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Estimation of the Radiological Consequences of Fukushima Dai-ichi Nuclear Power Plant Accident using MACCS2

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1. Introduction

On 11 March 2011, Fukushima Dai-ichi Nuclear Power Plant (FDNPP) was attacked by the tremendous earthquake and tsunami. Three of them have undergone fuel melting and hydrogen explosions. A significant amount of radioactive material was released into the atmosphere from FDNPP and dispersed all over the world. In this study, we assessed the offsite consequences of Fukushima disaster in the region within a 30-km radius of FDNPP using the MELCOR Accident Consequence Code Systems 2(MACCS2) code, which is the Nuclear Regulatory Commission's (NRC's) code.

2. Material and Methods

2.1. MACCS2 code

MACCS2 code is used for the assessment of the health and economic consequences of accidental atmospheric radiological releases. The principal phenomena considered are atmospheric transport, dispersion, and deposition under time-variant meteorology, mitigation actions and exposure pathways, deterministic and stochastic health effects, and economic costs. It uses the straight-line Gaussian plume model with Pasquill-Gifford dispersion parameters.[1, 2) Two aspects of the MACCS2 code's structure:

- Calculations are divided into modules and phases. (Figure 1)
- Region surrounding the facility is represented with an (r, θ) grid system centered on the location of the release.

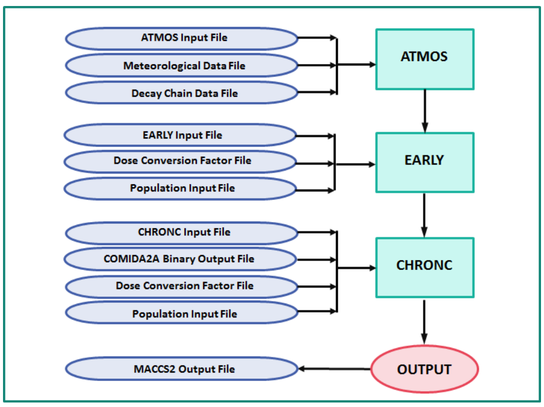

Fig. 1. Structure of MACCS2 code

2.2. Input parameters

The source term data was taken from published values estimated by Terada et al.[3)], which are based on reverse or inverse modelling.

The calculations were performed with 64 compass sectors, each being 5.625 degrees, and 30 radial divisions, extending out to a distance of 30 km. Site population data were derived from 2010 Japan census.

Meteorological data of Fukushima site from November 2010 to October 2011 was used for this analysis (KMA data). Figure 2 shows the annual wind rose for this meteorological data. Weather bin sampling method (METCOD2) was used to select multiple weather sequences.

Dose Conversion File (DCF) was generated by DOSFAC2 preprocessor, which are based on ICRP 26. The parameters of COMIDA-2 (MACCS2 Food chain model) were applied in this study without consideration of the circumstances in Japan. MACCS2 default values were used for other site-independent parameters.

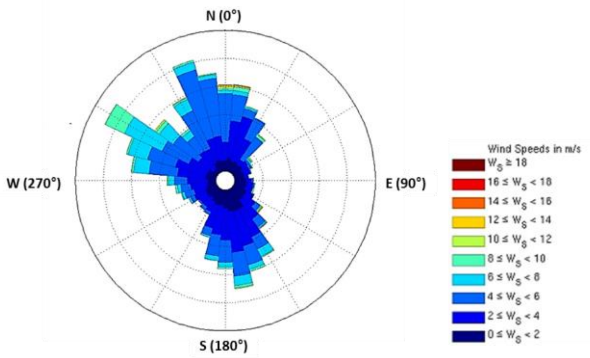

Fig. 2. Annual wind rose for the Fukushima site. Meteorological data were collected from November 2010 to October 2011.

3. Results and Discussion

3.1. Spatial distribution of deposited radionuclides on the ground surface

Figure 3 shows the averaged ground concentration (Bq/m^2) of Cs-137 and I-131 over the spatial interval within a 30-km radius of FDNPP after passage of plume segments.

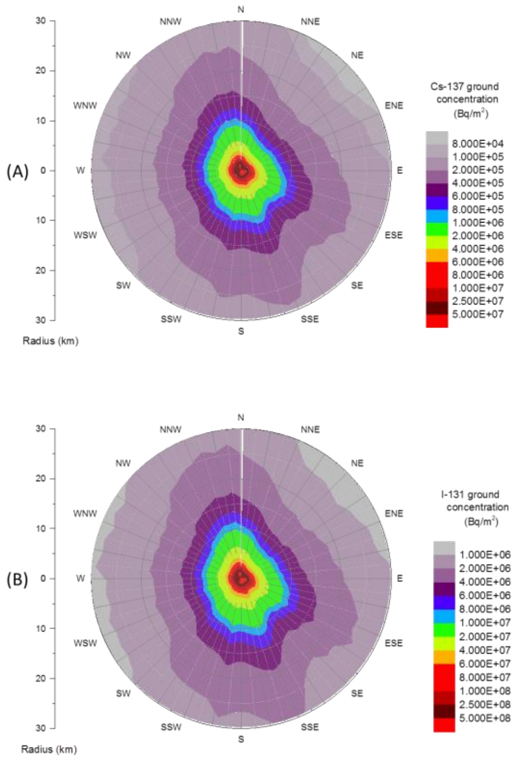

Fig. 3. Ground concentration (Bq/m^2) of (A) Cs-137 and (B) I-131 after passage of plume segments averaged over the spatial interval's length within a 30-km radius of FDNPP

Based on this result, the areas contaminated with released radionuclides were highly dependent on the prevailing wind direction during a given time period. In the annual wind rose (Figure 2), winds from the WNW, NNW and SSE directions are dominant. As a result, it is estimated that the north-northwest side of FDNPP was highly contaminated by deposited radionuclides. The southeast side of FDNPP is the sea, so it is not necessary to concern about ground concentration of this area. To assess the effect of radiological contamination in the ocean, marine dispersion model should be added to MACCS2 code.

3.2. Individual and collective effective doses

Figure 4 represents the total effective peak dose of individual residing at a particular (r, θ) location on the spatial grid. These results were estimated for evacuation and no-evacuation cohorts residing between a 20 to 30 km radius from FDNPP. Only direct exposure pathways were considered except the ingestion of contaminated food and water.

It was assumed that the evacuation cohort was evacuated radially away from the FDNPP. The result shows that evacuation cohort received significantly lower doses compared to no-evacuation population, but effective doses for evacuation cohort were still highly dependent on the prevailing wind direction. Therefore, the regional characteristics (e.g. meteorological and site-specific characteristics) should be taken into consideration to determine optimal evacuation paths, time and speed for minimizing the health effects.

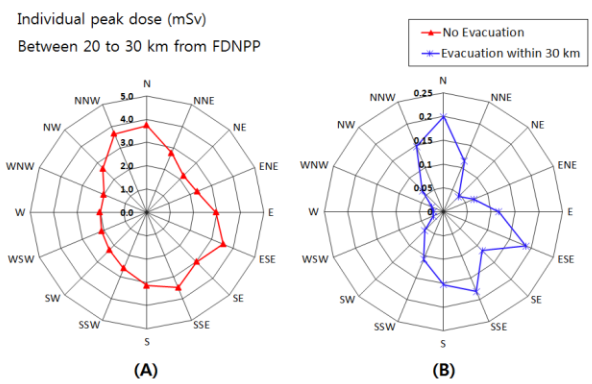

Fig. 4. Peak effective doses (mSv) for individual residing at each 16 compass sector between a radius of 20 to 30 km from FDNPP. (A) No evacuation cohort (dose-dependent relocation cohort), (B) Evacuation cohort

Total collective effective doses were estimated as a function of distance from FDNPP (Figure 5). This result was calculated by considering all exposure pathways including ingestion. It was assumed that 95% of people residing within 30 km from FDNPP were evacuated, and that the 5% of people remained behind.

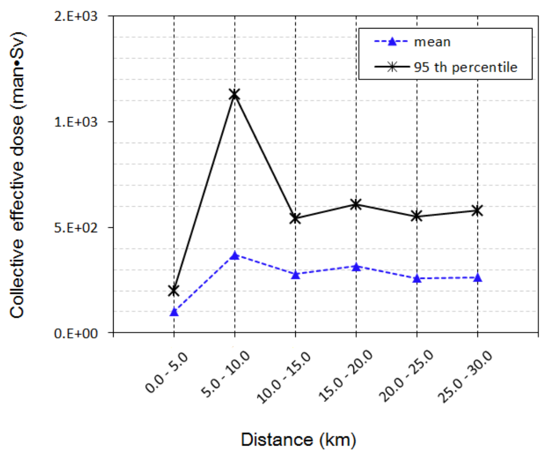

Fig. 5. Estimated collective effective doses to the populations of contaminated areas

Total long-term population dose from groundshine and resuspension, from the consumption of contaminated food and surface water, and from decontamination work was calculated as represented in Table Ⅰ. Total long term population dose is defined as the sum of long-term direct pathway dose and ingestion dose.

Table Ⅰ: Total long-term population doses received by various exposure pathways

		Population dose (man·Sv) 0 - 30 km		
		mean	95th	99.5th
Total long-term pathway		1.45E+03	3.03E+03	3.45E+03
Long-term direct exposure pathway	Ground shine	1.37E+03	2.88E+03	3.56E+03
	Resuspension	7.04E+00	1.25E+01	1.72E+01
Total ingestion pathway		1.87E+01	5.02E+01	6.05E+01

As can be seen in table Ⅰ, effective doses during the long-term exposure period are mainly caused by the external exposure from radionuclides deposited on the ground surface. Therefore, to assess long-term effective doses more accurately, behavior patterns (e.g. time spent indoors or outdoors, characteristics of occupation), site-specific data (e.g. shielding effect by surrounding environment), and decontamination efficiency should be taken into consideration when calculating the external dose from groundshine.

3.3. Risk of health effects

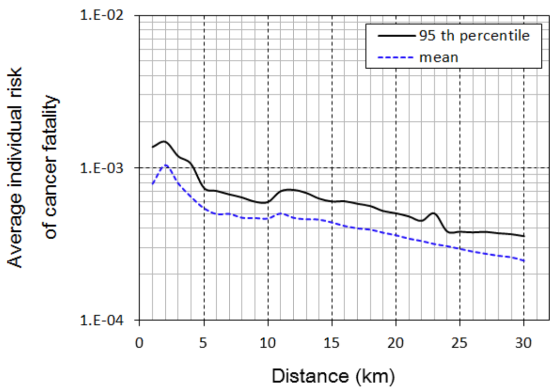

Fig. 6. Average individual risk of cancer fatality as a function of distance from FDNPP

The risk of health effects were estimated with assuming 95% evacuation and 5% non-evacuation. The risk of an early fatality remains zero and risk of latent cancer fatalities are represented in Figure 6.

4. Conclusions

A significant amount of radioactive material was released into the atmosphere from FDNPP and dispersed all over the world. The off-site consequences of accidental atmospheric radiological releases from FDNPP were estimated by using MACCS2 code in this study.

The reflection of the realistic regional characteristics, such as long-term meteorological data, site- and population-specific data, and radiation safety regulatory, is essential to accurately analyze the off-site consequences. The assessment that reflects regional characteristics would contribute to identify main causes of exposure doses and to find the effective countermeasures for minimizing the accidental off-site consequences.

ACKNOWLEGEMENT

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