Safety Injection System Filling Using Dynamic Venting

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1. Introduction

The U.S. Nuclear Regulatory Commission (NRC) issued Generic Letter 2008-01[1] to address the issue of gas accumulation in the emergency core cooling, decay heat removal, and containment spray systems. Instances of gas accumulation in the subject systems have occurred since the beginning of commercial nuclear power plant operation. More than 60 gas accumulation events have been reported since the 1997 Oconee Unit 3 event.

In the APR+, the water-level elevation of the in-containment refueling water storage tank (IRWST) is lower than the highest piping of the SIS. Since the gravity filling of water from IRWST cannot fill all SIS piping, an SIP or an SCP test line is newly provided in order to allow the dynamic venting of the SIS. NEI 09-10 Revision 1a-A[2] has concluded that use of dynamic venting is an effective means to remove gas from local high points and traps in piping when correctly based on the dynamic flow rate, void volume, Floude number, and the system water volume. In this study, feasibility of the dynamic vent is investigated.

2. Methods and Results

This study describes how to supply coolant to the Safety Injection System (SIS) and Shutdown Cooling System (SCS) using dynamic venting, which are supposed to be applied to the APR+ to satisfy the survaillence requirements (SR) in Technical Specifications in regard to GL 2008-01[1] and NEI 09-10[2]. The dynamic venting method is to fill the upstream and downstream of the pumps in the system with water and prevent air binding and water hammering in the operation of the pumps.

2.1 Previous SIS Filling Design

For the OPR1000, the minimum elevation of the water level of the refueling water storage tank (RWST) is 132 ft and 11 inches, which is higher than the maximum elevation of the SIS piping by 18 ft. There is sufficient head to fill the SIS with the water of the RWST. However, the elevation of the normal operation water level of the IRWST for the APR+ is 93 ft, which is lower than the maximum elevation of the SIS piping by 31 ft. Therefore, there is not sufficient head for gravity filling. That means that gas can accumulate at some portions of the SIS piping higher than the water level of the IRWST.

The APR+ safety injection system filling design has been reviewed. The SIS piping lower than the elevation of the IRWST normal water level is filled with water by the static pressure of the IRWST. However, for the areas of the SIS higher than the normal water level of the IRWST, the safety injection filling tank (SIFT) is used with throttling open the venting valves that are equipped in the SIS piping.

2.2 SIS Filling Using Dynamic Venting

The feasibility to fill the SIS using the dynamic venting has been investigated. The dynamic venting is performed by starting pumps that makes high flow rates through the piping in the systems and sweeps gas intruded and accumulated in the pipings into the IRWST. For this purpose, new recirculation piping to the IRWST is necessary. The ATF Fathom code is used to determine the appropriate diameter of the new recirculation pipings. This is because the system flow rate changes according to the resistance of the flow path.

The APR+ designs for the dynamic venting of SIS is as follows;

1. Use of SIPs with a new piping between IRWST and SIS
2. Use of SCPs with a new piping between IRWST and SIS

$$N_{FR} = \frac{V}{\sqrt{Dg}} \quad (1)$$

D = pipe diameter
V = liquid velocity based on total pipe flow area
g = gravitational constant

Table 1. The Effect of the Froude Number on the Dyanmic Venting [2]

Froude number, N_{FR}	Interim Gas Movement Criteria
≤ 0.31	No gas movement in horizontal pipe if Φ ≤ 0.20*
$0.31 < N_{FR} \leq 0.65$	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 points. 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 charactrerized.
≥ 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
≥ 2.0	All gas will be removed from pipe but localized gas pockets may remain where full flow remain where full flow conditions may not exist such as in the vicinity of valves or orifices.

*The Φ ≤ 0.20 criterion reasonably ensures there is sufficient flow area for liquid transport

(Φ : average non-condensable gas void fractions)

Table 2. Froude Number at the 12 inch piping with 6 inch recirculation piping

Length of recurculation Pipings	Number of elbow at recirculation piping				
	10	15	20	25	30
100 ft	3,727gpm N_{FR}=2.85	3,573gpm N_{FR}=2.73	3,437gpm N_{FR}=2.63	3,316gpm N_{FR}=2.54	3,207gpm N_{FR}=2.45
150 ft	3,483gpm N_{FR}=2.66	3,357gpm N_{FR}=2.57	3,244gpm N_{FR}=2.48	3,141gpm N_{FR}=2.40	3,048gpm N_{FR}=2.33
200 ft	3,281gpm N_{FR}=2.51	3,175gpm N_{FR}=2.43	3,079gpm N_{FR}=2.36	2,992gpm N_{FR}=2.29	2,911gpm N_{FR}=2.23

Froude number is defined by the equation (1). Table 1 shows the dynamic venting operation performed by the industry[2] with which the NRC agrees. Therefore, the evaluation results in Table 1 are used to determine the possibility of the dynamic venting in the APR+.

The Froude number is required to be over 2.0 to make dynamic venting available regardless of piping features. Therefore, under the criterion of the Froude number, N_{FR} = 2.0, for the dynamic venting design, two (2) different alternative dynamic venting designs are analyzed. For the Froude number calculation, the characteristics with the various Froud numbers. Temperature of water and gas in the piping is conservatively assumed as 120 ˚F which is the maximum temperature inside the containment building.

2.2.1 Using SIP with New Pipings to the IRWST

To apply dynamic venting for the APR+, new connection piping should be added.

Because the maximum operational flow rate of the SIPs for the APR+ is 1,460 gpm, the SIP is able to discharge higher flow rate than 459 gpm, which is the least flow rate satisfying the Froude number of 2.0 on the basis of 5 inches in diameter so that accumulated gas is swept out in 5 inches-pipings.

However, for the discharge-pipings of the SIS sharing with the SCS that expands to 12 inches, the Froude number should be over 2.0 to carry accumulated gas into the IRWST. The Froude number for the piping of 12 inches in diameter is 1.1 in the flow rate of 1,460 gpm but is not enough to use dynamic venting.

If the Froude number is $0.8 < N_{FR} < 2.0$, time for the dynamic venting varies with the flow rate and piping arrangement. Especially in the case of discharged water that flows down through the vertical piping, it is hard to evaluate whether gas in the vertical pipings is swept out of the pipings by the discharged flow. The APR+ design has not been completed yet, but if the design changes on the SIP and the pipings are made to allow flow rate to be over 2,617 gpm, more specific assessment should be performed for the dynamic venting.

2.2.2 Using SCP with New Pipings to the IRWST

The discharge flow rate, 5,000 gpm, of the SC/CS pump for the APR+ is sufficient flow to make the dynamic venting with the appropriate diameter of the pipings to be established. The SCS modeling is performed to calculate the flow rate required for the dynamic venting in Figure 1. The SIS piping arrangements in the Shin-Kori NPP 3 & 4 are assumed for the APR+. With the assumption of the proper length and fittings of the new recirculation pipings, the flow rate at the high points of the SIS and the SCS and the Froude number on the pipings of 12 inches in diameter are calculated. Two isolation valves are considered on the newly designed pipings for double isolation. According to the Table 1, if the pipings are designed with 6 inches in diameter, the Froude number at the 12 inch piping is over the criteria for dynamic venting, 2.0, with the SCP discharge flow rate, regardless of the piping length and the number of the elbows. Therefore, for effective vent at the 12 inch piping, SCP flow rate is necessary.

3. Conclusions

The work presented in this study evaluates the SIS and the SCS filling using the dynamic venting which is supposed to be applied to the APR+. The main ideas are as follows;

1. Dynamic venting using SIPs for the APR+ is not appropriate on the basis of 12 inches in diameter and with the flow rate, 1,460 gpm.

2. Because the high point of the SIS and the SCS is located at the piping that the two systems are sharing, the accumulated gas at the highest point can be removed by using the SCPs, and the dimension of the new piping will be determined by its length of them and the number of elbows. The calculated results are shown in Table 2.

3. The applicability of the dynamic venting methods using the SCPs that are mentioned above should be evaluated in the aspect of the system operation after the piping arrangements are settled in the APR+. The assessments to determine the pump opertation time are also required.

REFERENCES

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

[2] NEI 09-10, "Guidelines for Effective Prevention and Management of System Gas Accumulation," Rev. 1a-A, April 2013

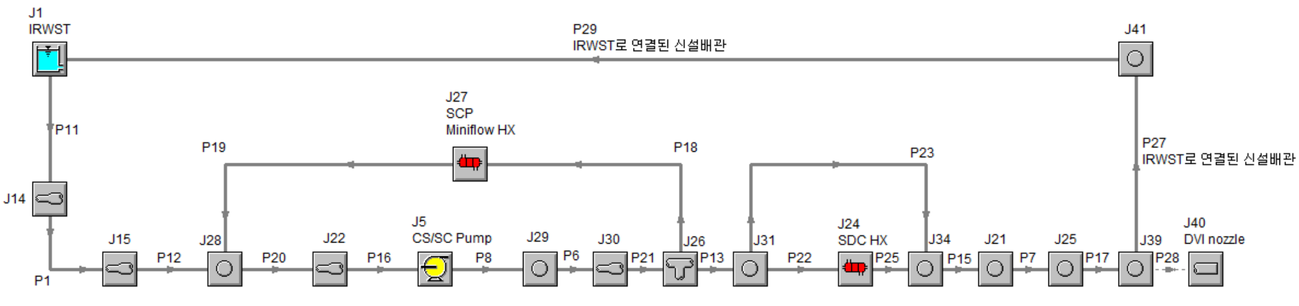

Fig. 1. Fathom Modeling for the SCS Dynamic Venting