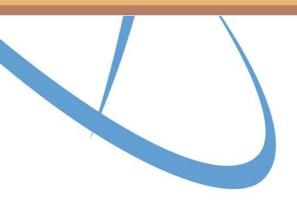
Risk and Operational Insights of St. Lucie Flooding Event



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PFHA Workshop Rockville, MD February 21, 2020



Topics Covered



- 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

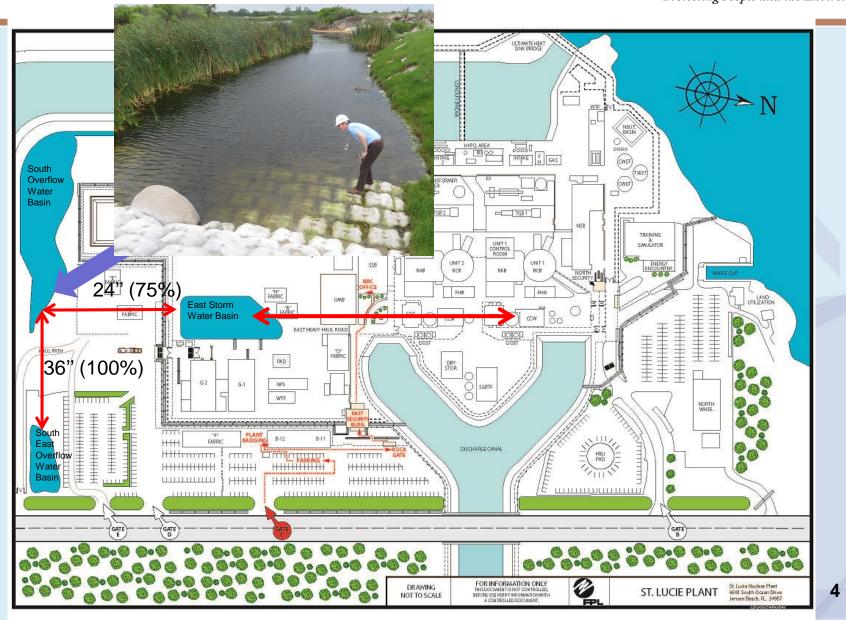
January 9, 2014 Event



- 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

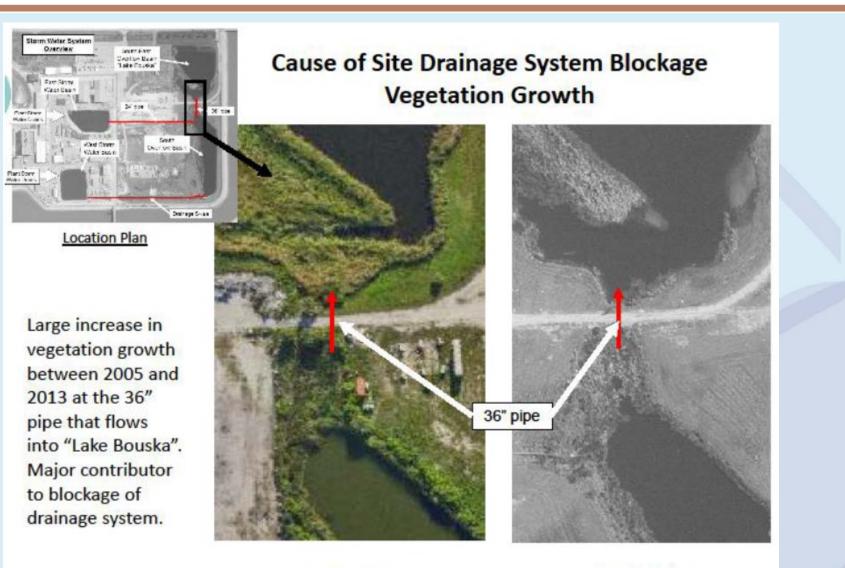
Root Cause – Storm Drain





Root Cause – Storm Drain



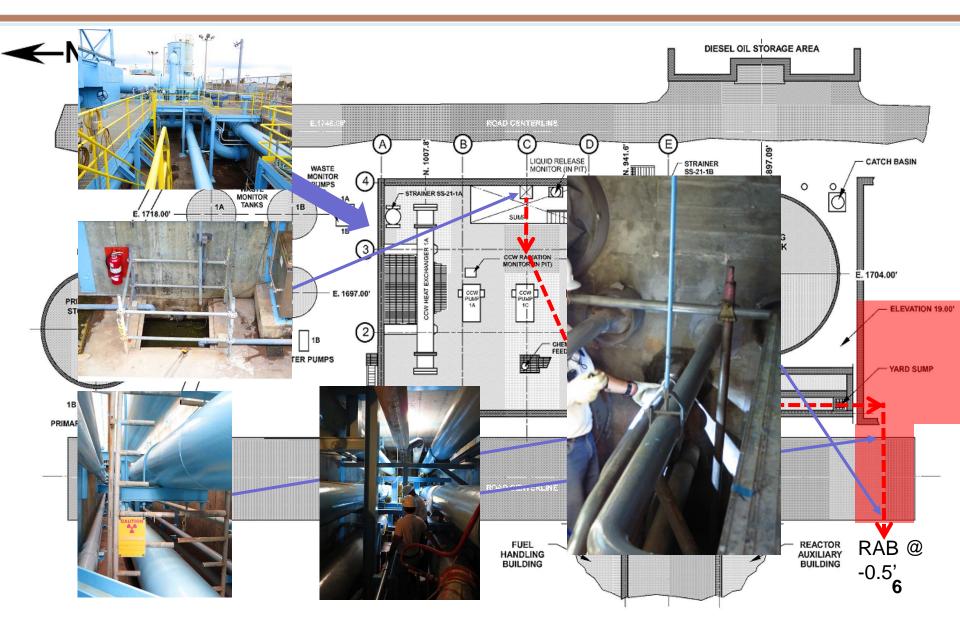


July 2013

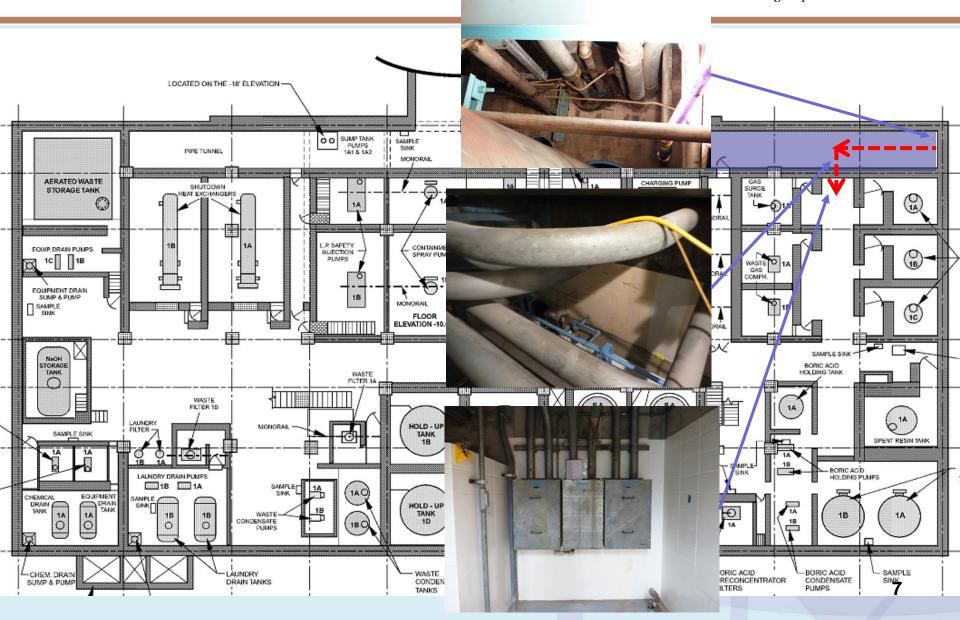
March 2005

Root Cause – CCW Pit





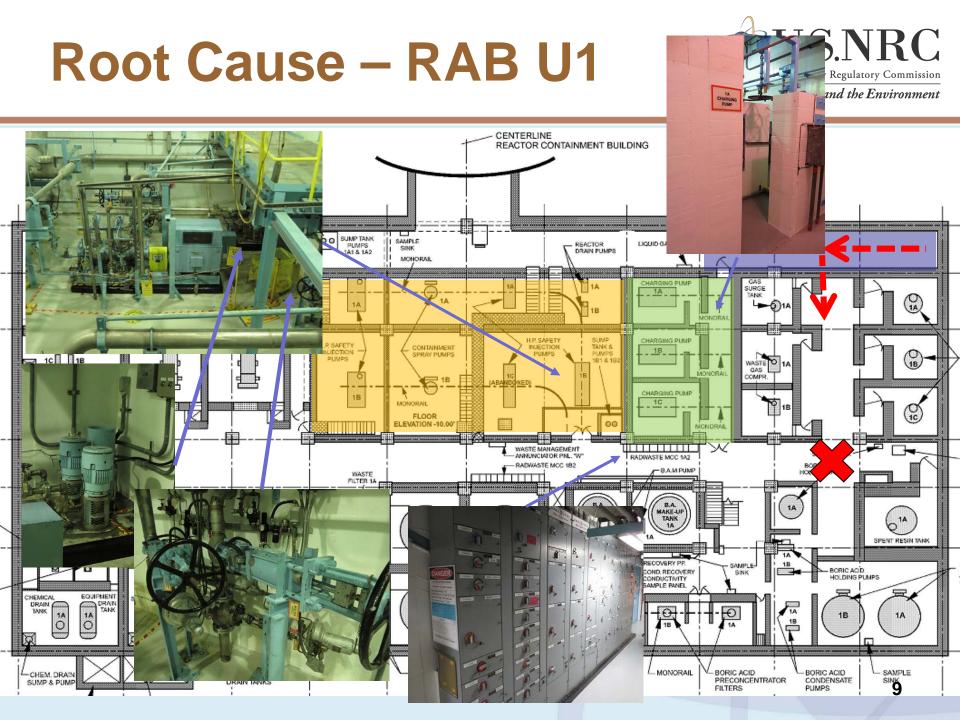
Root Cause – RABU1



RAB (-0.5') on Jan 9, 2014

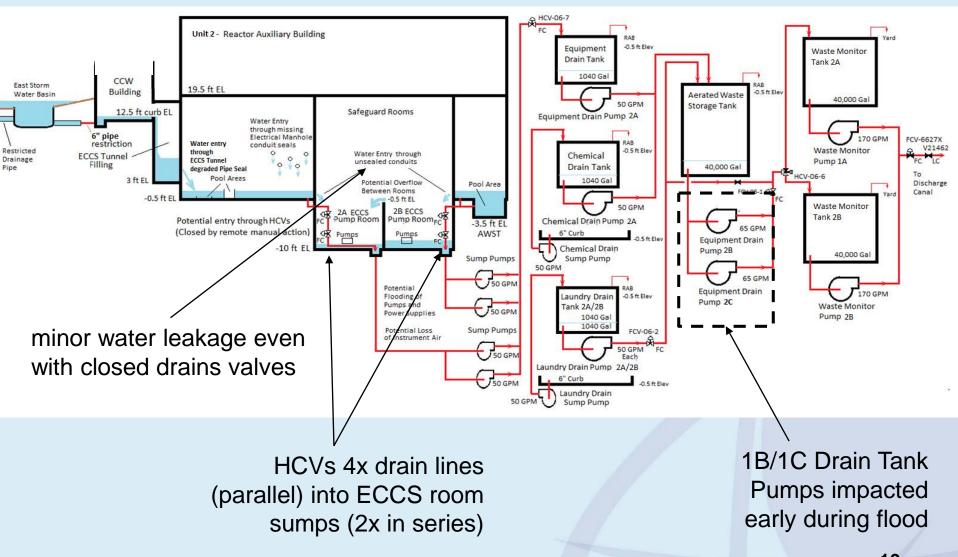






Hydraulic Paths – RAB U1





Performance Deficiency



- 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



- 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

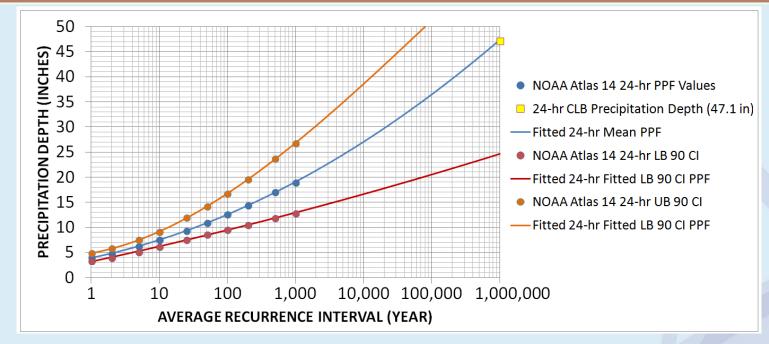
Precipitation Data



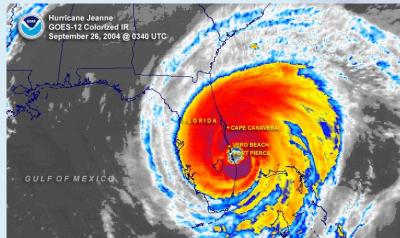
 Precipitation frequency from NOAA Atlas 14 @ St. Lucie based on a 24-hour duration storm

	Precipitation frequency estimates (in inches) at St. Lucie													
Duration		Average recurrence interval(years)												
Duration	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 U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment



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



Frequency – Int. Flooding



- 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 $\triangle CDF$ contributor

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	1-24"-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

List of Piping in ECCS Pipe Tunnel Area



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

Affected Components- Rain U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment

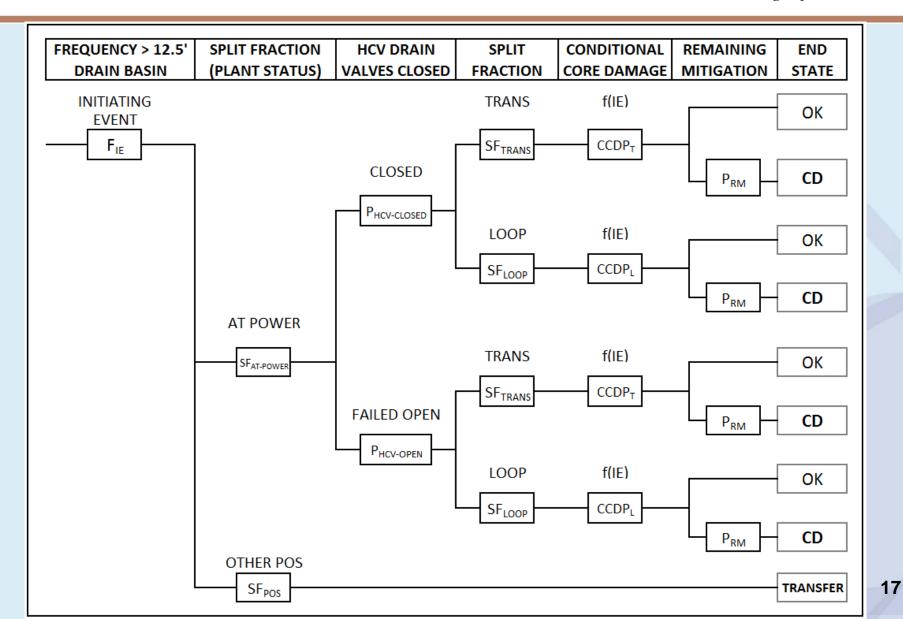
 Based on licensee's site hydraulic model coupled with a plant flooding model (precipitation→ elevation→ SSCs)

Ν	IMPACTED SSCs	PrecipRange	PrecipFreq	PrecipRange	PrecipFreq
	Demonstration and the Demonstration of the State Sta	(in) (Non- LOOP)	(/yr) (Non- LOOP)	(in) (LOOP)	(/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

BIN	IMPACTED SSCs	PrecipRange	PrecipFreq	PrecipRange	PrecipFreq
		(in) (Non-LOOP	(/yr) (Non-LOOP)	(in) (LOOP)	(/yr) (LOOP)
1	BAM	11.44 - 11.72	1.76E-03	11.47 - 11.56	5.82E-04
2	BAM + B HPSI		5°	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		numps not affected durin	a 24 hour missio	on time with valves closed
8	BAM + CHG + B HPSI/LPSI + SDC + A HPSI/LPSI		oumps not affected dum	iy 24-nour missic	in time with valves closed

Risk Assessment





Risk Analysis Approach



- 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



- 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



- 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



Any comments or questions?

Backup Slides



Protecting People and the Environment

BACKUP SLIDES

Additional Info. Resources



- 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





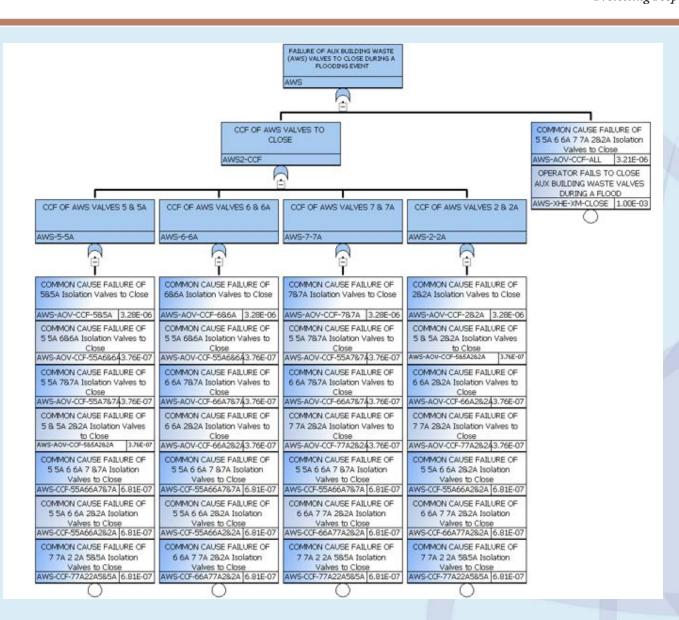
Penetration Details





Fault Tree Modeling HCV





Rain, At-power (NRC)



Protecting People and the Environment

PLANT-CONDITIC	N STORM-SURGE	HCV-DRAIN-VLVS	TRANS-LOOP	SEVE	RITY	REMAINING-MITIG	End State	e Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CE Assumed?
				0.747.04							
				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	3.60E-01	0			4			
operating @ 100% po	wer		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		ОК	7			
			9.40E-01								
			TRANS	1.70E-02	1.04E-06						
							CD	8	1.49E-10	Yes	
		1.00E-02		4 747 00	1.105.01						
		failed open		4.71E-03	1.40E-04		CD	9	5.58E-09	Yes	
							LD .	3	0.06E-03	res	
				1.30E-02	1.41E-04		-				
							CD	10	1.55E-08	No	1.10E-04
				9.68E-01	0		OK	11			
				1.075.00	7.405.00		-				
			6.00E-02	1.07E-02	7.46E-06		CD	12	4.33E-11	Yes	
			LOOP	-			- CD	12	4.33E-11	res	
				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)



PLANT-CO	DITION	STORM-SURGE		HCV-DRA	IN-VLVS	TRANS-LOOP		SEVERITY		REMAINING-MITIG		End State	Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CD Assumed?
2.50E-02												ОК	15			
POS-1																
								9.92E-01	0			ОК	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				-								
				ranca oport				4.71E-03	1							
								4.112.00	•			CD	20	1.08E-06	No	1.08E-06
													20	1.002-00	UPI	1.00E-00
5.20E-02												OK	21			
													21			
POS-3																

Hurricane, Mode 3 (NRC)



Protecting People and the Environment

UPT	PLANT-CONDITION		HCV-DRAIN-VLVS	TRANS-LOOP	SEVI	ERITY	REMAINING-MITIG			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) U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment

PLANT-CC	DITION	STORM-SURE	E HCV-DRA	IN-VLVS	TRAN	S-LOOP	SEVE	RITY	REMAININ	G-MITIG	End State	Seq Num	Initial Result	Safe&Stable at 24 Hrs?	Result If CD Assumed?
1.005.01											ОК	37			
1.80E-01											UK	37			
POS-1		0.07									ОК	38			
		0.67										38			
		less than 12.5'													
							0.5	0			ОК	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				ОК	41			
			1.00E-02				 TH OF 1 TB/								
					LORHR	NOK WUR		1.00E-02			-				
			failed open		LUNHR		3.30E-01	1.00E-02			CD	42	1505.00		
							DOTUTO				ιD	42	1.50E-09	Yes	
							BOTH TRA	INS .							
							3.30E-01	1							
											CD	43	1.50E-07	No	1.50E-07
5.20E-02											OK	44			

ICCW Pipe Break (NRC)



TYPE-OF-RUPT	PLANT-CONDITION	STORM-SURGE	HCV-DRAIN-VLVS	TRANS-LOOP	SEVE	BITY	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	
	0.005.04				1.00E-02	4.57E-06				4 405 40		
	9.00E-01							CD	47	1.18E-12	Yes	
	operating				9.00E-01	0		ОК	48			
					9.00E-01	0		UN	48			
					9.00E-02	1.04E-06						
			1.00E-02		0.002 02	1.042.00		CD	49	2.44E-14	Yes	
2.90E-05			failed open						10	2.112 11	100	
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			50	0.075.00		
	shutdown on RHR							CD	53	2.87E-09	Yes	
					9.00E-01	0		ОК	54			
					3.00E-01	0			- 34			
			1.00E-02									
			failed open		9.00E-02	1.00E-02						
			Tanca open		0.002 02	1.002 02		CD	55	2.61E-11	Yes	
										2.012 11		
					1.00E-02	1						
								CD	56	2.90E-10	No	2.90E-10
								OK	57			
CCW												
									l l	3.51E-06		1.19E-04

31