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Review of Methodology for Stack Design in Nuclear Power Plant

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1. Introduction

Venting characteristics and dispersion behavior would be dependent on the stack specification. For example, the dilution/dispersion of toxic gases and discharge velocity are dependent on the height and the top diameter, respectively. Furthermore, the adjacent building configurations and intake locations should be considered for stack design.

Though the stack design (i.e., location, height and top diameter) is important to on/off-site radiological consequences, there is no clear regulation and guideline for stack design in nuclear power plant. It may be because the emphasis has been given on preventing the release of radioactive materials to the environment and filtering them below the allowable radioactivity level. However, in case of the stack of Containment Filtered Venting System (CFVS) in which the containment atmosphere containing radioactive noble gases and toxic gases would be released intentionally, the realistic regulatory guideline for determining the stack design considering on/off-site radiological effects would be necessary.

In this study, the code/standards and the methodologies applicable to stack design have been reviewed and compared. Especially, we focus on the CFVS stack to ensure the control room habitability. As preliminary study, the stack height has been calculated for hypothetical nuclear power plant, and the feasibility and applicability of the methods have been examined.

2. Review of Regulations and Methods

It is complex to determine the stack specification because it should take into account several variables: the stack exit velocity, the velocity and the directions of wind, the ambient temperature profile, the adjacent building configurations and etc. Especially, the adjacent building configurations would have great influence on downwash, eddies, or wakes which can result in excessive pollutant concentrations [1]. The recommendations for stack height in various documents are summarized in Table 1.

Considering the building heights on nuclear power plant site, the stack height of 2.5 times higher than adjacent buildings would not be feasible. Actually, there is no stack with such height in nuclear power plant in Korea and the ground release (i.e., zero stack height) has been assumed in siting for licensing. Major focus has been given on the preventing the release of radioactive materials to environment to satisfy the on/off-site dose limits. However, in case of the intentional release of radioactive materials (e.g., CFVS), the realistic design guideline for minimizing the radiological consequences of off-site environment and public and on-site field worker and operators should be established.

In an effort to support the establishment of stack design guideline, two methods are investigated: plume-path method and on-site dose method. The comparison of two methods is presented in Table 2.

Table 1. The recommendations for stack height

	Recommendations	References
(1)	$H_s = H + 1.5 B_s$ Hs: Stack height H: Height of nearby structure B_s: Lesser dimension (height or projected width of nearby structure)	EPA[2]
(2)	$H_s = 2.5 H$	EPA[2], Reg. Guide 1.194[3]
(3)	$H_s > 65$ m from the ground-level elevation	EPA[2]
(4)	$H_s = H + 10$ ft	ANSI/ AIHA Standard Z9.5[4]
		Standard NFPA 45[5]
(6)	The height demonstrated by an approved fluid model or a field study	EPA[2]

2.1 Plume-Path Method

The design procedure for stack height which can avoid contaminating air intake was suggested in "2015 ASHRAE Handbook-HVAC Applications"[6]. To avoid exhaust reentry, the lower edge of the exhaust plume should lies above air intakes and wind recirculation regions on the roof.

Table 2. Comparison of Methods for Estimating Stack Height

Methods	Plume-Path Method	On-Site Dose Method
Code	1. Simple hand calculation	1. ARCON 96 2. RADTRAD (The code modification considering CFVS operations in SA should be required.
Design Input Data	1. Adjacent building configurations 2. Horizontal distance from stack to air intake 3. Location and height of air intake	1. Input data for ARCON 96 (Data for adjacent building, Horizontal distance from stack to air intake, Data for stack emission, Meteorological data, etc.) 2. Input data for RADTRAD (χ/Q_s , Data for CFVS operations, MCR, and containment, Nuclide Inventory, Dose Conversion Factor, etc.)
Assumptions	1.The slope of plume spreading downward: 1:5(11.3°) 2.The slope of recirculation region spreading downward: 1:10 3. Flat-roofed building	1. Atmospheric dispersion model: Gaussian plume model 2. Dose limit: 5 rem (whole body) based on DBA.
Reliability Assessment	1. Large uncertainties about the plume dispersion 2. The radiological effect cannot be known	1. Low reliability of a vent release model 2. Estimation accuracy issue of a Gaussian plume model 3. Large uncertainties about the RADTRAD modeling and input data considering CFVS operation in a SA.

Location and height of recirculation regions between the control room air intake and stack are determined by building configurations. It is assumed that the plume spreads down from stack exit with a 1:5 slope (11.3°), and the building roof is flat. By considering the shape of plume and the size of recirculation and high turbulence zones (1:10 downward from the wind recirculation zone), the stack height can be determined.

In case of applying this method to the estimation of stack height, required data are as follows. The stack height should ensure control room habitability by keeping plume above the control room intakes, the recirculation regions. It is assumed that the least contaminated intake of dual intakes is manually selected.

1. Adjacent Building Width (W)
2. Adjacent Building Height (H)
3. Horizontal distance from Stack to Air intake (L)
4. Air Intake Height

The wind direction is conservatively set. Also, the plume rise is not considered. Fig. 1 shows an example of the plume-path method. In this case, to avoid excessive pollutant concentrations in the air intake, the stack height above the roof level should be at least 20% of the horizontal distance between the air intake and the stack.

This method is comparatively simple because the stack height can be estimated by a hand calculation. However, there are large uncertainties associated with a 1:5 plume spread slope because the plume dispersion varies with weather condition and stack emission, etc. Furthermore, the radiological effect on a control room cannot be addressed. In order to use this plume-path method for determination of stack height, it is needed to apply a dispersion model which can estimate transportation of radioactive materials accurately.

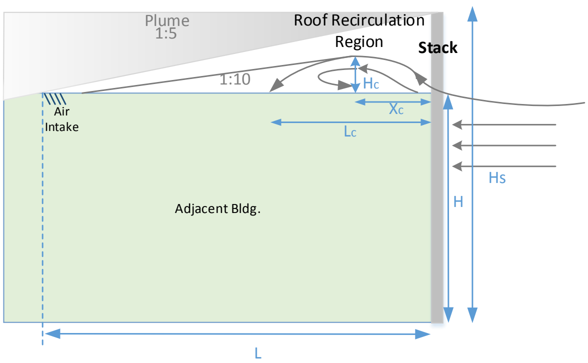

Fig. 1. An Example for the Plume-Path Method

2.2 On-Site Dose Method

On/off-site dose assessment requires the radiological source term, atmospheric relative concentration (χ/Q_s), and dose conversion factor. Those are mainly inputs of RADTRAD code for dose estimation. The stack height affects the calculation of χ/Q_s.

According to NUREG/CR-6331[7], ARCON96 code which is a general code for calculating χ/Q_s is the improved model for the control room habitability evaluation. If the stack height is below 10 m, the ground level release mode is applied. In case of the stack height of 2.5 times higher than the adjacent building, the elevated (stack) release mode is appropriate for calculating χ/Q_s. Meanwhile, when the stack height is above 10 m and below 2.5 times the height of adjacent building, the vent release mode treated as a mixed ground level and elevated release is applicable.

The atmospheric dispersion model used in ARCON 96 is a Gaussian plume model which has been suggested in licensing processes and radiological consequence evaluation. ARCON 96 calculates the 95th percentile average χ/Q_s for standard averaging periods. (0-8 hours, 8-24 hours, 24-96 hours, 96-720 hours)

All domestic stacks in nuclear power plants are not high enough to avoid being influenced by adjacent structures so that the ground level release mode has been used for licensing.[8] Because the control room intake is generally located in the upper part of an auxiliary building, applying the ground level release mode to calculate the on-site dose for the control room habitability assessment may not be conservative.

The CFVS stack height which will be installed is expected to be above 10 m, but below 2.5 times the height of adjacent building. Thus, χ/Q_s can be calculated with varying stack heights by applying the vent release mode. χ/Q_s estimated by ARCON 96 are input data for RADTRAD code[9]. Since RADTRAD code mainly assesses radiation doses for DBA (Design Basis Accident) scenarios, most of inputs for RADTRAD have been focused on the DBA. The RADTRAD modeling and setting for SA (Severe Accident) with CFVS operation are needed. It is possible to figure out an appropriate stack height that ensures the control room habitability by using the method mentioned above.

However, there are many limitations for using this method. First of all, the vent release mode based in part on limited field experiment may not be sufficiently conservative for accident assessments.[3] Also, a Gaussian plume model used in ARCON 96 assumes dispersion over flat, a steady-state condition(flow, source, meteorological conditions), and non-depositing materials, etc.[10] Therefore, this model may not be suitable for SA with CFVS operation whose condition. It is also required to improve dispersion model for dose estimation.

Meanwhile, it is difficult to simulate CFVS operation scheme and flow condition in RADTRAD code, and much more input data based on SA are needed. For these reasons, the method of on-site dose assessment for SA with CFVS operation should be established in order to reduce uncertainties of the dose assessment result.

The off-site dose limit for SA is established as a 250 mSv (whole body/effective dose) in 2016[11]. On the other hand, the on-site dose limit for SA is not currently established. Thus, the on-site dose limit for DBA as a 5 rem whole body described in general design criteria 19 in 10 CFR 50 Appendix A[12] can be used for the on-site dose limit for SA. If stack height is determined by applying this dose limit, the stack height may be conservatively estimated.

The flowchart of the on-site dose method for stack height determination is shown as Fig. 2.

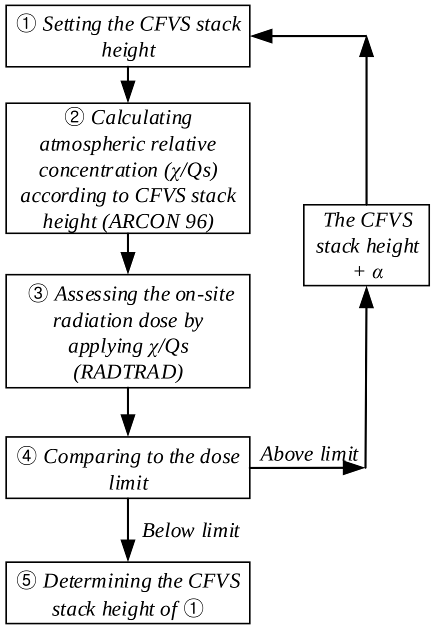

Fig. 2. The Flowchart of the On-Site Dose Method for Stack Height Determination

3. Numerical Demonstration

Preliminary analyses for two methods above are conducted. Site characteristics and design data are assumed conservatively by considering the information of Korean nuclear power plants. The site specific data assumed are as follows in Table 3.

Table 3. The Site Specific Data Assumed for the Determination of CFVS Stack Height

Control Room Intake Height (m)	40
Horizontal Distance from Stack to Air Intake (m)	70
Vertical Velocity (m/s)	40
Stack Flow (m^3/s)	20
Building Width (m)	50
Building Height (m)	40

As a result of applying the plume-path method, the minimum CFVS stack height which can avoid contaminating air intake is estimated to be about 63.3 m. It means the CFVS stack height 23.3 m higher than the control room air intake height can prevent the exhaust plume entering into the control room air intake. This method is considered as conservative guidance.

In case of using the on-site dose method, the accumulate dose for control room operators are calculated with varying stack heights. The calculation result of the method is shown in Table 4. The limit for radiation dose is assumed to be a 5 rem. As the CFVS stack height is higher, the dose for control room operator would decrease. Comparing to the dose limit, the CFVS stack height 8 m higher than the control room intake height is determined to satisfy the dose limit.

Table 4. The Preliminary Analysis Result for the On-Site Dose Method

Case #	Intake height (m)	Distance from stack to intake (m)	Stack height (m)	Accumulated dose(rem), Whole Body
1	40	70	40	255.88
2			41	215.05
3			42	140.58
4			43	88.45
5			44	53.56
6			45	29.66
7			46	15.98
8			47	8.52
9			48	4.74
10			49	3.00
11			50	2.14
Dose limit				5 (0.05 Sv)

4. Conclusions

The methods applicable to stack design have been reviewed and compared. Those have been applied to CFVS stack for numerical demonstration. The applicability and limitations have been examined. It is obvious that the various factors should be considered simultaneously and a single method would not resolve all issues (e.g., on/off-site radiological consequences, structural integrity, installation cost). In addition to establishing the stack design guideline, the operational procedure (e.g., timing of venting, field worker evacuation, opening/closing intake) should be prepared and considered in stack design process.

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