SAFETY EVALUATION REPORT

STEAM GENERATOR WATER HAMMER

BEAVER VALLEY

POWER STATION

UNIT NO. 1

FEBRUARY 12, 1979

7903140190

1.0 INTRODUCTION

Steam generator water hammer has occurred in certain nuclear power plants as a result of the rapid condensation of steam in a steam generator feedwater line and the consequent acceleration of a slug of water which upon impact within the piping system causes undue stresses in the piping and its support system. The significance of these events varies from plant to plant. Since the total loss of feedwater could affect the ability of the plant to cool down after a reactor shutdown, the NRC is concerned about these events occurring, even though an event with potentially serious consequences is unlikely to happen.

Because of the continuing occurrence of water hammer events, the NRC, in September 1977, informed all PWR licensees that water hammer events due to the rapid condensation of steam in the feedwater lines of steam generators represented a safety concern and that further actions by licensees for Westinghouse and Combustion Engineering designed nuclear steam supply systems are warranted to assure that an acceptably low risk to public safety due to such events is maintained. Accordingly, these licensees were requested to submit proposed hardware and/or procedural modifications, if any, which would be necessary to assure that the feedwater lines and feedrings remain filled with water during normal as well as transient operating conditions. At the same time, the NRC provided each PWR licensee with a copy of its consultant's report, "An Evaluation of PWR Steam Generator Water Hammer," NUREG-0291.

The feedwater system and steam generator at the Beaver Valley Power Station, Unit No. 1 (BVPS-1) were designed and built with provisions to preclude the potential for steam generator water hammer. The feedwater piping has loop seals or inverted U-tubes, the steam generator feedrings discharge through J-tubes on the top of the feedwater sparger, auxiliary feedwater flow is automatically initiated and as a result of the NRC review of the BVPS-1 for an operating license, a licensing condition was imposed limiting the flow of auxiliary feedwater in the event that a feedwater line might contain steam.

2.0 EVALUATION

Our consultant, EG&G Idaho Inc., prepared the enclosed evaluation of steam generator water hammer at BVPS-1 as part of our technical assistance program. We have reviewed this report together with the licensee's submittals listed under item 4.0.

3.0 CONCLUSION

Based on our knowledge of water hammer phenomena, and our review of the licensees responses and the enclosed evaluation report, we concur with our consultants conclusion that the existing means for reducing the potential for steam generator water hammer at this facility are adequate. These means are, therefore, acceptable to the staff and no further action is required of the licensee with regard to steam generator water hammer.

4.0 REFERENCES

1. Letter from E. J. Woolever to A. Giambusso, Subject - "Steam Generator Secondary System Fluid Flow Instability", July 9, 1975.

2. Letter from C. N. Dunn to R. W. Reid, Subject - "Response to September 2, 1977 NRC letter on Feedwater Water Hammer", January 25, 1978.

TECHNICAL EVALUATION
BEAVER VALLEY POWER STATION

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EG&G IDAHO, INC.

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I. INTRODUCTION

A safety evaluation was performed for the Beaver Valley Power Station (BVPS) 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.

Although a steam generator water hammer event has not been experienced to date at the BVPS, additional means were implemented to further limit the potential for water hammer at this facility. These means were adopted based on a review of events that occurred at several other facilities.

Since the rapid condensation of steam in the feedwater system can be avoided by keeping it full of water, this evaluation was based on the effectiveness of the modifications to maintain the feedwater system full of water during normal and transient operations. The information for this review was obtained from the licensee, from its submittals of July 9, 1975[1] and January 25, 1978[2], and from the Beaver Valley Power Station Final Safety Analysis Report[3].

A description of the feedwater system at the BVPS and its general operation during a transient are presented in Section II. The modifications*to reduce the potential for water hammer and a general discussion of the effectiveness of these modifications during transients conducive to water hammer are presented in Section III. Finally, conclusions are presented in Section IV concerning the acceptability of the modifications* made at the BVPS.

*Note added by NRC: Refers to design changes incorporated in the construction of Beaver Valley Power Station, Unit No. 1 prior to the issuance of the operating license.

II. FEEDWATER SYSTEM

1. DESCRIPTION

The feedwater system for the BVPS was designed to provide an adequate supply of feedwater to the secondary side of the three steam generators under all load conditions. Two half-size steam generator feedwater pumps, each rated at a flow rate of 15,200 gpm and 1900 feet total developed head (TDH), supply main feedwater to the three steam generators. Each feedwater pump is equipped with two 4000 hp electric motors connected in tandem. The pumps receive water from a common header supplied by the condensate pumps via the low pressure feedwater heaters.

Feedwater from the main feedwater pumps is supplied to a main header via the high pressure heaters. The main header splits into three 16" lines with individual feedwater regulating valves. Each feedwater line supplies water to a feedwater ring inside of each steam generator. Water is discharged from the top of the feedring via inverted "J" tubes which direct the flow downward.

The auxiliary feedwater system supplies water to the steam generators for cooling the reactor after shutdown. Auxiliary feedwater can be supplied to the steam generators by two independent pumping systems consisting of two electric motor driven and one turbine driven auxiliary feedwater pumps. The two motor driven pumps, each rated at 350 gpm and 2696 ft. TDH, operate with normal off-site power or power supplied by the emergency diesel generators. The turbine driven pump, rated at 700 gpm and 2696 ft. TDH, is driven by steam supplied from each steam generator outlet header. The auxiliary feedwater pumps are supplied with water from the 140,000 gallon primary plant demineralized water storage tanks. The backup water source is supplied by the river water pumps or the engine driven fire pumps which all take suction from one of the river water system headers. Redundant lines carry water from the auxiliary feedwater pumps and connect to each of the three main feedwater lines just outside of the containment building.

2. GENERAL OPERATION

During normal operation, the main feedwater system supplies feedwater to the three steam generators for heat removal from the primary system. This flow can be interrupted by the loss of off-site power or by a manual action or an automatic system protective action (such as a safety injection signal), all of which cause the main feedwater pump breakers to open. Depending upon the type and extent of such an action, closure of the main feedwater isolation, bypass, and control valves can also occur as a result of the opening of the main feedwater pump breakers. Complete isolation of the main feedwater system is initiated by (1) a reactor trip in coincidence with two out of three low primary coolant average temperature (T_{ave}) signals in the water returning from any one steam generator, (2) two out of three high-high steam generator levels in any one steam generator, or (3) a safety injection signal. The isolation of the feedwater system serves the dual purpose of (1) limiting excess reactivity resulting from a lowered T_{ave} due to continued feedwater flow entering the steam generators following a reactor shutdown and (2) preventing further addition of steam to the containment building in the event of a steam line break.

The interruption of feedwater for an extended period while the feedring is uncovered can result in drainage of the feedrings and feed-piping. Drainage of the feedrings and feedpiping results in admission of steam which is conducive to slugging and subsequent water hammer when auxiliary feedwater flowing in the main feedwater piping enters the piping at the entrance to the steam generators. Significant drainage is unlikely, however, due to installation of "J" tubes on the feedrings (described in a subsequent section) and prompt initiation of auxiliary feedwater after main feedwater flow has been terminated. Also, when the main feedwater control valve receives a closure signal, a significant amount of feedwater continues to enter the steam generators during the 15 second closure time of this valve. This feedwater flow during valve closure keeps the feedring full and contributes to the recovery of normal steam generator level.

The motor driven auxiliary feedwater pumps start on (1) two out of three steam generator low-low water level signals in one steam generator, (2) the opening of the main feedwater pump breakers, or (3) a safety injection signal. The turbine driven auxiliary feedwater pump starts on (1) any steam generator low-low level signal or (2) two out of three primary coolant pump low voltage signals. The maximum hypothesized time delay from feedring uncovery to delivery of auxiliary feedwater to the steam generators is about 20 seconds. This delay is based on a hypothetical transient which isolates the main feedwater system and automatically initiates auxiliary feedwater flow upon receipt of one or more of the preceding auxiliary feedwater pump start signals. Automatic interruption of auxiliary feedwater flow will result from a high-high steam generator level. Normally, however, the automatically initiated auxiliary feedwater is manually controlled shortly after feedring uncovery occurs. The auxiliary flow is then regulated and adjusted to refill the steam generators and maintain the water levels above the feedrings.

III. MEANS TO REDUCE THE POTENTIAL FOR WATER HAMMER

1. DESCRIPTION

The following procedures and hardware are employed in the BVPS to reduce the potential for water hammer in the feedwater system:

1. "U" shaped loops in the feedwater lines were installed at the entrance to the steam generators.

2. "J" shaped tubes were installed on top of the feedrings and the bottom discharge holes were plugged.

3. The auxiliary feedwater pumps automatically start within 20 seconds to supply auxiliary feedwater to the steam generators after the loss of the main feedwater pumps.

4. Administrative control limits the feedwater flow to an equivalent of 1.2 inches of steam generator secondary water level per minute within 2 minutes of determining that the level in any steam generator has been below the feedring.

The "U" shaped loops were installed in the feedwater lines with the first elbow of each loop connected to the steam generator nozzle. This loop "seal" reduces the length of feedpiping that could fill with steam should feedring uncovery and substantial drainage occur. By reducing this length of piping, the potential for water hammer is also reduced. The "J" shaped tubes were installed on top of the feedrings to provide for top discharge of water from the feedrings rather than bottom discharge. This arrangement keeps the feedrings full much longer after feedring uncovery occurs. Maintaining the feedrings and feedpiping full of water while the feedrings are uncovered greatly reduces the potential for water hammer. Under cold conditions an observer visually determined that the feedring drainage time for an uncovered feedring was about

2 1/2 hours. It was assumed that the only leakage from the feedring occurred through the thermal expansion clearance between the feedring nozzle and the steam generator nozzle. The prompt automatic start up of the auxiliary feedwater pumps after the loss of the main feedwater pumps will insure sufficient flow to keep the feedrings and feedpiping full of water during feedring uncovery. The auxiliary feedwater pumps are also used to recover the feedrings and maintain recovery under manual control. The motor driven auxiliary feedwater pumps are backed up by the turbine driven auxiliary feedwater pump. Both types of pumps have independent power supplies (Section II) to ensure that auxiliary feedwater is availabl- during any transient which causes interruption of main feedwater flow.

Administrative control limits the equivalent feedwater flow to 1.2 inches of steam generator level per minute (about 150 gpm) when the level is below the feedring. The flow limit is in effect within 2 minutes of feedring uncovery and allows time for the operator to become aware of feedring uncovery and to manually reduce auxiliary feedwater from full flow to the administrative limit.

2. EFFECTIVENESS DURING TRANSIENTS CONDUCIVE TO WATER HAMMER

2.1 Reactor Trip

During normal operation the water level in the steam generator is maintained above the feedring and therefore steam cannot enter the feedring to react with cold feedwater. After a reactor trip, however, the liquid levels in all steam generators "shrink" to a level below the feedrings. Within 15 seconds after the resulting steam generator low-low level signals, the motor driven and turbine driven auxiliary feedwater pumps automatically start up to supply auxiliary feedwater to the steam generators. The main feedwater system is isolated after a low reactor T_{ave} signal or a steam generator high-high level signal. Auxiliary feedwater is normally under manual control within 2 minutes after feedring uncovery. The manually controlled flow is then maintained until feedring recovery occurs and subsequently adjusted to maintain the steam generator levels above the feedrings. If the auxiliary flow is not manually reduced after its initiation, the auxiliary feedwater pumps will stop upon receipt of a high-high steam generator level signal.

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 systems keep the feedrings and feedwater piping full of water while feedring recovery occurs.

2.2 Loss of Main Feedwater Pumps

Any event that causes the main feedwater pump breakers to open will result in automatic startup of the motor driven and possibly the turbine driven auxiliary feedwater pumps within 15 seconds after the breakers open. The auxiliary feedwater is more than sufficient (even under manual control with the administrative flow limit) to keep the feedrings and feedpiping liquid full while the steam generators refill and feedring recovery occurs.

The loss of the main feedwater pumps would not result in drainage of the feedrings because auxiliary feedwater would be supplied to the feedrings and feedpiping before any significant drainage occurred. Therefore, the conditions necessary for water hammer are avoided.

2.3 Loss of Off-Site Power

Loss of off-site power which supplies the main feedwater pumps will cause the diesel generator to start automatically. The diesel generator is the backup power source for the motor driven auxiliary feedwater pumps which start after the loss of the main feedwater pumps. Within 20 seconds after the off-site power loss, the motor driven and turbine driven auxiliary pumps will start up to supply auxiliary feedwater to the steam generators. The turbine driven pumps are not dependent upon AC electrical power since steam to drive the pumps is drawn from the steam generator main steam lines and electrical controls are powered by the station batteries. Auxiliary feedwater continues until the feedrings are recovered and the steam generator levels are then maintained by manual auxiliary feedwater control.

As was the case for the loss of the main feedwater pumps, auxiliary feedwater maintains the feedrings and feedpiping full of water until feedring recovery occurs and again the conditions conducive to water hammer are avoided.

2.4 Operator Error

The potential for water hammer in the feedwater system increases 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 or recovery of the drained feedrings and feedpiping could then result in water slugging and subsequent water hammer.

After the uncovery of one or more feedrings, automatic auxiliary flow in conjunction with feedring "J" tubes greatly reduce the chance of substantial feedring drainage. If the feedpiping and uncovered feedring were to inadvertently drain partially or completely, the potential for water slugging would be decreased by (1) the administrative flow limitations and (2) the U-shaped geometry of the feedpiping at the entrance to the steam generators.

Administrative control limits the equivalent feedwater flow to 1.2 inches of steam generator level per minute (about 150 gpm) when the level is below the feedring. The flow limit is in effect within 2 minutes of feedring uncovery and allows time for the operator to become aware of feedring uncovery and to manually reduce auxiliary feedwater from full flow to the administrative limit.

2.5 Steam Line Break

The possibility of water hammer events occurring as a result of or in conjunction with a steam line break is also considered in order to determine whether this water hammer event could occur and cause a feedwater line rupture. Such a rupture could result in the blowdown of more than one steam generator or result in the loss of capability to supply auxiliary feedwater.

In the event of a steam line break, the flow of auxiliary feedwater would be automatically initiated by low-low water level signals from any one steam generator, opening of the main feed pump breakers, or by a safety injection signal. Thus the feedrings in the unaffected steam generators will be kept full of water by the automatic operation of the auxiliary feedwater system.

The auxiliary feedwater system provides sufficient redundancy to ensure the required flow to a minimum of two steam generators while subjected to a single failure. To maintain a safe condition, water need be supplied to only one steam generator for primary heat removal. Thus the means for precluding water hammer in the unaffected steam generators would be fully effective under the conditions of a steam line break.

2.6 Loss of Coolant Accident (LOCA)

Since the consequences of a LOCA might be increased by the blowdown of a steam generator during the LOCA, the possibility of a steam generator water hammer event resulting from the plant trip or safety injection operations initiated by the LOCA should be considered. At the Beaver Valley Power Station, a LOCA would result in a safety injection signal that would automatically initiate the flow of auxiliary feedwater.

Thus the conditions necessary to produce a water hammer event after a LOCA are avoided by the same means employed in the case of an ordinary reactor trip or the loss of off-site power discussed previously. These means will be effective in precluding water hammer events because the conditions in the steam generator and feedwater piping that might be conducive to water hammer will not be substantially influenced by whether or not the reactor trip is the result of 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 at the BVPS was discussed in Section III. This assessment has shown that under conditions which are most conducive to water hammer in the feedwater system (specifically, an uncovered and draining feedring and feedwater piping subjected to admission of cold auxiliary feedwater), the means to reduce the potential for water hammer at the BVPS are adequate to maintain a sufficiently full feedring and feedwater piping until feedring recovery occurs. Therefore, since keeping the feedrings and feedwater piping full of water eliminates the potential for slugging, we find that the means to reduce the potential for steam generator water hammer at this facility are adequate.

V. REFERENCES

1. Letter from E. J. Woolever to A. Giambusso, Subject - "Steam Generator Secondary System Fluid Flow Instability", July 9, 1975.

2. Letter from C. N. Dunn to R. W. Reid, Subject - "Response to September 2, 1977 NRC letter on Feedwater Water Hammer", January 25, 1978.

3. Final Safety Analysis Report, Beaver Valley Power Station, Duquesne Light Co., DOE Docket No. 50-334.