Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 23-25, 2019

A Study on Leakage Flowrate from Small-Size Pipe Break of RCPB

Jaehyung Park*, Kunwoo Yi, Seongho Jee, Yongsang Ko, Seougbeom Kim, Seongchan Park

KEPCO E&C, 111 Daedeok-daero 989 Beon-gil Yuseong-gu, Daejeon, Korea
**Corresponding author: fogmans@kepco-enc.com*

1. Introduction

The purpose of present study is to evaluate the leakage flow rate from the RCPB (Reactor Coolant Pressure Boundary).

10 CFR 50, Appendix A to Part 50_General Design Criteria 33 for Nuclear Power Plants requires the design of nuclear power plant meets the below requirements:

1) A system to supply reactor coolant makeup for protection against small breaks in the RCPB shall be provided.
2) The system safety function shall be to assure that specified acceptable fuel design limits are not exceeded as a result of reactor coolant loss due to leakage from the RCPB and rupture of small piping or other small components which are part of the boundary.

The event of small size pipe break is classified as a normal operation condition if the leakage can be made up by a normal makeup system. Reactor coolant makeup during normal operation is provided by the chemical and volume control system (CVCS). The CVCS should have the capability of making up the flow loss to the containment due to leaks in small reactor coolant lines such as instrument and sample lines. Therefore, the leakage flow rate from a small size pipe break should not exceed the CVCS makeup capability.

The leakage flow from a small break during operation is the critical flow (choked flow) because the pressure of RCPB is 2250 psia, temperature is over 600 °F and the ruptured nozzle diameter is sufficiently small. Critical flow is a limiting condition where the mass flow does not increase with a further decrease in the downstream pressure for a fixed upstream pressure and temperature

In this study, the leakage flow rate through a break in an instrument line during normal operation was investigated using a hand calculation, a computer program (Break Flow Calculation) and the RELAP5 analysis.

2. Methods and Results

In this study, it is assumed that a pressure measuring instrument line on the pressurizer is ruptured. The 7/32 inch diameter flow restriction orifice is installed on the instrument line and the reactor coolant flows through the orifice.

The maximum CVCS makeup flow rate is 130 gpm. 130 gpm is the flow rate that excludes the normal RCPB leakage flow and the RCP controlled bleed-off.

The normal operation condition of the pressurizer is 2250 psi, 652.7 °F and the quality is different in different position. The outside pressure of the pressurizer is assumed 15 psi. Therefore, the leak flow from pressurizer is a critical flow.

The RELAP5 and Break Flow Calculation are used to estimate the rate of the critical flow.

2.1 Leakage flow calculation (for design)

The calculation method of leakage flow rate is based on the mass & energy balance equations to calculate the leakage flow rate in consideration of the pressurizer heater and the makeup flow from hot leg.

Except 2500 psia, the selected pressures (1800, 2000, 2200 psi) are the pressures at normal operation. 2500 psia is selected to investigate the leakage flow rate for out of the normal operation. The pressurizer heater capacities (500, 1000, 1500 kW) on normal operation are selected.

The leakage flow rate from the pressurizer steam will be a function of the pressurizer heater capacity. The schematic for calculating the leakage flow rate is as shown in Fig.1.

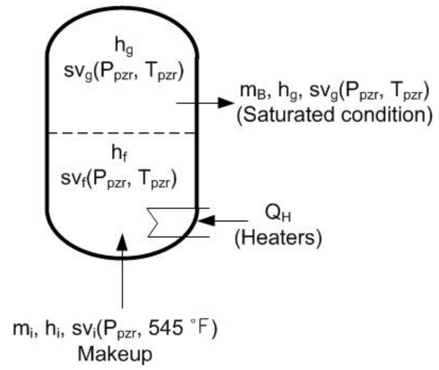

Fig 1. Schematic diagram of calculation

The heater is installed in pressurizer. The makeup flow from the hot leg is considered.

The volume of pressurizer:

$$V = V_g + V_f = constant$$

$$dV_g = -dV_f$$

Assume constant water level in the pressurizer.

$$dV_g = dV_f = 0$$

$$m_i - m_B = 0$$

The following assumption is applied:

(Steam) $m_i h_i + Q_H - m_B h_g = 0$

$$m_i = \frac{Q_H}{h_g - h_i}$$

(Water) $m_i h_i + Q_H - m_B h_f = 0$

$$m_i = \frac{Q_H}{h_f - h_i}$$

The result of the above calculation is as shown in Tables 1 and 2.

Table 1. Break on steam space (quality = 1)

Pressure	500 kw	1000 kw	1500 kw
1800 psi	5.65 gpm	11.31 gpm	16.96 gpm
2000 psi	5.78 gpm	11.57 gpm	17.35 gpm
2250 psi	5.99 gpm	11.97 gpm	17.96 gpm
2500 psi	6.25 gpm	12.50 gpm	18.75 gpm

Table 2. Break on water space (quality = 0)

Pressure	500 kw	1000 kw	1500 kw
1800 psi	32.32 gpm	64.63 gpm	96.95 gpm
2000 psi	26.40 gpm	52.81 gpm	79.21 gpm
2250 psi	21.54 gpm	43.07 gpm	64.61 gpm
2500 psi	18.08 gpm	36.15 gpm	54.23 gpm

Table 1 is the result that is applied to the assumption that the steam leaks from pressurizer. Table 2 is the result that is applied to the assumption that the water leaks. The leakage flow rate on water space is greater than that of steam space. As the heating power increases and the pressure decreases, the flow rate increases.

The maximum leakage flow rate in Table 2 is 96.95 gpm and does not exceed the CVCS makeup flow rate (about 130 gpm). It is considered that the leakage flow calculation method is a conservative and safe method for design purpose for makeup capability.

According to GDC 33, on normal operation, the reactor coolant shall be maintained when the small size pipe line is ruptured. In connection with the above requirement, the allowable pipe ruptured diameter needs to be investigated.

The equation used in leakage flow calculation is the mass and energy balance equation. The break size is not a parameter of the above equation, and therefore the maximum allowable pipe rupture diameter could not be calculated in this section.

In the next sections, the calculation methods to calculate the leakage flow rate with break diameter are investigated.

2.2 Break Flow Calculation

The Break Flow Calculation is a KEPCO E&C's computer program to calculate the critical flow rate. The Break Flow Calculation has been referred to in References 1, 2, 3, 4 & 5 and the references have the information about Moody model (M), Henry-Fauske model (HF), Henry-Fauske-Moody modification model (HF-M) and CRITCO Code. [1][2][3][4][5] The Break Flow Calculation can calculate the mass flux, energy rate and throat pressure related to critical flow.

First, the critical flow rate with quality is calculated using the calculation program. The condition of pressurizer is 652.7 °F, 2250 psia and the diameter of ruptured pipe is 7/32 inch. Additionally, the calculations for 2100 psia, and 2500 psia are performed.

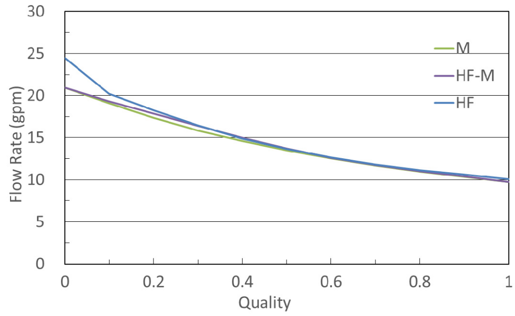

Fig 2. Break flow rate with the system pressure 2250 psia

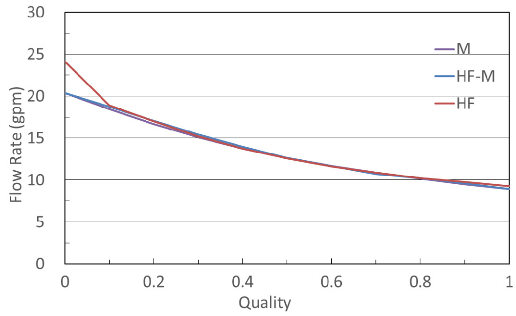

Fig 3. Break flow rate with the system pressure on 2100 psia

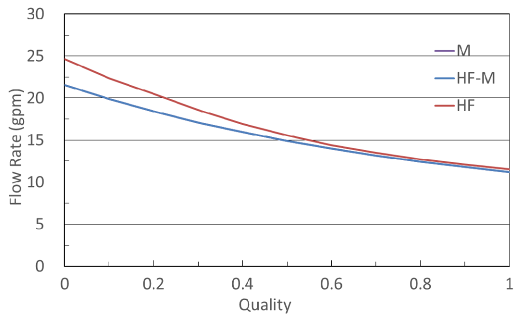

Fig 4. Break flow rate with the system pressure on 2500 psi

In the result, the leakage flow rate depends on the quality. Maximum break flow rates shown in the above figures are summarized in Table 3.

Table 3. The maximum break flow rates

Method	2100 psi	2250 psi	2500 psi
M	20.37 gpm	20.92 gpm	21.57 gpm
HF-M	20.37 gpm	20.92 gpm	21.57 gpm
HF	24.13 gpm	24.45 gpm	24.64 gpm

In Table 3, the results of Moody model and Henry Fauske-Moody modification model are the same. The result of Henry Fauske model is slightly conservative than others.

Second, the critical flow rate with break size is calculated using Henry-Fauske Model. The pressure is 2250 psia and the temperature is 652.7 °F. The calculated result is shown in Figure 5.

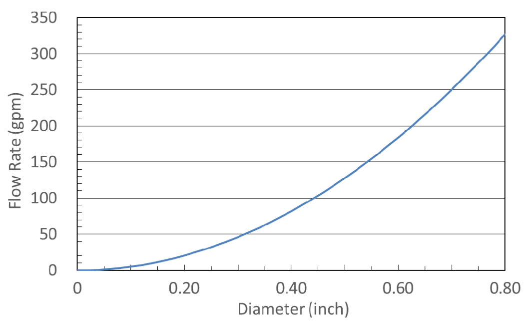

Fig 5. Leakage flowrate vs break size (2250psia)

The flow rate is proportional to pipe area. The reason is the mass flux is constant. In Figure 5, the maximum allowable pipe rupture diameter that the leakage flow rate does not exceed the CVCS makeup capability is about 0.504 inch.

2.3 RELAP Analysis

To increasing the confidence of Break Flow Calculation result, the RELAP5 analysis is performed.

The RELAP5 code is used by government regulators and the power industry in the United States and many foreign countries to analyze the thermal-hydraulic transient behavior of reactors.[6] The base deck for APR1400 made by KEPCO E&C is used in this study.

First, the leak flow rates when 7/32 inch diameter pipe is ruptured in normal operation for 200 second are confirmed using RELAP5.

Three leak positions on pressurizer are selected to confirm the flow rate with quality. The positions are marked on Figure 6.

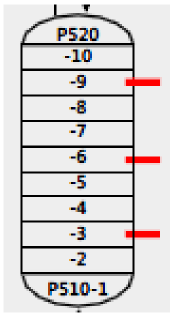

Fig 6. Break locations on the pressurizer

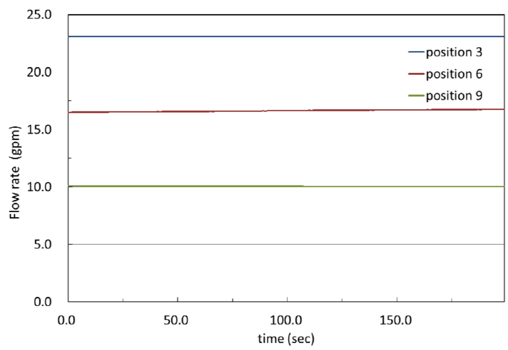

Fig 7. Break flowrate with the system pressure 2250 psia

The flow rates of Figure 8 are arranged in Table 4.

Table 4. Leakage flowrate depending on the break locations

Position 3	23.09 gpm
Position 6	16.49 ~ 16.77 gpm
Position 9	10.04 ~ 10.09 gpm

The flow rate is almost constant. The reason for the different flow rates in the positions is that the fluid quality varies in the locations.

Second, the analyses are performed to confirm the flow rate according to the break size. The each analysis is performed for 200 sec.

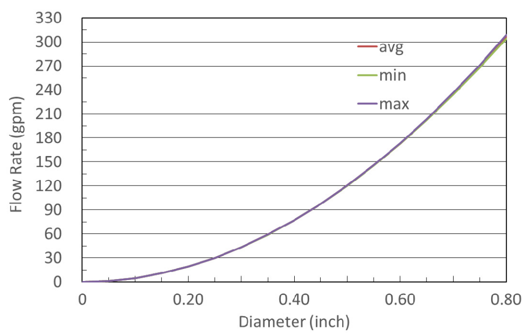

Fig 8. Leakage flowrate vs break size

In the result, as the break size increases, the flow rate increases almost proportionally to the pipe area. The flow rates are almost constant during 200 sec. In Figure 9, the maximum allowable pipe rupture diameter that the leakage flow rate does not exceed the CVCS makeup capability is about 0.519 inch.

2.4 Results

In this study, the leakage flow rate from the RCPB is investigated. In Leakage flow calculation (for design), the maximum flow rate with the system pressure 1800 psia is 96.95 gpm. The Leakage flow calculation is based on mass & energy balance equation, and therefore it cannot calculate the flow rate with break size.

Break Flow Calculation and RELAP5 analysis that can calculate the leakage flow rate with ruptured pipe diameter are selected. Break Flow Calculation and RELAP5 is used for calculating critical flow rate.

The results of Break Flow Calculation and RELAP5 analysis are compared in Table 5. In Break Flow Calculation, the value obtained using Henry-Fauske model is selected.

Table 5. Comparison between the maximum and minimum results

Flow rate	Break Flow Calculation	RELAP5
Liquid flow	24.45 gpm	23.09 gpm
Steam flow	10.08 gpm	10.04 gpm

The result of Break Flow Calculation is more conservative than that of the RELAP5 analysis.

The reason for the difference between the maximum and minimum flow rates of Break Flow Calculation and RELAP5 analysis is that quality is different. As the quality decreases, the flow rate increases.

The results of the flow rate with the diameter of Break Flow Calculation and RELAP5 analysis are compared.

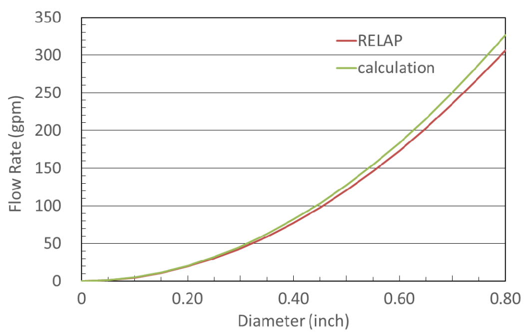

Fig 9. Break flowrates vs. break size

The result of Break Flow Calculation is more conservative than that of the RELAP5 analysis. The flow rate is almost proportional to the pipe area.

The maximum allowable pipe rupture diameters that leakage flow rate does not exceed the CVCS makeup capability are 0.504 inch on Break Flow Calculation and 0.519 inch on RELAP5 analysis.

3. Conclusions

The purpose of the present study is to evaluate the leakage flow rate from a small break in the reactor coolant pressure boundary (RCPB) and to see if it is within the makeup capacity according to GDC 33 of 10CFR50.

In Leakage flow calculation, the maximum leakage flow rate on 1800 psi is 96.95 gpm. The leakage flow rate does not exceed the CVCS makeup capability and it is confirmed that CVCS design meets the requirement of 10CFR50, Appendix A, GDC 33.

The design base calculation method of CVCS makeup capability for small size pipe break event is mass & energy balance equation. It is considered that the CVCS makeup calculation method is a conservative and safe method for design purpose for the CVCS makeup capability.

In the results of Break Flow Calculation and RELAP5 analysis, the maximum allowable pipe rupture diameter that the leakage flow rate does not exceed the CVCS makeup capability is 0.504 inch.

REFERENCES

[1] Digital Computer Program for Critical Flow Discharge of Two-phase Steam-water Mixtures (CRITCO CODE), Westinghouse Electric Corporation, 1962
[2] The Two-Phase Critical Discharge of Initially Saturated or Subcooled Liquid, NASA, Robert E. Henry, 1970
[3] Two-Phase Critical Flow at Low Qualities Part II, Analysis, Notre Dame, Robert E. Henry and Hans K. Fauske, 1970
[4] Two-Phase Critical Flow at Low Qualities Part I, Experimental, Notre Dame, Robert E. Henry and Hans K. Fauske, 1970
[5] Maximum Flow Rate of a Single Component, Two-Phase Mixture, General Electric Co. F.J. Moody, Trans ASME
[6] RELAP5/MOD3 CODE Manual