Determination of the Optimized Design Flow Rate for Containment Purge System

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1. Introduction

Nuclear power plants should be shutdown every 12~15 months for refueling, periodic maintenance, and inspection of systems and components. For post-shutdown work in containment, the airborne radioactivity is exhausted to the environment through the low or high volume containment purge systems (LVCPS or HVCPS). The high capacity flow rate of the system decreases occupational radiation exposure (ORE) in containment and may increase public radiation exposure (PRE) in environment. But in existing plants, the low capacity of LVCPS causes a waiting period for workers to access containment and the high capacity of HVCPS without charcoal filter limits operating time due to the need to minimize PRE. Therefore, the capacity of containment purge system (CPS) needs to be optimized to keep ORE and PRE at acceptable levels and also to reduce the capacity.

In this paper, the method to determine the optimized capacity of CPS is introduced. The optimized capacity is proposed by consideration of the important parameters changed during reactor shutdown operation and by sensitivity analysis for CPS capacity on the ORE and PRE.

2. Design Basis of Containment Purge System

As shown in Table 1, design bases of containment purge systems are based on ANSI/ANS-56.6 [1]. Even though the standard has not revised since 1986 and there are many nuclear power plants in United States not applying the standard, the design basis is being applied to current CPS designs in Korea.

The capacity of LVCPS for KSNP [2] and APR1400 [3] is 1,500 cfm with charcoal filter and the capacities of HVCPS for these plants are 47,000 and 54,000 cfm, respectively without charcoal filter. In United States, the capacity of AP600 was optimized to 8,000 cfm without classifying LVCPS and HVCPS [4].

3. Method and Procedures

The method and procedures to optimize the capacity of containment purge systems are described below:

(1) Calculation of leakage from reactor coolant system (RCS) and flashing to containment atmosphere based on shutdown operation procedure and RCS condition after shutdown
(2) Calculation of radioactive airborne concentration in containment and environment with CPS capacity
(3) Estimation of ORE and PRE
(4) Sensitivity analysis for CPS capacity on ORE and PRE
(5) Determination of optimized design capacity in consideration of radiation protection criteria

Table 1. Design Basis of Containment Purge System

Contents	Design Basis	
	LVCPS	HVCPS
Operation Mode	Normal Operation and Hot Shutdown (for 20 hrs after shutdown)	Cold Shutdown and Refueling (at 20hr and thereafter)
Capacity	100% containment air change per 40 hours	100~150% containment air change per hour
Post LOCA	Containment Isolation Hydrogen Purge	Containment Isolation
Radiation Dose	Offsite Dose Limit (10CFR50 App.I)	Offsite Dose Limit

The assumptions and design variables used for this analysis are as follows:

- Fraction of defective fuel is 0.25%.
- During normal operation, the leakage of RCS coolant is 1 gpm, and the rate is changed with RCS pressure after shutdown.
- 55 fission products in RCS coolant are considered.
- Decontamination factors of iodine and other nuclides in CVCS are 10.
- Iodine spike is not considered.
- LVCPS is operated for 20hrs after shutdown, and HVCPS is operated thereafter.
- Access to containment for preparing refueling work is required at 48 hr after shutdown.
- Dose is estimated in effective dose [5].
- Atmospheric dispersion is $1.0\text{x}10^{-4}$ sec/m^3.

As shown in Figure 1, the RCS pressure and temperature are changed during shutdown operations such as shutdown, hot standby, hot shutdown, cold shutdown, and refueling. The leak rate and flashing fraction of reactor coolant depend on RCS pressure and temperature after shutdown.

4. Calculation of Concentration and Exposure Rate

Airborne concentrations in containment and environment, ORE and PRE, are calculated by analytic solution. The calculation results are used to optimize the CPS capacity.

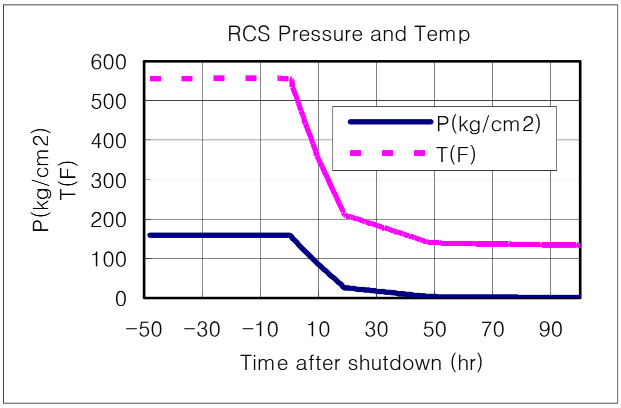

Figure 1. RCS Pressure and Temperature with Time after Shutdown

The airborne radioactivity in containment comes from RCS by leakage. The airborne concentration of each nuclide is calculated using the following equation:

$$C_{ctmt,i} = \frac{R_i}{\lambda_{eff} \cdot V_{cont}} \cdot (1 - exp(-\lambda_{eff} \cdot t)) + C_{ctmt,i}(0) \cdot exp(-\lambda_{eff} \cdot t) \qquad (1)$$

where, R is in-leakage rate of nuclide to containment atmosphere, λ_{eff} is effective removal rate in containment by decay and purge, and V_{cont} is containment volume. The in-leakage rate and removal rate is calculated using Eq(2) and Eq(3) with RCS coolant leak rate (L), nuclide concentration in RCS ($C_{rcs,i}$), flashing fraction (ff) of the leaked coolant to containment atmosphere, and CPS capacity (Q_{pg}).

$$R_i = L \cdot C_{rcs,i} \cdot ff \qquad (2)$$

$$\lambda_{eff} = \lambda_i + Q_{pg}/V_{ctmt} \qquad (3)$$

The flashing fraction can be calculated using the enthalpy of RCS coolant, and saturated steam and liquid in containment. The nuclide concentration in coolant is estimated using radioactive decay and removal in the chemical and volume control system.

The concentrations in environment are estimated using the concentrations in containment, capacity and removal efficiency of CPS, and atmospheric dispersion factor.

$$C_{env,i} = (x/Q) \cdot Q_{pg} \cdot (1 - e_{pg}) \cdot C_{ctmt,i} \qquad (4)$$

The concentration in containment and environment can be converted into the unit of derived air concentration (DAC), 1 DAC means 0.01 mSv/hr by immersion or inhalation of airborne radioactivity at the concentration. The concentrations in units of DAC are expressed as follows:

$$DAC_{ctmt,i} = (C_{ctmt,i}/DAC_i) \cdot CF \qquad (5)$$

$$DAC_{env,i} = (C_{env,i}/DAC_i) \qquad (6)$$

where DAC_i is the derived air concentration of each nuclide and CF is the correction factor for immersion exposure to noble gases in finite containment volume.

In this paper, ORE is expressed in unit of DAC. The PRE rate in mSv/hr are estimated by using the following equation:

$$PRE = 0.01 \cdot \sum_i DAC_{env,i} \qquad (7)$$

where 0.01 is conversion factor (mSv/DAC-hr).

5. Sensitivity Analysis

This sensitivity analysis is performed to determine the optimized capacity of LVCPS and HVCPS. The reference plant of this analysis is Shin Kori 3,4, which is a typical APR1400 plant. The capacity of Shin Kori 3,4 LVCPS is 1,500 cfm and that of HVCPS is 54,000 cfm, which is treated as the base case for this analysis. The results of this analysis are shown in Table 2.

Table 2. DAC in Containment at 20 hr and 48 hr after Shutdown and Integrated PRE for 100 hrs after Shutdown

Capacity of CPS (cfm)		DAC	Integrated
LVCPS	HVCPS	at 20 hr / at 48 hr	PRE (mSv)
1.5k	**-**	**55,980 / 25,250**	**0.04**
1.5k	**54k**	**50,620 / 0.18**	**0.47**
3k	54k	32,440 / 0.18	0.32
10k		4,079 / 0.18	0.09
20k		220.8 / 0.18	0.07
30k		18.0 / 0.18	0.07
3k	20k	34,620 / 1.60	0.22
	30k	33,970 / 0.36	0.25
	60k	32,070 / 0.16	0.34
5k		19,690 / 1435	0.12
10k		4,438 / 25.4	0.07
20k		**235.6 / 0.60**	**0.06**
30k		18.8 / 0.35	0.07
60k		3.00 / 0.16	0.10

* k means 1,000 cfm

6. Conclusion

This paper provides an analytic method to optimize the capacity of CPS in a point of ALARA to ORE and PRE. The results of sensitivity analysis using CPS capacity show that ORE is sensitive to capacity of HVCPS and PRE is sensitive to that of LVCPS. The optimized capacity of LVCPS and HVCPS to keep ORE and PRE at acceptable level is estimated to be about 20,000 cfm.

REFERENCES

[1] ANSI/ANS-56.6, "Pressurized Water Reactor Containment Ventilation Systems", 1986.

[2] KHNP, "Ulchin 5,6 Final Safety Analysis Report".

[3] KHNP, "Shin Kori 3,4 Preliminary SAR".

[4] M.O'Connor, et at al., "AP600 Containment Purge Radiological Analysis", Proceedings of the 23rd DOE/NRC Nuclear Air Cleaning and Treatment Conference, p454~477, Buffalo New York, USA, 1994.

[5] ICRP, ICRP Publication 68, "Dose Coefficients for Intakes of Radionuclides by Workers", 1994.