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Off-site Consequence Analysis of VVER-1200 at El Dabaa Nuclear Power Project in Egypt

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1. Introduction

In order to integrate nuclear generation into the energy mix, Egypt has reached a preliminary agreement with Rosatom (Russia) and Korea Hydro and Nuclear Power (KHNP) to build four units of nuclear power plants at El Dabaa site. According to the deal, Rosatom subsidiary company Atomstroyexport and the KHNP will build over 80 structures at El-Dabaa site. Egypt will also acquire equipment for the turbine islands from the KHNP [1]. According to the International Atomic Energy Agency (IAEA), the proposed nuclear power plants at the El Dabaa site will feature four VVER-1200/V-529 reactors, each having a gross electric-power capacity of 1200 MWe [2]. Many unpredictable natural occurrences can happen anywhere in the world at any time like earthquakes and tsunami as we have already experienced them in turkey (2023) and Japan (2011) respectively. Egypt is also vulnerable to these calamities so we need to evaluate post-accident safety measures before the commercial operation of plants at El Dabaa Site. In case of a severe accident, the public may be exposed to internal as well as external doses from radioactive plumes or from nuclides. There is requirement of protective measures to safeguard pubic against these exceptional occurrences. This include evacuation, administering iodine thyroid blocking tablets and sheltering [3]. Previously, a study has also been carried out for Design Basis Accidents (DBA) [4] .Therefore, it is crucial to determine the protective actions against Beyond Design Basis Accidents (BDBA) for the public and the environment. In our study, we have considered the BDBA scenario and provided recommendations for the safety of general public and the environment. Moreover, the analysis can also be used for developing an evacuation policy and preparedness plan.

2. Methods

This study uses Wind and Rain Rose Plots software (WRPLOT)to draw the wind rose for meteorological data for the summer season for the duration of ten years (2013-2023). Additionally, the Radiological Assessment System for Consequence Analysis (RASCAL 4.3.3) Code is used as a simulation tool for Long Term Station Blackout (LTSBO). Moreover, Minitab software has been used in our statistical analysis to represent results.

2.1 Wind Rose Models

A wind rose is a visual representation of the average wind speed distribution and direction at a specific area in terms of duration. The wind direction is one of the most critical parameters in meteorological data. In addition, it plays a key role in spreading radioactive materials after a nuclear accident. The wind rose is drawn for summer season as a worst case over the period of ten years (2013-2023). The Predominant wind direction in Egypt for the summer is Northwest by North (NW by N) which expands from North with a range of 315~333 degrees as shown in Fig. 1. The most frequent direction between this range is 319 degrees, so it has been considered as a representative value of the wind direction in our accident scenarios in the summer period.

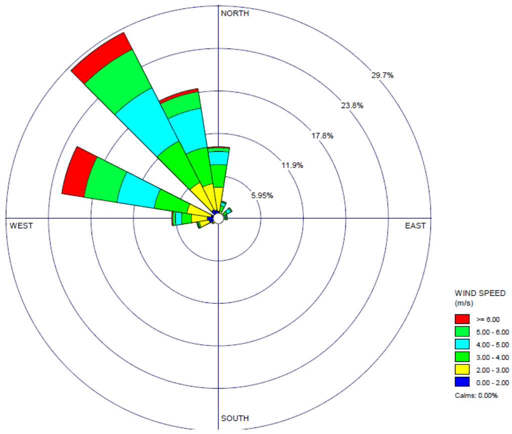

Fig. 1. Wind speed and direction for El Dabaa site in summer

2.2 Meteorological Data

The meteorological data combines many conditions such as Temperature (T), wind Direction (D), Rain (R), Stability classification (SC), and wind Speed (S), all data collected for the period of 10 years from 2013 to 2023 from weather archive in Dabaa site. Minitab has been used to analyze the data to choose the most appropriate value to represent the data for each condition. According to statistical analysis for all the meteorological conditions (T, R and S), it has been found that the P-value of the Anderson-darling test is less than 0.005, so the null hypothesis, which indicates that the data is normally distributed is rejected (data not normally distributed) so there is no significant difference between the specified data. Therefore, the median is selected to represent the date for the above-mentioned meteorological conditions, temperature is 26 °c, wind speed is 3 m/s and with no rain.

2.3 Rascal Code Models

Radioactive Assessment System for Consequence Analysis (RASCAL) is a tool developed by Nuclear Regulatory Commission (NRC) Operations Center by the Protective Measures Team at the U.S to independently forecast doses and consequences during radioactive accidents and emergencies. RASCAL provides help for decision-making during an emergency in case of accident at a nuclear facility. The latest version is RASCAL 4.3.4 based on the input data on the circumstances at the plant, the Source Term to Dose model is used to assess the expected radiation doses from the plume of the released radioactive chemicals to people downwind. The inhalation of the plume, ground shine from the radioactive nuclides deposited to the ground, and cloud shine from the plume make up the dosage pathways. RASCAL uses the gaussian plume model. The fundamental Gaussian puff model can be created by expanding the diffusion equation's one-dimensional solution to three dimensions using the superposition principle , Equation 1 represents a basic version of the puff model in RASCAL [5].

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

Where χ is the concentration (Bq/m^3 or g/m^3), Q is the amount of material unconfined (Bq or g) and σ is the dispersion parameter (m) which is a function of distance from the release point. When joint with a transport mechanism to passage the center of the puff (x_o, y_o, z_o).

2.3.1 Input data for the simulation model

I. Meteorology: for the simulation of the radioactive plum, which contains the radioactive chemicals to the public and the environment in specific directions, the meteorological conditions are required as input, accident consequences assessment was conducted in July, to respectively summer period. Temperature is 26 (°c), wind direction 310 (degrees), wind speed 3 (m/s), precipitation (mm/hr) is no rain and stability classes are D.

II. Accident scenario: El Dabaa NPP Unit-1 onsite and offsite Ac power are lost due to an earthquake, which started the LTSBO scenarios. All Ac-powered safety systems were inoperative after the reactor SCRAM. Dc batteries also ran out of power after a while. The turbine "stop valve" then closed. Water evaporated from the steam generators, and steam from the secondary circuit was released into the atmosphere via the BRU-A valve. The core was exposed due to the steam generators loss of water, which increased the core's temperature and caused LTSBO, a severe accident. Two scenarios are taken into consideration in this study to assess the unintended consequences. Scenario A, is when Emergency core cooling system (ECCS) not available and Scenario B is under the condition of that ECCS is available as shown in Table I.

Table I: Parameters of VVER-1200 for LTSBO simulation

Event Type (NPP)	
Location, NPP Name Country, city Latitude/Longitude	El Dabaa site Egypt, El dabaa 31.0275° N, 28.4429°
Reactor parameters	
Reactor power	3,200 MWt [6]
Average burnup	33,500 MWd/MTU (assumed)
Assemblies in core	163 [6]
Containment volume	2.150E+06 ft3 (assumed)
Design pressure	56 lb/in2 [6]
Coolant mass	2.58E+05 kg (assumed)
SG water mass	61,740 kg (assumed)
Design leak rate	0.2%/day [6]
Containment height	42.2 m [6]
Release Pathway PWR - Dry Containment Leakage or Failure	

3. Results and Discussion

The purpose of the present study is to evaluate practical protective actions during a hypothetical BDBA. The identification of preventive measures needs to be implemented to prevent or reduce any potential radiation exposure based on IAEA guidelines 1997 and the Protective Action Guides (PAGs). Protection of the public against unnecessary radiation exposure after a radiological accident with an uncontrolled discharge of radioactive material may necessitate some type of intervention that may interfere with daily life. The following are the main precautionary measures used to prevent unwanted exposure:

- Evacuation;
- Sheltering;
- Action of administration of Iodine Thyroid Blocking (ITB) [7].

For a hypothetical radiological accident LTSBO one scenario without passive ECCS and the other with passive ECCS, Total Effective Dose Equivalent (TEDE) for the El Dabaa site has been calculated for both scenario A &B of LTSBO in the summer season received by people residing within 40 km.

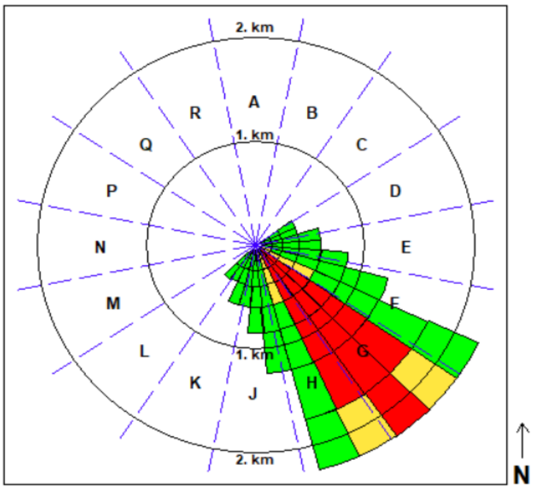

Fig. 2. TEDE Footprint of LTSBO in Case of passive ECCS

Legend

0.1 to 10 mSv Below EPA PAG Range
10 to 50 mSv EPA Early Phase PAG Range
> 50 mSv Exceeds EPA PAG Range

In case scenario when the ECCS is passive the plum which will expands the area with the direction from 140-150 up to 2 km will carry dose with 190 mSv as it is illustrated in Fig. 2. So depending on the IAEA guide lines and PAGs the protective actions which will be effective to protect people within those area are evacuation or sheltering in addition providing citizens with Iodin thyroid blocking tablets to minimize exposure to unreasonable radiation doses.

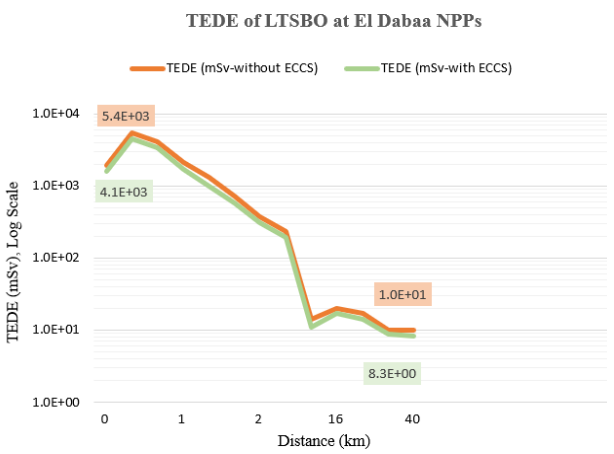

Fig. 3. TEDE with Log scale for LTSBO scenario

As the passive safety ECCSs functional time increases, radionuclide activity and dosages decrease. The dosage distributions are impacted by meteorological circumstances, at 2 km the dose reached 5.4E+03 and 4.1E+03 as the maximum for scenario A and B respectively however the public with these area should evacuate or shelter and supported with ITB tablets depending on PAGs as the dose >10 mSv.at 40 km when ECCS is not available the dose will be almost 10 mSv so it would be exposed to evacuation or sheltering but when the ECCS is activated the dose will be less than the dose limits for evacuation 8.3 mSv there is no need to evacuate these area. Comparing to a LTSBO in VVER 1200 Rooppur NPP, Bangladesh in the summer season with wind speed 8 m/s, rain 31.2 mm/hr. ,temperature 17 and stability class D ,without ECCS the max TEDE almost near 2 km 4.4E+03 mSv and without ECCS the max dose is around 3.6E+03 mSv ,with some different meteorological conditions data there is no dose at 40 km from the site as meteorological conditions has effective impact on in spreading radioactive materials after a nuclear accident [8].

4. Conclusion

The present analysis shows a simulation of a severe accident for the VVER1200 reactor of the El Dabaa site BDBA, LTSBO. The source term released and the consequences of the accident have been assessed using the RASCAL4.3.4 code. The results of the calculations demonstrated that the occurrence of the scenario with the activation of ECCS and without it will affect the dispersion of the plum around the areas of the nuclear power plant. As the passive safety ECCS functional time increases, radionuclide activity and dosages decrease. Values of TEDE are calculated in both scenarios, to achieve goals of radiation protection for protecting the public and environment from any unjustified exposure doses. Areas with doses above 10 mSv at the early emergency phase according to PAG should be evacuated or sheltered provided with iodin thyroid blocking tablets. The study can also be used to create a preparedness strategy and evacuation policy under emergency situations.

Acknowledgment

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