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Dose estimation for nuclear power plant 4 accident in Taiwan at Fukushima nuclear meltdown emission level

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ABSTRACT

An advanced Gaussian trajectory dispersion model is used to evaluate the evacuation zone due to a nuclear meltdown at the Nuclear Power Plant 4 (NPP4) in Taiwan, with the same emission level as that occurred at Fukushima nuclear meltdown (FNM) in 2011. Our study demonstrates that a FNM emission level would pollute 9% of the island's land area with annual effective dose ≥50 mSv using the meteorological data on 11 March 2011 in Taiwan. This high dose area is also called permanent evacuation zone (denoted as PEZ). The PEZ as well as the emergency-planning zone (EPZ) are found to be sensitive to meteorological conditions on the event. In a sunny day under the dominated NE wind conditions, the EPZ can be as far as 100 km with the first 7-day dose ≥20 mSv. Three hundred sixty-five daily events using the meteorological data from 11 March 2011 to 9 March 2012 are evaluated. It is found that the mean land area of Taiwan in becoming the PEZ is 11%. Especially, the probabilities of the northern counties/cities (Keelung, New Taipei, Taipei, Taoyuan, Hsinchu City, Hsinchu County and Ilan County) to be PEZs are high, ranging from 15% in Ilan County to 51% in Keelung City. Note that the total population of the above cities/counties is as high as 10 million people. Moreover, the western valleys of the Central Mountain Range are also found to be probable being PEZs, where all of the reservoirs in western Taiwan are located. For example, the probability can be as high as 3% in the far southern-most tip of Taiwan Island in Pingtung County. This shows that the entire populations in western Taiwan can be at risk due to the shortage of clean water sources under an event at FNM emission level, especially during the NE monsoon period.

1. Introduction

Conventionally, the permanent evacuation zone (PEZ) as well as plume exposure pathway emergency planning zone (EPZ) are determined by using Gaussian plume formulation such as MACCS2 (Chanin and Young, 1997). Basic Gaussian plume formulation is derived based on the assumptions of steady state and homogeneous, which assume that wind-vector and stability class remain constant along a plume. Hence, the plume is always following straight-line (straight-line-type plume). However, in general, the wind field is neither homogeneous nor stationary, especially in complex terrain such as in Taiwan, where land-sea breeze and valley-mountain wind dominate.

Recently, trajectory-type Gaussian plume models have been developed, such as CALPUFF (Scire et al., 1990) and GTx (Tsuang, 2003). This trajectory-type plume models determine wind-vector and stability class in each segment of a plume, using in-situ meteorological data. Hence, the PEZ and EPZ determined by these trajectory-type plume models are much more realistic than those determined by the conventional straight-line-type plume models. In addition, more advanced dry deposition and wet scavenging mechanisms have been implemented in these trajectory-type models. These two mechanisms are important to determine PEZ.

A magnitude of 9.0 earthquake hits the eastern coast of Japan on March 11th, 2011. The earthquake triggered a tsunami, which caused widespread death and destruction (NPA, 2011). The tsunami was also responsible for a catastrophic nuclear accident involving hydrogen explosions at the Fukushima Daiichi Nuclear Power Plant (FDNPP) (Holt et al., 2012). Following the accident, radioactive materials were released into the surrounding environment, dispersed through the atmosphere, and deposited on the ground as well as through water released into the ocean. Most radionuclides were distributed in the top soil layer, as observed in rice paddy, orchards and cedar forests, in highly contaminated areas within an 80 km radius zone of the Fukushima power plant (MEXT, 2011;

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Ohno et al., 2012; Yamamoto et al., 2012, 2014). Milk, vegetables, and other foodstuffs were found to be contaminated at levels that exceeded regulation values for ^{131}I, ^{134}Cs and ^{137}Cs in or near Fukushima prefectures (MHLW, 2011; Hamada and Ogino, 2012).

Unfortunately, the nuclear power plant 4 (Fig. 1; Table 1) built in Taiwan is very similar to FDNPP. The plant is built close to the sea, with a distance within 500 m to the coastline (AEC/TW, 2013d) and is at elevation 12 m above sea level (ASL). Note that in northern Taiwan, the Ryukyu Trench off the eastern coast could prompt an earthquake, and the Tatun Volcano Group may still be potentially active rather than extinct (Konstantinou et al., 2007). Furthermore, Taiwan has the second highest national population density in the world (MOI, 2011); its mountain ridges, which reach a height of 3952 m ASL, occupies much of Taiwan's total land area of 36,000 km^2. Taiwan's approximately 23 million people mostly live on the coastal plain along the western part of the island, especially in large metropolitan areas like Taipei, Taichung and Kaohsiung. Nuclear power plants in northern Taiwan had been ranked as the most dangerous nuclear power plants in the world (Butler, 2011). NPP4 is located in New Taipei City, and the direct distance to Taipei City, the capital of Taiwan, is only 40 km. The population in the Taipei metropolitan (Taipei City + New Taipei City) is as high as 6.6 million (MOI, 2013). What would happen if a nuclear meltdown was to occur at the NPP4? Could we accept or deal with the consequences? Timely evacuation would be impossible due to the massive population and all emergency resources would be catastrophically overwhelmed. This study tries to quantify the consequences based on the emission scenario from the Fukushima nuclear power plant accident (WHO, 2012).

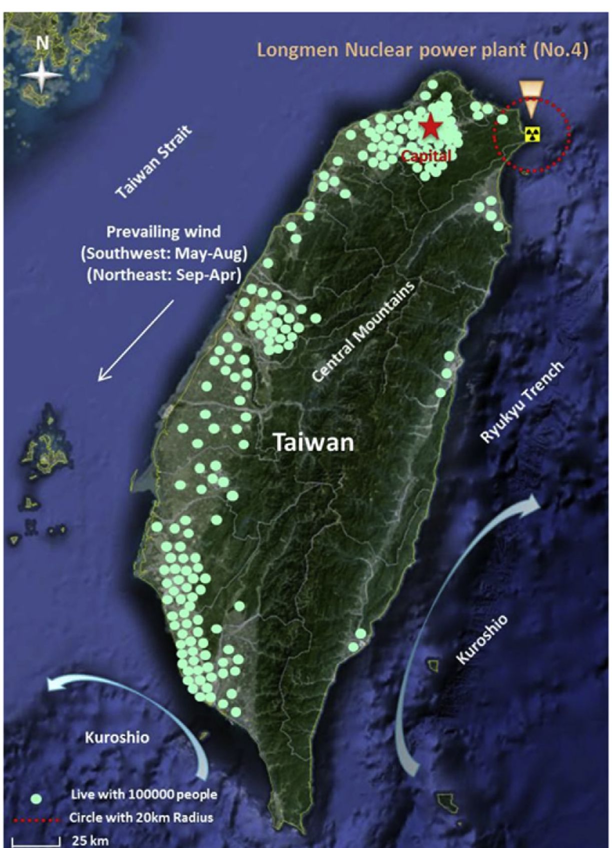

Fig. 1. Geographic features, population distribution, and location of the NPP4 in Taiwan (MOI, 2013).

Table 1
Information of the nuclear power plant 4 in Taiwan (AEC/TW, 2012).

Unit	NPP4 (also known as Lungmen NPP)	
	1st	2nd
Operation since	Under construction	
Location	Gongliao District, New Taipei City	
Coordinates	121.924° E, 25.039° N	
Reactor supplier	General Electric Company	
Reactor type	Advanced boiling water reactor	
Capacity (MW)	2700	

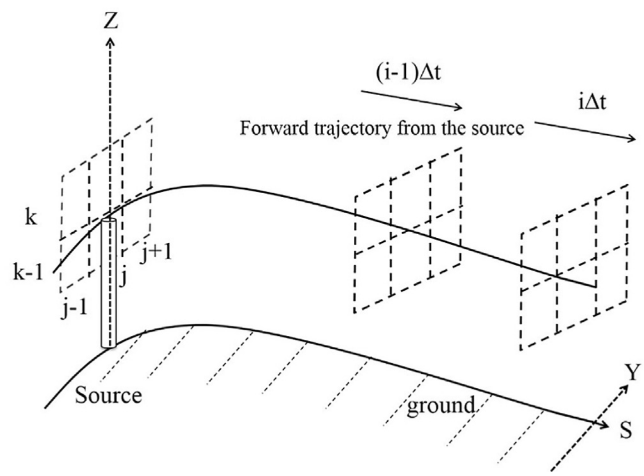

Fig. 2. Schematic description of Gaussian trajectory transfer coefficient model (GTx). S-coordinate is along the forward-trajectory from a source.

2. Methodology

To address the questions about radiation behavior which would follow a nuclear power plant accident in Taiwan, we used the Gaussian trajectory transfer-coefficient model (denoted as GTx) (Fig. 2) (Tsuang, 2003; Chen et al., 2002) to simulate surface deposition and air concentration of radionuclides. To quantify the radioactive fallout, we used the dry and scavenging deposition mechanisms of the Gaussian trajectory transfer-coefficient modeling system (GTx) to calculate air concentration and surface deposition. GTx combines the trajectory model with the Gaussian puff equation to simulate the trajectory of plume and the receptor/source relationship, and the dispersion of air pollutants in Taiwan (Tsuang, 2003; Chen et al., 2002; Kuo et al., 2009). The simulation domain is all of Taiwan and the surrounding ocean (119.74–122.10 °E, 21.69–25.39 °N); grid resolution is 1 km × 1 km, and our study is particularly focused on the land subject to radionuclide coverage. More detailed descriptions of dry and scavenging deposition mechanisms are derived, as shown in the Appendix, and more details of the results will be shown later in the paper.

We assumed radionuclides adsorbed in small particle size with each element, constituted by aerosol and vapor and based on aerodynamic diameters, aerosols with <0.95 μ m bore 75–80% of the aerosol activity as observed at the sites of the Fukushima and Chernobyl accidents (Malá et al., 2013). According to the characteristics of radionuclides, the mean ratio of gas-plus-particle I-131 to particle I-131 is 5.28 (Ten Hoeve and Jacobson, 2012). The iodine radionuclides were in the forms of aerosol and vapor, and all other radionuclides were in aerosol form in the model. The emissions data were adopted from a World Health Organization report collected on 13 species of radionuclides (Table 2); the data was