TECHNICAL EVALUATION
INDIAN POINT UNIT NO. 2

DECEMBER 1978

EG&G IDAHO, INC.

CONTENTS

I. INTRODUCTION

A safety evaluation was performed for the Indian Point Unit No. 2 feedwater system. This evaluation was concerned with the effectiveness of the means to reduce the potential for water hammer in the feedwater system during normal and hypothesized operating conditions. The potential for water hammer due to steam-water slugging was considered in this review.

Following a steam generator water hammer that occurred on November 13, 1973 at Indian Point Unit No. 2, an extensive test program was initiated by the licensee. The program was to identify plant conditions conducive to steam generator water hammer and to determine possible means which could be implemented to reduce the potential for future water hammer incidents. Since steam generator water hammer can be avoided if the system is maintained full of water, this evaluation was based on the effectiveness of these means to maintain the system full of water during conditions conducive to water hammer.

The information for this review was obtained from 1) informal licensee conversations, 2) licensee submittals of July 25, 1975[1] and January 13, 1978[2], 3) the Indian Point Final Facility Description and Safety Analysis Report[3], 4) Nuclear Power Experience[4,5], and 5) "An Evaluation of PWR Steam Generator Water Hammer", NUREG-0291[6].

A description of the feedwater system at Indian Point Unit No. 2, its general operation, and an account of steam generator water hammer incidents at this facility are presented in Section II. The water hammer test program and means to reduce the potential for water hammer are described in Section III including a general discussion of the effectiveness of these means during operating conditions conducive to water hammer. Finally, conclusions are presented in Section IV concerning the adequacy of the means to reduce the potential for water hammer at this facility.

II. FEEDWATER SYSTEM

1. DESCRIPTION

The feedwater system for Indian Point Unit No. 2 was designed to provide an adequate supply of feedwater to the secondary side of the four steam generators under all load conditions. The two main feedwater pumps are single-stage, horizontal, centrifugal pumps. The pumps, rated at a flow rate of 15,300 gpm and 1839 ft. total developed head, supply main feedwater to the steam generators. The feedwater pumps are each driven by an 8350 hp steam turbine which draws steam from the discharge of the one bank of reheater moisture separators. The pumps are supplied with feedwater by the high pressure heater drain pumps and the condensate pumps via a common discharge header of the low pressure heater banks.

Feedwater from the main feedwater pumps is supplied to a main header via the high pressure heaters. The main header splits into four 18" feedwater lines to supply a feedring inside each steam generator. Feedwater is discharged downward through inverted "J" shaped tubes on top of the feedrings.

The auxiliary feedwater system provides feedwater to the steam generators for primary heat removal during reactor startup, low power operation and reactor shutdown. Auxiliary feedwater can be supplied to the steam generators by two independent pumping systems employing electric motor driven and turbine driven auxiliary feedwater pumps. Lines from the auxiliary feedwater pumps carry water to the main feedwater lines at a point in each main line just outside the containment building. The two motor driven pumps, each with a capacity of 400 gpm to supply two steam generators, operate with normal offsite power or, if offsite power is lost, power is supplied by the emergency diesel generators. The turbine driven pump, with a capacity of 800 gpm to supply all four steam generators, is driven by steam supplied from the outlet headers of two steam generators. The main water supply source for both auxiliary systems is by gravity feed from the condensate storage tank. An alternate supply source is the 1.5 million gallon tank for plant storage of city water.

2. GENERAL OPERATION

During normal power operation of the reactor, the main feedwater system supplies feedwater to the steam generators for heat removal from the primary system. The feedwater flow is regulated to each steam generator by individual regulating valves in the main feedwater lines. The positions of the valves are automatically controlled based on steam generator level, secondary steam flow and feedwater flow. At low power levels and during startup and hot standby conditions, feedwater is manually regulated to maintain adequate water levels in the steam generators. The feedwater is supplied by the auxiliary feedwater system or by the main feedwater system via the feedwater bypass lines. The bypass lines and other modifications to reduce the potential for water hammer in the feedwater system are discussed in Section III.

After the loss of main feedwater flow to one or more steam generators, automatic initiation of auxiliary feedwater flow will result. The motor driven auxiliary feedwater pumps will automatically start on 1) a low-low water level signal from any steam generator, 2) the automatic trip of either main feedwater pump, 3) a safety injection signal, or 4) the loss of offsite power concurrent with a reactor trip. The turbine driven auxiliary feedwater pump will automatically start on 1) a low-low water level signal from any two of the four steam generators or 2) the loss of offsite power concurrent with a reactor trip. The motor driven and turbine driven pumps can also be started manually (local or remote). The auxiliary feedwater flow would be initiated quickly (less than 30 seconds) to begin refilling the steam generators. This flow is usually under manual control shortly after main feedwater flow is lost to complete refilling of the steam generators and to maintain the water levels above the feedrings.

3. WATER HAMMER EXPERIENCE

The most severe steam generator water hammer incident reported to date occurred at Indian Point Unit No. 2 on November 13, 1973. The unit was being started up and was at 7 % power when a turbine trip occurred due to a high steam generator level in the No. 23 steam generator. Automatic initiation of the motor driven auxiliary feedwater pumps followed, and shortly thereafter a water hammer event occurred in the feedwater line to the No. 22 steam generator. A second event occurred in the same feedwater line about 50 minutes after the turbine trip. The inability to achieve proper level in the No. 22 steam generator after the first event indicated a rupture in the feedwater piping had probably occurred. Increasing sump level, temperature, and humidity in the containment building after the second event further substantiated the existence of a pipe break.

After cold shutdown, an inspection of the No. 22 feedwater line revealed a 180° fracture equivalent to about 2 square in. of break area in the line just inside the containment penetration. Localized pipe bulging and stress cracking was present in the feedwater piping around the containment penetration and in the horizontal piping near the No. 22 steam generator. However, the integrity of the containment was not breached at the penetration.

An evaluation of the magnitude of the piping damage revealed the probable cause for this water hammer incident. The magnitude of the forces to cause such damage was hypothesized to have been the result of a steam-water reaction in the feedwater piping or feedring. This reaction occurred when auxiliary feedwater entered the drained and steam filled feedwater piping adjacent to the steam generator.

After a ten week shutdown, normal operation of Unit No. 2 continued until January 29, 1974. On this date, three days after normal operation was continued, a reactor trip occurred with the plant at 35% power. Feedring uncovery resulted with subsequent admission of auxiliary feedwater to the main feedwater piping. A slight non-destructive water hammer occurred in the No. 21 feedwater piping causing a loud noise and observable pipe movement outside the containment. Following an investigation of the incident, it was concluded that this incident resulted from the same type of steam-water reaction attributed to the November 13, 1973 water hammer event.

III. MEANS TO REDUCE THE POTENTIAL FOR WATER HAMMER

1. DESCRIPTION AND RELATED WATER HAMMER TESTS

As a result of the water hammer incident on November 13, 1973, an extensive research and testing program was undertaken by the utility which eventually required four months to complete. This was the first extensive program of its kind to better understand the steam generator water hammer phenomenon. After an evaluation of the tests and previous water hammer events, many modifications were implemented at Indian Point Unit No. 2 to reduce the potential for future water hammer events.

After the November 13, 1973 incident, repairs and modifications were made to the Unit No. 2 feedwater system. One modification was made only to the No. 22 feedwater line to eliminate the 10.7 ft. length of horizontal piping attached to the nozzle of the steam generator. This modification consisted of lowering the horizontal piping immediately outside the steam generator to preclude significant drainage of the piping through the feedring should feedring uncovery occur. Since the feedwater lines to the other steam generators have horizontal runs less than 5.4 ft., those lines were not modified. Other modifications to all four feedwater lines included 1) the addition of restraints at the first elbow just inside the containment to prevent future excessive piping rebound under water hammer conditions and 2) the installation of hydraulic dampeners to the main feedwater valves to prevent rapid closure when a closure signal is received.

Phase 1 of the test program was begun after these modifications were implemented and extensive instrumentation was installed throughout the feedwater system to measure pressures, temperatures, strains, steam generator water levels, feedwater flow rates, and piping displacements.

Two tests were run with the reactor subcritical and at 7% power without any evidence of water hammer. A final test was planned with the reactor at 100% power until the January 29, 1974 incident occurred. Phase 1 was aborted at this point and the test data from the first two tests were compiled.

Phase 2 of the test program was a series of 13 tests conducted to investigate the effect of varied auxiliary feedwater flow rates. Each test was conducted by introducing feedwater via the main feedwater piping to an individual steam generator in which the water level was below the feedring. A specified flow rate (ranging from 75 to 240 gpm) was used to subsequently refill the steam generator. No water hammer events were observed in any test when the flow rate was less than or equal to 200 gpm. However, water hammer was experienced in two of four tests with a flow rate of 240 gpm.

The tests further substantiated the fact that water hammer is quite possible during recovery of a steam filled feedring. Water hammer that occurs when the rising water level reaches the bottom holes of a feedring implies that slug formation occurs in the feedring. If water hammer occurred when the feedring was uncovered it would imply that slug formation occurs in the feedwater piping. Liquid level recordings made during the November 13, 1973 incident indicate that the level in the steam generator was below the feedring when the water hammer occurred. Unfortunately, instrumentation uncertainties did not allow precise verification of the actual level at the time of the event.

The decision was made to install "J" tubes on top of the feedrings in the Unit No. 2 steam generators and to plug the bottom discharge holes. This arrangement, although previously untried, would prove effective in increasing the time for complete drainage of the feedrings and associated horizontal feedwater piping from less than 1 minute to about 30 minutes. Also, the maximum auxiliary feedwater flow (about 400 gpm per steam generator), was not sufficient to maintain the feedring and feedwater piping full when the feedrings had bottom discharge holes. The feedrings equipped with "J" shaped discharge tubes, however, permit feedwater flow rates as low as about 10 gpm per steam generator to keep the feedrings and feedwater piping full of water during feedring uncovery. Maintaining feedrings and feedwater piping full of water while the feedrings are uncovered eliminates the potential for water hammer in that portion of the system.

The tests comprising Phase 3 of the program were conducted to verify that conditions conducive to the water hammer event that occurred on November 13, 1973 would not recur. Four tests were run (one for each steam generator) to determine the drainage time of uncovered feedrings under cold conditions. The data show that substantial drainage does not occur in any feedring for about 5 minutes. Three additional tests were run at various power levels to simulate potentially abnormal operating conditions conducive to water hammer. During these tests, no evidence of water hammer was observed.

After all testing was completed, an auxiliary feedwater flow limitation of 150 gpm was put into effect. This flow limitation would only be implemented after a 5 minute period following an event that caused loss of feedwater flow to one or more steam generators. This flow limitation would be necessary to reduce the potential for water hammer since greater than a 5 minute lapse in feedwater flow could allow substantial feedring drainage and subsequent admission of steam.

Subsequently, low flow bypass lines equipped with bypass regulating valves were installed in the main feedwater lines to each steam generator. The bypass lines allow finer feedwater flow control during startup and low power operating conditions. The operators, therefore, are able to more easily maintain steam generator secondary levels during these conditions since the main regulating valves will allow only coarse flow adjustments when under manual control.

2. EFFECTIVENESS DURING TRANSIENTS AND CONDITIONS CONDUCIVE TO WATER HAMMER

2.1 Reactor Trip

A reactor trip with the plant in normal power operation would cause the water level in all steam generators to collapse to a level below the feedrings. Within 20 seconds of the resulting steam generator low-low water level signals, the motor driven and turbine driven auxiliary feedwater pumps would automatically startup to supply auxiliary feedwater to the steam generators. If the initiating event for the reactor trip did not close the main feedwater regulating valves, the valves would close upon receipt of low primary coolant average temperature signals or steam generator high-high level signals. Auxiliary feedwater flow is normally under manual control shortly after an event that causes feedring uncovery. The flow is regulated to refill and maintain the steam generator levels above the feedrings.

The potential for water hammer occurring in the feedring and feedwater piping after a reactor trip is very low because the main and auxiliary feedwater keeps the feedrings and feedwater piping full of water until feedring recovery occurs.

2.2 Loss of Main Feedwater Pumps

Interruption of main feedwater flow would cause automatic startup of the turbine driven auxiliary feedwater pump and both motor driven auxiliary feedwater pumps upon receipt of the resulting low-low steam generator water level signals. Either pumping system can provide more than sufficient flow to the feedrings and associated horizontal feedwater piping of the steam generators to keep them full of water since the "J" tubes reduce the drainage rate to about 10 gpm per steam generator during feedring uncovery periods.

The loss of main feedwater flow and the likely uncovery of the feedrings would not result in substantial feedring and feedwater piping drainage since the auxiliary feedwater pumps would startup within 30 seconds to supply feedwater to the steam generators. Therefore, the potential for water hammer is significantly reduced.

2.3 Loss of Off-Site Power

The interruption of the off-site power supply would result in a reactor trip and closure of the main feedwater regulating valves. The subsequent actuation of the auxiliary feedwater system, refilling of the steam generators, and recovery of the feedrings would occur in the same manner described in Section III.2.2. The motor driven auxiliary feedwater pumps would, however, receive power from the emergency diesel generators which are actuated immediately after the loss of normal off-site power. The turbine driven auxiliary feedwater pumping system is not dependent on off-site power and would be fully operable since 1) steam for the turbine would be supplied from the main steam lines and 2) electrical D.C. power for controls would be supplied by storage batteries.

As was the case for the loss of the main feedwater pumps, auxiliary feedwater would maintain the feedrings and feedwater piping full of water until feedring recovery occurs and thus the potential for water hammer is avoided.

2.4 Operator Error

The potential for water hammer in the feedwater system incrases greatly if uncovered feedrings are allowed to drain substantially after an event causes the steam generator water levels to go below the feedrings. Admission of feedwater into the drained feedrings and feedwater piping could then result in water slugging and subsequent water hammer. The uncovery of one or more feedrings is most likely when the plant is operating at low power or is shutdown since feedwater is being regulated manually, rather than automatically. The use of the main feedwater bypass piping and associated regulating valves helps reduce the chance of feedring uncovery during low power situations since the feedwater flow rate is more easily and finely regulated. Should feedring uncovery occur, the "J" shaped discharge tubes help maintain the feedrings from draining substantially for about five minutes. This time delay would allow sufficient time for the operator to become aware of feedring uncovery and to readjust the steam generator water level(s) to recover the feedrings. Should feedring uncovery occur and the feedrings and horizontal piping were to drain, feedwater flow would be limited to the administrative limit of 150 gpm until recovery to ensure a low potential of water slugging.

2.5 Steam Line Break

The potential for water hammer events resulting from or concurrent with the rupture of a steam line inside the containment building was considered. The sequence of events following such a failure was evaluated to determine if the break would result in the 1) blowdown of one or more additional steam generators and/or 2) inability to supply auxiliary feedwater to the unaffected steam generators.

The rupture of a steam line would automatically result in a safety injection signal (SIS) and subsequent isolation of all feedwater lines. The SIS or a low-low water level signal from the blowndown steam generator would actuate the motor driven auxiliary feedwater pumps to supply feedwater to the steam generators for subsequent refill and feedring recovery.

The potential for water hammer is low after a steam line break since prompt delivery of auxiliary feedwater in conjunction with the "J"-tubes maintain full feedrings and feedwater piping in the unaffected steam generator until feedring recovery. The turbine driven auxiliary pump (if actuated) would receive adequate steam for driving power even if one of the two interconnected steam lines for the pump turbine was supplied by the blowndown steam generator. Check valves in each supply line would prevent "crossover" blowdown through the supply lines from one steam generator to the associated blowndown steam generator.

Thus, the means for avoiding water hammer would be fully effective under the conditions of a steam line break.

2.6 Loss-of-Coolant Accident

The potential for feedwater water hammer during a postulated loss-of-coolant accident (LOCA) was examined because 1) a rupture of the feedwater piping could increase the consequences of a LOCA and 2) the plant protective systems which function during a LOCA could result in conditions (such as those during a reactor trip) which are conducive to water hammer if the feedwater system is not kept full of water.

A LOCA would result in a SIS, a reactor trip, and subsequent isolation of the feedwater system. The startup of the motor driven and turbine driven auxiliary feedwater pumps would result and feedwater would be supplied to the steam generators within 60 seconds of the reactor trip. Refill of the steam generators and recovery of the feedrings would occur in a manner typical of a reactor trip or the loss of off-site power.

The conditions conducive to water hammer in the feedring and feedwater piping resulting from a LOCA would be very similar to those from a reactor trip. Therefore, the means to reduce the potential for water hammer would be fully effective during a LOCA.

IV. CONCLUSIONS

The assessment of the capability of existing means to reduce the potential for steam generator water hammer during various hypothesized transients and conditions was discussed in Section III. This assessment has shown that under conditions which are most conducive to water hammer in the feedwater system (specifically, uncovered and draining feedrings and feedwater piping subjected to admission of cold auxiliary feedwater), the means to reduce the potential for water hammer at Indian Point Unit No. 2 are adequate to maintain sufficiently full feedrings and feedwater piping until feedring recovery occurs. Therefore, since keeping the feedrings and feedwater piping full of water eliminates the potential for water hammer, we find that the means to reduce the potential for steam generator water hammer at this facility are adequate.

V. REFERENCES

1. Letter from W. J. Cahill to G. Lear, Subject - "Response to May 27, 1975 NRC letter on Feedwater Water Hammer", July 25, 1975.

2. Letter from W. J. Cahill to R. W. Reid, Subject - "Response to September 2, 1977 NRC letter on Feedwater Water Hammer", January 13, 1978.

3. Final Facility Description and Safety Analysis Report, Indian Point Unit No. 3, Consolidated Edison Company of New York, Inc., DOE Docket No. 50-286.

4. Nuclear Power Experience, Nuclear Power Experience, Inc., PWR Vol, VI. E. 34.

5. Ibid, PWR Vol. V. D. 41.

6. J. A. Block, et al, An Evaluation of PWR Steam Generator Water Hammer, Creare, Inc., NUREG-0291, December 1976.

DOCKET NO. 50-3/247

DATE: 10-2-80

NOTE TO NRC AND/OR LOCAL PUBLIC DOCUMENT ROOMS

The following item submitted with letter dated 9-24-80 from Con. Ed. Co. is being withheld from public disclosure in accordance with Section 2.790.

PROPRIETARY INFORMATION

Addl Info to Security Plan

Don Lauham

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Distribution Services Branch