

Pre-deployment Radiological Disaster Assessment of Atmospheric Radionuclide Dispersion under Typhoon Conditions in the Philippines

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1. Introduction

The Philippines is actively pursuing the introduction of nuclear energy to enhance national energy security, diversify its electricity generation portfolio, and achieve long-term decarbonization goals. Following the adoption of the International Atomic Energy Agency (IAEA) milestones approach, the Philippine government has accelerated the establishment of the institutional, regulatory, and technical infrastructure required for future nuclear power deployment [1]. The Department of Energy (DOE) has initiated feasibility studies for several candidate sites, including Bataan, Labrador (Pangasinan), Camarines Norte, Masbate, and Palawan, while simultaneously evaluating both large commercial nuclear power plants and small modular reactors (SMRs) as potential options for future electricity generation [2]. An essential component of nuclear infrastructure development is the establishment of a scientifically sound emergency preparedness and disaster assessment framework prior to plant construction. According to IAEA safety standards, radiological consequence assessment and emergency planning should be incorporated during the early stages of nuclear power development to support regulatory decision-making, site evaluation, and emergency response planning [3]. For nuclear newcomer countries such as the Philippines, pre-deployment assessments are particularly important because they provide technical information before the reactor technology and final plant location are determined. The Philippines presents unique challenges for nuclear emergency preparedness because of its complex geographical and meteorological environment. The archipelagic country is frequently affected by tropical cyclones and intense monsoon rainfall that can influence the atmospheric transport and deposition of radioactive materials following a hypothetical nuclear accident. Consequently, atmospheric dispersion assessment should be considered as an integral component of feasibility studies for future nuclear power plant deployment rather than only after a specific reactor site has been selected.

Atmospheric dispersion modeling has become one of the most widely adopted techniques for radiological consequence assessment and nuclear emergency planning. The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed by the U.S. National Oceanic and Atmospheric Administration (NOAA) has been extensively validated

through applications to the Chernobyl accident, Fukushima-related studies, and numerous hypothetical nuclear accident scenarios [4]. However, previous studies have primarily focused on countries with operating nuclear power plants, whereas relatively few investigations have addressed atmospheric dispersion assessment for nuclear newcomer countries during the pre-deployment phase [5]. Since neither the reactor technology nor the final deployment site has been selected in the Philippines, this study adopts the publicly available Fukushima Daiichi source term as a representative reference accident scenario for a preliminary assessment. The objective is not to evaluate the safety of a specific reactor design, but to establish an atmospheric dispersion assessment methodology under typhoon conditions applicable to multiple candidate sites under consideration by the DOE. The proposed approach can therefore serve as a technical basis for future site-specific feasibility studies, radiological consequence assessments, and nuclear emergency preparedness associated with the deployment of both large nuclear power plants and SMRs in the Philippines.

2. Methods and Results

HYSPLIT was used to model atmospheric dispersion and generate trajectory and concentration fields. A Lagrangian approach was used for particle transport and dispersion, while concentrations were computed on a fixed Eulerian grid [4]. Forward trajectory calculations were performed to characterize atmospheric transport from the five candidate sites. The starting locations were candidate sites for nuclear power plants in the Philippines, namely Bataan (14.58° N, 120.47° E), Labrador (16.03° N, 120.15° E), Camarines Norte (14.17° N, 122.71° E), Masbate (12.37° N, 123.62° E), and Palawan (9.74° N, 118.73° E). The release activities for ^{137}Cs and ^{131}I were assumed to be 1.8×10^{16} Bq and 1.7×10^{17} Bq, respectively, based on the Fukushima Daiichi Nuclear Power Plant accident. The Fukushima-derived source terms were adopted solely to serve as a reference release scenario, uniform across all five candidate sites. This should not be interpreted as source terms specific to future nuclear reactor technology considered for deployment in the Philippines. Both radionuclides were modeled as particles. Although ^{131}I can exist in particulate, elemental, and organic forms, only the particulate form was considered in this preliminary study as a simplifying assumption. The

emission duration for both radionuclides was set to 24 hours. The simulation ran for 216 hours (9 days). HYSPLIT uses gridded meteorological data that can be in different formats. For this study, the data were in the GDAS1 format, with data gridded in a pressure (absolute) coordinate system at 1° horizontal resolution, provided in regular 3-h intervals on a weekly basis [4]. The period covered was 1 to 10 November 2013, encompassing the generation and landfall of Super Typhoon Haiyan in the Philippines to simulate atmospheric dispersion under extreme tropical cyclone conditions.

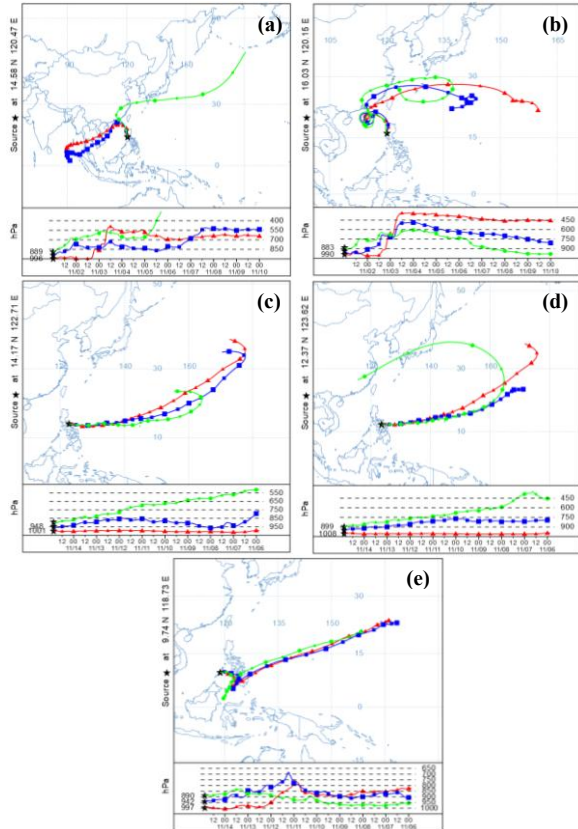


Fig. 1. Calculated forward air-mass trajectories from (a) Bataan, (b) Labrador, Pangasinan, (c) Camarines Norte, (d) Masbate, and (e) Palawan during Super Typhoon Haiyan.

The movement of particles in air generally follows wind currents, which vary depending on altitude. Fig. 1 shows the projected forward trajectories starting from the five candidate sites. The calculated trajectories were strongly influenced by the atmospheric wind fields associated with Super Typhoon Haiyan. The trajectories showed tight clustering and looping that reflect the influence of the typhoon. In general, the trajectories exhibited predominantly eastward transport from the candidate sites. The airborne concentrations and ground deposition of ^{137}Cs and ^{131}I from the candidate sites were modeled. Table I summarizes the maximum airborne concentrations and ground deposition for each radionuclide and site. For maximum airborne concentration, Palawan showed the highest values for both ^{137}Cs ($1.8 \times 10^5 \text{ Bq/m}^3$) and ^{131}I ($1.7 \times 10^6 \text{ Bq/m}^3$). For

maximum ground deposition, Bataan and Masbate showed the highest deposition for ^{137}Cs ($1.9 \times 10^7 \text{ Bq/m}^2$ for both), and Camarines Norte had the highest deposition for ^{131}I ($1.1 \times 10^8 \text{ Bq/m}^2$). The differences among the candidate sites likely reflect spatial variations in atmospheric transport, plume dispersion, and deposition processes associated with the typhoon meteorological field. In particular, the locations of maximum airborne concentration do not necessarily coincide with those of maximum ground deposition, indicating that atmospheric concentration and surface contamination are influenced differently by atmospheric transport, dispersion, and deposition processes. The site-dependent transport patterns shown in Fig. 1 and the variations in airborne concentration and ground deposition summarized in Table I provide preliminary technical information that may support site-specific emergency preparedness planning and future radiological risk assessment under the emerging regulatory framework of the Philippine Atomic Energy Regulatory Authority (PhilATOM) [6].

Table I: Maximum airborne concentrations and ground deposition values of ^{137}Cs and ^{131}I for five candidate sites.

Candidate Sites	Max. Airborne Concentration (Bq/m^3)		Max. Ground Deposition (Bq/m^2)	
	^{137}Cs	^{131}I	^{137}Cs	^{131}I
Bataan	5.9×10^4	5.5×10^5	1.9×10^7	9.7×10^7
Labrador	3.8×10^4	3.5×10^5	1.0×10^7	4.7×10^7
Camarines Norte	9.4×10^4	9.2×10^5	1.8×10^7	1.1×10^8
Masbate	4.4×10^4	4.2×10^5	1.9×10^7	1.0×10^8
Palawan	1.8×10^5	1.7×10^6	9.5×10^6	9.1×10^7

3. Conclusions

The atmospheric dispersion of hypothetical radionuclide releases from five candidate nuclear sites in the Philippines was assessed under typhoon conditions as a preliminary step toward pre-deployment radiological disaster assessment. HYSPLIT simulations using the meteorological fields of Super Typhoon Haiyan demonstrated site-dependent atmospheric transport patterns, including looping and predominantly eastward trajectories. Despite the application of a uniform reference source term, the maximum airborne concentrations and ground deposition of ^{137}Cs and ^{131}I varied among the candidate sites, reflecting differences in atmospheric transport, dispersion, and deposition processes. These results highlight the importance of considering site-specific typhoon meteorological conditions when assessing the potential radiological consequences of hypothetical releases. This study provides preliminary technical information to support future site-specific radiological disaster assessments and

emergency preparedness planning for nuclear power development in the Philippines.

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