Annals of Nuclear Energy 55 (2013) 230–237

Contents lists available at SciVerse ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

The effect of calm conditions and wind intervals in low wind speed on atmospheric dispersion factors

Hyojoon Jeong *, Misun Park, Wontae Hwang, Eunhan Kim, Moonhee Han

Nuclear Environment & Safety Research Division, Korea Atomic Energy Research Institute, 1045, Daedeok-daero, Yuseong, Daejeon 305-353, South Korea

ARTICLE INFO

Article history:
Received 9 October 2012
Received in revised form 12 December 2012
Accepted 13 December 2012
Available online 24 January 2013

Keywords:
Calm condition
Low wind speed
Atmospheric dispersion factor
Gaussian plume model
XOQDOQ

ABSTRACT

The effects of wind speed defined for calm conditions and wind interval at a low wind speed on the atmospheric dispersion factors (ADFs) using a Gaussian plume model, statistical approach, and XOQDOQ program were analyzed in this study. There was a statistically significant difference in the ADFs calculated on 1000-m concentric circles from the release when the wind speed is adjusted from 0.5 m/s to 0.2 m/s for calm conditions. If a dispersion model as the input of the joint frequency distribution is used for an estimation of ADFs, it was found that the ADFs were affected by the classification of wind intervals at a low wind speed of lower than 2.0 m/s. To minimize the effect of wind speed intervals at a low wind speed to ADFs, the wind interval should be adjusted considering the frequency distribution of a low wind speed and adjusted in either way to narrow the interval for a low wind speed or widen it for a high wind speed.

1. Introduction

In evaluating the radiation dose of residents caused by the operation of nuclear power facilities or accidents, the behavior characteristics of radionuclides in the atmosphere must be analyzed. The method of quantifying the dilution and dispersion characteristics of radionuclides in the atmosphere includes a method that uses the emission inventories of nuclear facilities and the actual measurements at the points of interest, and a method that uses the atmosphere dispersion model. The former provides more accuracy, but is difficult to use if the emission is low because the measurements fall below the detection threshold. It is also difficult to observe the overall radiation dose when the monitoring network is not dense. On the other hand, the accuracy of the results from the atmosphere dispersion model largely depends on the assumption of the model equations and the relevance of the meteorological data, but it enables an overview of the radiation dose in the surrounding areas of nuclear facilities and a simulation of a hypothetical accident. The main input in the atmosphere dispersion model is meteorological data, and the estimates of the atmospheric dispersion factor (ADF) calculated using the dispersion model are used in the assessment of radiation dose. Calm conditions and low wind speed have very significant effects on ADFs (Hongwei et al., 2011).

Although a calm condition is the state in which the wind speed is lower than the staring threshold of the wind speed measuring equipment, a calm condition in the atmospheric dispersion model is defined as below a 0.5 m/s of the wind speed (US NRC, 2007; Hanna et al., 1982). Wind speed is one of the variables that affect ADFs, and is inversely related to them. Calm conditions recorded in meteorological data are excluded or transformed into standard wind speed in the calculation of ADFs (US EPA, 2000; PNNL, 1997). When time-series meteorological data are input after being transformed into a joint frequency distribution, which is the ratio between wind direction and speed according to atmospheric stability, the data may be used after being distributed to the first wind speed interval (PNNL, 1982).

A low wind speed means a wind speed of lower than 2 m/s. At a low speed, the dilution and dispersion of radioactive substances are not active. If meteorological data are processed with joint frequency distribution, the value of the ADF may vary according to the classification of the wind interval at a low wind speed.

This study analyzed the difference in the value of ADFs according to different definitions of wind speed in calm conditions using the meteorological data at the Wolsung nuclear site in 2009 measured in 1-h intervals. The Gaussian plume model, which uses time-series meteorological data with 1-h intervals, was used as its input in the estimation of ADFs, and we verified whether the differences in ADFs under the different definitions of calm conditions are statistically significant. Also, we evaluated the effects of the classification of wind speed interval at a low wind speed when meteorological data are transformed into a joint frequency distribution in the atmospheric dispersion model using the statistical method of ANOVA (analysis of variance) and the dispersion model of XOQDOQ.

* Corresponding author. Tel.: +82 42 868 2087; fax: +82 42 868 2368.
E-mail address: jeong1208@kaeri.re.kr (H. Jeong).

0306-4549/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.anucene.2012.12.018

2. Analysis of atmospheric dispersion characteristics

2.1. Gaussian plume model

To analyze the effects of a calm definition on ADFs, the Gaussian plume model as an input of hourly time-series meteorological data and the *t*-test are used. The atmosphere promotes the dilution and dispersion of radioactive materials emitted from nuclear power facilities. It is ADFs that quantify the dilution and dispersion effects of the atmosphere. Assuming that a radioactive substance is emitted continuously at a constant rate for a fixed period of time, the concentration of radioactive substance in the downwind direction is explained in the Gaussian plume model as follows (Nazaroff and Alvarez-Cohen, 2001):

$$\chi(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u_H} \times \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \quad (1)$$

where χ is the concentration of radioactive substance (Bq/m^3), Q is source emission rate (Bq/s), σ_y, σ_z is horizontal and vertical dispersion coefficients (m), x is distance from emission point in downwind direction (m), y is vertical distance from plume center line (m), u_H is average wind speed at effective emission height (m/s), H is the effective emission height (m).

Assuming Q in Eq. (1) as the unit mass emission, and if Q is moved to the left side, Eq. (1) is as follows:

$$\chi/Q(x,y,z) = \frac{1}{2\pi\sigma_y\sigma_z u_H} \times \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \quad (2)$$

This is the ADF, the unit being s/m^3. Multiplying the ADF by the source emission rate, the product is the concentration of radioactive substance in the atmosphere. In the analysis of radiological risk assessment from normal operations of nuclear facilities, the average annual ADFs are used. In the case of design-based accidents, the short-term ADFs such as 0–2 h, 0–8 h, 8–24 h, and 24–96 h, are used in the exclusion area boundary (EAB) and low population zone (LPZ) (US NRC, 1977; US NRC, 1982).

2.2. XOQDOQ

To analyze the effect of wind speed intervals at a low wind speed on ADFs, XOQDOQ computer program as a meteorological data input of a joint frequency distribution and the ANOVA test are used. XOQDOQ is a computer code developed by PNL (Pacific Northwest Laboratory) for the calculation of the ADFs in normal operations of nuclear facilities. XOQDOQ is based on the Gaussian plume equation, and it used measured wind direction, wind speed and atmospheric stability in the form of a joint frequency distribution (PNNL, 1982). The general Gaussian plume equation was modified to be suitable for regulatory purposes as shown in Regulatory Guide 1.111 of U.S. Nuclear Regulatory Commission:

$$\frac{\chi}{Q}(x,K) = \frac{2.032}{x}\cdot \mathrm{RF}(x,K)\sum_{i,j}^{N,7}\frac{\mathrm{DEPL}_{ij}(x,K)\mathrm{DEC}_i(x)f_{ij}(K)}{U_i(x)\sigma_{zj}(x)} \cdot \exp\left(-0.5\frac{h_e^2}{\sigma_{zj(x)}^2}\right) \quad (3)$$

where χ/Q is the atmospheric dispersion factor (s/m^3), U is mean of wind speed interval (m/s), σ_{zj} is vertical dispersion coefficient (m), DEPL is depletion coefficient by deposition, DEC is attenuation coefficient by radioactive decay, he is effective height of plume (m), RF is plume adjustment coefficient for stagnation and recirculation, K is wind direction, f is frequency, i is ith wind speed interval, j is the jth level of atmospheric stability.

This study used the meteorological data from the meteorological tower of Wolsung nuclear site in Korea in 2009.

2.3. Statistical test

ADFs for two groups according to the different definitions of calm condition, i.e., wind speeds of 0.2 m/s and 0.5 m/s were estimated. A *t*-test was conducted to verify whether there is any statistically significant difference in the ADFs calculated from 16 different points of compass of 1000-m concentric circles from the nuclear reactor owing to the definition of calm conditions.

The ANOVA test was conducted to verify the effects of classification of wind speed interval on the ADFs calculated by the computer code using a joint frequency distribution as an input. MATLAB Statistical Toolbox was used for the t-test and ANOVA test (The Mathworks, 2001).

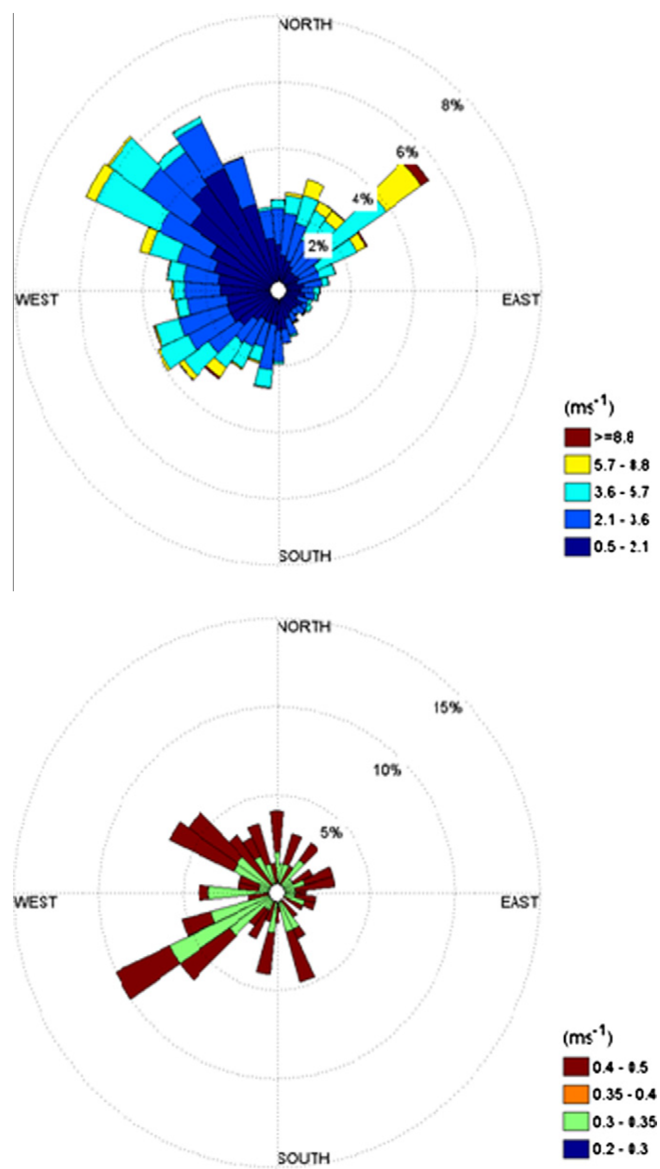

Fig. 1. Wind rose measured in the Wolsung nuclear site in 2009: used over 0.5 m/s of wind speed (top) and used between 0.2 m/s and 0.5 m/s of wind speed (bottom).