Jet Impingement Pressure Contour and Zone of Influence Calculation Methodology

Sang Won Lee*, Tae Hyub Hong and Hyeong Taek Kim
Nuclear Engineering & Technology Institute, Korea Hydro & Nuclear Power Co., Ltd., 25-1 Jang-dong, Yuseong-gu, Daejeon, Republic of Korea
**Corresponding author: sangwon@khnp.co.kr*

1. Introduction

In the event of a loss-of-coolant accident (LOCA) at a nuclear power plant, the impingement of a high-energy two phase jet can dislodge thermal insulations, coatings, and other materials. Some of these materials can fall near the containment sump or can be transported in the containment water pool to the vicinity of the sump. This debris can lead to an increase the pressure drop (i.e., head loss) across the sump screens.

The amount of debris generation is dependent on the upstream thermo-hydraulic condition in the break location and on the jet impingement pressure. The Zone of Influence (ZOI) concept, an equivalent spherical radius that represents the total isobar volume of the jet, is adopted to determine the debris generation.

PWR ZOI has already been developed, but PHWR ZOI calculation has not yet been performed. So, in this paper, PHWR ZOI, which reflects the PHWR thermo-hydraulic condition, has been developed.

2. ANSI Jet Model Description

The ANSI standard jet model [1] has been developed and applied in nuclear power plant design. The purpose of this standard is to prevent potential adverse effects after a postulated pipe rupture; such as a pipe whip, a pipe internal load, jet impingement, compartment pressurization.

The ANSI jet model subdivides the expanding jet into three regions. The characteristics of distinct three regions are described in Table I and Fig. 1.

Table I: ANSI Jet Model Subzone Description

Zone	Description	Major characteristics
1	Core	Same stagnation condition as upstream
2	Expansion	Continued isentropic expansion
3	Mixing	Jet boundary expansion ~ 10-degree

Each region has a pressure contour equation and the characteristic jet geometry equation. The Henry-Fauske critical flow model is used to determine the mass flux boundary condition when sub-cooled water is discharged at the break.

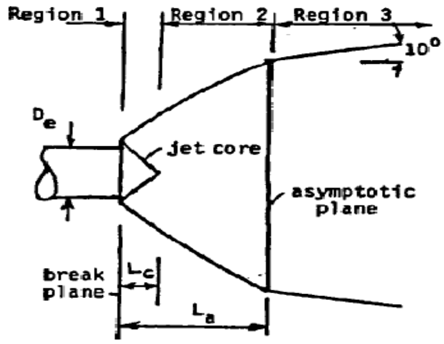

Fig.1. Typical ANSI Jet Model Geometry

3. Calculation Method and Results

3.1 Calculation Method

To calculate the pressure contour and the jet expansion geometry, a simple FORTRAN program was developed based on the ANSI standard jet model equation. The Henry-Fauske critical flow subroutine is used in NRC published Safety Evaluation Report on NEI 04-07 [2]. The NIST Steam Table [3] is used to calculate the critical mass flux and the jet model equation.

3.2 Benchmarking calculation on PWR

The ZOI calculation for PWR has already been completed [2]. To verify the calculation program developed in this study, a benchmarking calculation with the same conditions used in the previous work is performed. The results show that two cases are almost identical, within 1% deviation. The detailed calculation pressure contour is shown in Fig. 2 and the comparison results are summarized in Table III.

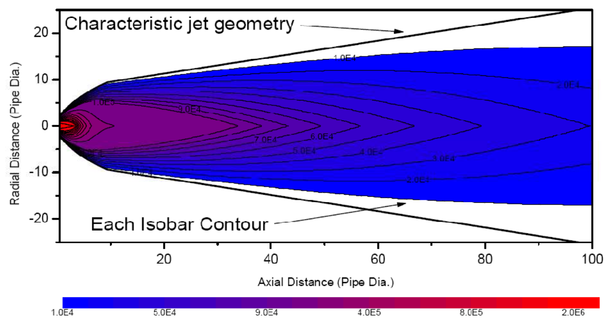

Fig.2. ANSI Jet Model Pressure Contour for PWR Cold Leg Break (530F, 2250psia)

3.3 Calculation of PHWR Pressure Contour

The PHWR pressure and temperature conditions are quite different to the PWR ones. Especially, the degree of sub-cooling is the key factor for pressure propagation. This parameter leads to a different critical mass flux and the pressure contour. Considering these factors, the typical PHWR condition pressure contour is calculated.

The thermo-hydraulic boundary conditions and detailed jet geometry and summarized in Table II.

As shown in Table II, critical mass flux of PHWR is ~20% smaller than that of PWR. Isobar contour for each pressure are shown in Fig. 3.

Table II: Envelope Geometry Calculation Results

Parameter	PWR	PHWR	Remark
Pres., [MPa]	15.51	11.05	B.C
Temp., [K]	549.8	539.15	
Exit quality, [-]	-0.429	-0.231	Sub-cooling parameter
Mass Flux, [kg/m2/s]	123573	99075	Henry-Fauske model
Jet Core Length, Lc	3.381	3.026	Enveloping Geometry
Exit Plane Dia., De	1.282	1.254	
Asymptotic Dia., Da	18.82	17.66	
Asymptotic Length, La	8.91	8.33	

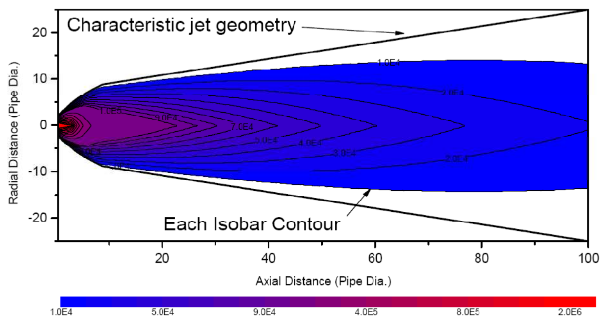

Fig.3. ANSI Jet Model Pressure Contour for PHWR Inlet Header Break (266C, 11.05MPa)

3.4 Comparison of ZOI

Destruction pressure of debris is different because it is a material specific property. And destruction pressure of various kinds of material was determined based on the experimental test results.

However, ZOI is the non-dimensional parameter of spherical radius per unit pipe diameter that can represent the three dimensional isobar cone volumes. The analytic formula for the frustum of a cone is used and total volume of a cone is multiplied by two to consider double-ended guillotine break scenario.

Table III shows the ZOI calculation results. PHWR ZOI is ~20% smaller than that of PWR as shown in Table III. This means that the total debris generation volume is ~50% smaller than that of PWR because cube of ZOI (ZOI^3) is proportional to debris generation volume.

This is mainly due to the smaller critical mass flux and exit quality than PWR ones as shown in Table II.

Table III: ZOI Calculation Results

P (psig)	PWR ZOI		PHWR ZOI Calc.	PHWR/PWR ZOI Ratio (%)	Related Debris
	NRC SER	Bench -mark			
2	31.5	31.6	25.9	82.2	
3	25.4	25.4	20.7	81.5	
4	21.7	21.7	17.5	80.6	
6	17.0	17.0	13.5	79.4	Fiberglass
10	11.9	12.0	9.2	77.3	
17	7.5	7.6	5.5	73.3	
24	5.4	5.4	4.1	75.9	Cal-Sil
40	4.0	3.8	3.0	75.0	
80	2.6	2.5	2.0	76.9	RMI (114psig)
150	1.5	1.5	1.0	66.7	

3. Conclusions

PHWR ZOI calculation methodology and program is developed based on the ANSI 58.2 standard jet model.

To verify the calculation methodology, benchmarking analysis on existing PWR ZOI is performed. Results show good agreement within 1% deviation.

Then, PHWR specific ZOI calculation is performed and results show that the critical mass flux and ZOI are 20% smaller than those of PWR. These results will be used in optimized debris generation calculation to resolve domestic PHWR sump blockage issues.

REFERENCES

[1] "Design Basis for Protection of Light Water Nuclear Power Plants against the Effects of Postulated Pipe Rupture," ANSI/ANS-58.2-1988, October 1988.
[2] "Safety Evaluation Report for NEI04-07 Appendix I, ANSI/ANS Jet Model," Dec 06, 2004.
[3] HARVEY, A. H., PESKIN, A. P., KLEIN, S. A., "NIST/ASME Steam Properties: Formulation for General and Scientific Use," Version 2.11, 1996.