*Transactions of the Korean Nuclear Society Spring Meeting*
*Jeju, Korea, May 29-30, 2014*

# RCS Core Cooling Response Evaluation for Potential Gas Accumulation Location of Accumulator Discharge side in Westinghouse 3-Loop

**Seung-Chan LEE**[a*] , Duk-Joo Yoon[a] , Jong-Chan LEE[b] and Jong-Uk Kim[b]
[a] *Korea Hydro Nuclear Power Electricity Co., KHNP Central Research Institute, Reactor Safety Laboratory, Yuseong-daero 1312-gil, Yuseong, Daejeon 305-343 Korea.*
[b] *FNC Technology Co., LTD.Heungdeok IT Valley 32th floor, 13, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 151-742 Korea*
[*] *Corresponding author: babel2lsc@khnp.co.kr*

## 1. INTRODUCTION

The U.S Nuclear Regulatory Commission(NRC) issue a Generic Letter 2008-01 to address the issue of gas intrusion and accumulation into the Emergency Core Cooling System, the Residual Heat Removal System and the Containment Spray System. This document request that each licensee evaluate its ECCS, RHR and CSS licensing basis, design, testing and corrective actions to ensure that gas accumulation is maintained less than the amount that challenges operability of these systems, and that appropriate action is taken when conditions adverse to quality are identified. In relation to this, utilities should develop and maintain a method for determining and documenting all system high points and other potential gas void locations[1,2].

During performing a review of system design document on Westinghouse 3-loop nuclear power plant(NPP), including piping and instrument diagram, isometric drawing, technical specification and operating procedures to identify potential gas void location, inverted-U shaped piping on the discharge side of accumulator could impact the ability of the system to perform its function.

The results for the review of fill/vent activities and procedures, the existing procedures do not currently identify the amount of gas accumulated in the system after the related procedure of the accumulator. This location should be evaluated for possible options which could prevent or minimize gas accumulation because Technical Specification Surveillance Requirements state that Each ECCS subsystem shall be verify that the ECCS piping is sufficiently full of water

These findings will be used to develop acceptance criteria, evaluate potential void locations, exclude locations form further evaluation, and identify additional desired vent valve locations, monitoring point, etc.

## 2. IDENTIFY POTENTIAL GAS ACCUMULATION LOCATION

Figure 1 shows Emergency Core Cooling System between accumulator and RCS cold leg in Westinghouse 3-loop. The accumulators are pressure vessels partially filled with borated water and pressurized with nitrogen gas. During normal operation, each accumulator is isolated from the RCS by two check valves. Motor operated isolation valve is closed during plant shutdown. As part of the plant shutdown procedure, the operator is required to close this valve. This prevents a loss of accumulator water inventory to the RCS. During the plant startup, the operator is open isolation valve when the RCS pressure reached the safety injection unblock set point[3].

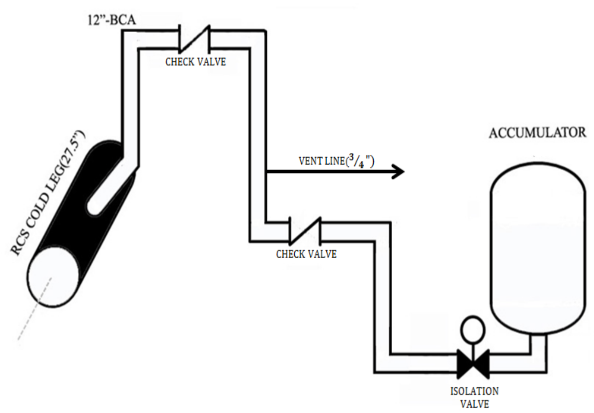


Fig.1. The discharge piping on accumulator in Westinghouse 3-Loop NPP

If non-condensable gas is trapped in inverted-U horizontal piping, it may affect delay or reduction in ECCS flow rate exceeding the point assumed in the safety analyses and have adverse effects on flow delivery or performance. Also, the impact of the gas voids on heat transfer in the core region under this void condition is expected to have an impact on the RCS core cooling response[4].

In the cases of Westinghouse 3-loop NPP, the horizontal piping located on the discharge side of each accumulator has inverted-U shaped configuration and there are currently no way to vent directly this location of potential gas accumulation.

Periodic test procedures, including check valve leak test, accumulator fill/vent procedure, RCS fill/vent procedure, may influence on the piping fill/drain condition in the inverted-U piping. Again, it is most important thing that this location may not comply with Technical Specification requirements and there are no any Surveillance Requirement for monitoring/venting of gas accumulation.

## 3. ANALYSIS AND RESULTS

### *3.1 Evaluation of Gas Movement Using Froude Number*

The initial consideration to a simplified approach to prediction of gas transport is to determine if the Froude number is large enough so that gas will be moved by flowing rate[5]. The sequence of events is as figure 2.

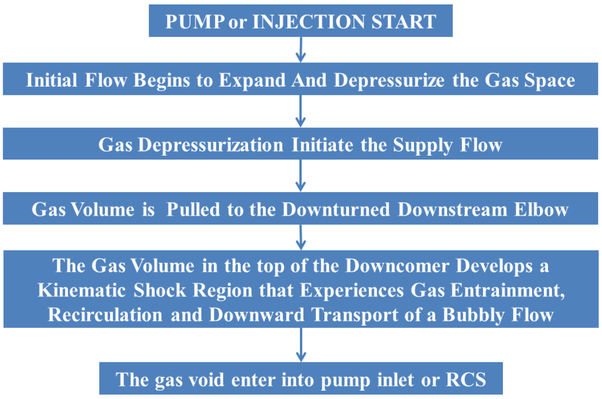


Fig. 2. The Sequence of Gas Movement Events in Inverted-U Piping

With respect to operability determination, use of Froude number could determine the gas movement[5,6]. Froude number is defined by :

$$N_{FR} = \frac{V}{\sqrt{\dfrac{Dg_c(\rho_L - \rho_g)}{\rho_L}}} \qquad (1)$$

D = pipe diameter
V = liquid velocity based on total pipe flow area
$g_c$ = gravitational constant
ρ = density
subscript L indicates liquid
subscript g indicated gas

Froude number is that $N_{FR} \leq 0.31$ with $\Phi \leq 0.2$ is a condition where gas will not move in a horizontal pipe or downcomer in a vertical pipe. It also included that at $N_{FR} \leq 0.65$, some gas may be transported and if NFR $\geq 2.0$, all gas will be carried out of a pipe with the following water. Time to clear gas from a pipe for $0.8 < N_{FR} < 2.0$ is a function of flow rate. Dynamic venting may not be assumed effective for $N_{FR} < 0.8$[6].

Use of Froude number that is consistent with NRC acceptance criteria is summarized in the following table.

Table 1. $N_{FR}$ and Gas Movement Effect

| NFR | Effect |
|---|---|
| $\leq 0.31$ | No gas movement in horizontal pipe if $\Phi \leq 0.20$ |
| $0.31 < N_{FR} < 0.65$ | Some gas may be transported depending on pipe geometry |
| $>0.54$ | Gas will move toward the downstream end of a horizontal pipe that has no local high point. Some bubbles may move downward in a vertical pipe. |
| $<0.8$ | Dynamic venting not effective |
| $0.8 < N_{FR} < 2.0$ | Time to clear gas is a function of flow rate and piping geometry. Timing is not well characterized. |
| $\geq 1$ | Gas will be removed from an inverted U tube heat exchanger for steady state flow lasting several minutes. Criterion not applicable at bottom of vertical pipe that connects to a horizontal pipe |
| $>1.2$ | Horizontal pipe that is open at the downstream end will run full |
| $\geq 2.0$ | All gas will be removed from pipe but localized gas pockets may remain where full flow conditions may not exist such as in the vicinity of valves or orifice |

It is assumed that the conditions of the discharge piping on accumulator at plant shutdown are 20℃ and 1 atm. In relation to trapped gas in inverted-U piping, the results of $N_{FR}$ calculation represents in Table 2.

Table 2. Input and Results of $N_{FR}$ calculation

| Variable | Value |
|---|---|
| Input | |
| $\rho_L$ | 998.23 kg/m$^3$ |
| $\rho_g$ | 1.204 kg/m$^3$ |
| D | 0.26676 m |
| $g_c$ | 9.80665 m/s$^2$ |
| A | 1.293 m/s |
| Results | |
| V | 1.293 m/s |
| Q | 1146 gpm |

The minimum flow rate of 1146 gpm is needed for that the trapped gas could be removed from horizontal pipe and/or dynamic venting effective.

### *3.2 Evaluation of RCS Core Cooling Response*

The evaluation of this section is to qualitatively evaluate through engineering judgment the impact on the reactor coolant system of a small amount of non-condensable gas in ECCS piping in PWR designs during accident conditions. For the high pressure system piping, an initial sum total of 5ft$^3$ of gas at a system pressure of 400 psia and ambient temperature of 68°F is assumed. The initial condition pressure assumptions are based on hot shot-down conditions with ECCS pressurized to that of the RCS, and what could be tolerated in those portions of the ECCS without adverse effects on flow delivery or performance. Any void volumes observed in the ECCS piping can be adjusted accordingly to accommodate for pressure and temperature as long as they do not exceed the equivalents at the specified conditions. This gas volume criteria is based on gas void quantities which are larger than the anticipated gas volume in the ECCS system under any circumstance[4].

It is assumed that inverted-U piping, including vertical piping, on the discharge piping of accumulator A,B and C is totally empty. It is conservative evaluation to evaluate RCS core cooling ability effected by accumulated gas in ECCS system. The results are listed below.

Table 3. Comparison Between Allowable Criteria and Maximum Expected Gas Void Size in Accumulator

| Variable | | Gas volume |
|---|---|---|
| Allowable Criteria | | **3.44 $ft^3$** |
| Accumulator A | Plant Shutdown | 15.527 $ft^3$ |
| | Normal Operation | 0.391 $ft^3$ |
| Accumulator B | Plant Shutdown | 13.921 $ft^3$ |
| | Normal Operation | 0.350 $ft^3$ |
| Accumulator C | Plant Shutdown | 13.536 $ft^3$ |
| | Normal Operation | 0.341 $ft^3$ |
| Total | Plant Shutdown | 42.984 $ft^3$ |
| | Normal Operation | **1.08 $ft^3$** |

With 5$ft^3$ at 400 psia as a starting point, the results under variations in pressure and temperature assuming ideal gas behavior. As a result in table 3, gas void meet allowable criteria although all inverted-U piping on the discharge piping of accumulator are totally empty.

## 4. DISCUSSION ON POSSIBLE CORRECTIVE ACTIONS

Although we confirm that potential gas accumulation locations in Westinghouse 3-Loop, inverted-U piping on the discharge piping of accumulator, are not exceed allowable gas volume, corrective action may need to ensure the ECCS integrity and cope with regulatory authority's requirements. To fill this location and verify sufficiently full of water, new operating procedure should be developed. It is proposed as possibility option, which uses existing facility with having no design modification. It presents in figure 4 below.

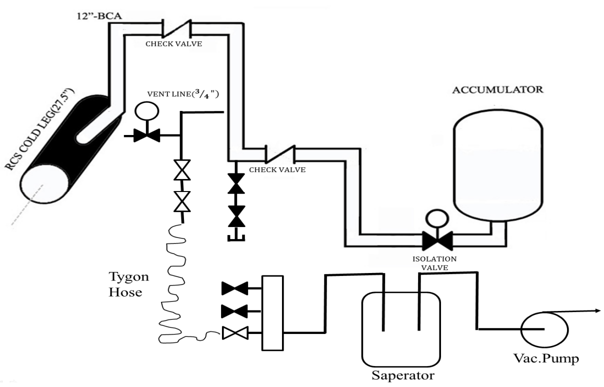


Fig. 3. Fill and Drain Method Using Vacuum Pump

Its more detail steps are described below in table 4. This procedure doesn't include verification method of full of water. So, it may need to perform ultrasonic testing to verify keeping it full of water in this piping when finishing this procedure.

Table 4. Fill/Drain Procedure Using Vacuum Pump

| FILL/DRAIN PROCEDURE USING VACUUM P/P | |
|---|---|
| 1 | Drain Using Drain Valve Between Two Check Valves |
| 2 | Identify that Isolation Valve is Closed on the Discharge Piping of Accumulator |
| 3 | Open the accumulator vent valve |
| 4 | Connect Tygon Hose between Drain Valve and Vacuum Pump when drain is finished |
| 5 | Vacuum Pump Startup |
| 6 | Close Drain Valve after Forming a Vacuum, |
| 7 | Open Isolation Valve and Fill the Piping |
| 8 | Return to the Normal Line-up |

## 5. CONCLUSIONS

Consequently, assumed gas void 1.08$ft^3$ satisfy the allowable criteria when it is postulated that all inverted-U piping are empty in the discharge piping of accumulator A,B and C.

For LBLOCA, also, the addition of the extra gas volume to the RCS will have no impact. Gas that is injected prior to accumulator empty time is either ejected through the break via ECCS bypass or will have negligible effects on core heat transfer since a large amount of vapor may already present in the core region at that time. In the longer term, the majority of these gas either migrate to the upper space of the RCS or out into containment where they have no bearing on core cooling response[4].

To ensure the ECCS integrity and comply with regulatory commission's requirements, new operating procedure is proposed with having no design change. These findings could be used for evaluation basis to develop acceptance criteria and identify additional desired vent valve locations, monitoring point, etc.

## ACKNOWLEDGEMENT

This work was carried out by Central Research Institute (CRI) of Korea Hydro and Nuclear Power (KHNP) in relation with "Development of Evaluation Methodology and Management Program of Gas Accumulation of Safety Related Systems" project.

## REFERENCES

[1] USNRC, Managing Gas Accumulation in Emergency Core Cooling, Decay Heat Removal, and Containment Spray Systems, Generic Letter 2008-01, 2008.

[2] NEI, Guideline for Effective Prevention and Management of System Gas Accumulation, NEI-09-10 Revision 1a-A, 2013

[3] FSAR Chapter 6, KRNPP-3,4, 2013

[4] Non-condensable Gas Voids in ECCS Piping ; Assessment of Potential Effects on Reactor Coolant System Transients Including Chpater 15 Events, LTR-LIS-08-627, Westinghouse Electric Company, 2008

[5] Technical Basis for Gas Transport to the Pump Suction, Fauske and Associates, LLC, 2010

[6] NRC, Final Safety Evaluation for Nuclear Energy Institute Topical Report NEI 09-10 Revision 1a " Guidelines for Effective Prevention and Management of System Gas Accumulation", 2013