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RCGVS Design Improvement and Depressurization Capability Tests for Ulchin Nuclear Power Plant Units 3 and 4

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Abstract

The Reactor Coolant Gas Vent System(RCGVS) design for Ulchin Nuclear Power Plant Units 3&4(UCN 3&4) has been improved from the Yonggwang Nuclear Power Plant Units 3&4(YGN 3&4) based on the evaluation results for depressurization capability tests performed at YGN 3&4. There has been a series of plant safety analyses for Natural Circulation Cooldown(NCC) event and thermo-dynamic analyses with RELAP5 code for the steam blowdown phenomena in order to optimize the orifice size of UCN 3&4 RCGVS. Baesd on these analyses results, the RCGVS orifice size for UCN 3&4 has been reduced to 9/32 inch from the 11/32 inch for YGN 3&4. The depressurization capability tests, which were performed at UCN 3 in order to verify the FSAR NCC analysis results, show that the RCGVS depressurization rates are being within the acceptable ranges. Therefore, it is concluded that the orificed flow path of UCN 3&4 RCGVS is adequately designed, and can provide the safety-grade depressurization capability required for a safe plant operation.

1. Introduction

The U. S. NRC Branch Technical Position, Reactor Systems Branch(BTP RSB) 5-1[1] requires that the nuclear power plant demonstrate that it can be brought from normal operation to cold shutdown under the NCC condition using only safety-grade systems with either onsite or offsite power available(not both) and assuming a single failure. In response to these requirements, an NCC analysis from normal operation to shutdown cooling system entry conditions was performed[2, 3]. In this analysis, the RCGVS was credited as a safety grade mean for RCS depressurization because both the main and auxiliary pressurizer spray systems are not designed as safety grade systems.

According to the evaluation results for RCGVS depressurization capability tests performed at YGN 3&4[4], it was concluded that the depressurization capability of YGN 3&4 RCGVS was somewhat higher than the required. Therefore, there has been a series of evaluations for the test results including the re-analysis of NCC event as well as the RELAP5/MOD3.1 code analysis for steam blowdown through the RCGVS[6]. Based on the evaluation results, the optimum RCGVS orifice size has been determined and implemented into the UCN 3&4 design. Also, the tests were performed at UCN 3 in order to verify the RCGVS depressurization capability as well as the effect of design improvement. The purpose of this paper is to describe the RCGVS design improvement and its effect on the RCGVS depressurization capability using the UCN 3 test results.

2. Reactor Coolant Gas Vent System

The RCGVS, which is originally designed for high point venting, consists of gas vent lines connected to the top of pressurizer(PZR) as well as to the Reactor Vessel Upper Head (RVUH) as shown in Figure 1. The PZR Gas Vent(PGV) lines has two flow paths; one with two solenoid valves and the other with a flow restricting orifice and a solenoid valve. The RVUH gas vent lines have a common flow restricting orifice and two flow paths with a solenoid valve in each path. Both lines from the PZR and RVUH are connected to the reactor drain tank via the PZR safety valve discharge line. Of the two PGV paths, the orificed line was used to depressurize the RCS during the NCC analysis[2, 3].

The piping lengths for the total branch line from the PZR nozzle to valve are: approximately 6.9 meters from the PZR nozzle to the orifice, 1.2 meters from the orifice to the first valve, and 10.8 meters from the first valve to the second valve, respectively. The pipe diameters are: 1.9 cm(PZR nozzle to orifice), 2.5 cm(valve through branch tee), 5.0 cm (branch tee to valve), respectively.

3. Design improvement of the RCGVS

3.1 Background

Based on the YGN 3&4 test evaluation results for RCGVS[4], the depressurization capability was acceptable in the view point of the minimum flowrate, which was determined to be a limiting case for the NCC analysis[2]. However, all test data for YGN 3&4 exceeded the upper limit of the original test acceptance criteria. In order to determine the impact of measured depressurization rate exceeding the upper limit, a series of safety analyses has been performed with the flowrate based on the test results including some additional margin, and with as-built instrument uncertainties. The depressurization test results met the new test acceptance criteria based on the reanalysis results and as-built instrument uncertainties. However, it was concluded that the depressurization capability of YGN 3&4 RCGVS was somewhat higher than the required.

3.2 NCC Analysis for UCN 3&4

The NCC analysis utilizes both minimum and maximum flowrates through the orificed flow path of RCGVS. A lower flowrate would make more limiting in the view point of auxiliary feedwater usage and, however, a higher flowrate would make the failure of the isolation valve to close(i. e., stuck-open PGV valve case) more limiting. Analysis results for

U. S. NRC BTP RSB 5-1 case, which uses a minimum flowrate, are described in the FSAR, Appendix 5D in detail[3].

In order to optimize RCGVS flowrate requirement, a sensitivity analysis for the maximum allowable steam flowrate through the PGV flow path has been performed for the PGV valve stuck-open case. In this case, the operator initiates RCS depressurization by opening the PGV valve of orificed flow path. When the RCS subcooling margin reaches 15 °C(27 °F), the operator tries to close the PGV valve, but the valve fails to close and remains stuck-open throughout the rest of transient. In this case, an uncontrolled RCS depressurization occurs resulting in a rapid decrease in the RCS subcooling margin. By realizing the stuck-open PGV valve at 30 minutes after trying to close the PGV valve, the operator increases the cooldown rate by increasing steam flowrate through the steam generator atmospheric dump valves in order to prevent a complete loss of subcooling margin(below 11.1 ℃(20 °F) for UCN 3&4). The cooldown is secured when RCS hot leg temperatures reach shutdown cooling entry conditions while the PGV valve remains stuck-open. The purpose of this analysis is to demonstrate that an NCC to the shutdown cooling entry conditions can be performed even with the single failure of PGV valve stuck-open. Therefore, the maximum flowrate through the orificed flow path is used since this results in conservative result with respect to the subcooling margin in the RCS.

According to the predicted RCS subcooling margin during NCC transient for various steam flowrates, a higher flowrate results in a lower subcooling margin in the RCS. Based on the sensitivity analysis results, the maximum acceptable steam flowrate through the orificed flow path is determined to be 1.13 kg/s(9,000 lbm/hr) at 175.8 kg/cm^{2}A(2,500 psia) which is about 30% higher than that of YGN 3&4(see Table 1). However, minimum steam flowrate requirement is the same with that of YGN 3&4[2]. Based on the NCC analysis results, the test acceptance criteria for depressurization rates, which correspond to the minimum and maximum acceptable steam flowrates through the orificed flow path, were generated by using the LTCUCN computer code as shown in Figure 5.

3.3 RCGVS Design for UCN 3&4

The computer code RELAP5/MOD3.1[5] is used to calculate the choked flowrate for UCN 3&4 RCGVS. As shown in Figure 1, the PZR including the RCGVS are modeled since the total discharged volume during the steam blowdown is much smaller than total PZR volume. In addition, the heat transfer to containment atmosphere through the piping wall is neglected since the piping is sufficiently insulated and the flow velocity is very high during steam blowdown. A fine node model is used in the present analysis which consists of 230 volumes and 233 junctions. The orifice is modeled as a junction with an area, which includes the discharge coefficient(Cd) and a friction loss coefficient.

The RELAP5 code simulation results revealed that the liquid quality in the steam vent line increased due to the pressure drop. This increased liquid quality may result in difference between the calculated flowrate by RELAP5/MOD3.1 with the assumed flowrate by homogeneous equilibrium model. The RCGVS for YGN 3&4 was designed using the classical Fanno flow correlation technique which did not consider such uncertainties, droplet quality and choked flow location, etc.[6].

The best estimate Cd value of the orifice discharge is determined to be 0.8 based on the sensitivity analysis for RCGVS test results for YGN 3&4[6]. Based on the RELAP5/MOD3.1 code analysis, the orifice size for UCN 3&4 is determined to be 0.71 cm(9/32 inch) in diameter as shown in Table 1.

4. Depressurization Capability Test for UCN 3

The depressurization capability of RCGVS has been tested at UCN 3 by opening the solenoid valve in the orificed line off the pressurizer in order to verify the safety analysis results. The pressurizer level and the RCS temperature are maintained as steady as possible throughout the test to prevent their changes from affecting the measured depressurization rate. During the blowdown period through the orificed vent line, the PZR pressure changes are recorded. Based on the measured data, the depressurization rate is calculated by dividing the PZR pressure decrease by the total elapsed time. The whole process is repeated for three different initial pressure plateau of 84.4, 133.6, 158.2 kg/cm^{2}A(1,200, 1,900 and 2,250 psia). Also, a separate measurement has been performed at each pressure plateau without opening the vent valve to characterize the effect of PZR Wall Heat Loss(WHL) to the ambient on the depressurization rate.

Figures 2, 3 and 4 show the time dependent PZR pressure changes measured at the initial pressure plateau of 84.4, 133.6 and 158.2 kg/cm^{2}A, respectively. Based on the measured data, the calculated total depressurization rates are -0.0092, -0.0142 and -0.0200 kg/cm^2/s and the WHL effects are determined to be -0.0007, -0.0012, and -0.0044 kg/cm^2/s for pressure plateau of 84.4, 133.6, and 158.2 kg/cm^{2}A, respectively. Therefore, the net depressurization rates after subtracting the WHL effects are calculated to be -0.0085, -0.0130, and -0.0156 kg/cm^2/s(-0.1209, -0.1842, -0.2213 psi/sec) for pressure plateau of 84.4, 133.6, and 158.2 kg/cm^{2}A, respectively. As compared in Figure 5, all measured depressurization rates are well within the test acceptance criteria.

5. Conclusions

A quantitative evaluation of the depressurization capability test results for UCN Unit 3 has led the following conclusions:

(1) Based on the test evaluation results, the depressurization capability of the UCN 3 RCGVS are within the acceptable ranges. Therefore, the PZR depressurization phenomena and critical flowrate through RCGVS vent line can be accurately predicted by LTCUCN and RELAP5/MOD3.1 code.

(2) The UCN 3&4 RCGVS can provide the safety-grade depressurization capability required for a safe plant operation.

References

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Table 1. Comparison of the RCGVS Design

Parameters	UCN 3&4	YGN 3&4
Analysis Model	RELAP5/MOD 3.1	Classical Fanno Flow Correlation
Orifice ID	0.71 cm (9/32 inch)	0.87 cm (11/32 inch)
Maximum Flowrate	1.13 kg/s (9,000 lbm/hr)	0.88 kg/s (7,000 lbm/hr)
Minimum Flowrate	0.64 kg/s (5,110 lbm/hr)	0.64 kg/s (5,110 lbm/hr)

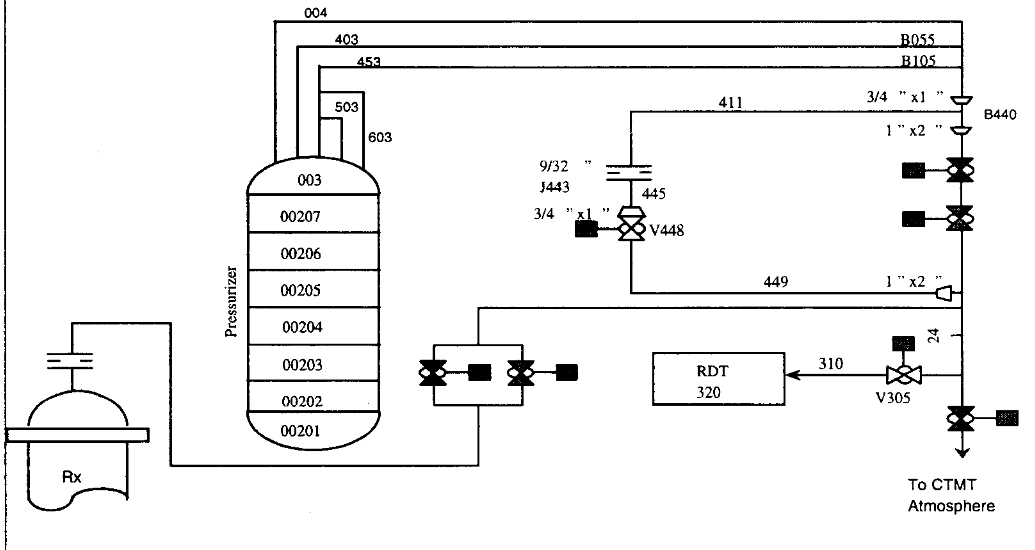

Fig.1 Schematic Diagram of the RCGVS for RELAP5

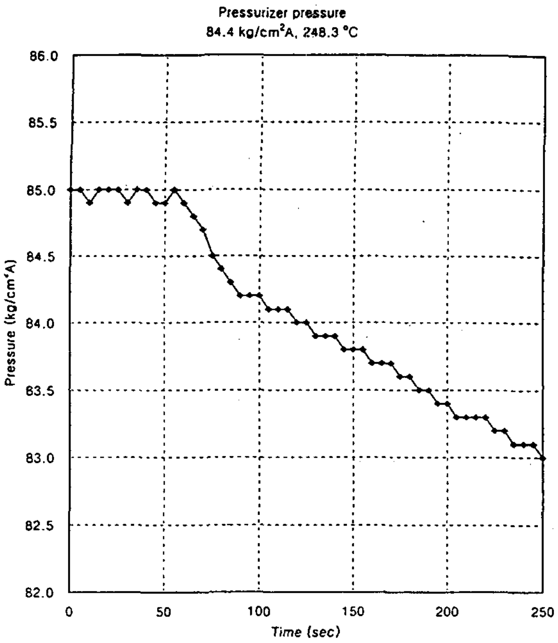

Figure 2. Measured Pressurizer Pressure at 84.4 kg/cm^2 Pressure Plateau

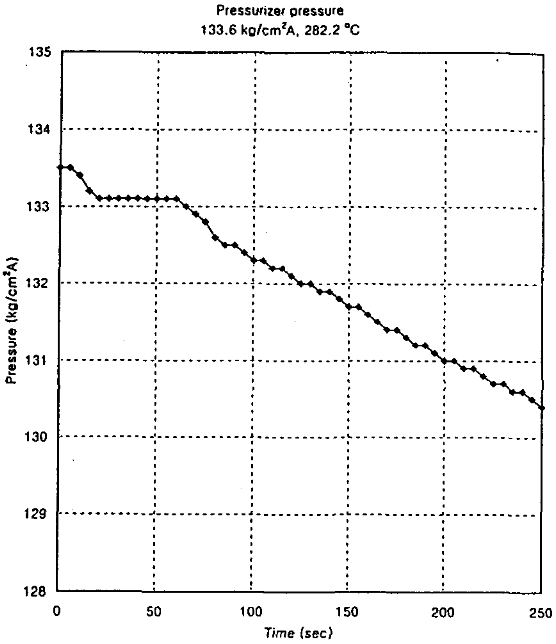

Figure 3. Measured Pressurizer Pressure at 133.6 kg/cm^2 Pressure Plateau

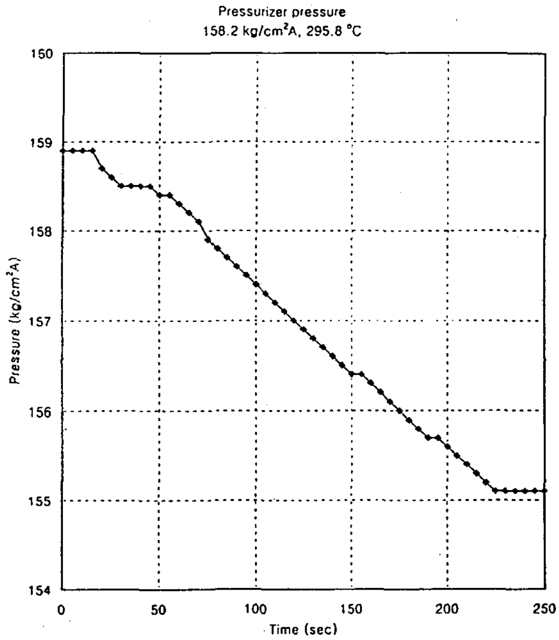

Figure 4. Measured Presurizer Pressure at 158.2 kg/cm^2 Pressure Plateau

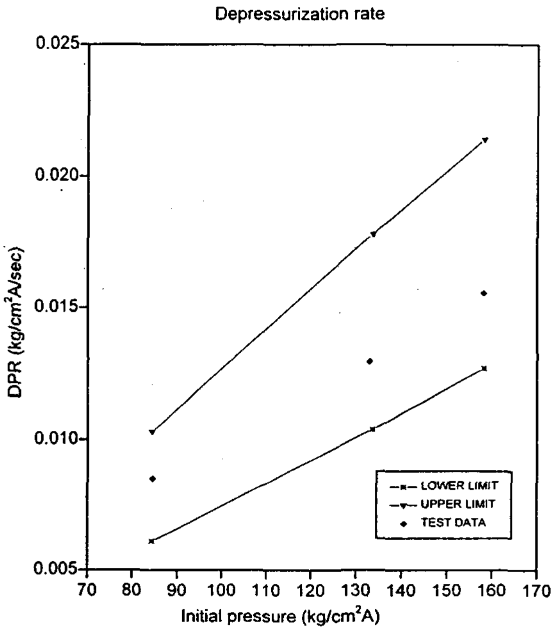

Figure 5. Measured Depressurization Rates with Wall Heat Loss Effects