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Quantification of Dilution Characteristics of Radioactive Materials in Korean Nuclear Sites

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1. Introduction

The location of a power plant site is decided prior to the installation of the nuclear reactors, after full consideration of the potential damage to neighboring residents through the analysis of meteorological data in the event that radioactive materials are released into the air. According to the research [1], it was reported that all of the four nuclear sites in Korea were suitable for a nuclear power plant site as they had good atmospheric dispersion. However, in the event of an accident related to the leakage of radioactive materials from a nuclear power plant, the damage scale is decided depending on the meteorological conditions and it is necessary to quantify the dilution characteristics in case of the same-scale accident that might occur in any of the four nuclear power plant sites.

This study quantified the annual dilution characteristics of radioactive materials in four power plant sites in Korea. The air concentrations resulting from an assumed unit release of radioactivity were used for the quantification and discrepancy among the dispersion levels of radioactive materials tested in each site statistically with ANOVA.

2. Materials and Method

2.1 The Atmospheric Dispersion Model

This study conducted a comparison analysis on the characteristics of atmospheric dispersion in four nuclear power plant sites in Korea using the Gaussian Plume Model with meteorological data, which were updated on an hourly basis. Assuming that radioactive materials were emitted continuously for a certain period at the same rate, the concentration of radioactive materials in the downwind side can be expressed in the Gaussian formula as follows [2].

$$C = \frac{Q}{2\pi\sigma_y\sigma_z U} EXP\left(-\frac{y^2}{2\sigma_y^2}\right)\left[EXP\left(\frac{-(z+H)^2}{2\sigma_z^2}\right) + EXP\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)\right] \quad (1)$$

C : Atmospheric concentration of radioactive materials (Bq/m^3), Q : Source release rate (Bq/s), σ_y : Horizontal dispersion coefficient (m), σ_z : Vertical dispersion coefficient (m), x : Distance from the release point in the downwind direction (m), y : Vertical distance from the central line of the plume (m), u_H : Average wind speed at effective release height (m/s), H : Effective release height (m)

The horizontal and vertical dispersion coefficients are the parameterized value of horizontal and vertical turbulences according to the downwind distance. This study used an equation suggested by Pasquill-Gifford. As for the meteorological data, this study use meteorological data at 4 nuclear sites which are Uljin, Wolsung, Kori and Yeoungkwang in Korea with one-hour intervals in 2011.

2.2 Statistical Analysis

ANOVA (Analysis of variance) is a statistical test to check the difference of mean among several groups. This study was conducted using ANOVA to determine if there is any statistical significant difference in the atmospheric concentration of radioactive materials within a 1000m concentric circle from the center of each of the four sites. Following analysis of multiple comparisons with ANOVA was used to identify the difference of atmospheric dispersions among 4 nuclear sites separately. The null hypothesis (H_0) and test statistics are as follows:

$$H_0 : \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 \quad (2)$$

$$\text{Test statistic : } F = \frac{SS_{tr}(I-1)}{SSE/I(n-1)} \quad (3)$$

where, a_1~a_4 represent the atmospheric concentrations of radioactive material within a 1000m concentric circle from the center of each of the four sites. Using the degree of freedom which is a function of the number of nuclear power plants for treatment (I) and the value of atmospheric concentrations estimated in a 1,000m concentric circle (n), this study tested the SSE, which is the error sum of squares and SS_{tr}, which is the sum of squares for treatment at a 95% confidence level with an F-statistic.

3. Results and Discussion

3.1 Air Concentration of Radioactive Materials by Nuclear Sites

This study estimated the atmospheric concentrations of radioactive materials near the four nuclear power plants, assuming that radioactive materials are released into the air by 1 Bq/sec from the four nuclear power plant sites in Korea. Fig. 1 represents the average concentration distribution within the radius of 20 km for one hour after a release in the four nuclear sites. Fig. 1(a) shows the distribution of atmospheric concentration for radioactive material in the Uljin site and generally shows the opposite trend of wind-rose. This means a distribution of high concentration in the northwest because the southeastern wind dominates. On the other hand, as the northeastern wind is very slight, the concentration of radioactive materials in the southwest direction is very weak. Fig. 1(b) shows the distribution of atmospheric concentration in the Wolsung site. As the areas of the Uljin and Wolsung sites have a high concentration of radioactive materials and are located in the sea, it is assumed that the exposure effect to the human body caused by respiration and absorption through the skin inland is minute. Fig. 1(c) shows the atmospheric concentration of radioactive materials at the Kori site. As it is a site where the northeastern wind is dominating, the concentration in the southwest direction is represented by a high value. Since the southwest area of the Kori site is located in Busan, a metropolitan city, there is high possibility of damage to Busan citizens in the case of a nuclear accident. Fig. 1(d) shows the concentration of radioactive materials in the Yeoungkwang nuclear site. With the dominating northeastern wind, the site shows a high concentration in the southwest part of the site. Because the majority of the southwest area is in the sea, it is assumed that the exposure effect to the human body caused by respiration and absorption through the skin in land is minute, similar to the Wolsung region.

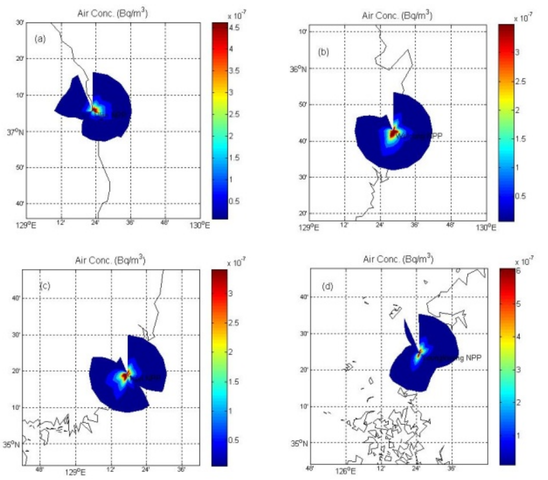

Fig. 1. Atmospheric concentrations of radioactive materials by the nuclear power plant site (Bq/m^3): (a) Uljin site, (b) Wolsung site, (c) Kori site, and (d) Yeoungkwang site

3.2 Statistical Analysis for Dilution Characteristics

Fig. 2 illustrates multiple comparison results to quantify the difference in dilution actions of radioactive materials in each site. You can see that the most active dilution action of released radioactive materials was done in the Kori sites. The atmospheric dispersion characteristics of radioactive materials in the Uljin and Kori site were statistically significant in comparison to the atmospheric dispersion characteristics of the Wolsung and Youngkwang sites. However, the difference in atmospheric dispersion characteristics of radioactive materials in Uljin and Kori sites were not statistically significant. In addition, the difference in atmospheric dispersion characteristics of radioactive materials in the Wolsung and Youngkwang sites are not significant statistically, but there was a significant difference between Uljin and Kori.

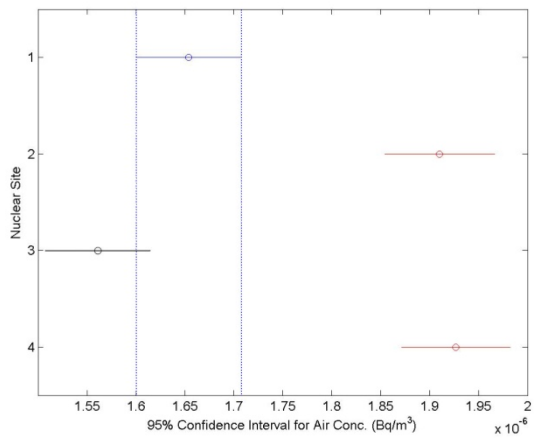

Fig. 2. 95% confidence interval for multiple comparisons of air concentrations for radioactive materials at a 1000 m concentric circle in the nuclear power plant sites: (1) Uljin site, (2) Wolsung site, (3) Kori site, and (4) Yeoungkwang site

3. Conclusions

Among the four nuclear power plant sites in Korea, the most active atmospheric dispersion of radioactive materials was at the Kori site, and the weakest atmospheric dispersion was at the Yeoungkwang site. On the other hand, at the Kori site which is the most advantageous for the dilution of radioactive materials, the main wind direction is toward the city. Thus, special attention is required to protect residents from a nuclear accident. To identify and generalize the dilution characteristics for nuclear sites, more analysis using many years of meteorological data will be needed, whether for routine releases or an accidental release.

REFERENCES

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[2] W.W. Nazaroff, L., Environmental engineering science, John Wiley & Sons Inc, 2001.