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March 18, 1985

MEMORANDUM FOR: Richard H. Vollmer, Deputy Director
Office of Inspection and Enforcement

FROM: Thomas A. Ippolito, Deputy Director
Office for Analysis and Evaluation
of Operational Data

SUBJECT: TRANSMITTAL OF TECHNICAL REVIEW REPORT, COMPARATIVE ANALYSIS OF RECENT FEEDLINE WATER HAMMER EVENTS AT MAINE YANKEE, CALVERT CLIFFS, SALEM, MCGUIRE, AND PALISADES

Enclosed is an AEOD technical review concerning the recent feedline water hammer events. This review concludes that procedural inadequacies were the underlying cause of the events. It is suggested that IE consider issuing an Information Notice that emphasizes the need for procedures that cover the restart of pumps following shutdowns for periods long enough to permit draining of piping or creation of voids that could lead to water hammer.

If you have questions concerning this report or this suggestion, please contact Eric Leeds on extension 24445.

Original signed by
Thomas A. Ippolito

Thomas A. Ippolito, Deputy Director
Office for Analysis and Evaluation
of Operational Data

Enclosure:
As Stated

cc w/enclosure:
E. Jordan, IE
E. Rossi, IE
R. Baer, IE

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AEOD/T502

MEMORANDUM FOR: Karl V. Seyfrit, Chief
Reactor Operations Analysis Branch
Office for Analysis and Evaluation
of Operational Data

THRU: Stuart D. Rubin, Chief
Reactor Systems Section 1
Reactor Operations Analysis Branch
Office for Analysis and Evaluation
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FROM: Eric J. Leeds, Engineer
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of Operational Data

SUBJECT: COMPARATIVE ANALYSIS OF RECENT FEEDLINE WATER HAMMER EVENTS AT MAINE YANKEE, CALVERT CLIFFS, SALEM, MCGUIRE, AND PALISADES

Enclosed is a technical review concerning the recent feedline water hammer events. This review concludes that procedural inadequacies were the underlying cause of the events. It is recommended that these events be summarized in the PRE to re-emphasize the importance of operating procedures in preventing water hammer events. It is suggested that IE consider issuing an Information Notice that emphasizes the need for procedures that cover the restart of pumps following shutdowns for periods long enough to permit draining of piping or creation of voids that could lead to water hammer.

/s/

Eric J. Leeds, Engineer
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Enclosure:
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AEOD TECHNICAL REVIEW*

UNIT: Multiple PWRs
DOCKET NOS.: Multiple PWRs
LICENSEE: Multiple PWRs

TR REPORT NO. AEOD/T502
DATE: March 18, 1985
EVALUATOR/CONTACT: E. J. Leeds

SUBJECT: COMPARATIVE ANALYSIS OF RECENT FEEDLINE WATER HAMMER EVENTS AT MAINE YANKEE, CALVERT CLIFFS, SALEM, McGUIRE AND PALISADES

EVENT DATE: Multiple

SUMMARY

A review was conducted to determine if a common root cause contributed to the recent PWR feedline water hammer events. Several of the events reviewed indicate that feedwater system procedural inadequacies were the underlying cause of the water hammer occurences. Specific hardware and operating procedures were previously identified during the staff evaluation of Unresolved Safety Issue A-1, Water Hammer, as important measures needed to reduce the incidence of severe water hammer in PWR feedwater and steam generator systems. This technical review concludes that the recommended actions formulated by the staff are adequate to prevent or mitigate the damage caused by water hammer and that there is limited safety significance involved in these water hammer events.

*This document supports ongoing AEOD and NRC activities and does not represent the position or requirements of the responsible NRC program office.

DISCUSSION

In the study of Unresolved Safety Issue (USI) A-1, Water Hammer, the staff found that 40 of the 67 reported PWR water hammer events involved either the feedwater or the steam generator system. The staff evaluation report for USI A-1 concluded that operational experience was also a factor in the frequency of water hammer events. Approximately one-half of the 150 reported water hammer events since 1969 have occurred during preoperational testing or during the first year of commercial operation. Because design and operating changes have been instituted throughout the industry to prevent water hammers, the frequency of water hammer events in general, and feedline water hammer events in particular, have declined. For PWRs, after a peak of 12 reported water hammer events of all types in 1976, the number of events declined to four in 1980 and two in 1981. However, since the completion of USI A-1, five feedline water hammer events have been reported.

At the completion of USI A-1 in December 1982, the staff's generic study concluded that the total elimination of water hammers was not possible because of inherent design and operational conditions of nuclear power plant systems. The purpose of this technical review is to determine if: (1) The lessons learned from the staff's generic review address the cause of these recent events and; (2) if a common root cause contributed to the five feedline water hammer events. A discussion of the circumstances and evaluation of each of the five events follows:

Operating Experience

1. On January 25, 1983, the Maine Yankee plant experienced a reactor trip from full power. Prior to the reactor trip, the plant had been operating with the 100% capacity turbine driven main feedwater pump. The steam driven main feedwater pump had been installed during the previous outage to provide diverse feedwater capability. Prior to the installation of the steam driven pump, the motive force was provided by electrically driven feed pumps which continued operation following a reactor/turbine trip. In this event both motor driven main feedwater pumps were unavailable. The main turbine tripped as designed following the reactor trip. The turbine driven main feedwater pump, driven by high pressure extraction steam, became unavailable when the main turbine tripped, causing Maine Yankee's first reactor trip with total loss of feedwater. When auxiliary feedwater (AFW) flow was manually initiated on low steam generator (SG) level, a loud noise was heard in the plant machine shop located directly beneath the main feedwater lines. Shortly after initiating AFW flow, operators noticed a rise in containment humidity, an increase in containment sump level, and the actuation of a containment fire detection alarm. The visual inspection made upon containment entry revealed substantial leakage from the main feedwater line in the vicinity of the No. 2 SG inlet nozzle. A plant cooldown was initiated and the licensee declared an unusual event.

When the main turbine tripped and the turbine driven feedwater pump became unavailable, the plant experienced a loss of normal feedwater flow to the SGs. The reduction in steam demand after the turbine trip caused SG level to drop due to void collapse. SG level fell below the level of the feedring, allowing the water in the feedring to drain through the seventy-six 1-inch diameter discharge nozzles in the bottom of the ring. A water hammer occurred when the relatively cool AFW flow was manually initiated on low SG level causing the steam in the partially filled feedring to condense. The water hammer caused a pre-existing crack in the main feedwater line to the No. 2 SG to become a through-wall crack. During the analysis of the Maine Yankee event pre-existing cracks were discovered in the lines feeding two of the three SGs. These cracks were caused by fatigue from excessive thermal cycling.

Because the Maine Yankee plant had never experienced a SG water hammer event in its previous operating history, the SG feedrings had never been modified with the 'J-tube' hardware fix recommended in the USI A-1 generic report to prevent SG water hammer. Prior to the addition of the 100% capacity turbine driven main feedwater pump, the feedwater system consisted of two motor driven main feedwater pumps and the plant had never experienced a reactor trip from 100% power without main feedwater available. As a result of the water hammer event, the licensee sealed the seventy six 1-inch discharge nozzles on the bottom of the feedrings and installed twenty eight 3-inch J-tubes on the top of the feedrings. The J-tubes will extend the time required for the feedring to drain once it is uncovered. Automatic initiation of auxiliary feedwater along with operational instructions and procedures were also instituted to reduce the probability of another water hammer occurrence and to reduce the thermal cycling of the main feedwater lines to prevent fatigue cracking.

2. On April 22, 1984, the Calvert Cliffs Unit 2 plant was operating in Mode 3 (1400 psig, 406°F). The operators were in the process of realigning the main feedwater system following the testing of a newly installed motor driven auxiliary feedwater pump. During the auxiliary feedwater pump test, SG level had been lowered below the feedring, main feedwater flow had been secured, and the main feedwater isolation valve was shut due to leakage past the feedwater regulating valve. Approximately thirty minutes later, the main feedwater isolation valve was reopened to feed the SG using the main feedwater system. Upon opening the main feedwater isolation valve a severe water hammer occurred. The water hammer damaged a main feedwater isolation valve, a main feedwater regulating valve and a main feedwater regulating bypass valve.

During the thirty minutes that SG water level remained below the level of the feedring, water in the feedring drained through the slip fit joint where the feedring enters the thermal sleeve. Apparently, leakage past the feedwater regulating valve was significant enough that when the main feedwater isolation valve was opened a severe water hammer occurred. According to written procedure, the AFW system is required to be used whenever SG water level is below - 26 inches, which corresponds to a conservative level for the top of the feedring. At Calvert Cliffs, the AFW pumps feed through a separate nozzle located lower in the SG than the main feedring. Had AFW flow been initiated as required by procedure, the main feedring would have been reflooded prior to restoring main feedwater flow and the water hammer event would not have occurred. Thus, the event could be attributed to a failure to follow established procedures.

The licensee had previously installed J-tubes on the SG feedrings in late 1978 for Unit 2 and mid-1979 for Unit 1. The licensee also implemented the other modifications designed to prevent or mitigate the effects of SG water hammer as described in Branch Technical Position (BTP) ASB 10-2. However, the modification did not prevent the SG water hammer from occurring. It appears that the J-tube modification only extended the time required for the feedring to drain once uncovered. The feedring apparently drained through the fitting at the thermal sleeve. Thus, the J-tube modification will not prevent a SG water hammer in all circumstances. The licensee's actions to prevent recurrence of this event included strengthening the procedural precautions already in place (to prevent water hammer) and increasing operator awareness of water hammer phenomena through training.

3. On April 6, 1984, the Salem Unit 2 plant was in hot shutdown (Mode 3) and in the process of stroke time testing each of the feedwater regulating valves and bypass valves. Testing had been satisfactorily completed on two sets of valves. SG pressure was approximately 1000 psig. With the feedwater system secured, one operating condensate pump was circulating condensate to provide secondary system cleanup and maintaining approximately 500 psig in the main feedwater header. When the feedwater regulating valve in loop 3 was opened for its stroke time test a loud rumbling noise was heard. Upon hearing the noise, the maintenance personnel closed the feedwater regulating valve and the rumbling noise stopped. The transient lasted for approximately 20 - 30 seconds. An inspection revealed that damage to the feedwater regulating valve and the feedwater piping support systems had occurred.

   At Salem-2, there are two valves in the main feedwater line between each feedwater regulating valve and its associated SG; a normally open isolation valve and a motor operated stop check valve. The check valve prevents reverse flow from the SG whenever the main feedwater pumps are secured. It was determined that the stop check valve in loop 3 failed to close against the 1000 psig loop 3 SG pressure. The licensee believes that the check valve failed to close because of crud buildup. Magnetite was found in the bowl section of the valve in the post-event inspection. When the feedwater regulating valve in loop 3 was opened for its stroke time test, reverse flow occurred due to the high differential pressure across the valve, 1000 psig on the downstream (SG) side and 500 psig on the upstream (condensate pump) side. This reverse flow slammed shut the stuck open check valve generating a water hammer compression wave upstream of the valve and a rarefaction wave downstream into the SG. The check valve and all damaged equipment were repaired.

On the subsequent plant startup on April 23, 1984, a turbine trip and reactor trip occurred due to high-high level in the loop 3 SG. The licensee attributed the event to sluggish response of the feedwater level control system at low power operation and minor binding of the feedwater control bypass valve. After taking corrective action, the licensee conducted another startup on April 27, which again resulted in a reactor trip due to high-high level in the loop 3 SG. A thorough investigation conducted by the licensee revealed that the loop 3 feedwater flow nozzle had been displaced approximately 24 inches from its original location. The feedwater flow nozzle provides the pressure drop for flow measurements used for indication, level control and protection signals. Apparently, the pins holding the nozzle in place had been broken. The licensee attributed this to the earlier April 6, feedline water hammer event.

To prevent a similar occurrence, the licensee modified the plant test procedures to require that the stop check valves be locked in the closed position using the valve motor operators, prior to opening the main feedwater regulating valves when performing the stroke time test. Also, a review of the feedwater system's piping support was to be performed to determine whether modifications were necessary to prevent similar water hammer damage.

4. On August 21, 1984, McGuire Unit 1 was operating at 100% power and supplying steam to the Unit 2 main feedwater pump turbines in preparation for a restart of Unit 2. The McGuire switch yard computer malfunctioned, opening multiple 230 KV switch yard breakers resulting in a loss of offsite power and a trip of the Unit 1 reactor. The Unit 1 reactor coolant system cool-

down was greater than expected after the trip because Unit 1 was supplying steam to Unit 2. To prevent an excessive cooldown and depressurization of the RCS, the main steam isolation valves (MSIVs) were manually closed and the steam generator power operated relief valves were used to control steam line pressure and remove decay heat from the reactor. The loss of offsite power and subsequent closing of the MSIVs resulted in a loss of all condensate and feedwater pumps. When power was restored and the pumps restarted, water hammers occurred in the condensate and feedwater systems.

The licensee determined that following the trip, the feedwater pump recirculation valves failed as designed to the full open position. Once the condensate and feedwater pumps were lost, the full open recirculation valves allowed water to drain back to the condenser creating voids in the condensate system and draining the section of piping between the main feedwater pumps and their discharge check valves. The depressurization of the feedlines caused by the tripped feedwater pumps also allowed the 400° F feedwater to flash to steam. When power was restored and the pumps restarted, the steam and water flow in the voided sections of piping caused water hammers in the condensate and feedwater systems.

Inspection revealed that the water hammers caused no damage to any pipe hangers although minor damage to the condensate booster pump discharge pressure gauges occurred. The licensee is modifying the condensate and feedwater procedures to minimize the possibility of a water hammer in these systems following a loss of offsite power.

5. On March 13, 1984, at the Palisades plant, the licensee reported that an SG inspection revealed extensive damage to the AFW feedring piping in both SGs. An inspection conducted just prior to the discovery of the internal SG damage also revealed several loose and damaged AFW piping hangers. Although no specific event was identified as causing the damage, it appeared that the damage was the result of a water hammer. However, subsequent review and analysis determined that the internal SG damage was caused by flow induced vibration resulting in cyclic fatigue failure. The internal SG damage is thought to have contributed to the AFW piping hanger damage by allowing the system to become susceptible to water hammer events. The licensee is planning to completely remove the present AFW feedring piping and replace it with an entirely different design to prevent a similar occurrence. Since the event at Palisades was not a water hammer occurrence, it has not been examined further in this report.

Of the five events, only the water hammer event at McGuire Unit 1 may be of potential generic concern. At this unit, the feedwater pump recirculation valves are in a line which tees off the main feedwater lines between the main feedwater pumps and the feedwater pump discharge check valves. This configuration allowed water to drain to the condenser creating voids in the condensate system and draining the short section of piping between the main feedwater pumps and the discharge check valves on a loss of offsite power. If the feedwater pump recirculation valves were located downstream of the feedwater pump discharge check valves, water in the feedwater piping downstream of the main feedwater pump discharge check valves might drain to the condenser when the recirculation valves fail open after a loss of offsite power. The resultant voiding of the main feedwater piping could conceivably contribute to a water hammer event if the piping was not filled prior to starting the main feedwater pumps. To determine if any plants had this postulated secondary piping configuration, we reviewed the feedwater piping at four PWRs: Sequoyah, Catawba Unit 1, Salem Unit 1, and Palisades. None of these plants had a feedwater system that would have allowed a large portion of the feedwater piping to drain to the condenser after a loss of offsite power, i.e., their recirculation piping was between the main feedwater pumps and the pump check valves.

Findings

The root cause of each water hammer event can be summarized as follows:

1. At Main Yankee, the SG water hammer was traced to the draining of the feedrings following the loss of main feedwater flow. The installation of J-tubes on the feedrings, automatic initiation of AFW flow and operating procedure modifications were made to prevent recurrence.

2. The water hammer event at Calvert Cliffs Unit 2 occurred when operators failed to observe the written operating procedure to feed the SGs using the AFW system whenever SG water level is below -26 inches, a conservatively chosen level for the top of the feedring.

3. At Salem Unit 2, personnel following inadequate test procedures caused a water hammer which resulted in two reactor trips.

4. At McGuire Unit 1, a loss of offsite power resulted in the voiding of sections of condensate and feedwater system piping. Operating procedures allowed operators to restart secondary system pumps when power was restored which caused condensate and feedwater system water hammers.

In all four events, plant procedures failed to prevent water hammers and were subsequently modified to prevent future recurrence.

CONCLUSION

The USI A-1 staff's study concluded that the total elimination of water hammer is not feasible due to design and operational conditions wherein steam, water and voids can co-exist within a system. However, it appears that procedural inadequacies continue to contribute to the frequency of water hammer events. This technical review concludes that the staff's recommended actions are adequate to prevent or mitigate the damage caused by water hammer and that there is limited safety significance involved in these water hammer events.

Suggestion

It is suggested that IE consider issuing an Information Notice that emphasizes the need for procedures that cover the restart of pumps following shutdowns for periods long enough to permit draining of piping or creation of voids that could lead to water hammer.