UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, D.C. 20555

August 20, 1991

NRC INFORMATION NOTICE NO. 91-50: A REVIEW OF WATER HAMMER EVENTS AFTER 1985

Addressees:

All holders of operating licenses or construction permits for nuclear power reactors.

Purpose:

This information notice is intended to alert addressees to a U.S. Nuclear Regulatory Commission (NRC) evaluation of water hammer events between January 1986 and March 1990. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. However, suggestions contained in this information notice do not constitute NRC requirements; therefore, no specific action or written response is required.

Background:

The NRC originally addressed water hammer in Unresolved Safety Issue (USI) A-1, reviewing 148 reported events from 1969 to 1980. The NRC considered this USI resolved with the issuance of "Evaluation of Water Hammer Occurrence in Nuclear Power Plants," NUREG-0927, Revision 1, in March 1984. The NRC concluded that cost-benefit considerations did not support new requirements to reduce the number of water hammer events. However, the NRC included guidelines on measures to prevent and reduce water hammer.

After the event at the San Onofre Nuclear Generating Station, Unit 1, in November 1985, the NRC reassessed the occurrence of water hammer, reviewing 40 events from 1981 to 1985. In the reassessment, the NRC confirmed the original conclusions that new or additional requirements to reduce the number of water hammer events were not cost-effective. The frequency of water hammer events had decreased significantly since the initial review. The NRC identified no new causal mechanisms for water hammer.

Description of Circumstances:

The NRC evaluated water hammer events that have occurred since January 1, 1986. The staff searched NRC databases from January 1986 through March 1990 and found about a dozen reports of water hammer events or events related to the water hammer phenomenon. In February 1991, the staff documented its findings in "A Review of Water Hammer Events After 1985," AEOD/E91-01. A copy of this report is available in the NRC Public Document Room, 2120 L Street N.W., Washington, D.C. The staff reviewed each of these reports to identify new physical phenomena, common mode aspects, and ways to prevent situations that could result in water hammer. The following events at Dresden Units 2 and 3, South Texas Unit 1, Trojan, and Susquehanna Unit 2 exhibit characteristics not emphasized in previous studies and offer lessons beyond implementing the guidance in NUREG-0927, Revision 1. In addition, a recent event at Big Rock Point 1 involved damage to a gate valve. Such damage has not been previously identified in a nuclear power plant.

Big Rock Point 1: On May 28, 1991, while the reactor was operating at 97% of full power, the licensee was performing a routine surveillance test of the emergency core spray (ECS) injection valves. After successfully testing both injection valves in the primary ECS system and the upstream injection valve in the backup ECS system, a signal to open the downstream injection valve was generated. A few seconds after the valve started to open, a reactor operator at the valve heard a water hammer and observed movement of the 4-inch piping that continued for several seconds. The water hammer bent one pipe hanger, partially pulled a bolt for another from the wall, and misaligned or damaged switches attached to the valve operators.

The backup ECS system is intended to deliver water from the fire suppression system at 150 psi to the reactor vessel after it has been depressurized following a loss of coolant accident. Fire water would be delivered to a nozzle located within the reactor vessel. The elevation of this nozzle is slightly higher than the elevation of the nozzles for the piping which connects the reactor vessel to the steam drum. The length of backup ECS piping from where it penetrates the head of the reactor vessel to the nearest injection valve is approximately 60 feet. This piping is routed horizontally and vertically upwards. An 18-foot section of horizontal piping has a rise in excess of 4 inches in the downstream direction and thus acts as a water trap. The upstream side of the injection valve nearest to the reactor vessel connects to a short pipe spool, a check valve, another short pipe spool, and the upstream injection valve. A short length of 1-inch pipe connects to the bottom of the upstream spool and terminates at a blind flange with an eighth-inch hole. The pipe serves to demonstrate that the check valve is not leaking.

The backup ECS piping normally contains noncondensible gases and saturated steam and water at 1350 psi. The relative concentrations of these constituents depend on the temperature distribution in the piping, the length of time that the reactor has been at power, and the number of surveillance tests that have been performed since the last startup. On May 28, 1991, conditions in the pipe led to acceleration of a slug of water that struck the gate of the downstream injection valve as it was opening during the surveillance test. The impact was great enough to leave imprints of the valve seats on both sides of the gate and to cause some cracking of the gate. Leakage of the valve prior to the event and consequent steam cutting of the upstream side of the gate and seat may have contributed to the event. The licensee's corrective actions included changing the slope of the horizontal section of piping, so that it will drain back to the reactor, and repairing the valves, valve operators, and pipe hangers.

Dresden Unit 2: A series of events occurred in the high pressure coolant injection (HPCI) system at Dresden Units 2 and 3 over several months. They are discussed in order of occurrence to enhance the understanding of changes in system valve positions. This event is also discussed, but in less detail, in NRC Information Notice No. 89-80, "Potential for Water Hammer, Thermal Stratification, and Steam Binding in High-Pressure Coolant Injection Piping," December 1, 1989. On October 31, 1989, while the plant was operating at 100 percent full power, the licensee declared an unusual event and began an orderly shutdown because time had expired for the limiting condition of operation (LCO) with the HPCI system inoperable. During the 5 months before taking this action, the licensee had observed high temperatures in the piping at the HPCI pump discharge and between two motor-operated valves (MOVs) (Points A and B on Figure 1 showing the normal configuration) near the interface between the HPCI system and the feedwater system. During this time, the licensee concluded that feedwater was leaking back through feedwater isolation check valve No. 7 and the normally closed HPCI injection MOV No. 8, found deficiencies in about one-half of the pipe supports (16/34), and concluded that steam voids could form. On October 23, the licensee declared the HPCI system inoperable. To correct the problem temporarily, the licensee realigned the HPCI system valves to open MOV No. 8 and close MOV No. 9 to serve as the normally closed HPCI injection valve. In a later inspection, the licensee found a bent stem and erosion of the disc and the seat in MOV No. 8. In the realignment, the normally closed MOV No. 10 becomes subject to feedwater pressure. If MOV No. 10 is not fully closed, then the open MOV No. 15 in the HPCI test return line to the condensate storage tank (CST) allows a condition conducive to water hammer when check valve No. 7 is leaking. This alignment permits hot pressurized feedwater to flow in a cold low pressure test system (LER 50-237/89-29-01).

Dresden Unit 3: On October 31, 1989, while the plant was operating at 100 percent full power, the licensee declared the HPCI system inoperable, having found conditions similar to those at Unit 2 described above: similarly elevated temperatures, deficiencies in about one-half of the pipe supports (21/40), and valves that could be leaking. The licensee found the discharge piping in the steam tunnel to be insulated, contrary to the original construction documentation. Initially, the licensee revised the alignment of the HPCI system as it had at Unit 2, to open MOV No. 8 and close MOV No. 9. The licensee later determined that feedwater was leaking back through MOV No. 10. Accordingly, the licensee closed MOV No. 15 to return the HPCI system to operable status. In a later inspection, the licensee identified damage in the seating surfaces in MOVs No. 8 and 10 and check valve No. 7 to confirm feedwater back leakage. Closure of MOV No. 15 offers protection from a potential water hammer condition that could develop if MOV No. 10 does not fully close when check valve No. 7 is leaking (also LER 50-237/89-29-01).

Dresden Unit 2: On March 19, 1990, while the plant was operating at 96 percent full power, the licensee was conducting HPCI system surveillance. Before testing, the valve alignment corresponded to that described above for the short-term correction to the October 23, 1989 event, i.e., MOV No. 8 was open and MOV No. 9 was closed. To conduct certain tests, the licensee temporarily closed MOV No. 8 to isolate the HPCI system from the feedwater system, even though both MOV No. 8 and check valve No. 7 were still leaking. After completing the routine surveillance tests, including a test of MOV No. 10, the licensee began a quarterly valve timing test of the HPCI pump discharge valve MOV No. 9. The licensee heard banging noises and observed HPCI pump discharge pipe movement. The licensee terminated the timing test, restored system valves to the pretest configuration, and monitored the noises and movement until they ceased about one and a half hours later (also LER 50-237/89-29-01).

Subsequent valve manipulation and HPCI pump discharge pipe temperature measurement led the licensee to conclude that the root cause of the event was feedwater that had leaked back through the HPCI test return MOV No. 10. The licensee postulated that this valve did not fully close after one of the required manipulations. This valve did not have a seal-in feature to complete the stroke after initiation, and the limit switch was set to bypass the torque switch in the open direction until the valve was 25 percent open. This same limit switch also controlled illumination of the "valve closed" indication light in the control room. Consequently, the "valve closed" light would be illuminated over the part of the valve stroke for which the open torque switch was bypassed. Thus, a control room operator who removed a closure signal when the light indicated the valve was closed would leave the valve approximately 25 percent open. Accordingly, the licensee revised the appropriate procedures to maintain the closure signal for 30 seconds after the "valve closed" light illuminates.

In addition, the licensee revised the valve alignment of the HPCI system to protect against backleakage through MOV No. 10 by closing MOV No. 15.

<u>South Texas Unit 1</u>: On November 5, 1987, before the plant attained initial criticality, the licensee, Houston Lighting & Power, declared the A train of the auxiliary feedwater (AFW) system inoperable when a one-inch double valve vent line in the pump discharge piping was severed completely. A second failure occurred three days later in a double valve instrument tap in the D pump discharge line. In making the initial assessment, the licensee attributed the cause as water hammer resulting from improper venting of the system. The licensee continued to note vibrations in the AFW system. During later testing, the licensee found that pressure pulsed when the flow control valves were in highly throttled positions. The resulting combination of both hydraulic and structural resonances was sufficient to cause the damage. The licensee made design changes to eliminate this problem (LER 498/87-016-01).

<u>Trojan</u>: On May 12, 1987, while the plant was in a refueling outage, the licensee, the Portland General Electric Company, was transferring water from the pressurized A accumulator (583 psig) to the depressurized D accumulator to prepare for maintenance on the A accumulator. This event has also been discussed from a different perspective in NRC Information Notice No. 88-13, "Water Hammer and Possible Piping Damage Caused by Misapplication of Kerotest Packless Metal Diaphragm Globe Valves," April 18, 1988. The nozzle-to-pipe weld in the A accumulator one-inch fill line ruptured, spilling 2000 gallons of borated water. The licensee repaired the line, satisfactorily hydrotested it, and again aligned the system for the transfer. The licensee had not released the system for operations, but no controls were on the system because the clearance had been released. This time, differential pressure was about 650 psig. When the transfer was started, the licensee heard loud noises, stopped the operation, checked the arrangement of the valves and restarted the transfer. After

one more cycle of this sequence of events, the nozzle-to-pipe weld in the A accumulator fill line ruptured again.

The licensee performed metallurgical analysis of the accumulator nozzle welds after each failure and found that the ruptures resulted from low cycle, high stress fatigue cracking. This cracking resulted from excessive flow back through the packless diaphragm globe valve in the A accumulator fill line. This backflow imposed a high differential pressure across the valve, causing the valve disc to vibrate. The licensee concluded that operator error and insufficient procedures had contributed to this failure. The operators had failed to follow procedures and to determine the causes of the loud noises before proceeding. The licensee had a procedure for transferring water through the sample lines but not through the fill lines.

The licensee developed a model for dynamic analysis and found that the backflow through the fill line resulted in the load on the nozzle-to-pipe weld being far greater than the pipe's failure threshold. During a backflow test using a similar packless globe valve, the licensee found that the pipe would fail at a flow of about 70 gpm. The licensee revised operating procedures to prohibit water transfer between the accumulators and developed an operation improvement plan (LER 344/87-013-01).

Susquehanna Unit 2: On October 12, 1986, while the plant was shut down, a water hammer occurred. This event is discussed in more detail in NRC Information Notice No. 87-10, "Potential for Water Hammer During Restart of Residual Heat Removal Pumps," February 11, 1987. The licensee, the Pennsylvania Power and Light Company, had established a temporary pathway from the B recirculation loop to the condenser for control of reactor water level while the residual heat removal (RHR) system was in service. With the D RHR pump running, the licensee started the B RHR pump and then stopped the D RHR pump. However, at approximately the same time, the outboard isolation valve in the letdown line from the B recirculation loop to the suction of the B RHR pump closed automatically, tripping the pump. To compensate for the resulting loss of shutdown cooling, the licensee established alternate cooling using the control rod drive cooling system and the reactor water cleanup system. The licensee reset the logic and reopened the valve to the B RHR pump suction without filling and venting the system. The system had partially drained to the condenser through the temporary pathway and a water hammer resulted when the suction valve was opened. To prevent water hammer from occurring in the future, the licensee reviewed this event and two previous similar events and revised procedures for reestablishing RHR service (LER 388/86-015-01).

Other Plants: Other water hammer events are discussed in the following reports. These events resulted from causes similar to those discussed in the USI assessment and reassessment.

PLANT	SYSTEM	REPORT
Palisades	Accumulator Injection	NRC Inspection Report 255/90-14
Oconee 3	Main Steam	LER 50-287/89-02
Waterford 3	Steam Generator Blowdown	LER 50-382/89-15
ANO 2	Steam Supply to AFW	LER 50-368/88-23
Indian Point 3	Feedwater	LER 50-286/88-02
Oyster Creek	Isolation Condenser	LER 50-219/88-21
Shearon Harris 1	Steam Generator Blowdown	LER 50-400/87-29-01

Discussion:

These water hammer events occurred at both boiling water reactor (BWR) and pressurized water reactor (PWR) plants. In BWRs, the events occurred in the RHR (shutdown cooling mode), isolation condenser, and HPCI systems. In PWRs, the events occurred in the feedwater, main steam, auxiliary feedwater (AFW), steam generator blowdown, and accumulator systems. These systems have been associated with water hammer in previous studies.

Some aspects differ between these events, such as the location of the water hammer. For example, the accumulator fill lines and injection lines and the AFW vent lines were not previously recognized as typical sites of water hammer. However, the physical phenomena involve the previously identified mechanisms of formation of steam voids and fluid transfer between high and low pressure systems. The licensees have cited a number of causes for these events, including improper filling and venting, the overly rapid stroking of valves, a lack of guidance about system configuration, accumulating water at low points, depressurizing a system to cause local flashing, and bypassing steam traps. Such causes were addressed in NUREG-0927, Revision 1.

These events illustrate the complex nature of water hammer events and hydrodynamic interactions. The events at Dresden Units 2 and 3 point out the care that is necessary in altering system alignment during operation or to perform testing. Such alignments can increase the susceptibility to water hammer. Details of component operability and control features may easily be overlooked when the immediate goal is to find a means to continue operation.

This information notice requires no specific action or written response. If you have any questions about the information in this notice, please contact one of the technical contacts listed below or the appropriate NRR project manager.

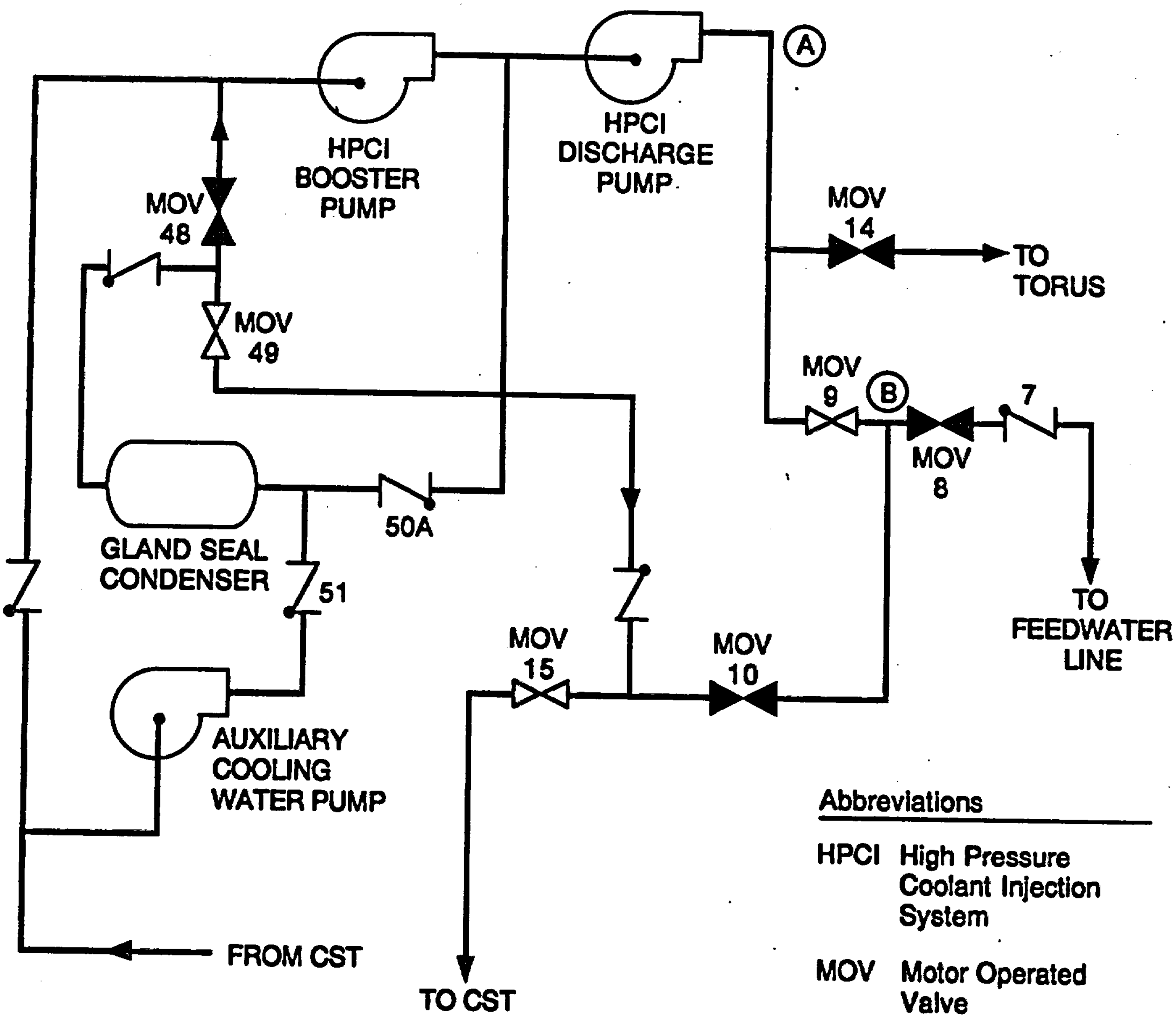
Charles E. Rossi

Charles E. Rossi, Director
Division of Operational Events Assessment
Office of Nuclear Reactor Regulation

Technical Contacts: Earl J. Brown, AEOD
(301) 492-4491

C. Vernon Hodge, NRR
(301) 492-1861

Attachments:
1. Figure 1. High Pressure Coolant Injection System Normal Valve Configuration
2. List of Recently Issued NRC Information Notices



Abbreviations

HPCI High Pressure Coolant Injection System

MOV Motor Operated Valve

CST Condensate Storage Tank

Figure 1
High Pressure Coolant Injection System Normal Valve Configuration

LIST OF RECENTLY ISSUED NRC INFORMATION NOTICES

Information Notice No.	Subject	Date of Issuance	Issued to
91-49	Enforcement of Safety Requirements for Radiographers	08/15/91	All Nuclear Regulatory Commission (NRC) licensees authorized to use sealed sources for industrial radiography.
91-48	False Certificates of Conformance Provided by Westinghouse Electric Supply Company for Refurbished Commercial-Grade Circuit Breakers	08/09/91	All holders of OLs or CPs for nuclear power reactors.
91-47	Failure of Thermo-Lag Fire Barrier Material to Pass Fire Endurance Test	08/06/91	All holders of OLs or CPs for nuclear power reactors.
89-56, Supp. 2	Questionable Certification of Material Supplied to the Defense Department by Nuclear Suppliers	07/19/91	All holders of OLs or CPs for nuclear power reactors.
91-46	Degradation of Emergency Diesel Generator Fuel Oil Delivery Systems	07/18/91	All holders of OLs or CPs for nuclear power reactors.
91-45	Possible Malfunction of Westinghouse ARD, BFD, and NBFD Relays, and A200 DC and DPC 250 Magnetic Contactors	07/05/91	All holders of OLs or CPs for nuclear power reactors.
91-44	Improper Control of Chemicals in Nuclear Fuel Fabrication	07/08/91	All nuclear fuel facilities.
91-43	Recent Incidents Involving Rapid Increases in Primary-to-Secondary Leak Rate	07/05/91	All holders of OLs or CPs for pressurized-water reactors (PWRs).

OL = Operating License
CP = Construction Permit

Discussion:

These water hammer events occurred at both boiling water reactor (BWR) and pressurized water reactor (PWR) plants. In BWRs, the events occurred in the RHR (shutdown cooling mode), isolation condenser, and HPCI systems. In PWRs, the events occurred in the feedwater, main steam, auxiliary feedwater (AFW), steam generator blowdown, and accumulator systems. These systems have been associated with water hammer in previous studies.

Some aspects differ between these events, such as the location of the water hammer. For example, the accumulator fill lines and injection lines and the AFW vent lines were not previously recognized as typical sites of water hammer. However, the physical phenomena involve the previously identified mechanisms of formation of steam voids and fluid transfer between high and low pressure systems. The licensees have cited a number of causes for these events, including improper filling and venting, the overly rapid stroking of valves, a lack of guidance about system configuration, accumulating water at low points, depressurizing a system to cause local flashing, and bypassing steam traps. Such causes were addressed in NUREG-0927, Revision 1.

These events illustrate the complex nature of water hammer events and hydrodynamic interactions. The events at Dresden Units 2 and 3 point out the care that is necessary in altering system alignment during operation or to perform testing. Such alignments can increase the susceptibility to water hammer. Details of component operability and control features may easily be overlooked when the immediate goal is to find a means to continue operation.

This information notice requires no specific action or written response. If you have any questions about the information in this notice, please contact one of the technical contacts listed below or the appropriate NRR project manager.

Original Signed by
Charles E. Rossi

Charles E. Rossi, Director
Division of Operational Events Assessment
Office of Nuclear Reactor Regulation

Technical Contacts: Earl J. Brown, AEOD
(301) 492-4491

C. Vernon Hodge, NRR
(301) 492-1861

Attachments:
1. Figure 1. High Pressure Coolant Injection System Normal Valve Configuration
2. List of Recently Issued NRC Information Notices

*SEE PREVIOUS CONCURRENCES

			D/DOEA:NRR	*C/OGCB:DOEA:NRR
			CERossi	CHBerlinger
			08/15/91	07/12/91
*OGCB:DOEA:NRR	*ROAB:DSP:AEOD	*C/ROAB:DSP:AEOD	*D/DSP:AEOD	*RPB:ADM
CVHodge	EBrown	JERosenthal	TMNovak	TechEd
05/13/91	06/24/91	06/26/91	06/26/91	05/13/91

DOCUMENT NAME: IN 91-50

Discussion:

These water hammer events occurred at both boiling water reactor (BWR) and pressurized water reactor (PWR) plants. In BWRs, the events occurred in the RHR (shutdown cooling mode), isolation condenser, and HPCI systems. In PWRs, the events occurred in the feedwater, main steam, auxiliary feedwater (AFW), steam generator blowdown, and accumulator systems. These systems have been associated with water hammer in previous studies.

Some aspects differ between these events, such as the location of the water hammer. For example, the accumulator fill lines and injection lines and the AFW vent lines were not previously recognized as typical sites of water hammer. However, the physical phenomena involve the previously identified mechanisms of formation of steam voids and fluid transfer between high and low pressure systems. The licensees have cited a number of causes for these events, including improper filling and venting, the overly rapid stroking of valves, a lack of guidance about system configuration, accumulating water at low points, depressurizing a system to cause local flashing, and bypassing steam traps. Such causes were addressed in NUREG-0927, Revision 1.

However, these events exhibit the following new characteristics:

(1) Hydrodynamic interactions of systems or trains that can produce water hammer

(2) System realignments involving changing the position of MOVs that can introduce complex issues concerning component operability and water hammer

(3) The energization of RHR pumps in BWR plants that has resulted in a number of isolation valve closures followed by water hammer and a loss of shutdown cooling

This information notice requires no specific action or written response. If you have any questions about the information in this notice, please contact one of the technical contacts listed below or the appropriate NRR project manager.

Charles E. Rossi, Director
Division of Operational Events Assessment
Office of Nuclear Reactor Regulation

Technical Contacts: Earl J. Brown, AEOD
(301) 492-4491

C. Vernon Hodge, NRR
(301) 492-1861

Attachments:
1. Figure 1. High Pressure Coolant Injection System Normal Valve Configuration
2. List of Recently Issued NRC Information Notices

*SEE PREVIOUS CONCURRENCES
Document Name: WATHAM 0503

D/DOEA:NRR	C/OGCB:DOEA:NRR
CERossi	CHBerlinger
07/ /91	07/12/91

*OGCB:DOEA:NRR	*ROAB:DSP:AEOD	*C/ROAB:DSP:AEOD	*D/DSP:AEOD	*RPB:ADM
CVHodge	EBrown	JERosenthal	TMNovak	TechEd
05/13/91	06/24/91	06/26/91	06/26/91	05/13/91

Discussion:

These water hammer events occurred at both boiling water reactor (BWR) and pressurized water reactor (PWR) plants. In BWRs, the events occurred in the RHR (shutdown cooling mode), isolation condenser, and HPCI systems. In PWRs, the events occurred in the feedwater, main steam, auxiliary feedwater (AFW), steam generator blowdown, and accumulator systems. These systems have been associated with water hammer in previous studies.

Some aspects differ between these events, such as the location of the water hammer. For example, the accumulator fill lines and injection lines and the AFW vent lines were not previously recognized as typical sites of water hammer. However, the physical phenomena involve the previously identified mechanisms of formation of steam voids and fluid transfer between high and low pressure systems. The licensees have cited a number of causes for these events, including improper filling and venting, the overly rapid stroking of valves, a lack of guidance about system configuration, accumulating water at low points, depressurizing a system to cause local flashing, and bypassing steam traps. Such causes were addressed in NUREG-0927, Revision 1.

However, these events exhibit the following new characteristics:

(1) Hydrodynamic interactions of systems or trains that can produce water hammer

(2) System realignments involving changing the position of MOVs that can introduce complex issues concerning component operability and water hammer

(3) The energization of RHR pumps in BWR plants that has resulted in a number of isolation valve closures followed by water hammer and a loss of shutdown cooling

This information notice requires no specific action or written response. If you have any questions about the information in this notice, please contact one of the technical contacts listed below or the appropriate NRR project manager.

Charles E. Rossi, Director
Division of Operational Events Assessment
Office of Nuclear Reactor Regulation

Technical Contacts: Earl J. Brown, AEOD
(301) 492-4491

C. Vernon Hodge, NRR
(301) 492-1861

Attachments:
1. Figure 1. High Pressure Coolant Injection System Normal Valve Configuration
2. List of Recently Issued NRC Information Notices

*SEE PREVIOUS CONCURRENCES
Document Name: WATHAM 0503

			D/DOEA:NRR	C/OGCB:DOEA:NRR
			CERossi	CHBerlinger
		JER	06/ /91	06/ /91
*OGCB:DOEA:NRR	ROAB:DSP:AEOD	C/ROAB:DSP:AEOD	D/DSP:AEOD	*RPB:ADM
CVHodge	EBrown	JERosenthal	TMNovak	TechEd
05/13/91	06/ /91	06/26/91	06/21/91	05/13/91

Division of Operational Events Assessment
Office of Nuclear Reactor Regulation

Technical Contacts: Earl J. Brown, AEOD
(301) 492-4491

C. Vernon Hodge, NRR
(301) 492-1861

Attachments:
1. Figure 1. High Pressure Coolant Injection System Normal Valve Configuration
~~2. List of References~~
3. List of Recently Issued NRC Information Notices

Document Name: WATHAM 0503

			D/DOEA:NRR CERossi 05/ /91	C/OGCB:DOEA:NRR CHBerlinger 05/ /91
oh OGCB:DOEA:NRR CVHodge 05/13/91	ROAB:DSP:AEOD EBrown EJB 05/24/91 06	C/ROAB:DSP:AEOD JERosenthal 06/[illegible]/91	D/DSP:AEOD TMNovak 05/ /91	RPB:ADM TechEd JMain JM 05/13/91