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OFFSITE DOSE ASSESSMENT AND ZONE PLANNING FOR NINH THUAN NUCLEAR POWER PLANT IN VIETNAM

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ABSTRACT: *This study is an attempt to develop and to evaluate a practical methodology to assess the offsite dose of a hypothetical nuclear power plant (NPP) accident at the Ninh Thuan 2 NPP in Vietnam. The dose factor of radioactivity releases in airborne that enter the human body through inhalation exposure pathway is primarily focused to evaluate the human dose of interest. Based on the estimation of offsite dose, this research provides the comparative results of estimating exclusion zone and low population zone by the deterministic and the probabilistic approach. The deterministic approach is the scheme carried out based on the assumption that the weather condition is at steady state along the pathway of radionuclide release. For this approach, the estimation of dose is performed under the unchanged circumstance of a hypothetical worst-case of atmospheric condition. From another perspective, our proposed probabilistic approach takes into account the probabilities of different atmospheric patterns based on our collection of the historical meteorological data in the period from the year of 1996 to 2009. The probabilistic assessment shows the advantage in reflecting the more reality of the NPP accident situation than the deterministic one. The results can be used by the government in planning the critical zones and in producing the evacuation policy in case of NPP accident to limit and minimize the consequence of the radionuclide to the public and the environment.*

KEYWORDS: Offsite Dose Assessment, Exclusion Area (EZ), Low Population Zone (LPZ), Population Center Distance, Probabilistic Assessment

INTRODUCTION

Vietnamese government has a nuclear energy program with the goal of producing 15,000 megawatts of electricity through nuclear power by 2030 [1]. Ninh Thuan Province was approved by the government for the construction of the two first nuclear power plants (NPP) in Vietnam. The Ninh Thuan 1 NPP site with four nuclear reactors (4 x 1000MWe) is to be built in the south-central province of Ninh Thuan under the partnership with Russian technicians. Vietnamese government has also chosen Japanese partner to develop the second NPP site – Ninh Thuan 2 NPP. For this site, two generation III NPPs – advanced boiling water reactors are considered to become operational in 2024-2025 in the coast of northeastern of Ninh Thuan Province [1]. The implementation of a long-term nuclear energy program for a new comer like Vietnam opens up many challenges such as technical infrastructure, human training and especially the safety issue. Estimating the risk of radionuclide spread and dispersion in the atmosphere in the case of NPP accident is currently the most essential task for Vietnamese policy planners to facilitate preparedness and mitigation strategies and to propose policies to protect public health and safety.

One of the most critical issues to be considered for the construction of a new NPP is the impact

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assessment of the radiation from the plant to surrounding environment. Although the technology of the NPP reactor by years has gained many advances in the control of radioactive materials leaking into the environment, even the best technology can not completely eliminate the possibility of radioactive substance emissions into the environment. Therefore, the evaluation of radioactive substance spreading from a NPP site to the environment is a critical and irreplaceable task for the process of NPP risk assessment.

In case of a NPP accident, the radioactive materials released as fine aerosol or gas will create a plume which is transported in downwind path [2]. The residents living in the areas along the exposure path of the radionuclides will be affected through many pathways such as breath, lung, skin or food chain [2]. The residents who are living in the locations affected by the highest level of radionuclide contamination is the most-affected people. Therefore, the evaluation of radioactive substances spreading from a NPP site must be able to estimate and record the concentration of radionuclides at a certain point around NPP sites. These tasks require a wide variety of input data. Besides the meteorological data of the monitoring site, the topographical data, the source term data are also needed. In addition, with distance from the exhaust stack and time from the starting of release, radionuclide concentrations become gradually lower along the spreading path [3]. When the radionuclides reach to a certain distance that is accepted as a safe distance from a nuclear reactor, the outer boundary by this distance will define the safe zones for the public.

This research implemented our methodology by applying it to the case of offsite dose assessment for Ninh Thuan 2 NPP site in Vietnam. The study assumed the hypothetical severe NPP accident source term scenario and combined with the actual hourly meteorological condition during the fourteen years period to describe the radionuclide ground-surface concentration in the form of Gaussian distributions for the domain of interest. In the next step, the human dose through inhalation pathway of radionuclide materials around the NPP offsite areas is estimated. Based on the offsite dose calculation, the study uses the deterministic and probabilistic approach to create the offsite zoning plan based on the reactor site criteria regulated by United States Nuclear Regulatory Commission (NRC).

Figure 1 is the illustration for the scheme followed by this research. In the beginning stage, the source term is created as the input data for the further stage. The source term was carried out via literature review about the source term of a hypothetical severe nuclear accident written by GE Hitachi Nuclear Energy for the case of advanced boiling water reactor (ABWR) - the world's first generation III reactor [4]. In the second stage, the atmospheric dispersion model is applied to calculate the concentration of radionuclide materials released in the atmosphere as well as the radionuclide dose to the human. This stage uses the hourly meteorological data in Ninh Thuan Province from 1998 to 2009 period to predict the radionuclide concentration for a wide range of atmospheric conditions. The final stage is to plan the critical zones for the areas around the NPP facilities, including exclusion zone (EZ), low population zone (LPZ) and population center distance for the nearest densely populated areas. The results can be served as recommendations for the government in producing the evacuation policy and the preparedness plan for the emergency case of NPP accident to limit and minimize the consequence of the radionuclide to the public and the environment.

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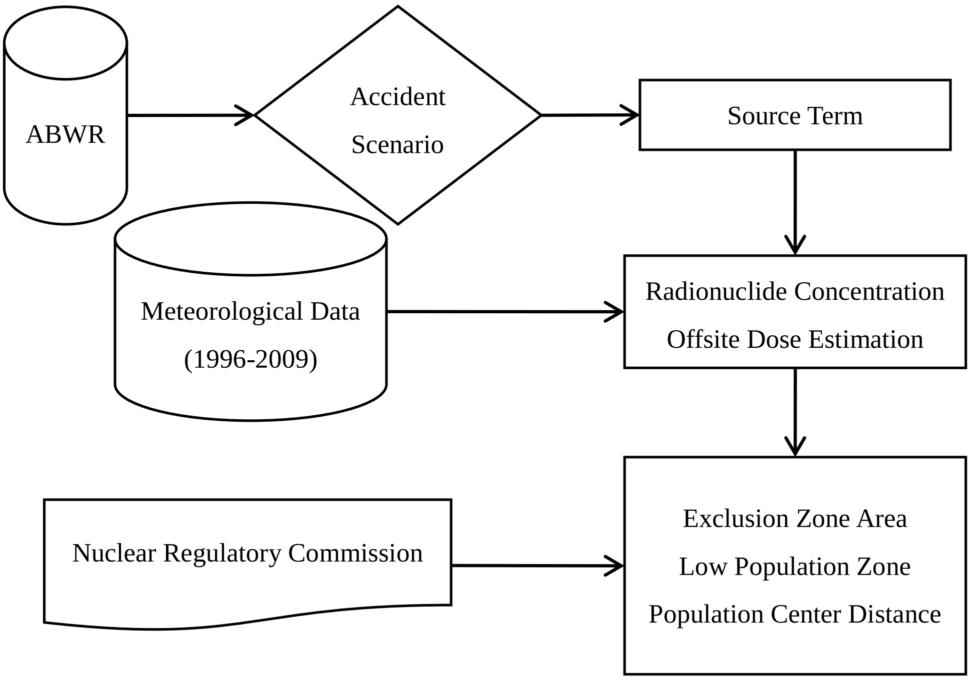

Figure 1: Research scheme

HYPOTHETICAL ACCIDENT SCENARIO

Source Term

A source term is a technical expression used to describe the accidental release of radioactive material from a nuclear facility to the environment [5]. One of the important parameters described in the source term is the inventory of radionuclides. In a nuclear reactor, various radioactive materials are generated in fission and activation process. The inventory of fission products and other radionuclides that are formed during the fission process in the reactor fuel and core can be grouped into a small set of categories of elements with similar physical or chemical behaviors [6].

Table 1: Radionuclide classification scheme

Nuclide Group	Nuclides
Noble Gases Group	Xe, Kr
Iodine Group (Halogens)	I, Br
Cesisum Group	Cs, Rb
Telleurim Group	Te, Sb, Se
Strontium Group	Ba, Sr
Ruthenium Group (Noble metals)	Ru, Rh, Pd, Mo, Tc, Co

To describe the NPP accident, the source term scenario must define the fraction of the total amount of the isotopes available in the reactor that release from a nuclear facility to the environment. For the Ninh Thuan 2 NPP site in Vietnam, the advanced boiling water reactors (ABWR) have been considered by the authorities to be installed and become operational in 2024-2025. To assess the risk of a hypothetical NPP accident at this research site, a source term for ABWR inventory is therefore applied. The assumption value of iodine isotopes inventory are given in

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Table **2**. For evaluating the potential radiological consequences of a loss of coolant accident of boiling water reactor type, the Regulatory Guide 1.3 of the United States Nuclear Regulatory Commission (NRC) is commonly used to assume the important parameters of the source term [7]. In this regulation, it is assumed that of the fission products found in the core, 100% of the radioactive noble gas inventory and 25% of the radioactive iodine inventory will be available for leakage from the reactor containment. Moreover, the release of available airborne radioactivity from the NPP reactor to the environment is assumed to occur at a constant leakage rate of 0.1% per day. Among the fission products and radionuclide materials, the iodine isotopes effects immediately to the human health after releasing from NPP accident. The internal radiation to the thyroid from radioiodine through the inhalation is root cause of subsequent thyroid cancer [8]. Therefore, this research primarily concerns on iodine group to assess the offsite dose of NPP accident.

Table 3 shows the amount of iodine isotopes released to the environment during the time T, simply referred here as R.

Table 2: Inventory of Iodine Isotopes

Iodine Isotope	Inventory (Bq)
I-131	3.46E+18
I-132	5.18E+18
I-133	7.36E+18
I-134	8.07E+18
I-135	4.37E+18

Table 3: Amount of Iodine Release to the Environment

Iodine Isotope	R_T(Bq)	
	T=2 hours Exclusion Area	T=30 days Low Population Zone
I-131	7.19E+13	9.93E+15
I-132	8.09E+13	1.78E+14
I-133	1.48E+14	2.30E+15
I-134	8.44E+13	1.06E+14
I-135	8.20E+13	4.33E+14

RELEASED RADIONUCLIDE CONCENTRATION

The plume of radionuclide released in the atmosphere can be separated as a series of puffs. Each puff is transported in downwind path. Along this path, it expands horizontally and vertically by dispersion process. The dispersion simulation estimates how radionuclide materials distribute along the exposure path. Dispersion estimates must be implemented in order to describe the distribution of radionuclide concentration at a point of interest. To estimate the distribution of radionuclide spread during NPP accidents, atmospheric dispersion simulation models such as Gaussian Plume Model are widely used. In this research, dispersion estimates are determined by using Gaussian plume equation. This equation is based on an analytical solution under the assumption of constant wind speed, no wind shear, and flat topography [9]. The equation for a continuous source point is defined as following:

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

The ground level of radionuclide concentration is defined in equation (2) which is transformed from equation (1). This average centerline value of the ground concentration χ_E will be used to estimate the radius distance of the critical zones around the NPP facilities, including the EZ and the LPZ.

$$\chi = \frac{Q}{\pi u\sigma_y\sigma_z} exp\left(-\frac{H^2}{2\sigma_z^2}\right) \quad (2)$$

where:

$\chi(x,y,z)$ The radionuclide concentration (Bq.m^{-3}) at point (x,y,z)
χ The average centerline value of the ground concentration (Bq.m^{-3})
Q Amount of material released (Bq.s^{-1})
σ_y, σ_z The standard deviations (m) of the normal crosswind and the vertical concentration distributions of plume materials, respectively
u The mean wind speed (m/s) at the effective release height H
H the effective release height (m)

The standard deviations of the normal crosswind and the vertical concentration distributions of plume materials are respectively [9]:

$$\sigma_y = ax^b \text{ and } \sigma_z = cx^d \quad (3)$$

where coefficients parameters *a*, *b*, *c* and *d* are defined in
Table 4.

Table 4: Values for standard deviation σ_y, σ_z

Pasquill-Gifford Stability Category	*a*	*b*	*c*	*d*
A	0.3658	0.9031	0.0003	2.1250
B	0.2751	0.9031	0.0019	1.6021
C	0.2089	0.9031	0.2000	0.8543
D	0.1474	0.9031	0.3000	0.6532
E	0.1046	0.9031	0.4000	0.6021
F	0.0722	0.9031	0.2000	0.6020

For simplifying the assumption, the diffusion factor (χ/Q) is used and the effective released height is set at 30 meters. Figure 2 represents the comparison of diffusion factor (χ/Q) at different atmospheric stability classes and wind speeds as a function of distance.

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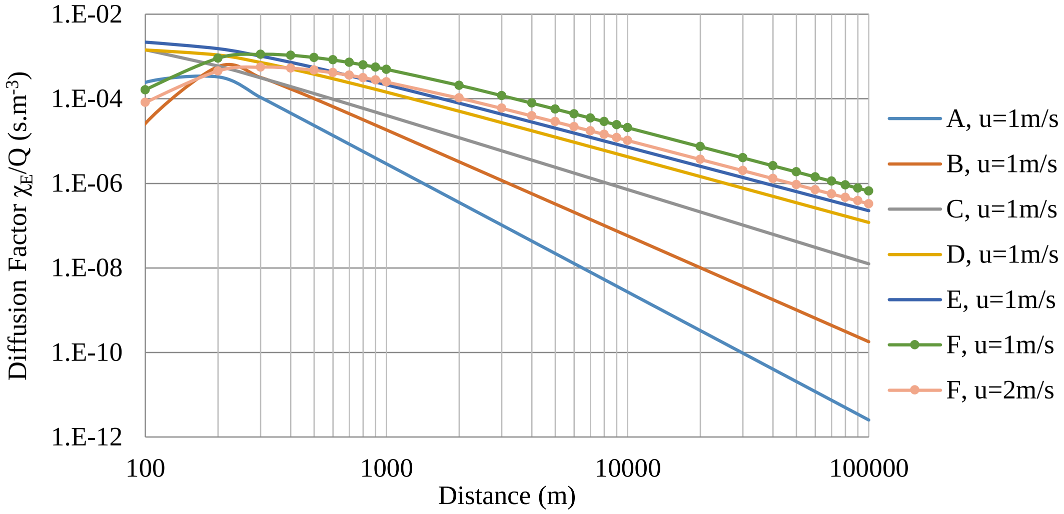

Figure 2: Diffusion factor for several stability categories and wind speed at effective height H = 30 m

It can be seen from Figure 2 that the curve of atmospheric stability class F (under the wind speed of 1 m.s^{-1}) covers all the curves of other stability categories. Therefore, it is called as the envelope of a set of curves represented by several stability categories and wind speeds. It can be said that if the NPP accident is happened under the meteorological conditions defined by atmospheric stability class F (under the wind speed of 1 m.s^{-1}), the release of radionuclide materials can lead to the worst consequences and the affected areas will be the widest one. Therefore, the atmospheric stability class F, combining with the wind speed of 1 m.s^{-1}, can be seen as the worst-case of the atmospheric condition for the hypothetical accident at the Ninh Thuan 2 NPP. By projecting every point in this envelope curve defined by F and wind speed 1 m.s^{-1} to the distance-axis of the graph, we can find the longest distance that the radionuclides can be released from the exhaust stack in the worst-scenario case of accident.

OFFSITE DOSE ASSESSMENT

Radiological offsite dose assessment is a quantitative process that characterizes the relationship between the environmental release of radioactive effluents and the potential effects on human health. The offsite dose assessment is a structured process that maps the progression of a radionuclide from its point of release to the environment, through various environmental pathways, resulting ultimately in exposure to man. Radionuclide release in the atmosphere will effect to the human through different dose exposure pathways. These exposure pathways may be grouped into three categories. The first group is composed of the airborne releases which are exposures resulting from radioactive materials released with gaseous effluents to the atmosphere. Another group of liquid releases includes the exposures resulting from radioactive materials released with liquid discharges to bodies of water. Other kind of exposure pathway is the radiation from contained radioactive sources. For our research, when performing radiation dose calculations, we focus only the exposure pathway through the atmosphere that often significantly contributes to the total dose of interest need to be evaluated. More precisely, the dose factor of radioactivity releases in airborne that enter the human body through inhalation is primarily focused. This dose component is referred as the committed effective dose equivalent (CEDE). The CEDE dose is the result from inhalation of material directly from the passing plume and is defined as [10]:

$$\mathbf{D_{CEDE}} = \sum_i \mathbf{CF_i} \sum_j \mathbf{R_{ij}} \mathbf{B_j} (\boldsymbol{\chi}/\mathbf{Q})_j \quad (4)$$

where:

D_{CEDE}	CEDE dose (rem)
CF_i	CEDE dose conversion factor (rem.Bq^{-1}) for isotope *i*
R_{ij}	Amount of isotope *i* released during time period *j* (Bq)
B_j	Breathing rate during time period *j* ($m^3.s^{-1}$)
$(\chi/Q)_j$	Diffusion factor during time period *j* ($s.m^{-3}$)

It is important to note that this study primarily concerns on iodine group to assess the offsite dose of NPP accident. Therefore, the evaluation is performed for the iodine isotopes only. The internal radiation to the thyroid from different iodine isotopes through the inhalation represents a different health risk.

Table 5 shows the dose conversion factors CF for adult inhalation of iodine isotopes [10].

Table 5: Adult Inhalation Thyroid Dose Conversion Factors (CF)

Iodine Isotope	CEDE Dose Conversion Factor (rem.Bq^{-1})
I-131	4.00E-05
I-132	1.45E-06
I-133	1.08E-05
I-134	6.76E-07
I-135	3.35E-06

OFFSITE ZONE PLANNING

Based on the analysis of offsite dose assessment, the study has constructed the plan for the classification of the critical areas around the NPP. It is intended that each area shall be considered individually based on its specific requires in determining its boundaries. Roughly circular areas around the facilities of reactors are classified in two main areas: EZ and LPZ.

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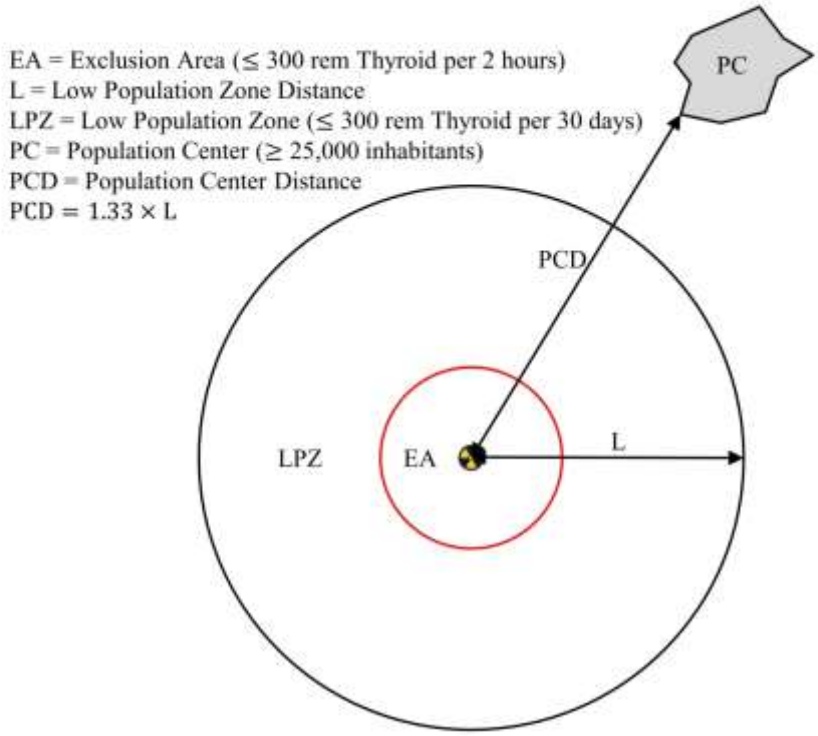

Figure 3. Zone Planning

EZ is the area surrounding the reactor, in which the reactor owner has the authority to determine all activities including exclusion or removal of personnel and property from the area. Residence within the EZ shall normally be prohibited. In any event, residents shall be subject to ready removal in case of necessity. Activities unrelated to operation of the reactor may be permitted in an EZ under appropriate limitations, provided that no significant hazards to the public health and safety will result. Immediately surrounding the EZ is the LPZ. This area contains residents, the total number and density of which are such that there is a reasonable probability that appropriate protective measures could be taken in their behalf in the event of a serious accident. Another factor to be considered in offsite zoning is the measure of population center distance. This is the distance from the reactor to the nearest boundary of a densely populated center containing more than about 25,000 residents. This section aims to the determination of EZ, LPZ, and population center distance which are carried out based the criteria for area zoning plan regulated by the United States Nuclear Regulatory Commission (NRC).

CRITERIA FOR AREA ZONING PLAN

Protection of the health and safety of the public in the operation of nuclear reactors is augmented through the implementation of federal regulations administered under the auspices of NRC. Title 10 part 100 of the Code of Federal Regulations (10 CFR 100), "Reactor Site Criteria," contains the federal regulations governing the siting factors and criteria in assuring that radiological doses from postulated accidents will be acceptably low. This base reflects that the primary factors that determine public health and safety are the reactor design, construction and operation. These include the criteria to define the emergency plans in case of reactor accident [11]. As required by 10 CFR 100, the size of an EZ is determined in the way that an individual located at any point on its boundary for *two hours* immediately following onset of the postulated fission product release would not receive a total radiation dose in excess of 300 rem to the thyroid from iodine exposure. For a LPZ, its boundary is the limitation that an individual located at any point on its outer boundary who is exposed to the radioactive cloud resulting from the postulated fission product release during the entire period of its passage (e.g. *30 days*) would not receive a total radiation dose in excess of 300 rem to the thyroid from iodine exposure. Based on the size of a LPZ, the nearest boundary of a densely populated center is at least one and one-third times the distance from the reactor to the outer boundary of the LPZ [11]. That distance is called population center distance. In applying this guide, due consideration should be given to the population distribution within the population center. Where very large cities are involved, a greater distance may be necessary because of total integrated population dose considerations.

The thyroid dose depends on the volume of air that the human inhales when appearing in the radionuclide plume. When human is working in the EZ, it is assumed that the breathing rate is based on eight hours of inhalation of the active portion of the normal working day [10] and is defined as:

$$\mathbf{B} = \frac{\mathbf{10m^3}}{\mathbf{8\ hours}} = \mathbf{3.47 \times 10^{-4} (m^3.s^{-1})} \quad (5)$$

For the case of human is living in the LPZ, the breathing rate is assumed to be at $20m^3$ per day [10] and is defined as:

$$\mathbf{B} = \frac{\mathbf{20m^3}}{\mathbf{24\ hours}} = \mathbf{2.32 \times 10^{-4} (m^3.s^{-1})} \quad (6)$$

ZONE PLANNING BY DETERMINISTIC APPROACH

First, the zone planning is carried out by applying the deterministic approach. Deterministic approach is the scheme based on the assumption that the weather condition is at steady state along the pathway of radionuclide release. The calculation is performed under the scenario that the NPP accident is happened under the worst-case of atmospheric condition when the weather remains at atmospheric stability class F and the wind speed $1m.s^{-1}$. This scenario can be representative for all cases of weather conditions during the time of accident. Under this assumed meteorological condition, the radius of the critical zones, EZ and LPZ is calculated based on the diffusion factor χ/Q that is inferred from the equation (4). Furthermore, the diffusion factor χ/Q is calculated under the dose conversion factor CF, the breathing rate B and the amount of released iodine isotope R. With the available data of CF, B and R, the result of iodine diffusion factor χ/Q will be 1.75×10^{-4} for the EZ and 3.05×10^{-6} for the LPZ. Based on diffusion factor χ/Q results, the radius distances for the EZ and for the LPZ are determined to be at 2.5 km and 36 km respectively. Figure 4 shows our calculated results for the EZ and LPZ represented in the map of Ninh Thuan NPP site. While the red circle represents for the boundary of the EZ, the black circle is used to identify the boundary of the LPZ. The LPZ, having the radius distance of 36 km, covers a wide range area of more than 4,000 km^2 ($\pi \times 36^2$). With the radius distance of 36 km, it is clear to say that in case of emergency, the evacuation of the population living in such wide range area around NPP site will surely take a huge cost and responsibility from the government. To avoid the overestimation of the LPZ, the study takes another approach by considering the actual weather conditions of the research site. Our proposed probabilistic assessment takes into account the probabilities of different weather condition patterns that had been happening in more than one decade in the area of the research site. Based on that, our methodology is an attempt to provide a practical scheme that can create a more realistic boundary distance that shapes the LPZ. The following section describes the details of the probabilistic approach and shows the result as compared with that in the deterministic approach.

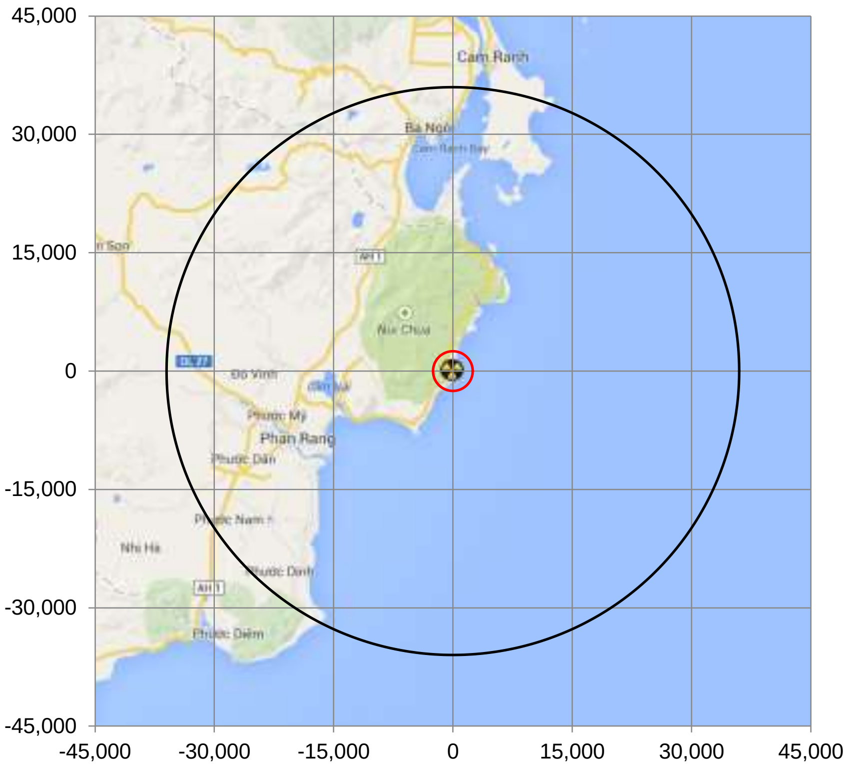

Figure 4. Exclusion Zone and Low Population Zone

ZONE PLANNING BY PROBABILISTIC APPROACH

Instead of planning the LPZ by the conventional approach (i.e. deterministic approach) which shapes this area in the circle of radius *r*, we have applied the probabilistic approach for each particular circular sector of this area which represents different atmospheric conditions during the NPP accident. This approach takes into account the probabilities of different atmospheric patterns based on our collection of the historical meteorological data in the period from the year of 1996 to 2009 in the area of the research site.After the incident of nuclear facilities, the radionuclide materials are dispersing in the atmosphere whose conditions are variably changing by time. At a certain point of interest, the radionuclide concentration varies depending on the atmospheric condition at that point in the given time of the observation. Therefore, points of the same distance from the nuclear stack center may contain different levels of radionuclide mass. It also means that people sitting in the affected areas with the same distance from the nuclear stack of release may receive different radiation doses to the thyroid from iodine exposure. While the deterministic approach assumes the case of NPP accident under the stable meteorological defined by the stability class F and the wind speed of $1 m.s^{-1}$, people sitting in the affected areas with the same distance from the nuclear stack will receive an equal radiation dose. Indeed, it may not entirely reflect the realistic situation. The LPZ which is defined by the limitation of a total radiation dose of 300 rem to the thyroid from iodine exposure will not be

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simply a circle round if we consider the atmospheric conditions under that the radionuclides disperse. From that observed fact, the probabilistic approach tries to produce more realistic results of the boundary of the LPZ than the deterministic approach by using historical weather conditions of the domain of interest. In the first step, we divided the affected area around the NPP reactor in 16 zone sectors representing 16 directions of the wind. They are: East (E), East-North-East (ENE), North-East (NE), North-North-East (NNE), North (N), North-North-West (NNW), North-West (NW), West-North-West (WNW), West (W), West-South-West (WSW), South-West (SW), South-South-West (SSW), South (S), South-South-East (SSE), South-East (SE), East-South-East (ESE). For each wind direction, we then combined the wind speed with the atmospheric stability classes (A, B, C, D and F) based on the categorization method defined by Pasquill (
Table 6). Our actual data of historical wind in the fourteen years period of Ninh Thuan 2 NPP produced the 37 cases of the wind speed combined with the atmospheric stability classes (
Table 7). These cases illustrate 37 different conditions of weather may probably happen in a particular location of the affected area during the time of accident.
Table 7 shows the frequency of these happening weather conditions for distinct wind directions cover 16 zone sectors of the affected area around NPP reactor.

Table 6: Definition of Pasquill Atmospheric Stability Categories [12]

Surface wind speed (at 10 m) ($m.s^{-1}$)	Daytime insolation			Night-time conditions	
	Strong	Moderate	Slight	>3/8 cloudiness[a]	≤3/8 cloudiness
<2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Note: Stability category characteristics are as follows: A is extremely unstable, B is moderately unstable, C is slightly unstable, D is neutral[b], E is slightly stable, F is moderately stable.
[a] The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon that is covered by clouds
[b] Applicable to heavily overcast day or night conditions.

Table 7: Weather case and its own probability at 16 directions

Case	Atmospheric Stability	Wind Speed ($m.s^{-1}$)	E (%)	ENE (%)	NE (%)	NNE (%)	N (%)	NNW (%)	NW (%)	WNW (%)	W (%)	WSW (%)	SW (%)	SSW (%)	S (%)	SSE (%)	SE (%)	ESE (%)
1	A	1	13	2.3	1.1	3.0	11	15	21	30	13	6.9	6.5	5.3	14	8.4	9.2	13
2	A	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	B	1	2.5	0.2	0.5	1.9	7.4	7.5	6.8	3.2	4.3	1.1	1.5	1.9	4.2	1.9	2.9	2.6
4	B	2	18	4.9	2.7	5.0	8.9	14	16	11	12	7.2	8.3	13	29	16	21	21
5	B	3	16	3.6	2.5	3.2	2.1	2.4	1.9	3.2	5.2	11	11	9.6	11	20	19	20
6	B	4	9.0	5.3	4.8	2.9	0.6	0.0	0.6	0.5	1.4	7.2	10	12	8.5	27	17	17

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7	C	2	3.3	0.8	1.0	1.8	2.4	0.8	1.3	0.0	0.9	0.5	0.5	0.5	0.0	0.0	1.3	0.0
8	C	3	4.1	4.9	6.2	7.3	5.0	1.6	1.0	2.1	0.0	3.5	3.7	2.9	1.4	0.6	2.0	1.7
9	C	4	3.3	9.7	9.0	6.4	0.9	0.0	0.6	1.1	0.5	1.1	2.9	3.4	0.0	0.6	1.0	2.6
10	C	5	2.5	4.4	5.0	2.4	0.9	0.0	0.3	1.1	1.9	5.1	7.1	6.3	4.2	4.5	6.9	2.6
11	C	6	0.8	3.2	4.4	2.4	0.0	0.0	0.0	0.0	0.0	2.7	4.9	2.9	0.0	1.9	0.0	0.9
12	C	7	0.0	1.7	1.8	1.4	0.0	0.0	0.0	0.0	0.0	0.5	1.2	1.9	0.0	0.0	0.0	0.0
13	C	8	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.5	0.0	0.0	0.3	0.5	0.0	0.0	0.0	0.0
14	C	9	0.0	0.0	0.1	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
15	C	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	C	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	C	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	C	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	D	3	1.6	1.1	2.5	3.4	0.3	1.6	0.3	0.5	1.9	2.9	2.8	1.0	1.4	0.0	0.0	0.0
20	D	4	0.8	1.7	1.9	2.7	0.9	0.0	0.3	0.0	0.9	3.2	1.7	1.0	0.0	0.0	0.0	0.0
21	D	5	2.5	11	12	7.5	1.2	0.0	0.0	0.5	0.5	5.3	3.2	1.4	1.4	0.0	0.3	0.0
22	D	6	0.8	8.9	7.8	4.6	0.3	0.0	0.3	0.0	0.5	1.1	1.2	1.9	0.0	0.0	0.0	0.0
23	D	7	0.0	3.0	3.4	2.1	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.5	0.0	0.0	0.0	0.0
24	D	8	0.0	0.6	0.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
25	D	9	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
26	D	10	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	D	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	D	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	D	13	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	E	2	0.8	0.6	1.2	3.0	3.0	5.5	2.6	3.7	3.8	5.1	2.6	2.9	1.4	0.0	0.7	0.9
31	E	3	0.0	3.2	4.1	5.1	1.8	0.8	0.0	0.5	0.9	2.4	1.7	4.8	0.0	0.6	0.3	0.0
32	E	4	1.6	6.3	5.3	3.7	0.6	0.4	0.3	0.0	0.0	2.9	1.5	1.9	0.0	0.0	0.0	0.0
33	E	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	F	1	4.1	3.0	2.7	7.8	32	27	26	23	31	10	7.3	5.8	8.5	2.6	1.3	0.9
35	F	2	0.0	4.2	4.0	6.1	5.0	7.1	3.9	2.1	4.3	4.5	4.0	2.9	0.0	0.0	1.3	0.0
36	F	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	Calm wind		14.8															

To estimate the radius distance for the roughly circular of the LPZ, we have implemented a simulation of the radioactive dispersion resulting from the postulated fission product release during the entire period of its passage (i.e. 30 days as it is assumed by 10 CFR 100). The atmospheric conditions in the affected area during these 30 days (i.e. 720 hours) are represented by a weather sequence that contains 720 weather elements corresponding to 720 hours of releasing. Theoretically, there are in total 37^{720} ways for creating this weather sequence from 37 actual cases of weather shown in

Table 7. Each case of weather will also be appeared in the sequence with the probability defined by

Table 7. The simulation that covers all such huge numbers of theoretical cases requires the huge cost and time of computing running. To reduce the size of computing, the Monte Carlo method is applied in this study to generate the sample of 100,000 weather sequences for each zone directions. In total 1,600,000 weather sequences for 16 zone directions are created as the input

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data of meteorological conditions for the radionuclide dispersion simulation. Under the condition of each weather sequence, how far the distance that the radionuclides can be dispersed from the stack of release to the point of 300 rem of dose can be estimated. Therefore, there are in total 100,000 resulted distances that correspond to 100,000 weather sequences for each zone directions. The probabilistic distribution function is created for these 100,000 distances based on their frequency. We had implemented a test to prove that our set of results is under normal distribution. Kolmogorov-Smirnov test provided by MATLAB tool helps us to confirm that with the confidence level above 95%.

By using the normal distribution theory, the range of less than two standard deviations away from the mean accounts for about 95 percent of the sample. Therefore, the sum of the mean and two times of standard deviation is used to be representative for the distance that the radionuclides can be dispersed from the stack of release to the point of 300 rem of dose.

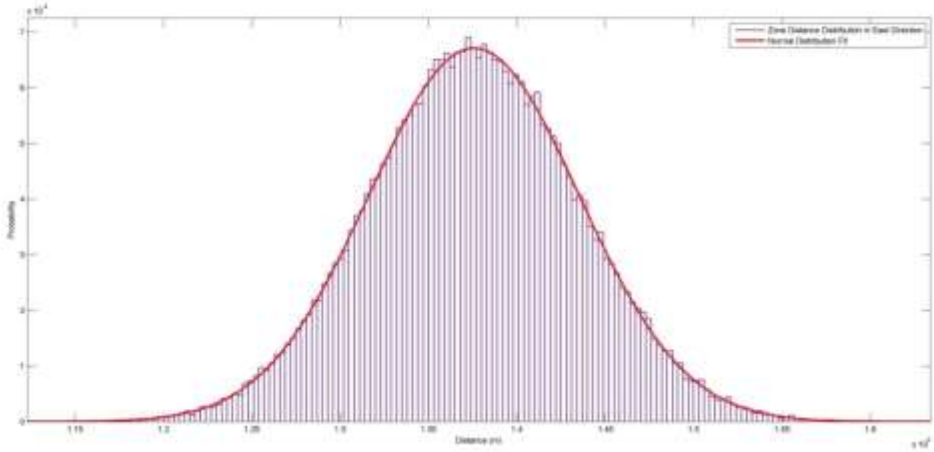

Figure 5. The distributed probability of zone distance in west direction

Table 8 shows the calculated distances for 16 different directions in the zone around the NPP. They used to define the boundary for the LPZ. It is then used to create the shape of the LPZ by the probabilistic approach.

Table 8: Statistics of the simulation for 16 directions

Direction	Mean (m)	Standard deviation (m)	Low Population Zone Distance (m)
E	13,757	594	14,945
ENE	7,040	407	7,855
NE	10,185	553	11,291
NNE	4,439	362	5,163
N	5,468	362	6,192
NNW	4,832	328	5,488
NW	2,137	208	2,554
WNW	2,101	176	2,452
W	14,177	593	15,362
WSW	11,700	575	12,850
SW	12,981	571	14,123
SSW	6,934	374	7,683

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S	4,730	258	5,247
SSE	3,112	260	3,632
SE	1,607	126	1,859
ESE	4,704	264	5,233

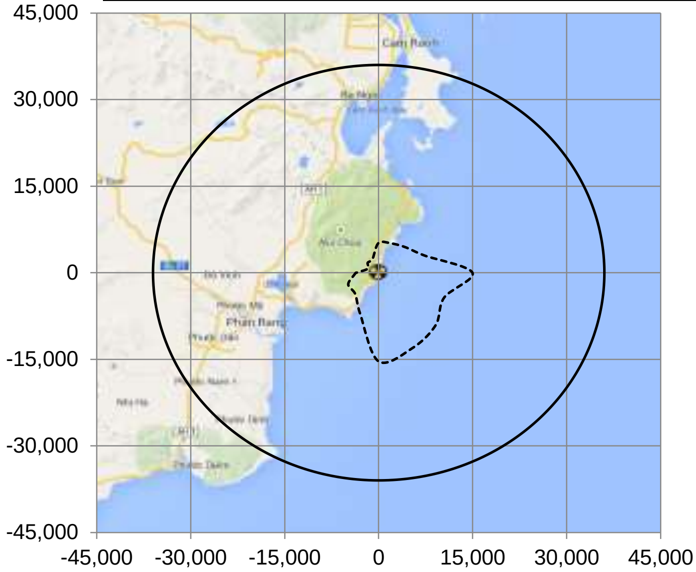

Figure 6. The comparative low population zone in deterministic (solid line) and probabilistic approach (dotted line)

Figure 6 is the map showing the LPZ defined by the deterministic approach as compared to that defined by the probabilistic approach. The difference in the shapes of the LPZ resulting from the two different approach suggest the useful information for the government in planning the critical zones around NPP site and the emergency action in case of NPP accident.

CONCLUSION

This study aims to provide the offsite dose assessment methodology of a hypothetical NPP accident and applied it to the case at the Ninh Thuan 2 NPP in Vietnam. The total radiation dose to the thyroid from iodine exposure through inhalation exposure pathway is primarily focused and estimated. The estimation of the offsite dose is then used as the criteria for the planning of the critical zones around the NPP, including the EZ and the LPZ, by applying two different approaches: the deterministic approach and our proposed probabilistic assessment. Deterministic approach is the scheme based on the assumption that the weather condition is at steady state along the pathway of radionuclide release. In this approach, the estimation of dose is performed under hypothetical worst-case of atmospheric condition when the weather remains at atmospheric stability class F and the wind speed $1 m.s^{-1}$. From another perspective, our proposed probabilistic approach takes into account the probabilities of different atmospheric patterns based on our collection of the historical meteorological data in the period from the year of 1996 to 2009. The attempt is to provide a more practical scheme. The comparative results in estimating the distance of LPZ show that the merit point of our proposed probabilistic approach is that it reflects the more reality of the NPP accident situation than the deterministic one by considering the huge historical weather conditions of the research site. The LPZ boundary by probabilistic approach covers the area of 250 km^2, accounting for only 6.25% as compared with the results from deterministic approach (4000 km^2), while it still can be represent for 95% of weather conditions during the accident. These comparative results of LPZ by two different methods suggests the useful information for authorities and government planners in arranging the critical zones around the NPP. The results can also be used by the government to produce the evacuation policy and the preparedness plan in case of NPP accident to limit and minimize the consequence of the radionuclide to the public and the environment.

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