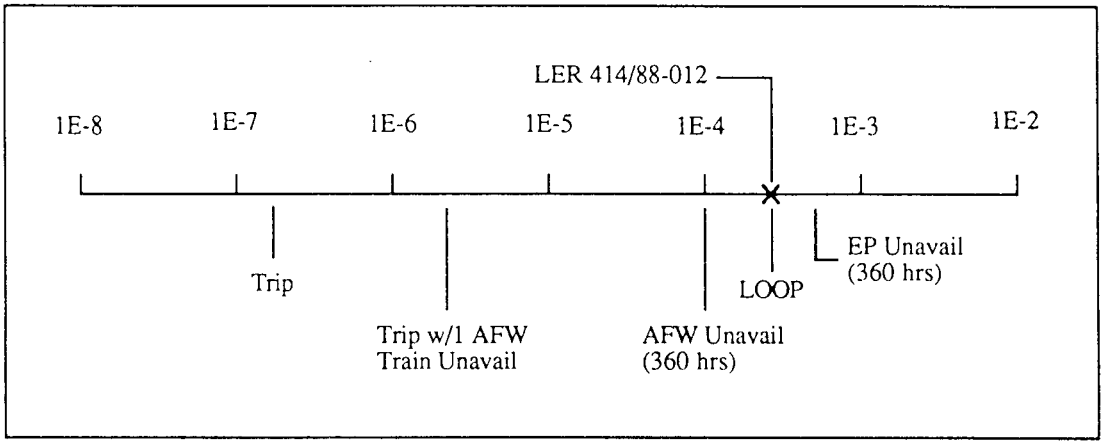
Accident Sequence Precursor Program Event Analysis

LER No: 414/88-012 and 413/88-015 R1
Event Description: Asiatic clams degrade auxiliary feedwater system
Date of Event: March 9, 1988
Plant: Catawba 2

Summary

Undetected presence of Asiatic clams in nuclear service water pumped to the steam generators via auxiliary feedwater caused the obstruction of two of four steam generator control valves during a reactor transient. Had the second AFW train suction switched to service water, additional degradation would likely have occurred. The conditional probability of core damage is estimated to be 2.7×10^{-4}, a relatively significant event from an ASP standpoint. The relative significance of this event compared with other potential events at Catawba 2 is shown below.



Event Description

At 1245 on March 9, 1988, the main turbine generator was placed on line following a refueling cycle. When the reactor reached 20% power, operators began swapping from the steam generator main feedwater bypass control valves to the steam generator main feedwater control valves for each steam generator. At 1825, an operator began the swap for the final steam generator. When he placed the steam generator 2B main feedwater control valve in the AUTO position, the valve unexpectedly opened due to a defective printed circuit card and controller driver card. This caused the levels in steam generators 2C and 2D to decrease and started

oscillation of the main feedwater pump 2A, which was in automatic control. The operator took manual control of the 2B SG main feedwater control valve, and a balance-of-plant operator took manual control of the turbine-driven main feedwater pump. Levels began to rise rapidly in the 2C and 2D steam generators. The balance-of-plant operator was unable to control excess feedwater flow into the 2C and 2D generators, and high-high level in SG 2D caused a feedwater isolation and main turbine trip. Main feedwater pump trip resulted in automatic start of both motor-driven auxiliary feedwater pumps and automatic steam generator blowdown isolation.

Forty seconds after the initial valve failure, a low suction pressure signal was initiated on AFW train A, and valves 2RN250A and 2CA15A automatically opened to provide water from the nuclear service water system to the AFW system. The low suction signal was a result of previous isolation of the condensate storage tank for leakage repairs, inadequate level in the Upper Surge Tank (65% full) due to a broken level indicator erroneously showing that the tank was 95% full, and instrument drift in two of three A train suction pressure sensors.

Level in the 2A steam generator continued to decrease to the low-low level alarm setpoint, causing a reactor trip. By this time, the nuclear service water valves had completely opened, providing raw water from Lake Wylie to AFW train A for steam generator 2A and 2B cooling. The capacity of the A train motor-driven auxiliary feedwater system was significantly degraded by the undetected presence of Asiatic clams in the nuclear service water system. Larvae of the Asiatic clams had been sucked from Lake Wylie into the nuclear service water system and had matured in the stagnant water lines between the service water and AFW system. When the valves were opened to supply the motor-driven auxiliary feedwater system, the Cavitrol cages for valves 2CA60 and 2CA56 (Steam Generator A and B control valves) became clogged with clam shells shredded by the auxiliary feedwater pump. With the continued drop in steam generator 2B level now aggravated by the obstructed steam generator control valves, the turbine-driven auxiliary feedwater pump automatically started on low-low level in two of four steam generators. On start of the turbine feedwater pump, feedwater flow to steam generator B increased from 330 gpm to 620 gpm, and then immediately degraded to 420 gpm due to the fouling by the clams.

The swap of Train A only indicates that at least two of the Train A pressure switches actuated, and the absence of a swap on Train B indicates that only one of the Train B switches actuated. This is supported by the calibration checks performed on the pressure switches. The lack of turbine-driven AFW pump suction swap is attributed to one of the Train A pressure switches having cleared at the time of the turbine-driven AFW pump start.

On March 10, work requests were initiated to investigate valves 2CA60 and 2CA56 to determine the reason for the degraded steam generator flow. Upon finding the valve Cavitrol cages clogged with shredded Asiatic clam shells, a decision was made to declare all auxiliary feedwater pumps for both units inoperable, and shutdowns were commenced. To

return Unit 1 to operability, a program was initiated to flush the stagnant nuclear service water lines leading to the auxiliary feedwater pumps to the condenser circulating water system. Following the flush, the lines were verified to be free of clam debris. The operation was completed by removing all raw water from the auxiliary feedwater pump suction lines. Similar procedures were used to clean the Unit 2 lines, and water lines of both units were radiographed to verify the effectiveness of the flushing.

Event-Related Plant Design Information

The main feedwater system contains two 50% capacity variable speed turbine-driven pumps that discharge through two stages of high-pressure heaters. Then the feedwater divides into four lines, each supplying one of the four SGs. Each of the four main feedwater lines contains a control valve and bypass control valve for SG flow control. The bypass control valves are utilized to control CF flow to the SG AFW nozzles up to approximately 15% of load, after which the control valves are utilized to control flow to the SG feedwater nozzles when the feedwater isolation valves are opened.

The auxiliary feedwater system ensures a sufficient feedwater supply to the steam generators in the event of a loss of the main feedwater system, to remove stored and residual energy from the reactor coolant system. There are two motor-driven AFW pumps and one steam turbine-driven pump per unit. Each motor-driven pump is capable of supplying two SGs, while the turbine-driven pump is capable of supplying all four SGs. AFW flow to each SG is modulated by air-operated control valves. These valves fail open to predetermined positions on an AFW autostart signal. The valves can be remotely operated from the control room within the preset limits after the AFW autostart signal has been reset. The Catawba FSAR accident analyses assume that a total of 491 gpm of AFW flow is delivered to only two intact SGs.

There are several sources of water available to the AFW pumps. The preferred sources are nonsafety-related condensate quality sources (condensate storage tank, upper surge tank, and condenser hotwell). The assured source of water to the AFW pumps is the safety-related portion of the nuclear service water system.

The automatic AFW switchover to service water takes place only if the AFW system has been automatically initiated by an AFW start signal and the AFW pump suction pressure is low. Low pressure in one of three Train A or B pressure switches will alarm the control room. Two out of three low-pressure actuations of the Train A or B pressure switches will align the associated service water train to its associated Train A or B motor-driven pump, if that pump has received an auto-start signal and a

time delay relay has timed out. Either Train A or B service water suction sources can align to the turbine-driven AFW pump if all of the following has occurred:

1. The turbine-driven pump has received an autostart signal.
2. The pump turbine steam supply valve SA2 or SA5 is open.
3. The pump turbine trip and throttle valve is open.
4. Two out of three low suction pressure indication from the Train A or B pressure switches and their time delay relay have timed out.

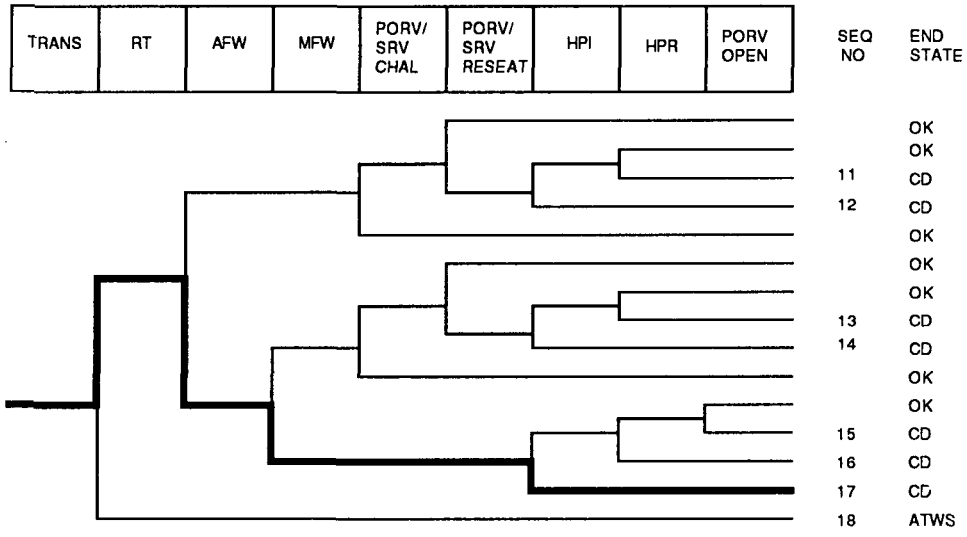
Asiatic clams are a non-native species of freshwater bivalve mollusk. They were first found in the United States in 1938 in the Columbia River near Knappton, Washington. Since then, they have spread across the country and are now found in at least 33 states. They first appeared in the Duke Power Company service area in the mid 1960s. Adult clams measure approximately 1 in. in diameter; however, the clam larvae measure approximately 1/125 in. in diameter.

ASP Modeling Assumptions and Approach

This event has been modeled as a reactor trip with feedwater isolation and degraded auxiliary feedwater. Main feedwater was assumed recoverable in the control room, but because of the flow control problems associated with SG 2B, this recovery was assumed not to be routine [p(non recovery) = 0.12]. The failure probability for the AFW system was assumed to be 0.1. Had the train A suction low-pressure signal not cleared at the time of turbine-driven AFW start, this pump would also have transferred to the A train service water system. In addition, had setpoint drift existed in one other train B pressure switch (it existed in two train A switches and one train B switch), then motor-driven AFW pump B would also have transferred to the service water suction source. Both of these suction transfers would have resulted in additional SG flow degradation as more AFW control valves became clogged with clam debris, potentially faulting the entire AFW system. Sensitivity analyses address the impact from the effective loss of one pump flow (observed) and loss of one motor-driven and the turbine-driven pump flows.

Analysis Results

The conditional probability of core damage estimated for the event is 2.7×10^{-4}, a significant event from an ASP standpoint. Dominant sequences to core damage involve failure of AFW (p = 0.01), failure to recover main feedwater (p = 0.07), and failure of feed and bleed (p = 0.02, including failure to initiate). The dominant sequence for the event is highlighted on the following event tree. Analyses assuming valves associated with only one AFW pump were faulted results in a core damage probability estimate of 3.7×10^{-6}; if valves associated with the one motor and one turbine pumps were faulted, this value increases to 7.0×10^{-5}.



Dominant Core Damage Sequence for LER 414/88-012

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 414/88-012
Event Description: Asiatic clams degrade AFW system (base case)
Event Date: 03/09/88
Plant: Catawba 2

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

TRANS	1.0E+00

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
TRANS	2.7E-04
Total	2.7E-04
ATWS	
TRANS	3.4E-05
Total	3.4E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
17	trans -rt AFW MFW hpi(f/b)	CD	1.3E-04	1.0E-01
15	trans -rt AFW MFW -hpi(f/b) -hpr/-hpi porv.open	CD	1.2E-04	1.2E-01
16	trans -rt AFW MFW -hpi(f/b) hpr/-hpi	CD	1.4E-05	1.2E-01
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
15	trans -rt AFW MFW -hpi(f/b) -hpr/-hpi porv.open	CD	1.2E-04	1.2E-01
16	trans -rt AFW MFW -hpi(f/b) hpr/-hpi	CD	1.4E-05	1.2E-01
17	trans -rt AFW MFW hpi(f/b)	CD	1.3E-04	1.0E-01
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\sealmod\pwrbseal.cmp
BRANCH MODEL: c:\asp\sealmod\cataw.sl1
PROBABILITY FILE: c:\asp\sealmod\pwr_bsl1.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	6.6E-04	1.0E+00	
loop	1.6E-05	5.3E-01	
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
emerg.power	2.9E-03	8.0E-01	
AFW	3.8E-04 > 1.0E-01 **	2.6E-01 > 1.0E+00	
Branch Model: 1.OF.3+ser			
Train 1 Cond Prob:	2.0E-02		

Train 2 Cond Prob:	1.0E-01		
Train 3 Cond Prob:	5.0E-02		
Serial Component Prob:	2.8E-04		
afw/emerg.power	5.0E-02	3.4E-01	
MFW	1.0E+00 > 1.0E+00	7.0E-02 > 1.2E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	1.0E+00		
porv.or.srv.chall	4.0E-02	1.0E+00	
porv.or.srv.reseat	3.0E-02	1.1E-02	
porv.or.srv.reseat/emerg.power	3.0E-02	1.0E+00	
seal.loca	2.7E-01	1.0E+00	
ep.rec(sl)	5.7E-01	1.0E+00	
ep.rec	7.0E-02	1.0E+00	
hpi	1.0E-03	8.4E-01	
hpi(f/b)	1.0E-03	8.4E-01	1.0E-02
hpr/-hpi	1.5E-04	1.0E+00	1.0E-03
porv.open	1.0E-02	1.0E+00	4.0E-04

* branch model file
** forced

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CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 414/88-012
Event Description: Asiatic clams degrade AFW system (one pump faulted)
Event Date: 03/09/88
Plant: Catawba 2

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

TRANS	1.0E+00

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
TRANS	3.7E-06
Total	3.7E-06
ATWS	
TRANS	3.4E-05
Total	3.4E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
17	trans -rt AFW MFW hpi(f/b)	CD	1.8E-06	2.6E-02
15	trans -rt AFW MFW -hpi(f/b) -hpr/-hpi porv.open	CD	1.7E-06	3.1E-02
16	trans -rt AFW MFW -hpi(f/b) hpr/-hpi	CD	1.9E-07	3.1E-02
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
15	trans -rt AFW MFW -hpi(f/b) -hpr/-hpi porv.open	CD	1.7E-06	3.1E-02
16	trans -rt AFW MFW -hpi(f/b) hpr/-hpi	CD	1.9E-07	3.1E-02
17	trans -rt AFW MFW hpi(f/b)	CD	1.8E-06	2.6E-02
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\sealmod\pwrbseal.cmp
BRANCH MODEL: c:\asp\sealmod\cataw.sl1
PROBABILITY FILE: c:\asp\sealmod\pwr_bsl1.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	6.6E-04	1.0E+00	
loop	1.6E-05	5.3E-01	
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
emerg.power	2.9E-03	8.0E-01	
AFW	3.8E-04 > 5.3E-03	2.6E-01	
Branch Model: 1.OF.3+ser			
Train 1 Cond Prob:	2.0E-02 > Failed		

Train 2 Cond Prob:	1.0E-01		
Train 3 Cond Prob:	5.0E-02		
Serial Component Prob:	2.8E-04		
afw/emerg.power	5.0E-02	3.4E-01	
MFW	1.0E+00 > 1.0E+00	7.0E-02 > 1.2E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	1.0E+00		
porv.or.srv.chall	4.0E-02	1.0E+00	
porv.or.srv.reseat	3.0E-02	1.1E-02	
porv.or.srv.reseat/emerg.power	3.0E-02	1.0E+00	
seal.loca	2.7E-01	1.0E+00	
ep.rec(sl)	5.7E-01	1.0E+00	
ep.rec	7.0E-02	1.0E+00	
hpi	1.0E-03	8.4E-01	
hpi(f/b)	1.0E-03	8.4E-01	1.0E-02
hpr/-hpi	1.5E-04	1.0E+00	1.0E-03
porv.open	1.0E-02	1.0E+00	4.0E-04

* branch model file
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CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 414/88-012
Event Description: Asiatic clams degrade AFW system (two pumps faulted)
Event Date: 03/09/88
Plant: Catawba 2

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

TRANS	1.0E+00

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
TRANS	7.0E-05
Total	7.0E-05
ATWS	
TRANS	3.4E-05
Total	3.4E-05

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
17	trans -rt AFW MFW hpi(f/b)	CD	3.4E-05	2.6E-02
15	trans -rt AFW MFW -hpi(f/b) -hpr/-hpi porv.open	CD	3.2E-05	3.1E-02
16	trans -rt AFW MFW -hpi(f/b) hpr/-hpi	CD	3.6E-06	3.1E-02
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
15	trans -rt AFW MFW -hpi(f/b) -hpr/-hpi porv.open	CD	3.2E-05	3.1E-02
16	trans -rt AFW MFW -hpi(f/b) hpr/-hpi	CD	3.6E-06	3.1E-02
17	trans -rt AFW MFW hpi(f/b)	CD	3.4E-05	2.6E-02
18	trans rt	ATWS	3.4E-05	1.2E-01

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\sealmod\pwrbseal.cmp
BRANCH MODEL: c:\asp\sealmod\cataw.sll
PROBABILITY FILE: c:\asp\sealmod\pwr_bsll.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	6.6E-04	1.0E+00	
loop	1.6E-05	5.3E-01	
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
emerg.power	2.9E-03	8.0E-01	
AFW	3.8E-04 > 1.0E-01	2.6E-01	
Branch Model: 1.OF.3+ser			
Train 1 Cond Prob:	2.0E-02 > Failed		

Train 2 Cond Prob:	1.0E-01		
Train 3 Cond Prob:	5.0E-02 > Failed		
Serial Component Prob:	2.8E-04		
afw/emerg.power	5.0E-02	3.4E-01	
MFW	1.0E+00 > 1.0E+00	7.0E-02 > 1.2E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	1.0E+00		
porv.or.srv.chall	4.0E-02	1.0E+00	
porv.or.srv.reseat	3.0E-02	1.1E-02	
porv.or.srv.reseat/emerg.power	3.0E-02	1.0E+00	
seal.loca	2.7E-01	1.0E+00	
ep.rec(sl)	5.7E-01	1.0E+00	
ep.rec	7.0E-02	1.0E+00	
hpi	1.0E-03	8.4E-01	
hpi(f/b)	1.0E-03	8.4E-01	1.0E-02
hpr/-hpi	1.5E-04	1.0E+00	1.0E-03
porv.open	1.0E-02	1.0E+00	4.0E-04

* branch model file
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