*IOSR Journal of Applied Physics (IOSR-JAP)*
*e-ISSN: 2278-4861.Volume 10, Issue 5 Ver. II (Sep. – Oct. 2018), 76-85*
*www.iosrjournals.org*

# Assessing the Emergency Planning Zones for the Egyptian Nuclear Power Plant Site

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***Abstract:*** *Off-site emergency planning, preparedness, and response to the Nuclear Power Plant (NPP) accidents are sharing responsibilities between the regulator, operator, local and national organizations. The specification of the Emergency Planning Zones (EPZs) around the NPP is essential for effectively making decisions as well as taking protective and other response actions which are required for protecting the public from the hazards of ionizing radiation. This study aims to apply the probabilistic safety assessment methodology for estimating the off-site emergency planning zones around the Egyptian NPP at El-Dabba site. The method is based on the analysis of the worst severe accident scenario for 1200 MWt Pressurized Water Reactor (PWR), taking into account the different probabilities of the atmospheric pattern. The investigation is carried out using the RASCAL-4.2 Code. The off-site consequences of this accident are assessed and compared to the criteria for protective actions recommended by International Atomic Energy Agency (IAEA). The results can be served as recommendations for establishing the evacuation policy and the preparedness plan for the NPP accidents to limit and minimize the effects of such accidents on the public and the environment.*

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Date of Submission: 04-10-2018 Date of acceptance: 19-10-2018

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## I. Introduction

The evaluation of EPZs around a NPP is based on deterministic analysis that helps in setting a national strategy for establishing protective actions to be applied during an emergency. The size and shape of these zones mainly depend on the analysis of severe accidents related to the specific NPP, consideration of geographical features and demographic information specific at each site [1]. The determination of EPZs varies from country to country. Generally, simplified deterministic approaches are used when a reference accident is defined for use as a basis for drawing up similar emergency plans [2]. Several countries use the outputs from Probabilistic Safety Assessment (PSA), Level 2 and 3 analyses, to estimate the off-site consequences of Beyond Design Basis Accidents (BDBA) and sever accidents of NPPs. This approach is used to provide an acceptable basis for the implementation of risk-informed support in decision-making processes [3, 4, 5 and 6]

One of the primary IAEA's requirements to the NPP utility is to carry a comprehensive assessment of the associated hazards based on graded approach and take into considerations those with very low probabilities of occurrence. In this hazard assessment, on-site and off-site areas should be identified for which a nuclear emergency could warrant i) Precautionary urgent protective actions, to avoid or to minimize severe deterministic effects. Such measures must take before any significant releases of radioactive material II) Urgent protective and other response actions, to avoid or to minimize severe deterministic effects and to reduce the risk of stochastic effects. These actions are taken, if possible, before the occurrence of any significant release of radioactive material, and after a release occurs by monitoring and assessment of the radiological situation [7]. EPZs are integral parts of Emergency preparedness and response. They have always been considered in the nuclear industry even before the Three Mile Island Accident in 1979. The U.S. NRC gave the idea of generic emergency planning zones which is based on the spectrum of the accidents, the consequences, and the probabilities [8]. Probabilistic safety assessment of a NPP provides a comprehensive study to identify accident scenarios and deriving the risk to members of the public from the operation of the plant. For a NPP, the PSA includes enumeration of sequences of events that could produce a core melt and clarification of containment failure modes. The probabilities , timing, and identification of quantity and chemical form of radioactivity released if the containment is breached; modeling of dispersion of radionuclides in the atmosphere; and dose assessment related to the released radionuclides before any emergency response and after taken different protective actions [9]. The protection of the public in existing exposure situations should follow the system of protection for interventions where the intervention is defining as any action intended to reduce or avert exposure or the likelihood of exposure related to an accident. Evacuation, sheltering and iodine tablet distribution are types of these intervention countermeasures [10]. Off-site dose assessment and estimation of population zones around Ninh Thuan NPP site in Vietnam was carried out using deterministic and probabilistic assessment approaches [11]. They showed that the probabilistic assessment has the advantage in reflecting the more reality of the NPP accident situation than the deterministic one. The Low Population Zone (LPZ) boundary by a probabilistic approach covers the area of 250 $km^2$, accounting for only 6.25% as compared with the results from the deterministic approach (4000 $km^2$).

In Belgium; the general EPZs are associated with the protective actions as evacuation (10 km), sheltering (10 km), stable iodine intake (20 km) and food chain (whole country). The size of these zones has been defined taking into account a rough (presumably mostly deterministic) estimation of the associated risks [12].

Internal zone 3-5 km, outer zone 7-10 km and ingestion exposure pathway zone 20 km are applied for NPP Tianwan (PWR)/ China [13].

In the Czech Republic, the predetermined evacuation of people was within 5 km internal zone around Temelín NPP (1000 MWt WWER PWR). The EPZ is a territory of 13 km around Temelín NPP. The proposed actions were sheltering and taking iodine tablets [6].

The study presented the application of Gaussian puff model using site meteorological data along with the latest IAEA Post-Fukushima Guidelines for the estimation of EPZs (PAZ and UPZ) around K-2/K-3 NPPs in Turki [14]. 3.0 km and 8.0 km around K-2/K-3 NPPs designated as PAZ and UPZ, respectively.

Egypt has a nuclear energy program starting with the goal of building the first NPP in El-Dabba site, 183.9 miles from Cairo on the north coast, with four nuclear reactors (4 x 1200MWt, WWER 1200 PWR). Egypt as a newcomer in this field has many challenges. One of these challenges is the emergency preparedness and response on local and national levels in respect to severe accidents of NPP as well as the implementation of early and long-term protective actions to protect the public and the environment.

This study aims to implement a methodology for estimating the EPZs around the NPP unit in El-Dabba site. The methodology based on using PSA L2 of severe accident scenario with the different atmospheric pattern using the U.S. NRC (United States Nuclear Regulatory Commission) RASCAL 4.2 (Radiological Assessment System for Consequence Analysis) computer code [15]. A parameter of WWER 1200 MWt reactor is taking a base for calculations [16]**.** The methodology helps the planner, regulatory body, and the operator in evaluating the EPZs around the NPP with their corresponding protective actions.

## II. Material And Methods

**Description of the Suggested Scenario**

The selected scenario is based on the principle of the highest radiological consequences on the environment and the public health. PWR 1200 MWt thermal nuclear parameters of VVER reactor are taken into consideration in the modeling technique [16]. The scenario is defined as a major leak from primary to a secondary circuit when the operator fails to cool the depressurized primary circuit. Damage to the core and significant release of radionuclides will occur after the loss of inventory to cool the core.

Following the IAEA Post-Fukushima Guidelines, *10%* of the nuclear reactor core volatile radioactive material is assumed to be released for *10-hour* duration into the environment [17]. Further, containment by-pass was considered as the release pathway as it may warrant protective actions early [1].

A source term is a technical expression used to describe the accidental release of radioactive material from a nuclear facility to the environment [15]. One of the essential parameters defined 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 formed during the fission process in the reactor fuel and core can group into a small set of categories of elements with similar physical or chemical behaviors as shown in the table no. 1 [18].

**Table no.1:** Radionuclide source term classification scheme [18]

| **Nuclide Group** | **Species** |
|---|---|
| Noble Gases Group | Xe, Kr |
| Iodine Group (Halogens) | I, Br |
| Cesium Group | Cs, Rb |
| Tellurium Group | Te, Sb, Se |
| Strontium Group | Ba, Sr |
| Ruthenium Group (Noble metals) | Ru, Rh, Pd, Mo, Tc, Co |

**Atmospheric Dispersion**

RASCAL 4.2 uses Gaussian models to describe the atmospheric dispersion of radioactive and chemical effluents from nuclear facilities. A straight-line Gaussian plume model, TADPLUME, is used near the release point where travel times are short. A Lagrangian-trajectory Gaussian puff model, TADPUFF, is used at longer distances for which temporal or spatial variations in meteorological conditions may be significant. Diffusion equation has a specific, closed-form algebraic solution that is Gaussian. In one dimension, the solution is

$$\frac{X(x)}{Q} = \frac{1}{2\pi^{1/2}\sigma} \exp\left[-\frac{1}{2}\left(\frac{x-x_0}{\sigma_x}\right)^2\right] \text{--------(1)}$$

where: $\chi(x)$ = concentration at a distance $x$-$x_0$ from the center of the concentration distribution $x_o$ (1/m) Q = amount of material released (Ci or g), and $\sigma$ = dispersion parameter (m). The basic Gaussian Puff model is based on expanding the one-dimensional solution of the diffusion equation to three dimensions and can be represented as:-

$$\frac{X(x,y,z)}{Q} = \frac{1}{2\pi^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{x-x_0}{\sigma_x}\right)^2\right].\exp\left[-\frac{1}{2}\left(\frac{y-y_0}{\sigma_y}\right)^2\right].\exp\left[-\frac{1}{2}\left(\frac{z-z_0}{\sigma_z}\right)^2\right]; ---(2)$$

Where; $\chi$ is the concentration (Ci/m$^3$ or g/m$^3$) and Q is the amount of material released (Ci or g), TADPLUME and TADPUFF models used for representing the diffusion of the release based on the wind direction and speed. TADPUFF accounts for transit time in all calculations because the model tracks the movement of individual puffs and calculates concentrations and doses based on puff positions. As a result, dose rates calculated by TADPUFF may be used to estimate the time of arrival of a plume and may be compared to dose rates measured in the field. TADPUFF represents the spatial variation of winds by two-dimensional fields of vectors that give the direction and speed of puff movement [15]. The atmospheric pattern for the studied site including wind direction, wind speed, and stability class were selected based on the data collected from Dabaa synoptic station with WMO No. 62,309 lie at Latitude 30° 56′58″N and longitude 28° 26′41″ E working 24 h per day from 7th Dec.1947 till now. Seasonally surface wind directions and speed in the period from 1981-2014 are described in Table no. 2 [19]**.** The selected atmospheric criteria used in the dispersion of the model listed in Table no.3.

**Table no.2:** Seasonal atmospheric pattern of El-Dabaa site (1981-2014) [19].

| **Season** | **Wind direction** | **Wind speed m/s** |
|---|---|---|
| Winter | W (247.5°-292.5°) | 1.5-4.5 |
| Spring | NW ( 292.5°-337.5°) | 1.5-4.5 |
| Summer | NW (292.5°-337.5°) | 1.5-4.5 |
| Autumn | NW ( 292.5°-337.5°) | 1.5-4.5 |

**Table no. 3:** Selected atmospheric patterns in El-Dabba site

| | |
|---|---|
| Wind direction | North-west (300°) |
| Wind speed m/s | 4 (1.0) |
| Stability class | D (F) |

- The value in parenthesis is the worst conditions

**Dose Criteria**

The determination of the EPZs is based on generic criteria of protection of humans in the emergency exposure situations. The IAEA developed them to be applied in preparedness and response to radiation emergency [20-22]. These generic criteria ensure the prevention of risk of development of severe deterministic effects and restriction of a chance of development of stochastic effects of radiation to reasonably achievable levels.

The following criteria are selected to be the bases for EPZ characterization:

- Criteria for the assessment of the risks of development of deterministic effect, which is acute redbone (RBE) weighted dose in organ or tissue T and an acute dose of thyroid ($AD_T$) [23]. Thyroid 50-year committed dose and are very similar because of the short half-life of the iodine isotopes that dominate thyroid dose and evident from IAEA Study [24]. Thyroid committed dose equivalent from inhalation has been used in this study for an acute dose to thyroid.
- Criteria for the assessment of the risk of developments of stochastic effects which are effective dose equivalent ($E_{inh}$) and effective dose equivalent of fetus or embryo ( $H_{fetus}$)

The IAEA's values of the selected generic criteria and its corresponding preventive actions as well as the emergency planning zones illustrate in a table (4). The size and shape of the recommended EPZs described in [NUREG-039][8] were established based on the level of the Protective Action Guides (PAGs) defined by the U.S. Environmental Protection Agency (EPA) [25]. PAGs are the projected doses to reference man from an accidental release of radioactive material at which specific protective actions to reduce or avoid that doses are recommended [26]. These PAGs are combined with different protective actions and aimed to protect the public from the hazardous of an accidental release in the early phase of the emergency situation. Table no.5 represents the values of PAGs and their corresponding protective actions.

The RASCAL4.2 calculations indicate that using a 5-degree angle for estimating changes in wind direction would have the effect of spreading a lower dose over a wider area such that the area exceeding the generic criteria would be reduced**.**

**Table no.4:** The generic criteria for selecting the emergency planning zones [17]

| Zone | Actions to prevent | Generic Criteria | |
|---|---|---|---|
| PAZ | Sever deterministic effect | $AD_{red\ marrow}$ | 1.0 Gy |
| | | $AD_{fetus}$ | 1.0 Gy |
| UPZ | Reduce stochastic effect | $E_{inh}$ | 100 mSv |
| | | $H_{fetus}$ | 100 mSv |

**Table no.5:** The value of PAGs and corresponding protective actions in the early phases [25]

| **Emergency phases** | **Exposure pathway** | **PAGs Value (mSv)** | **Protective Action** |
|---|---|---|---|
| Early phase | Sum of the effective dose equivalent resulting from exposure to external sources and the committed effective dose equivalent incurred from all significant inhalation pathways during the early phase. | 10-50 | Evacuation or sheltering |
| | Committed dose equivalent to the thyroid from radioiodine. | 250 | Distributed Iodine Tablet |

## III. Result

The total amount of I-131 and Cs-137 activities (Bq) and their release rate each 15 min as well as the projected radiological doses due to the inhalation, ground shine, and cloud shine were calculated. Based on the observed doses, the distances of the EPZs with their corresponding intervention measures like evacuation, sheltering or taken iodine tablets are determined. Table no. 6 illustrates the total amount of environmental radioactive release. While the time-dependent release rates of I-131 and Cs-137 each 15 min. are illustrated in Figure (1)

**Table no. 6:** Environmental radioactive release for the selected scenario

| **Group** | **Released Activity (Bq)** |
|---|---|
| Noble gases (Xe, Kr) | 5.69E+17 |
| Iodine | 1.90E+17 |
| Cesium | 3.00E+16 |

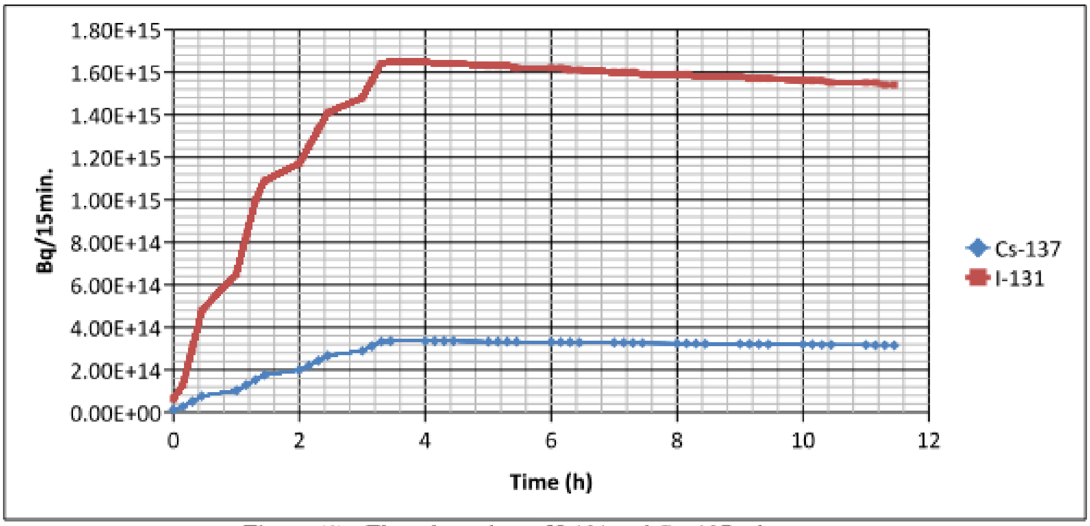


**Figure (1):** Time-dependent of I-131 and Cs- 137 release rate

The Acute dose to bone marrow profile with distance for the selected scenario in different stability classes and with wind direction 300° presented in Figures (2a &2b). The maximum value of the calculated acute dose to bone marrow for *D class* is found to be **7.62 Sv at 0.16 km** while the maximum value of the calculated acute dose to bone marrow for *F class* is found to be **10.7 Sv at 0.16 km** also.

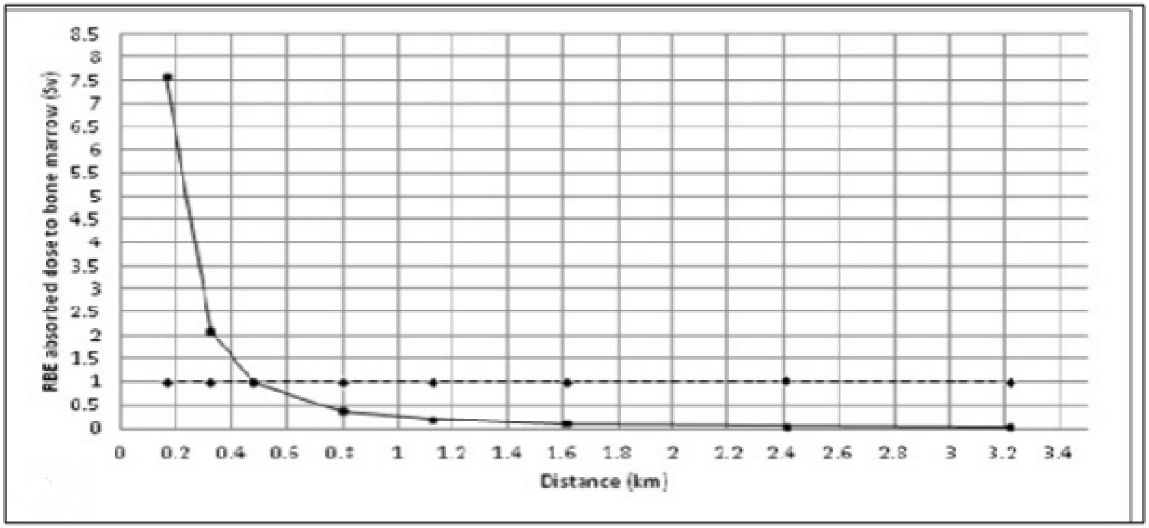


**Figure (2a):** RBE weighted absorbed dose to red marrow from cloud shine, inhalation, and ground shine, 300°wind direction at D stability class (---- is the IAEA criteria for acute dose).

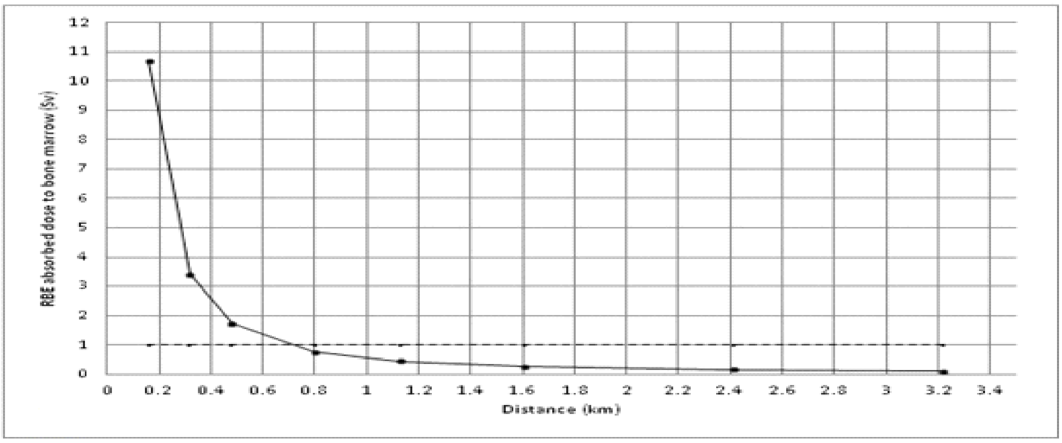


**Figure (2b):** RBE weighted absorbed dose to red marrow from cloud shine, inhalation, and ground shine, 300°wind direction at F stability class (---- is the IAEA criteria for acute dose). The profile of the calculated Thyroid committed doses for the selected wind direction and stability classes are shown in figures (3aand 3b).


**Figure (3a**): Variation of thyroid committed dose equivalent with distance; 300°wind direction at D stability class.

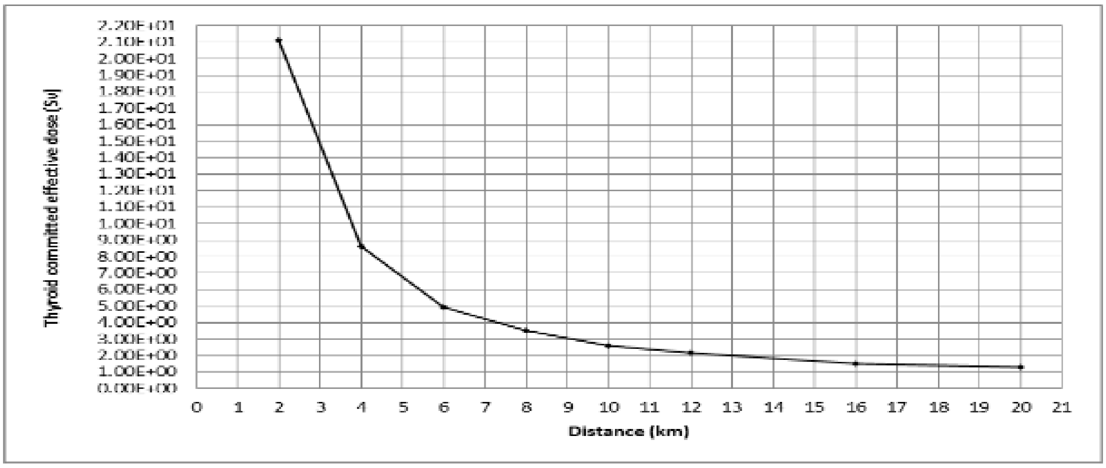


**Figure (3b):** Variation of thyroid committed dose equivalent with distance; 300°wind direction at F stability class.

The calculated total effective dose (Sv) profile with distance for the selected scenario in different stability classes are presented in figures (4a&4b). The maximum values of the calculated total effective dose for *D and Fclasess* are found to be **1.17 Sv and 2.95 Sv respectively both at 2.0 km**.

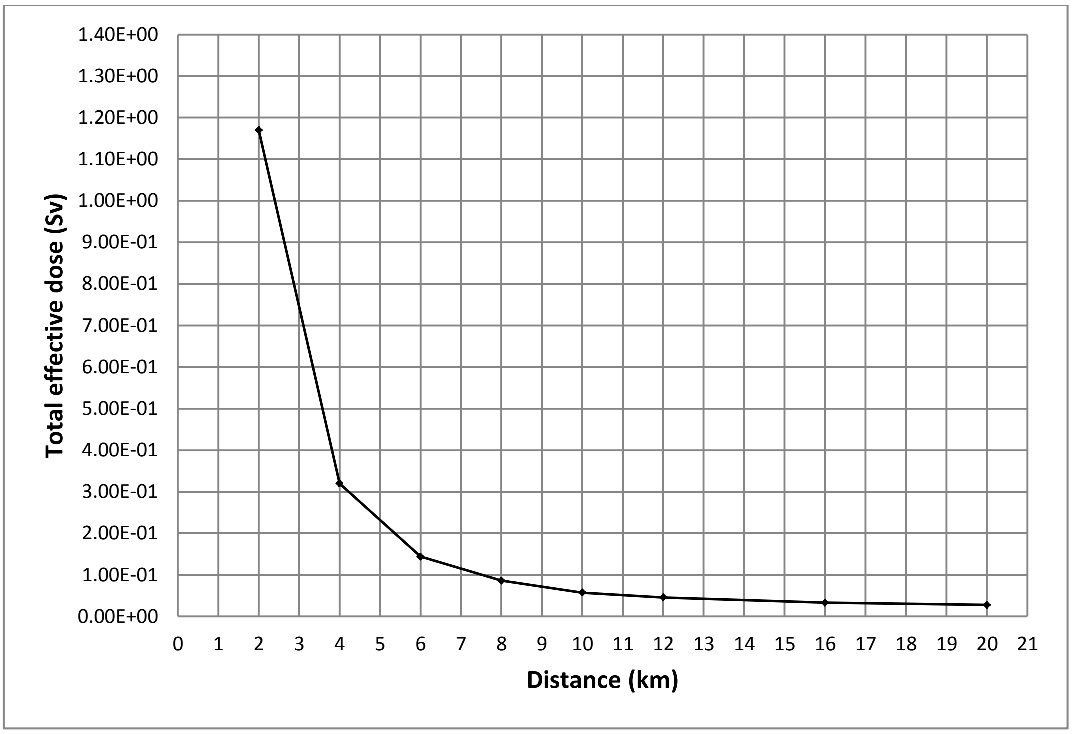


**Figure (4a):** Variation of total effective dose with distance, 300°wind direction at D stability class

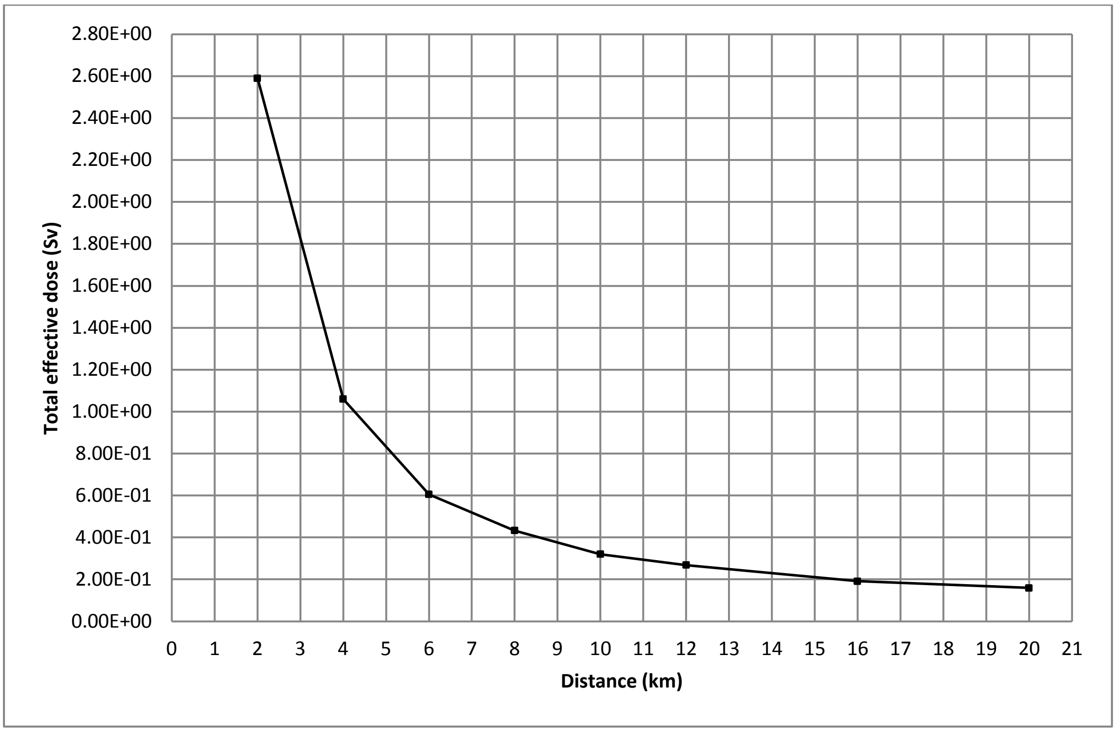


**Figure (4b):** Variation of total effective dose with distance, 300°wind direction at F stability class

Figures (5a,5b, 5c and 5d) show the distribution of the calculated doses in respect to wind direction and regarding the defined PAGs.

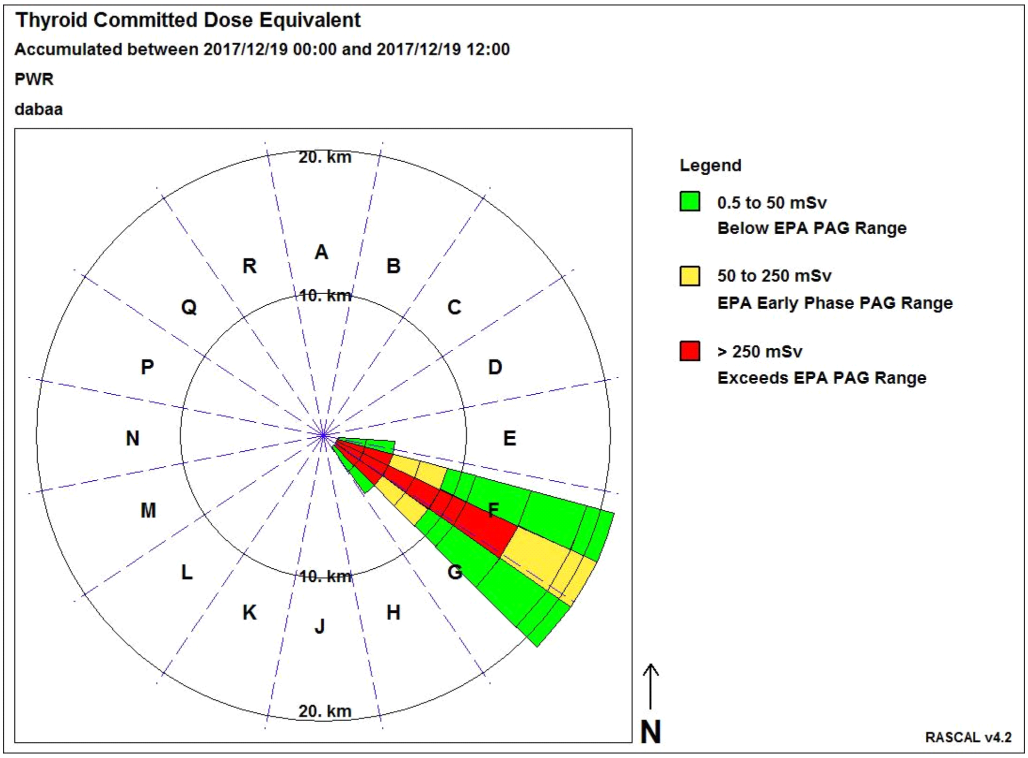


**Figure 5a:** Distribution of thyroid committed dose with wind direction 300 D class, regarding EPA PAGs.

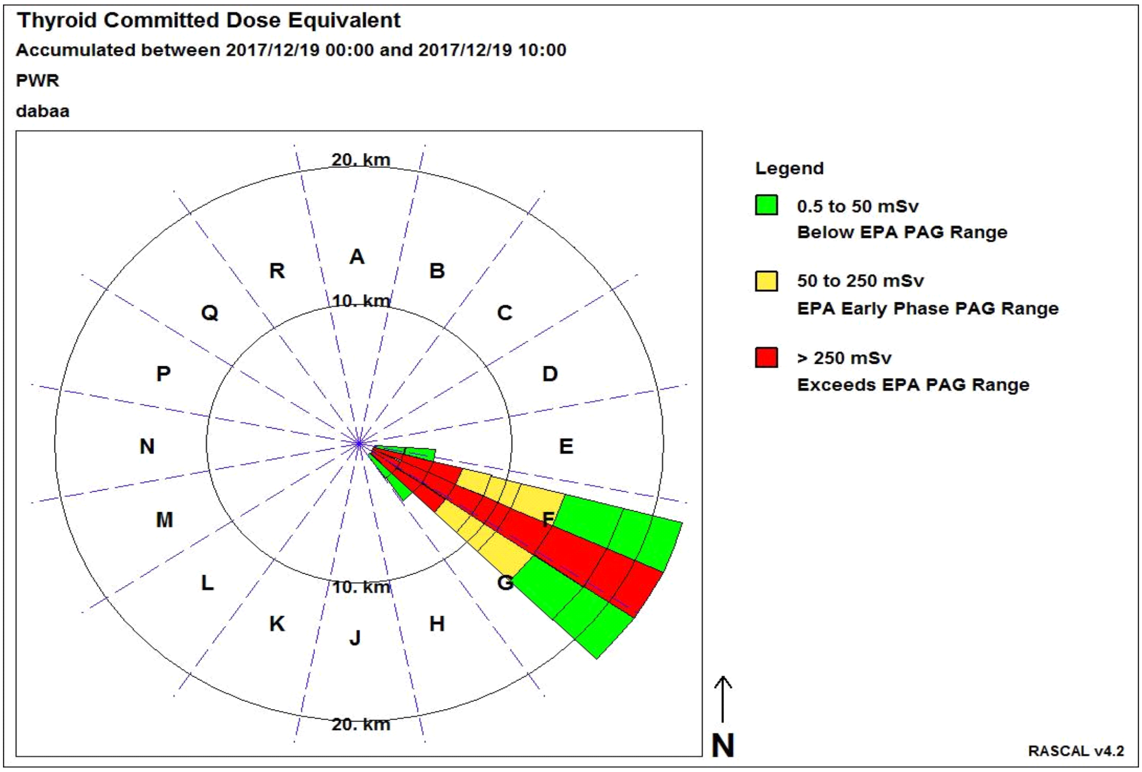


**Figure 5b:** Distribution of thyroid committed dose with wind direction 300 F class, regarding EPA PAGs.

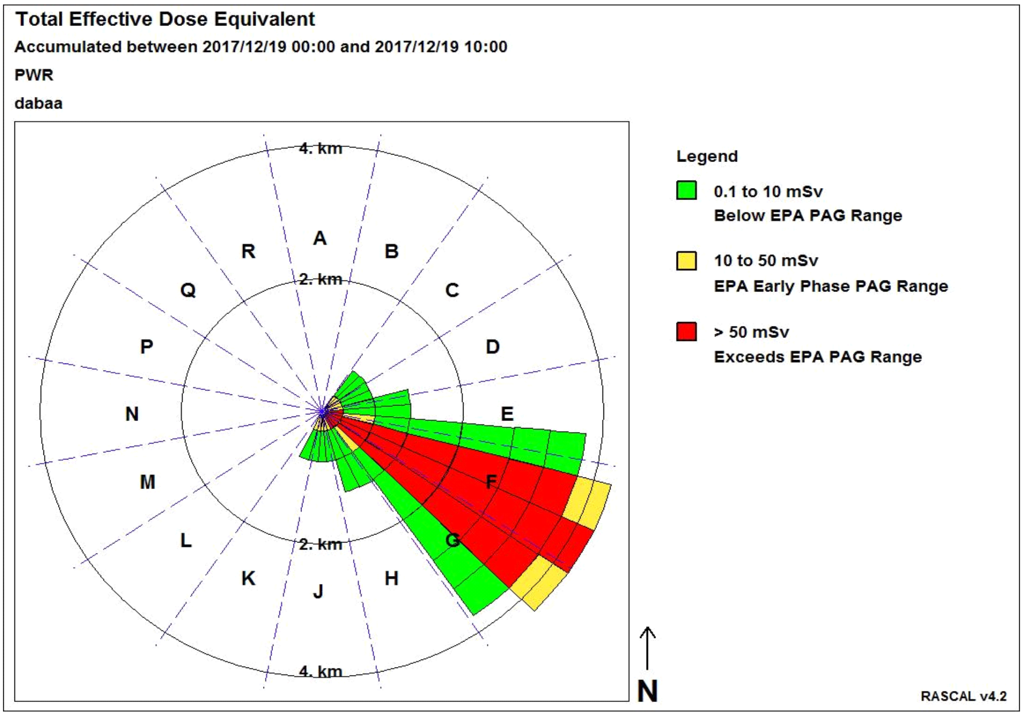


**Figure 5c:** Distribution of total effective dose with wind direction 300 D class, regarding EPA PAGs

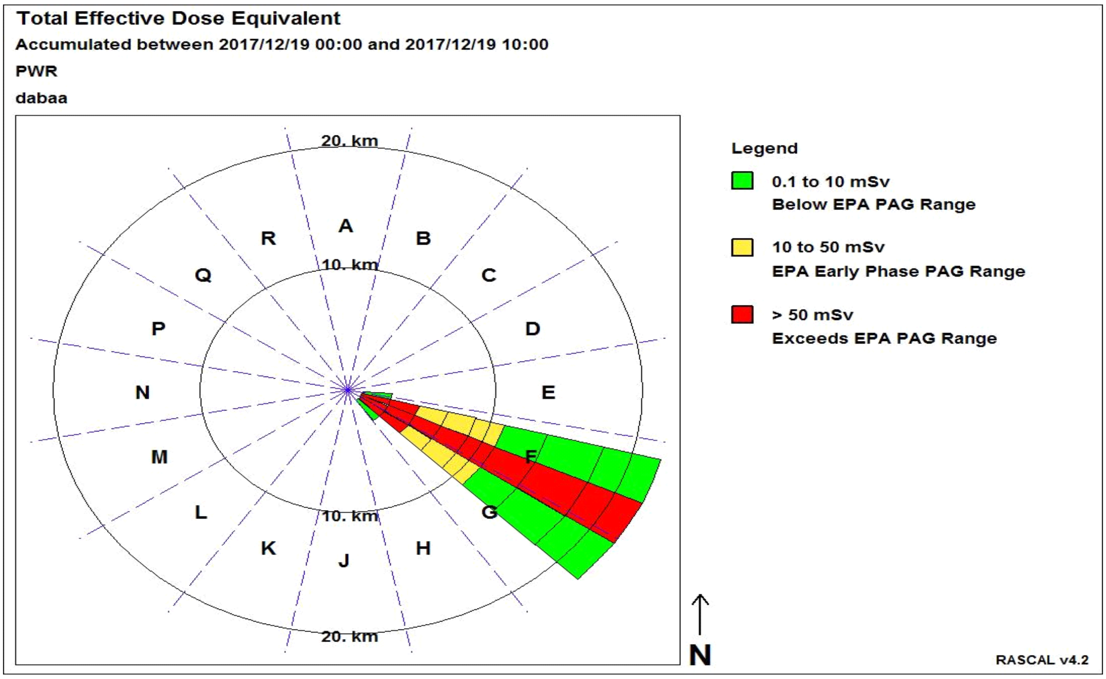


**Figure 5d:** Distribution of total effective dose with wind direction 300 F class, regarding EPA PAGs

## IV. Discussion

As shown in Table (6) and Figure (1), the amount of released Nobel gases and iodine group are near to the same order $5.69x10^{+17}$ Bq and $1.90x10^{+17}$ Bq respectively, while the amount of cesium group released is less 10 order in magnitude ($3.0x10^{+16}$ Bq). It is seen that I-13I and Cs- 137 release rates to the environment at the start of release is about $6.49 \times 10^{13}$ Bq/15min. and $1.32 \times 10^{13}$ Bq/15min, respectively, which increases as accident progresses and attains the maximum value of $1.65 \times 10^{15}$ Bq/15min and $3.36 \times 10^{14}$ Bq/15min at about 3.45 hours. The behavior of I-131 and Cs-137 release rate is concerning the accident progression through different phases of reactor core failure; cladding failure, core melt phase, and ex-vessel phase. After about 3.8 hours, both I-131 and Cs-137 show the slight decreasing trend as post-vessel melt-through phase has completed [26 &27].

The values of calculated acute dose to bone marrow are exceeding the IAEA generic criteria (1Gy) at distance reached 0.3 km for the NPP location. Evacuation is requiring as a protective action in these cases. The reported values of thyroid committed doses that exceeded the IAEA generic criteria (1Gy) for both D and F classes are reached the distance 6 km till 20 km respectively form NPP location. Upon the values of the calculated total effective doses (Sv), IAEA generic criterion is estimated at 8.0 km from the NPP location.

The figures for dose distribution regarding wind directions are drawing the plan for starting the protective actions in different phases in the emergency (early, intermediate and early phases). As the protective actions are required to be taken in the EPZs, the starting direction of implementing these actions is very important to enhance the protection of the public in these zones. Upon the illustrated figures and the predominant wind direction in the El-Dabba site (300), it is suggested that the protective actions like evacuation, sheltering and distributing iodine tablet will be started to the population present in the section (110) and then the remaining population in the defined zones.

## V. Conclusion

Based on the obtained results, it is concluded that, upon IAEA generic criteria to prevent the severe deterministic effects of a severe release, the area within 3.0 km from El-Dabba NPP should be evacuated in the early phase of emergency and an iodine thyroid blocking agent should be taken before a release to about a distance of 20 km away from the plant. Moreover, stochastic effects of the severe release of radioactive material may be minimized by evacuating the area within 8.0 km of El-Dabba NPP site. Therefore, it is suggested that 3.0 km and 8.0 km around El-Dabba NPPs can designated as PAZ and UPZ respectively, which are in good agreement of IAEA Post-Fukushima Guidelines. Using probabilistic safety analysis and current meteorological data of the site in our methodology make the protective actions become more effective and cost beneficial.

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