GE Hitachi Nuclear Energy

0000-0100-4963-R0-NP
eDRF 0000-0088-8662
Class I
April 2009

NON-PROPRIETARY INFORMATION

BWR Owners' Group Technical Report

Effects of Voiding in ECCS Drywell Injection Piping

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Abstract

This report was prepared for the BWROG Gas Intrusion Committee to address concerns with voiding in the ECCS, SDC and Containment Spray piping downstream (i.e. towards the vessel, containment, etc.) of the first normally closed motor operated isolation valve. The report is a qualitative assessment to address specific concerns of GL 2008-01 for potential of voids existing in these sections of piping.

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ACRONYMS and ABBREVIATIONS

BWR	Boiling Water Reactor
BWROG	BWR Owners Group
CST	Condensate Storage Tank
DBA	Design Basis Accident
ECCS	Emergency Core Cooling Systems
°F	Degrees Fahrenheit
GEH	GE Hitachi Nuclear Energy
GL	Generic Letter
HPCI	High Pressure Coolant Injection
INPO	Institute of Nuclear Power Operations
LPCI	Low Pressure Coolant Injection
MOV	Motor Operated Valve
NRC	Nuclear Regulatory Commission
OE	Operating Experience
Ref.	Reference
Rev.	Revision
RCIC	Reactor Core Isolation Cooling
RHR	Residual Heat Removal
SIL	Services Information Letters
SDC	Shutdown Cooling

1. INTRODUCTION

1.1 Background and Purpose

This report was prepared for the BWROG Gas Intrusion Committee to provide guidance in determining a response to GL 2008-01 for the section of piping downstream of the first normally closed motor operated isolation valve on the Emergency Core Cooling (ECCS), Shutdown Cooling (SDC) and Containment Spray Systems. All piping references in this report, unless specifically described to mean differently, is referring to the piping downstream of the first normally closed motor operated valve in the discharge piping to the vessel, feedwater line, recirculation lines or containment spray headers.

This report focuses on voids in the ECCS, SDC and Containment Spray systems, which could challenge the operability of these systems prior to being required to mitigate any postulated events. This report specifically addresses the concern that the piping downstream of the isolation valve may contain unventable voids due to valve bonnets, piping slope, etc. The report does not evaluate, or justify, not venting those sections, which were designed to be reasonably full and have vents installed.

The scope of review will be limited to voids existing prior to an accident or transient in which the systems initiate, either automatically or by manual action. Furthermore, this report does not address voiding upstream (towards the pump) of the closed isolation valve.

The following GL 2008-01 concerns are applicable to the discharge piping:

1. Waterhammer or Pressure Transient causing piping or component damage
2. Noncondensible gases injected into vessel that may affect core cooling
3. Time to fill voided piping that could delay delivery of water beyond timeframe used in analysis

The GEH analysis (except for those plants that have requested otherwise) credits full flow when the injection valve reaches full open. No credit is given for any flow that occurs as the valve opens. Also, since most, if not all, injection valves are gate valves full flow is reached before the valve is full open. Due to these two conservatisms in the analysis, a delay in injection due to voids in the discharge piping would be bounded by other conservatisms and should have no effect on the accident analysis. The time to fill voided piping and the effect that noncondensibles may have on core cooling (items 2 & 3 above) are further addressed in 0000-0100-5014-R0-P, *Investigation of Potential Effects of Gas Intrusion on ECCS Analysis as Part of GL 2008-01 Resolution.* In contrast, this report is only concerned with the potential for waterhammer effects from voids in the injection piping downstream of the first closed isolation valve. This report provides a basis for determining the extent of piping walk downs and slope measurements that are performed to satisfy the concerns of GL 2008-01.

2. SUMMARY

This report demonstrates that any voids for the sections of piping downstream of the first normally closed motor operated isolation valve will not create a waterhammer that could challenge the operability of those systems when required to mitigate any postulated events. A portion of piping that discharges into the vessel, or lines directly connected to the vessel, will void (due to flashing) during vessel de-pressurization and are designed accordingly. Any pressure transients occurring due to voids are accounted for in the original piping design margin. Piping design philosophy is to design piping to preclude severe waterhammer events. Part of this philosophy is to include hard pipe vents on piping sections where void formation is detrimental. For the piping downstream of the normally closed isolation valve, vents may be installed between the isolation and downstream check valve. These vents can be used to ensure that the piping is vented after a drain down or maintenance in a plant outage but usage at power needs to be carefully evaluated. Generally, the water in this section of piping can be above the saturation temperature at atmospheric pressure, so venting with the system above 212 °F will void the pipe. It will not vent noncondensibles.

Given the above, the concerns of GL 2008-01 are addressed for the Low Pressure Coolant Injection (LPCI), Shutdown Cooling (SDC), Isolation Condensers, High Pressure Core Spray (HPCS) and Low Pressure Core Spray (LPCS) systems. Containment Spray systems are designed to be voided in standby. No further actions in verifying the piping's actual configuration are necessary to address GL 2008-01 for the discharge piping downstream of the isolation valve.

During a normal vessel scram, which may not necessarily occur due to an accident, HPCI can automatically initiate and inject into a water solid system (feedwater). Due to the numerous waterhammer events and various plants' piping configurations, the recommendation is for each plant to perform a specific evaluation of HPCI to determine if further actions are warranted to address the concerns of GL 2008-01.

3. DISCUSSION

3.1 Approach and Methodology

A review of existing plant design information was performed to determine if the injection piping downstream of the closed isolation valve could present a potential water hammer transient if voids were present. The review included US plants from the BWR 2 to BWR 6 design.

3.2 Assumptions and Inputs

The analysis in this report is qualitative and no specific analysis is performed for any system. The assumption is further made that each plant has adequate procedures in place to ensure that applicable piping systems that are designed to be full are fully vented to the extent possible following draining or maintenance.

3.2.1 Water Hammer Mechanisms

Rapid flow transients create pressure changes in piping systems. This phenomenon is termed water hammer. If the pressure changes are large enough, the induced forces may impair the structural integrity of the piping. Additionally, the integrated effect of the transient pressure distribution along the piping causes a pipe reaction loading that may damage pipe supports. Classical conditions, which have the potential to create water hammer, include:

- Pump starts
- Pump trips
- Rapid valve closure / opening
- Pump discharge into voided pipes
- Condensation induced flows

Standard industry practice is to design and operate hydraulic systems in a manner to preclude severe waterhammer loads. As part of this design philosophy hard pipe vents may be installed to vent voids that form after a system drain down, whether for maintenance or a change in system line up.

3.3 OE review

There is no history of a vessel injection due to an accident, thus no Industry operating experience exists for most of the ECCS systems injecting into the vessel, or containment spray at power. A large amount of operating experience was found for the HPCI system and was reviewed as part of this report. The operating experience most applicable is INPO OE16542, *HPCI Support Failure Due to Lack of Venting,* (also referenced in GL 2008-01). Piping supports were damaged during vessel injection due to a combination of air upstream, and steam downstream, of the isolation valve (Ref. 3).

3.4 Design

The discharge piping was designed, fabricated, erected, and tested, in accordance with applicable ASME and ANSI and quality control procedures, so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture. The design process incorporated engineering practices to prelude waterhammer events, including installation of hard pipe vents and ensuring pipes are adequately sloped to allow venting.

3.4.1 Containment Sprays

While a number of Containment Spray configurations exist for the different BWR designs, they all spray into a voided atmosphere. There are no check valves or manual isolation valves downstream of the closed isolation Motor Operated Valve (MOV). Piping downstream of the injection MOV communicates directly with the nitrogen or air filled containment space and thus is always void of water. Since this portion of the line is voided by design, no further actions in regards to piping inspection or venting is needed, or required.

3.4.2 Shut Down Cooling

The Shutdown Cooling (SDC) mode is designed to remove the sensible and decay heat from the reactor primary system during a normal reactor shutdown. This non-safety operational mode allows the reactor to be cooled down within a certain time objective, so that the SDC mode of operation will not become a critical path during refueling operations. The system is manually initiated at low reactor pressure and procedurally controlled to preclude waterhammer transients. Since the system is utilized for refuel outages there is a high confidence that current operating procedures are correct. Plants may wish to review GE SIL No. 175, which provides guidance in procedure development. There are no known instances in which waterhammer has occurred due to unventable piping sections or a plant's physical design. Therefore, no further investigations are required for the SDC discharge piping.

3.4.3 Isolation Condensers

The isolation condensers inject into the suction of the recirculation pumps. Normally closed MOVs exist at the discharge of the heat exchangers with normally open MOVs at the recirculation line connection. The isolation condenser injection line discharges to the suction side piping of the recirculation pumps. There are no check valves between the normally closed isolation valve and vessel. Any small air void that may exist would be compressed to the suction pressure of the recirculation pump and, since the piping discharge path is open to the vessel, swept into the vessel.

3.4.4 Core Spray

Two loops of Core Spray inject into spargers above the core, but below the normal operating water level. Typical configuration is a closed isolation valve outside of the drywell, a check valve inside the drywell and a manual open isolation valve between the check valve and vessel. BWRs 2, 3 and 4 have two low pressure Core Spray loops; BWRs 5 and 6 have one loop of Low Pressure Core Spray and one loop of High Pressure Core Spray.

The Core Spray injection line downstream of the check valve is in communication with a steam atmosphere, of approximately 80% quality, during normal operation. Water in the discharge piping will also be steam, declining in quality as distance from the vessel increases. Between the vessel and, upstream, to the isolation valve the steam will become saturated and potentially sub-cooled. In an accident, the saturated water flashes to steam due to vessel de-pressurization. Thus, during an actual injection following a postulated accident, a portion of the piping downstream of the isolation valve will be voided due to flashing, and Core spray is injecting into a partially voided line.

Any pressure transients due to air pockets in the injection line at this time would be negligible compared to the pressure transients of vessel de-pressurization and injection into a steam environment. Furthermore, both theoretical and experimental research demonstrates that the pressure transient caused by a pump discharge into a steam void is lessened by air pockets in the steam void (Ref. 4).

3.4.5 Low Pressure Coolant Injection

For BWRs 3, some 4's and some 2's, two loops of LPCI inject into two recirculation lines. For BWRs 5 and 6, three loops of LPCI directly inject into vessel inside of the core shroud.

LPCI injects automatically when the vessel is rapidly de-pressurized during an accident below the plant specific low pressure value, generally 350 ~ 450 psig. The rapid de-pressurization will result in flashing in both the vessel and recirculation lines (for those BWRs that also inject into recirculation). Thus, LPCI is injecting into a voided atmosphere and the pressure transient would be similar to Core Spray. The effect of air pockets trapped in the injection piping between the isolation valve and recirculation line would be inconsequential.

3.4.6 High Pressure Coolant Injection

BWRs 2, 3 and 4 have HPCI. The system injects into the feedwater line between two feedwater check valves, although two BWR 4 plants also simultaneously inject into core spray and feedwater. The installed piping varies considerably and may or may not have a check valve downstream of the isolation valve. The initiation signal controlling the isolation valve opening also varies between plants, which can affect the pressure transient on a pump start. Since HPCI must overcome vessel pressure to inject, the last check valve, and not the motor operated isolation valve, acts as the isolation valve. Therefore, piping configuration and timing have significant effects on the potential for waterhammer.

Operating experience demonstrates that the HPCI system is the BWR system most prone to issues with waterhammer events. A number of waterhammer events were attributed to air in the discharge piping. Even though most of the events were in the test mode, and not an actual injection, due to the factors described above, the potential exists for air voids between the pump and last check valve to cause a waterhammer. Typically, the waterhammer events cause a low suction pressure trip, although one plant did experience piping support damage. The low suction pressure trip is caused by the reflected pulse, which causes "ringing" in the suction line of HPCI (and possibly RCIC if the two systems share a common header). Since low suction pressure trips on HPCI can be caused by a number of factors, including ramp time and piping configuration, many plants have installed a time delay on the low suction pressure trip instrumentation to preclude a turbine trip.

Small air pockets downstream of the isolation valve would be similar to LPCI injecting into recirculation and should not cause a problem. However, given the variety in plant piping configurations, the uniqueness of the HPCI system, and operating experience no generic definitive statement can be made to exclude the HPCI injection piping from a plant specific evaluation.

4. CONCLUSIONS and RECOMMENDATIONS

4.1 Discussion

Air void pressurization can reduce waterhammer magnitude since pulse magnitude rises slower, which can allow time for reflections from free surfaces to relieve pressure buildup. For the specific case of the injection piping downstream of the isolation valve the voids will compress until the void pressure equals the pressure of the reservoir the line is injected into and the fluid acceleration will be downstream towards the vessel or larger injection path (such as recirculation piping). Since the downstream area increases in volume, there will be no reflected pressure wave and the pressure pulse will be negligible. Therefore, no water hammer greater than the expected pressure transient that occurs during an accident during an actual injection will occur due to voids in this section of piping for all systems except potentially HPCI.

Given the variety in plant piping configurations for HPCI, the uniqueness of the turbine driven pump, and operating experience no generic definitive statement can be made to exclude the HPCI injection piping from a plant specific evaluation.

4.2 Conclusion and Recommendations

Except for possibly HPCI, even if voids did exist in the discharge piping downstream of the isolation valve for the ECCS systems, the pressure transient would not be greater than an actual injection in an accident. The HPCI system should be evaluated on a plant specific basis due to the uniqueness of the system and variety in piping configurations.

The GEH analysis (except for those plants that have requested otherwise) credits full flow when the injection valve reaches full open. No credit is given for any flow that occurs as the valve opens. In addition, since most, if not all, injection valves are gate valves full flow is reached before the valve is full open. Due to these two conservatisms in the analysis, a delay in injection due to voids in the discharge piping would be bounded by other conservatisms and should have no effect on the accident analysis.

No actions are required to verify the plant configuration of the SDC and Containment Spray discharge piping.

5. REFERENCES

1. GEH NEDM-22161, Assessment of Waterhammer in Hydraulic System Piping, July 1982.
2. NRC GL 2008-01, Managing Gas Accumulations in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems, January 2008.
3. INPO OE16542 (Event number 010719 & 010705 also NRC LER 2002-005-01), High Pressure Coolant Injection System Inoperable Due to Water Hammer Event, February 2003.
4. A. Lai, K.F. Hau, R. Noghrehkar, R. Swartz, Investigation of Waterhammer In Piping Networks With Voids Containing Non-condensable Gas, September 1999.