					9.00E-02 1.04E-06						
			1.00E-02				CD	49	2.44E-14	Yes	
2.90E-05			failed open								
ICCW					1.00E-02 1.40E-04						
							CD	50	3.65E-13	Yes	
					1.00E-03 1.41E-04						
							CD	51	3.68E-14	No	2.61E-10
					9.00E-01 0		OK	52			
			9.90E-01								
			shut								
	1.00E-01				1.00E-01 1.00E-02						
	shutdown on RHR						CD	53	2.87E-09	Yes	
					9.00E-01 0		OK	54			
			1.00E-02								
			failed open		9.00E-02 1.00E-02						
							CD	55	2.61E-11	Yes	
					1.00E-02 1						
							CD	56	2.90E-10	No	2.90E-10
							OK	57			
CCW											
									3.51E-06		1.19E-04