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Radiological dose assessments according to dilution characteristics of radioactive materials in nuclear sites

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A B S T R A C T

This study quantified the characteristics of atmospheric dispersion and exposure dose of radioactive materials in four power plant sites in Korea. As a tool to quantify atmospheric dispersion, this study used air concentrations based on an assumed unit release of radioactivity per time. The disparities in atmospheric dispersion degrees among the sites were tested statistically with an analysis of variance (ANOVA). The probabilistic distribution of exposure dose in consideration of meteorological conditions in the case of a nuclear accident was estimated with a Monte Carlo simulation. The Yeoungkwang nuclear site on the west coast was the poorest in dispersion, whereas the most active dilution of radioactive materials took place in the Kori nuclear site located on the east coast on an annual basis. In case of an accident with the worst conditions of atmospheric dispersion, assuming the emission rate was 1 Bq/s and the duration time of the accident is 1 h, the highest 99.5th percentile of dose–1.51E−14 mSv.

1. Introduction

Korea relies on nuclear power for more than 40% of its electrical energy. The nuclear power plant sites in Korea are located near seas where cooling water is easily accessible. The three nuclear power plants of Uljin, Wolsung, and Kori are located on the east coast and the Yeoungkwang nuclear power plant is located on the west coast.

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 by Han et al. (2008), 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 damage scale in case of the same-scale accident that might occur in any of the four nuclear power plant sites.

The assessment of atmospheric dispersion of radioactive materials and exposure dose in a nuclear power plant site can be largely classified into two categories. The first is the release of radioactive materials according to normal operation. The second is the release of radioactive materials caused by an accident. The environmental impact assessment and health impact assessment on the release of radioactive materials caused by normal operation of a nuclear power plant are generally done on a yearly basis (Sohrabi et al., 2013). For environmental and health impact assessments, one year of meteorological data and release data are used. This is for the purpose of monitoring health impacts on the residents near a nuclear power plant regularly by assessing the behaviors of radioactive materials caused by the normal operation of the nuclear power plant. On the other hand, since we cannot identify in advance the time of a nuclear accident, the release of radioactive materials caused by an accident is estimated by a probabilistic value according to meteorological conditions.

Health impacts can be estimated by quantifying the frequency distribution of air concentrations at the place to be assessed based on one year of meteorological data (Till and Grogan, 2008).

Since the Fukushima nuclear accident in Japan, much research on health impacts according to the behavior of radioactive materials has been conducted (Korsakissok et al., 2013; Kamada et al., 2012). In the case of an emergent nuclear accident such as Fukushima, because the accident time is specified, environmental and health impacts are estimated using the real-time meteorological data and measurement data of radioactive materials.

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. This study also estimated the probabilistic distribution of exposure dose that reflected the meteorological

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conditions in the case of a nuclear accident using a Monte Carlo method.

2. Material and methods

2.1. The atmospheric dispersion model

Many computer codes have already been developed and used for a behavior analysis of radioactive materials and risk assessment. Models for analysis of the atmospheric dispersion of radioactive materials can be classified according to the equations used as follows.

The Gaussian Plume Model was employed for the atmospheric dispersion analysis of radioactive materials by MACCS2 (MELCOR Accident Consequence Code system, Version 2) developed by the U.S. Nuclear Regulatory Commission (NRC) for a probabilistic risk assessment (PRA) of residents near a nuclear facility, HotSpot developed by National Atmospheric Release Advisory Center (NARAC) for a radioactive impact assessment caused by an accident and terror in a nuclear facility, and AIRDOS of U.S. Environmental Protection Agency (EPA) (Lawrence Livermore National Laboratory, 2009; U.S. EPA, 2007).

The Gaussian Puff Model was used for an atmospheric behavior analysis of radioactive materials for Radiological Assessment System for Consequence Analysis (RASCAL) which was developed for an environmental impact assessment at the time of emergency in a nuclear facility in the U.S. NRC, and the Regional Atmospheric Transport Code for Hanford Emission Tracking (RATCHET) which was developed for an analysis of environmental impact at the Hanford site (Pacific Northwest National Laboratory, 2006; U.S. NRC, 2004).

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 (Nazaroff, 2001):

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

where C is the Atmospheric concentration of radioactive materials (Bq/m^3), Q the Source release rate (Bq/s), σ_y the Horizontal dispersion coefficient (m), σ_z the Vertical dispersion coefficient (m), x the Distance from the release point in the downwind direction (m), y the Vertical distance from the central line of the plume (m), u the Average wind speed at effective release height (m/s) and H is the 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 (Hanna et al., 1982). As for the meteorological data, this study use meteorological data at 4 nuclear sites which are Uljin, Wolsung, Kori and Yeoungkwang in Korea with 1 h 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 1000 m 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 1000 m 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 1000 m 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 (Neter et al., 1996).

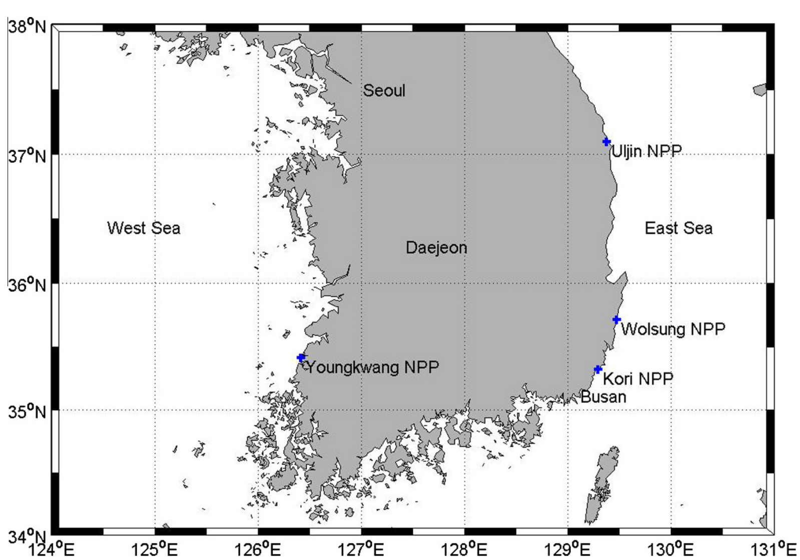

Fig. 1. Locations of the 4 nuclear power plants in Korea: (a) Uljin site, (b) Wolsung site, (c) Kori site, and (d) Yeoungkwang site.