engineering proceedings

MDPI

Proceeding Paper

Risk Assessment of Possible Hazards of El Dabaa Nuclear Power Plant Using FLEXPART Model †

Nourhan ElShafeey [1,*], Mohamed Mohamed Eid [2], Amgad Saber Mahmoud [2] and Ashraf Saber Zakey [1]

[1] Egyptian Meteorological Authority, Qobry EL-Kobba, Cairo P.O. Box 11784, Egypt; ashzakey@gmail.com
[2] Astronomy and Meteorology Department, Faculty of Science, Al-Azhar University, Cairo P.O. Box 11884, Egypt; mm_eid2000@yahoo.com (M.M.E.); astmet2011@azhar.edu.eg (A.S.M.)
* Correspondence: nourhan.elshafeey@yahoo.com
† Presented at the 3rd International Electronic Conference on Applied Sciences, 1–15 December 2022; Available online: https://asec2022.sciforum.net/.

Abstract: New Nuclear Power Plant (NPP), which is under construction in El Dabaa, Egypt, is expected to start working within few years. Such project should be associated with several scientific research works. The suitability of the NPP location as well as the assessment of the impact of its routine work and accidental failure is among the points that should be addressed. In this work, the contamination risks due to uniform accidental leakage of the radioactive aerosol ^{137}Cs that continues for eight hours is studied. FLEXPART version 10.4 at high resolution (55 km) is applied using six-hour NCEP FNL ($1^\circ \times 1^\circ$) gridded data to simulate the dispersion and deposition of ^{137}Cs for the subsequent five days. This process is repeated each day for the period of 2008 to 2018. It is shown that high concentration and total deposition are observed particularly during the summer season. In addition, the consideration of different emission scenarios indicates that Egypt is expected to be strongly affected. Moreover, dispersion and concentration of the radioactive materials is notably influenced by near-surface winds. In conclusion, FLEXPART is considered as a promising tool to explore the possible nuclear hazards under a variety of meteorological conditions. Further, a future study will consider the influence of the horizontal grid spacing and lateral boundary condition using the coupled Weather Research and Forecasting (WRF)-FLEXPART system.

Keywords: accident scenario; atmospheric dispersion; FLEXPART; risk assessment; total deposition

check for updates

Citation: ElShafeey, N.; Eid, M.M.; Mahmoud, A.S.; Zakey, A.S. Risk Assessment of Possible Hazards of El Dabaa Nuclear Power Plant Using FLEXPART Model. *Eng. Proc.* **2023**, *31*, 86. https://doi.org/10.3390/ASEC2022-13964

Academic Editor: Nunzio Cennamo

Published: 30 January 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In 2021, the total nuclear electricity production was about 2653 TW/h around the world [1], which amounts to 15% of global electricity production [2]. Egypt is building a nuclear power plant at El Dabaa (on the Northwest Coast) as an alternative source of energy. Since the beginning of obtaining power from the nuclear energy plants, fear of nuclear contamination has been associated with them. Chernobyl and Fukushima are examples of serious nuclear accidents. Risk assessment of a radioactivity contamination is necessary for decision-makers in order to plan precautions and enhance safety measures. These assessments include the estimation of the concentration and total deposition of released radioactive material to the surroundings. One of most known risk assessment methodologies is the Probabilistic Risk Assessment (PRA). PRA identifies the contribution of every weather situation to the overall risk, and it has been used [3] all over Europe to identify possible risks from nuclear reactors under study. The purpose of the present study is to identify the possible risks from a hypothetical accident at El Dabaa using the FLEXPART model. This paper is organized as follows: the data and methodology are presented in Section 2, the results are offered in Section 3, and the conclusions and discussion of the results are contained in Section 4.

2. Materials and Methods

2.1. Study Area

El Dabaa is located on the north coast of Egypt (Figure 1). It lies 296 kilometers (184 mi) from Cairo on the north coast and is served by the El Alamain International Airport (which is chosen to be as a location of a new nuclear reactor). In addition, El Dabaa is characterized by an average wind speed (at height 10 m) from 5 to 8 m/s during all seasons with the highest record in the winter season (between 7.5 and 8 m/s).



Figure 1. Map showing El Dabaa location.

2.2. Model Description and Experiment Design

One-degree 6-h NCEP FNL (Final; Operational Global Analysis data are on 1degree by 1 degree grids prepared operationally every six hours) data are used to drive the FLEXPART model [4].

Dispersion of radionuclides has been studied with the aid of both Eulerian and Lagrangian models. Lagrangian particle models compute trajectories of a large number of so-called particles to describe their transport and diffusion in the atmosphere. The main advantage of Lagrangian models over Eulerian models is the absence of numerical diffusion. Furthermore, in Eulerian models a tracer released from a point source is instantaneously mixed within a grid box, whereas Lagrangian models are independent of a computational grid and have infinitesimally small resolution.

In the current study, the Lagrangian Flexible particle dispersion model (FLEXPART version 10.4) is used to simulate transport, diffusion, dry and wet deposition of the radionuclide 137Cs [5]. Near-ground concentration and total deposition of 137Cs radionuclides were calculated in the period of 2008–2018.

In FLEXPART (forward mode), the radionuclide concentration is calculated as

$$C_{T_c} = \frac{1}{N} \sum_{i=1}^{N} C_{T_s},$$

where C_{T_c} is the output concentration at time Tc, while Ts is the sampling interval and N is the number of samples [6].

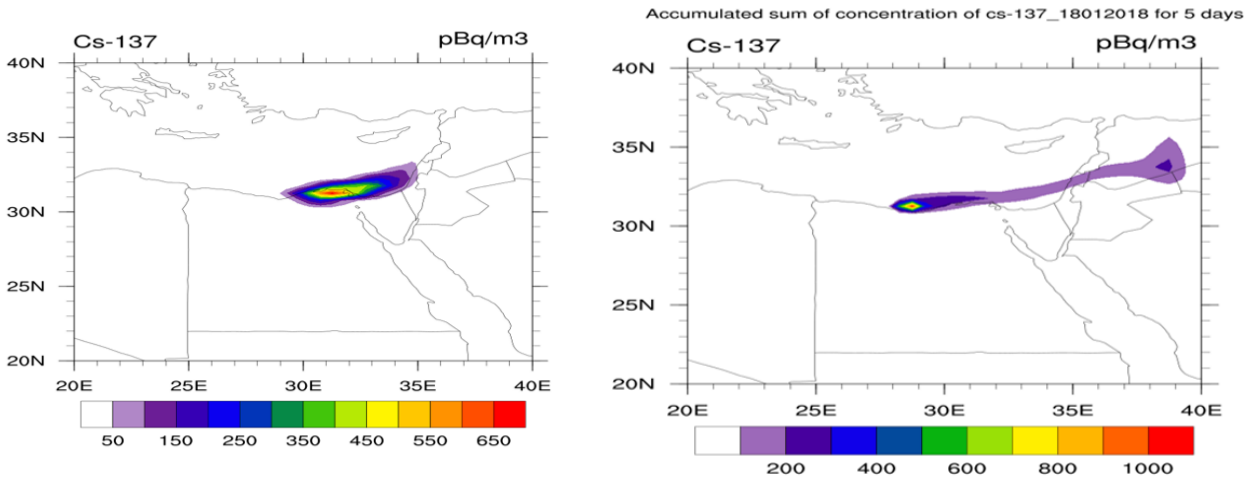
Our study assumes a constant total emitted mass of 1000 kg of 137Cs in 8 h. Upon radioactive release, the model simulates its dispersion and deposition for five days in the future for each day during the period of 2008–2018.

The modular approach was adopted by flexRISK. A catastrophe model integrates assessments of the probability of a specified hazard in a particular geographic region. In order to provide an output of the probability of losses exceeding a certain level, catastrophe modelers use two different approaches: (1) deterministic and (2) probabilistic. The probabilistic modelling technique runs many hypothetical events covering a range of possible outcomes. This allows the modeler to assess the probabilities and severity of loss and to create a distribution of probabilities, which makes it possible to identify the contribution of every single reactor and every weather situation to the overall risk this study [3].

For release shape, one dispersion calculation is conducted using 137Cs as an example. FLEXPART allows to specify a release as a vertical column. This is used to implement an effective release height, as FLEXPART has no mechanism for calculating an effective release height from heat flux and ambient meteorological conditions. The effective release height is not assumed as a single height but as a height interval.

3. Results

The wind is stronger in both winter and spring (Figure 2) and the direction is generally northwest to north. Winter is characterized by the passage of the Mediterranean cyclones on their way to Eastern Mediterranean with the westerly to northwesterly winds following the passage of the cold front. These systems also bring most of Egypt rain to the North Coast. Spring is different in that the weather is hotter and the country is affected by the thermal Saharan cyclones, which mostly originate south of the Atlas Mountain Range. These cyclones are fast and cause a considerable change in the temperature and wind along their paths. In addition, we investigated the influence of time scale (seasonal average versus daily accumulation) on dispersion of Cs-137. The winter season was selected (as an example) taking into account two time periods (Figure 2a,b) for further investigation.



(**a**) (**b**)

Figure 2. (**a**) Accumulated 5 days for winter, 25 December 2018; (**b**) accumulated 5 days for winter, 1 January 2008.

From Figure 2, it can be noted that accumulation of 5 days of Cs-137 is projected toward northeast in both time periods (Figure 2a,b). Also in Figure 3a, calculating the seasonal climatology eliminates the variability of the Cs-137 concentration and shows that the Cs-137 concentration pattern is restricted to the area of the emission source. Therefore, it can be observed that time period is important in investigating the dispersion of the Cs-137 depending on the purpose of the study.

Analysis of accumulated 5 days Cs-137 concentration in winter indicates that cesium will be dispersed by local wind toward north to northeast of Mediterranean.

In summer, the country is almost affected by the dominant extension of the Indian Monsoon, which raises temperature and brings considerable amount of humidity from the Mediterranean. In late autumn, weather conditions favor the decrease in the air temperature and sporadic rainfall events along the Mediterranean Coast.

The wind profile as represented by the wind rose in Figure 3 shows the calmer winds in both summer and autumn and the stronger winds in both winter and spring.

The range of directions in Figure 4 explains the relative concentration of 137Cs at emission sources is highest and then decreases when it moves away from its sources of emission.

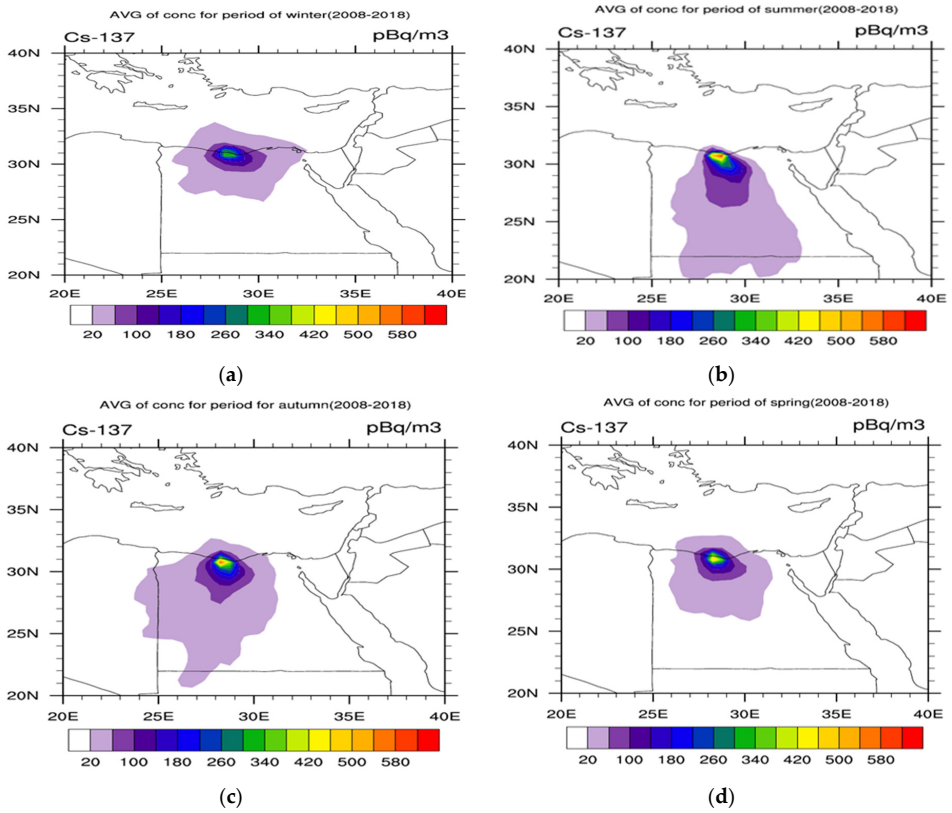


Figure 3. Average seasonal concentration of ^{137}Cs in pBq/m^3 in the period of 2008–2018 for: (**a**) winter, (**b**) summer, (**c**) autumn and (**d**) spring.

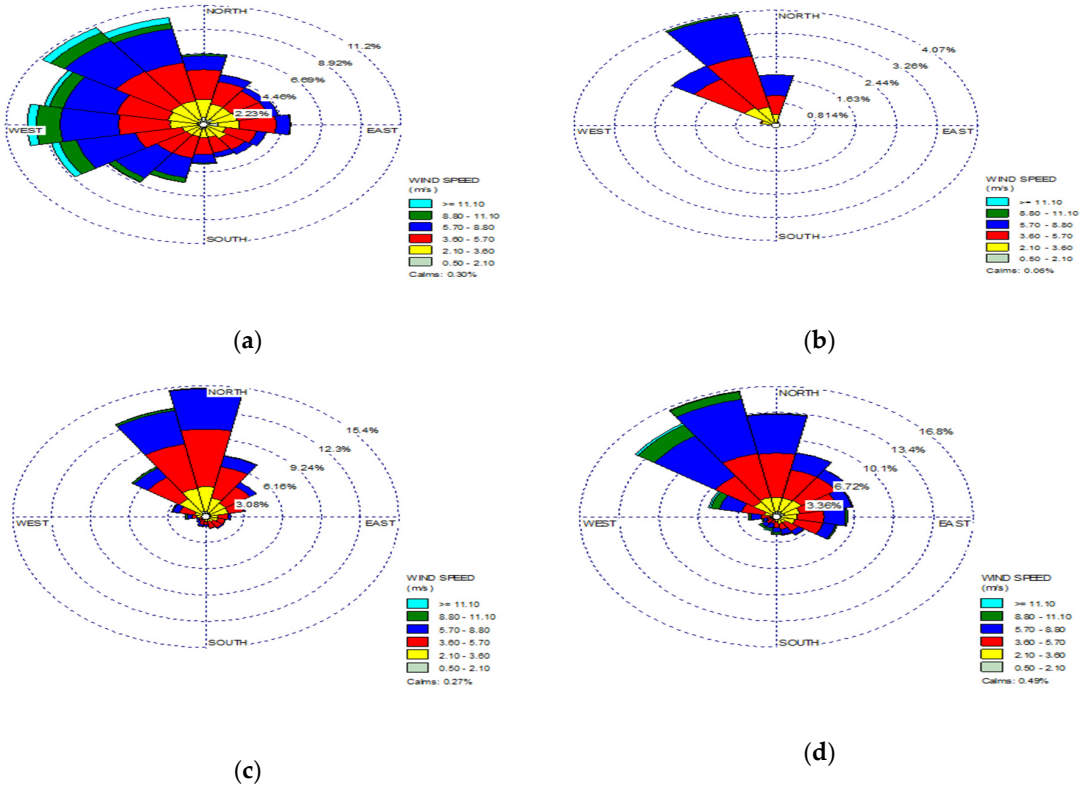


Figure 4. The average wind speed and direction at El Dabaa during the period of 2008–2018 for (**a**) winter, (**b**) summer, (**c**) autumn and (**d**) spring.

As a result, in winter, low dispersion of 137Cs is observed and it is further concentrated in a narrow area around its origin (El Dabaa Npp) with a maximum concentration of 300–340 pBq/m^3 (Figure 3a).

In summer, the wind pattern from north to northwest wind and wind speed ranges from 5.9 to 6.7 m/s, resulting in maximum concentration of 620–680 pBq/m^3 (Figure 3b).

Northwest direction shows high concentration of 137Cs at the emission source. In addition, the radioactive material 137Cs is concentrated downwind from emission source compared to other seasons. Worth noting is the fact that the speed of the contaminating nuclide towards south and east of Egypt including delta region poses a high risk since most of the country population lives there.

In the spring, there is a notable range of wind directions, and the winds themselves are relatively strong, which explains the relatively high concentration of 137Cs at emission source. In autumn, wind speed is lesser and the wind direction is between north to northwest, resulting in relatively higher concentration and deposition of 137Cs. Generally, the highest risk is reported in the vicinity of nuclear reactor.

3.1. Wind Rose

Wind rose in spring season shows that there is a notable range of wind direction and relative height of wind speed (but it is less than that in winter), which explains the relatively high concentration of Cs-137 at emission source compared to the one observed in winter season. Wind direction in autumn ranges from north to northwest, resulting in relatively higher concentration and deposition of Cs-137 compared to winter and spring, while it is lesser than that of summer.

3.2. Deposition

Winter, spring and autumn are characterized by considerable range of wind direction leading to a decrease in the deposited Cs-137 on the ground surface. On the other hand, in the summer season, northwest is the dominant wind direction leading to higher deposition of Cs-137 compared to other seasons (see Figure 5).

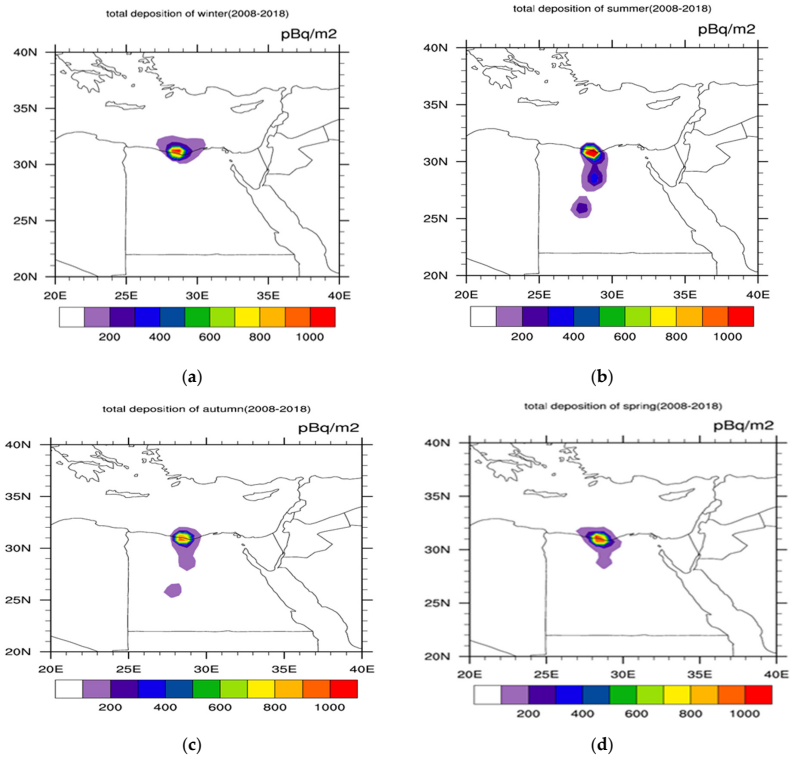


Figure 5. Average total deposition of ^{137}Cs in pBq/m^3 in the period of 2008—2018 for: (**a**) winter, (**b**) summer, (**c**) autumn and (**d**) spring.

4. Discussion and Conclusions

In this study, we simulated a leak of a radioactive nuclide for 8 h from El Dabaa reactor every day for 5 days in the future using the FLEXPART dispersion model. The results of the simulations were in agreement with those obtained in previous studies of the Chernobyl case, reporting that the radioactive material moved corresponding to the prevailing wind in the lower troposphere even though the maximum of emission height was more than 2000 m from the surface [7]. The risk estimates exhibit seasonal variability, with increased surface level concentration and deposition of 137Cs during summer where the pattern extended towards the south and east. Generally, as expected, the highest risks are reported in the area in the vicinity of the reactor. In addition, this study shows that when the prevailing wind blows continuously in a certain direction, the radioactive materials are concentrated downwind of their origins.

Author Contributions: Conceptualization, N.E.; methodology, N.E.; software, N.E.; validation, N.E.; formal analysis, N.E.; investigation, N.E.; resources, N.E.; data curation, N.E.; writing—original draft preparation, N.E.; writing—review and editing, N.E., A.S.Z. and M.M.E.; visualization, N.E.; supervision, M.M.E., A.S.M. and A.S.Z.; project administration, M.M.E., A.S.M. and A.S.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Egyptian Meteorological Authority (EMA) is acknowledged for providing the computational power for conducting the model simulations.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Nuclear Power Reactors & Uranium Requirements. Available online: https://world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requireme.aspx (accessed on 15 November 2022).
2. Shamsuddin, S.D.; Basri, N.A.; Omar, N.; Koh, M.-H.; Ramli, A.T.; Hassan, W.M.S.W. Radioactive dispersion analysis for hypothetical nuclear power plant (NPP) candidate site in Perak state, Malaysia. *EPJ Web Conf.* **2017**, *156*, 00009. [CrossRef]
3. Arnold, D.; Gufler, K.; Kromp, W.; Kromp-Kolb, H.; Mraz, G.; Seibert, P.; Sholly, S.; Sutter, P.; Wenisch, A. flexRISK—Flexible Tools for Assessment of Nuclear Risk in Europe. In *Air Pollution Modeling and Its Application XXI*; Springer: Dordrecht, The Netherlands, 2011; pp. 737–740. [CrossRef]
4. Aguilar, C.; Russo, B.J.; Mohebbi, A.; Akbariyeh, S. Analysis of factors affecting the frequency of crashes on interstate freeways by vehicle type considering multiple weather variables. *J. Transp. Saf. Secur.* **2022**, *14*, 973–1001. [CrossRef]
5. Pisso, I.; Sollum, E.; Grythe, H.; Kristiansen, N.I.; Cassiani, M.; Eckhardt, S.; Arnold, D.; Morton, D.; Thompson, R.L.; Zwaaftink, C.D.G.; et al. The Lagrangian particle dispersion model FLEXPART version 10.4. *Geosci. Model Dev.* **2019**, *12*, 4955–4997. [CrossRef]
6. Stohl, A.; Forster, C.; Frank, A.; Seibert, P.; Wotawa, G. Technical note: The Lagrangian particle dispersion model FLEXPART version 6.2. *Atmospheric. Meas. Tech.* **2005**, *5*, 2461–2474. [CrossRef]
7. Yoshikane, T.; Yoshimura, K. Dispersion characteristics of radioactive materials estimated by wind patterns. *Sci. Rep.* **2018**, *8*, 9926. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.