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Atmospheric modeling of radioactive material dispersion and health risk in Fukushima Daiichi nuclear power plants accident

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ABSTRACT

The radioactive material dispersion is investigated in terms of the radioactive concentrations. The risk of the radioactive hazard material is important with respect to the public health. The prevailing westerlies region is modeled for the dynamical consequences, whereby the Fukushima nuclear disaster in Japan is modeled. The multiplications effects of the wind values and plume concentrations are obtained. Monte Carlo calculations are performed for wind speed and direction. In Seoul and Pusan, Korea, the Cs-137 has the highest value among the chemical radioactive materials Cs-137, I-131, and Sr-90. The time for highest concentration is shown to be around 48th hour in Seoul and 12th hour in Pusan. Cesium has the highest value in both cities, and iodine has the lowest value in both cities. The wind is assumed to determine the direction of movement. Therefore, the real values are believed to be lower than the calculated results. This modeling could be used for other industrial accident cases in chemical plants.

1. Introduction

After nuclear power plants (NPPs) accident in Fukushima, Japan, the radioactive fallout has dispersed throughout the world. Especially, the adjacent countries had a tendency to be damaged easily. With respect to the Fukushima NPPs accident, Korea, which is the west part of the Japan, is modeled in this study. The prevailing westerlies region is not affected directly by the atmospheric pollutant according to the atmospheric consideration. In the real situation, the convection of the thermal air and global air circulation could affect the western part of the accident region. In fact, in the Fukushima accident, the radioactive contaminated fallouts had reached Korea by some rains. The air stream of the radioactive fallouts had come in from the southern regions by the air circulations. So, the air stream has too many uncertainties to predict exactly. It is calculated by random number generations in Monte Carlo method for the wind directions. The computational simulation of the north and south wind could give the preparations for the possible fallout for the NPPs accident site in real situations. The Monte Carlo simulation can give us the numerical values of the nuclear fallout possibility, where the random number is used of the decision of the radioactive material quantities and the wind directions. The final purpose of the study is to increase the reliability of the safety for the national standard in the nuclear accident.

In literature review, Periàñez studied a numerical three dimensional model to simulate the transport of Cs and Pu by the Rhone River plume (Periàñez, 2004). That is, this model solves the hydrodynamic equations, including baroclinic terms (that account for density variations) and a turbulence model, the suspended matter equations, including several particle classes simultaneously, settling, deposition and erosion of the sediment, and the radionuclide dispersion equations. In addition, the investigation was carried out to reveal the impact of solar radiation on pollutant dispersion in different urban street layouts using computational fluid dynamics (CFD) technique (Xie et al., 2005). For simulating the quantitative effects of regional biomass alternatives for energetic purpose (BfE) on air pollutant emissions, a dynamical model was developed and applied for the Eu Region Austrian–Hungarian cross-border area. The dynamic simulation program Vensim was used to build an overall regional model with economic, social and environmental sectors (Szarka et al., 2008). In addition, the National Atmospheric Release Advisory Center (NARAC) has been served as a national resource for the United States, providing tools and services to quickly predict the environmental contamination and health effects caused by airborne radionuclides, and to provide scientifically based guidance to emergency managers for the protection of human life. The NARAC was developed for the capabilities to respond to different types of release events (Bradley, 2007). The 2nd section explains the method of the study. The 3rd section describes results of the study. There are some conclusions in the 4th section.

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2. Method

For the simulations of the radioactive decay in the nuclear fallouts, it is assumed the wind is incorporated with the radioactive decay. The configurations are described for the atmospheric dispersions. The Gaussian plume model is applied, which is used for the pollution dispersion near source. Therefore, the radioactive fallouts flow to the modeled cities (Seoul and Pusan) simply by this model where the linear distance is assumed for the flying distance. In addition, the wind velocities are assumed by the measured values of two cities. The Gaussian plume dispersion model is written as follows.

$$C(x,y,z) = \frac{Q}{2\pi u\sigma_y\sigma_z} e^{-\frac{y^2}{2\sigma_y^2}} \left(e^{-\frac{(z+H)^2}{2\sigma_z^2}} + e^{-\frac{(z-H)^2}{2\sigma_z^2}} \right) \quad (2.1)$$

where Q (g/s): pollution rate emission rate, u (m/s): average wind speed, σ_y (m): y direction plume standard deviation, σ_z (m): z direction plume standard deviation, y (m): y position, z (m): z position, H (m): effective stack height.

This is the solution for the plume contaminant concentration at a point in space. For the $z = 0$, the concentration is shown at the ground level as follows:

$$C(x,y,0) = \frac{Q}{\pi u\sigma_y\sigma_z} e^{-\frac{y^2}{2\sigma_y^2}} e^{-\frac{H^2}{2\sigma_z^2}} \quad (2.2)$$

Also, at $y = 0$, the concentration is shown at the ground level along the plume centerline as follows:

$$C(x,0,0) = \frac{Q}{\pi u\sigma_y\sigma_z} e^{-\frac{H^2}{2\sigma_z^2}} \quad (2.3)$$

In addition, if the emission source is at the ground level,

$$C(x,0,0) = \frac{Q}{\pi u\sigma_y\sigma_z} \quad (2.4)$$

Therefore, the concentration of the plume contamination in the ground is proportional to the pollution rate emission rate over wind velocity. The Q_o is the initial value of the radioactive decay material, which is assumed as 100. So,

$$Q = Q_o e^{-\lambda t} = Q_o e^{-\frac{\ln 2}{t_{1/2}} t} \quad (2.5)$$

Therefore,

$$C \approx \frac{Q}{u} = \frac{Q_o e^{-\lambda t}}{u} = \frac{Q_o e^{-\frac{\ln 2}{t_{1/2}} t}}{u} \quad (2.6)$$

Fig. 1 shows the simplified configuration of the map of the geographic positions. The possible fallouts come from the north and south wind in Korea. There are measured wind speeds and directions in Korea in Tables 1 and 2 (Korea Meteorological Administration, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010). The azimuthal wind is numbered which are shown in Fig. 2. The values are from 0.1 to 0.9, which are generated by random numbers. The highest value is 0.9 of south wind and the lowest value is 0.1 of north wind. This value is multiplied to the concentration of the radioactive material for the wind adjustment. If the wind goes directly from Fukushima to Seoul, the time for reaching to Seoul, Korea is shown as follows:

$$1,170,000\ \text{m}/22.9\ (\text{m/s}) = 51,091.703\ \text{s} = 14.192\ \text{h} \quad (2.7)$$

This is assumed that this wind flows directly from Fukushima to Seoul. For the case of Pusan:

$$1,030,000\ \text{m}/33.2\ (\text{m/s}) = 31,024.096\ \text{s} = 8.618\ \text{h} \quad (2.8)$$

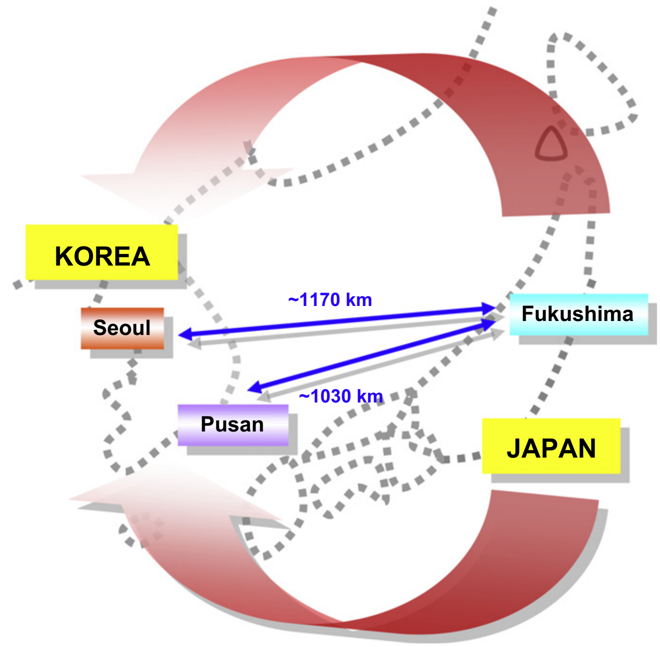

Fig. 1. Distance between Fukushima site and Seoul/Pusan of Korea. This shows the distance between Fukushima site and Seoul/Pusan of Korea where the possible wind is described as the reddish arrow lines. That is, the air is coming in Korea by northwest and southwest directions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Comparisons for mean speed (m/s) and most frequency direction from 2001 to 2010.

	Seoul	Pusan
2010	25, WNW	33, NNE
2009	24, WNW	34, NE
2008	24, WNW	32, NE
2007	24, WNW	33, NNE
2006	24, WNW	31, NNE
2005	25, WNW	31, NNE
2004	24, WNW	31, NNE
2003	20, NE	32, NNE
2002	21, W	39, ENE
2001	18, W	36, ENE

Table 2
Comparisons for mean speed (m/s) and most frequency direction of averaged values.

	Seoul	Pusan
Speed (m/s)	22.9	33.2
Direction	0.4 (WNW)	0.26 (NE)

The equation is changed as follows:

$$C \approx \frac{Q}{u} = \frac{Q_o e^{-\lambda t}}{u} = \frac{Q_o e^{-\frac{\ln 2}{t_{1/2}}(51,091.703\ \text{s})}}{(22.9\ \text{m/s})} \quad (2.9)$$

Then, for the case for Cs-137, $T_{1/2}$ = 30.17 years.

$$C \approx \frac{Q}{u} = \frac{Q_o e^{-\lambda t}}{u} = \frac{Q_o e^{-\frac{\ln 2}{(30.17\ \text{year})}(51,091.703\ \text{s})}}{(22.9\ \text{m/s})} \quad (2.10)$$

In the case of I-131, $T_{1/2}$ is 8.0197 days. Also, in the case of Sr-90, $T_{1/2}$ is 28.8 years.

As it is seen in the Eq. (2.10), the concentration depends on the half-life of each nuclide. It is very difficult to decide the source term in the accident. The failure of the protection systems in the NPPs