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Assessment of Dispersion Characteristics and Radiation Doses Consequences of a postulated Accident at a Proposed Nuclear Power Plant

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Abstract:

For site evaluation and environmental impact assessment for any nuclear power plant models are needed to predict consequences of a hypothetical accident and evaluate the suitable protection or mitigation actions for emergency plan.

This paper aims to predict the mitigation actions of emergency plan for a proposed site for NPP (El-Negila in the North Western coast in Marsa Matruh Governorate -Egypt) by calculating the radiation doses resulting from a hypothetical accident. The hypothetical accident postulated in this work is a large loss of coolant accident (LOCA) followed by core melting with early containment failure leakage and bypass.

After any accident, the impact of radioactive releases on the environment depends on several factors such as weather conditions, time of accident , the nature and activity of radiation release (source term) and topography. Total Effective Dose Equivalent (TEDE) caused *by accidental release was evaluated using Radiological Assessment System for Consequence Analysis code (RASCAL 4.2). RASCAL is the software developed and used by the U. S. Nuclear Regulatory Commission (NRC), in order to estimate the projected doses in case of radiological emergencies. The TEDE was assessed for all seasons of the year 2014 at a proposed site to study the effect of accident time on consequences of accident. These calculations take into account all exposure pathways such as cloudshine, inhalation and groundshine. Finally, the protection actions are evaluated in every case according to the dose threshold for sheltering, evacuation and administering potassium iodide (KI) as a supplementary action.*

Key words: nuclear accident, environmental impact assessment, RASCAL code, radiological accidents consequence analysis.

1. INTRODUCTION

The accident at a nuclear power plant that involves damage to fuel in the reactor core or in a spent fuel pool can cause deaths, severe health and psychological effects, and can also have economic and sociological consequences affecting the public [1]. These consequences can be mitigated by implementing protective actions promptly in the emergency planning zones (EPZs). The EPZs include precautionary action zone (PAZ) to reduce substantially the risk of severe deterministic effects, urgent protective action planning zone (UPZ) andlong-term protective action zone. The importance of EPZs has been demonstrated in Fukushima Accident as protective actions; that is, evacuation of public within 20 km and sheltering within 20–30 km (later on advised to evacuate voluntarily) prevented radiological consequences effectively [2, 3].The public can be exposed to direct radiation in the downwind direction and also to radioactivity deposited on the ground and vegetation resulting in exposure through different pathways [4]. Computer codes can be used to assess these actions by evaluating the dose consequences. RASCAL code[5] which stands for Radiological Assessment System for Consequence Analysis, is the software developed and used by the U. S. Nuclear Regulatory Commission (NRC), Emergency Operations Center in order to estimate the projected doses in case of radiological emergencies. The mitigation actions of the emergency plan should take place in the first few hours after an accidental release of radioactivity to atmosphere; model predictions will supplement monitoring data to increase understanding of the radiological situation and to form a basis for emergency health protection decisions.The nuclear power plants emergency plans include preparations for evacuation, sheltering, or other actions to protect the residents near nuclear power plants in the event of a serious incident. Each plant operator is required to exercise its emergency plan with offsite authorities at least once every two years to ensure state and local officials remain proficient in implementing their emergency plans.

2. MODEL DESCRIPTION

RASCAL (Radiological Assessment System for Consequence Analysis) [4] is currently used by NRC's emergency operations center for making dose projections for atmospheric releases during radiological emergencies. This code is widely used in several recent scientific work of radiological assessment [E. Farid Salem et al (2016)[6];N. Sadeghiet al (2017) [7].

RASCAL 4.2 uses Gaussian models to describe the atmospheric dispersion of radioactive and chemical effluents from nuclear facilities. In the calculation, RASCAL uses two models:

- the straight-line Gaussian plume model used near the release point where travel times are short and plume depletion associated with dry deposition is small

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

In a Cartesian coordinate system with x and y axes in a horizontal plane and z in the vertical plan.

- The lagrangian-trajectory Gaussian puff model used at longer distances where temporal or spatial variations in meteorological conditions and depletion of the plume due to dry deposition may be significant.Puff models represent plumes as a series of puffs. Concentrations at a point in the plume are calculated by adding the concentrations at the point associated with all puffs in the vicinity of the point. The simplified version of the straight-line Gaussian model used in RASCAL is given by

$$\frac{X(x,y,z)}{Q'} = \frac{F_y F_z}{2\pi u \sigma_y \sigma_z} \quad (2)$$

Where
X = average concentration Q' = release rate
F_x, F_y = lateral and vertical exponential terms,t= time
x = downwind distance at which X,σ_x,σ_y aσ_z are evaluated,
u= wind speed

The calculation scheme of RASCAL code (Radiological Assessment System for Consequence Analysis) was chosen to model the accidental atmospheric dispersion, compare of nuclear safety point of view and finally recommend possible convenient radiological emergencies such as define evacuation and sheltering zones. The TEDE dose was calculated to nuclide leakage from leakage containment and from bypass containment.

3. DESCRIPTION THE INPUTS

A postulated Nuclear Plant, a PWR 1200 MW pressurized water reactor (PWR)and it was assumed that nuclear plant's emergency core cooling system (ECCS) does not exist. The reactor scrammed at a certain time and the core was uncovered.

3.1 Source Term

The source term for an accident at a nuclear plant is the type and quantity of radioactive materials (fission products and transuranic elements) released from the core of a reactor, first into the containment atmosphere and then from within the containment into the surrounding environment. This depends on the design of a reactor, its operating power at the time of the accident, the type of fuel, and the degree of damage to fuel, to containment, and to other reactor components in the accident. In order to take into account the effects of seasonality on the discharge, simulations were run over the four seasons, leading to a total of simulations. To assess the source terms, we choose "time core is uncovered" option in RASCAL to quantify it. A 30m height containment bypass and leakage failure is used as a release pathway in the calculations. 30 meters is approximately the containment height .At the beginning of the accident, a reactor shutdown occurs and simultaneously the core become totally uncovered by loss of coolant and remains uncovered. It was assumed that releases continue for 10 hours. The duration of 10 hours was assumed for radioactive material release although it may continue many hours after initiation of severe accident [8]. The total amount of radioactivity released to atmosphere for bypass and leakage was: 3.3E+18 Bq and 1.8E+15 Bq respectively and detailed nuclides source term is given in table1

Table1. The source term for LOCA accident

Nuclide	Bq Bypass	Bq leakage	Nuclide	Bq bypass	Bq leakage	Nuclide	Bq bypass	Bq leakage
Am-241	9.7E+07	1.5E+05	**La-142**	2.0E+14	6.8E+10	**Sr-91**	1.8E+16	1.2E+13
Ba-139	4.8E+15	1.3E+12	**Mo-99**	1.7E+15	1.1E+12	**Sr-92**	9.0E+15	3.9E+12
Ba-140	3.9E+16	3.3E+13	**Nb-95**	1.6E+15	1.5E+12	**Tc-99m**	1.6E+15	9.8E+11
Ce-141	1.6E+15	1.5E+12	**Nb-97**	6.3E+13	5.6E+10	**Te-127**	5.1E+15	4.4E+12
Ce-143	1.4E+15	1.1E+12	**Nd-147**	6.0E+14	5.6E+11	**Te-127m**	8.1E+14	6.9E+11
Ce-144*	1.3E+15	1.2E+12	**Np-239**	2.0E+16	1.7E+13	**Te-129**	3.5E+15	2.2E+12
Cm-242	3.9E+13	3.6E+10	**Pm-147**	8.4E+10	1.3E+08	**Te-129m**	3.4E+15	2.9E+12
Cs-134	1.7E+16	1.1E+13	**Pr-143**	1.4E+15	1.3E+12	**Te-131**	2.3E+15	1.8E+12
Cs-136	6.9E+15	4.5E+12	**Pr-144**	1.2E+15	1.2E+12	**Te-131m**	1.0E+16	7.9E+12
Cs-137*	1.2E+16	7.7E+12	**Pu-238**	1.7E+08	2.5E+05	**Te-132**	7.5E+16	6.2E+13
Cs-138	2.8E+15	2.5E+11	**Pu-239**	3.0E+08	4.4E+05	**Xe-131m**	7.0E+15	5.0E+12
I-131	1.3E+17	7.0E+13	**Pu-241**	1.2E+14	1.1E+11	**Xe-133**	1.0E+18	7.3E+14
I-132	2.0E+17	9.1E+13	**Rb-86**	2.5E+14	1.6E+11	**Xe-133m**	3.2E+16	2.2E+13
I-133	2.3E+17	1.2E+14	**Rb-88**	2.0E+16	4.0E+13	**Xe-135**	4.5E+17	2.6E+14
I-134	2.3E+16	2.8E+12	**Rh-103m**	1.4E+15	9.8E+11	**Xe-135m**	4.3E+17	3.4E+13
I-135	1.7E+17	6.9E+13	**Rh-105**	1.0E+15	6.2E+11	**Xe-138**	3.0E+14	1.1E+10
Kr-83m	1.9E+16	4.1E+12	**Ru-103**	1.6E+15	1.0E+12	**Y-90**	8.6E+13	1.2E+11
Kr-85	4.2E+15	3.0E+12	**Ru-105**	6.2E+14	2.5E+11	**Y-91**	1.1E+15	1.1E+12
Kr-85m	7.5E+16	3.0E+13	**Ru-106***	4.3E+14	2.8E+11	**Y-91m**	4.5E+14	5.5E+12
Kr-87	4.8E+16	7.5E+12	**Sb-127**	4.7E+15	3.9E+12	**Y-92**	8.2E+14	2.1E+12
Kr-88	1.6E+17	4.8E+13	**Sb-129**	9.0E+15	4.8E+12	**Y-93**	6.4E+14	4.9E+11
La-140	1.7E+15	3.1E+12	**Sr-89**	2.0E+16	1.7E+13	**Zr-95**	1.5E+15	1.4E+12
La-141	6.8E+14	4.0E+11	**Sr-90**	1.5E+15	1.3E+12	**Zr-97***	1.2E+15	1.0E+12

3.2 Metrological data

The proposed site is located in the north western coast of the Mediterranean Sea in Egypt which is a coastal area. Hourly metrological data of this site for the year 2014 was obtained from (http://www.noaa.gov) ***[9]***. The data is temperature, wind speed, wind direction precipitation and cloud cover. The winds from the north and west accounted for more than 90 % of the wind directions. The stability classes were determined for each season are shown in figure (1), which represent the prevailing stability classes for winter was neutral(D), for spring was unstable(C), for summer was unstable (A) and for autumn was stable (F).We consider the following meteorological data in our simulations in table 2. The analysis of these data gives the following :

Table 2 Metrological data used in RASCAL simulations

Season	Prevailing Direction	Wind speed [m/s]	Stability class	Average Temperature C°
Autumn	300°	1.5	F	15
Winter	230°	10	D	12
Spring	330°	9.2	C	20
Summer	330°	12.2	A	25

Stability classes A, B, and C refers to daytime hours with unstable conditions. Stability D is representative of overcast days or nights with neutral conditions. Stabilities E and F refer to night time, stable conditions and are based on the amount of cloud cover. Thus, classification A represents conditions of the greatest instability, and classification F reflects conditions of the greatest stability.

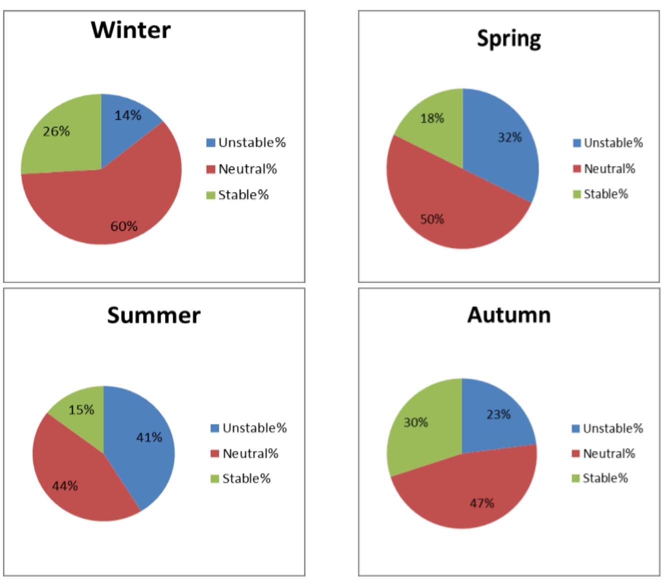
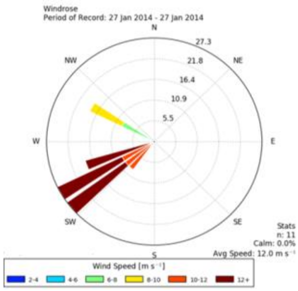
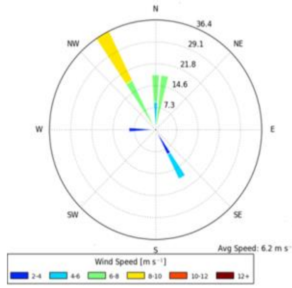


Figure (1) Seasonal variations of Atmospheric Stability condition for each season.

When assessing public exposure from accidents it is required to statistically consider the variability of weather-dependent dispersion conditions as well as any seasonal differences in radiation dose accumulating [10].



The wind rose for 27 January 2014



The wind rose for 13 April 2014

The wind rose for 14 July 2014

The wind rose for 17 November 2014

Figure 2. The wind roses for each season

In this paper a representative day was selected for each season: 27th January for winter season , 13th April for spring season, 14th July for summer season and 17h November for autumn season .

4. RESULTS AND DISCUSSION

RASCAL code which stands for Radiological Assessment System for Consequence Analysis, is the software developed and used by the U. S. Nuclear Regulatory Commission (NRC), Emergency Operations Centre in order to estimate the projected doses in case of radiological emergencies. Evacuation shall be taken if the dose to the public is ≥ 50 mSv. Among

protective actions: evacuating an area; sheltering-in-place within a building or protective structure; administering potassium iodide (KI) as a supplemental action; acquiring an alternate source of drinking water; interdiction of food/milk.
The following table lists the thresholds for each of these actions [11]:

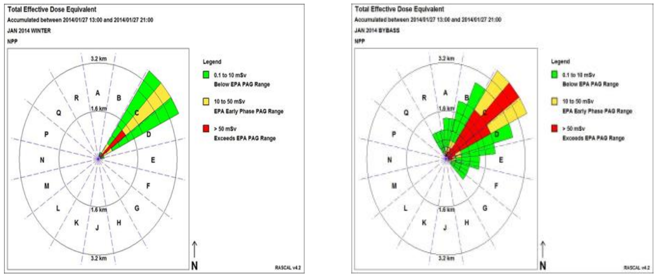
Table 3. Recommended protective actions for the Early Phase of a Radiological Incident

Protective Action **Recommendation**	Dose thresholds	Comments
Sheltering-in-place or evacuation of the public	10 to 50 mSv	The total dose by external exposure and the committed effective dose for internal exposure during 4 days
Potassium Iodine (KI) admission	50mSv received on thyroid child by exposure to Iodine	After the approval of a medical team

4.1. Results for Winter Scenarios:

The metrological data for winter 27th January 2014 used for RASCAL calculations are summarized as follow: Wind speed 10m/s, stability class D, there is rains and wind direction is 230^{0}. The wind rose for 27th of January shows that the direction of the wind is south west so the people living in the downwind direction are mostly affected and emergency measure should be taken to minimize their doses resulting from radiation exposure.

The first scenario is the actual metrological data for 27th of January, the code was run with selected source term time is uncovered. The reactor shutdown at time 10:00, the core uncovered at 13:00 and the core is not recovered. The release pathway option to be used in the calculations for the total effective dose (TEDE) is the containment leakage failure.



Leakage **Bypass**

Figure.3 Total effective doses equivalent for winter

A comparison between totaleffective doses equivalent (TEDE) at different scenarios for winter was illustrated in figure 3. Itis clear that there is highest (TEDE) in case of bypass. There is a slightly decrease in TEDE value for case leakage.

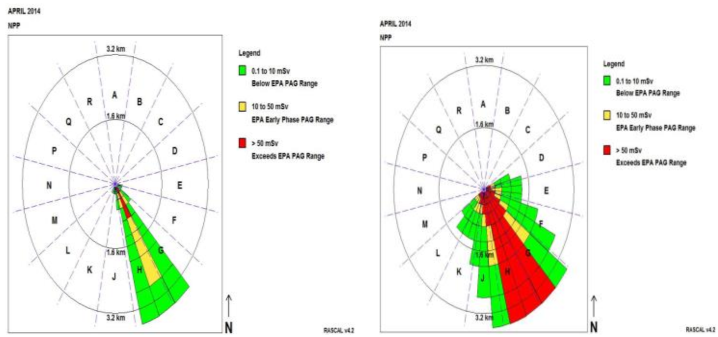
Leakage scenario: The results showed that for LOCA postulated accident, lead to evacuation countermeasures on public for winter scenario to area 0.16 Km. From the results we found that the maximum evacuation and sheltering zones are respectively 0.16Km and3.2 Km.

Bypass scenario: The results showed that for LOCA postulated accident, lead to evacuation countermeasures on public for winter scenario to area 8 Km because the dose was 51 mSv (≥ 50 mSv). From the results we found that the maximum evacuation and sheltering zones are respectively 8Km and11.3Km.

4.2. Result for Spring Scenarios

The metrological data for spring 13th April 2014 used for RASCAL calculations are summarized: Wind speed 9.2 m/s, stability class C, there is no rain and wind direction is 330 The spring scenario is the metrological data for 13th of April, the code was run with selected source term time is uncovered. The reactor shutdown at time 10:00, the core uncovered at 13:00

and the core is not recovered. The release pathway option to be used in the calculations for the total effective dose (TEDE) is the containment leakage failure and bypass.



Leakage **Bypass**

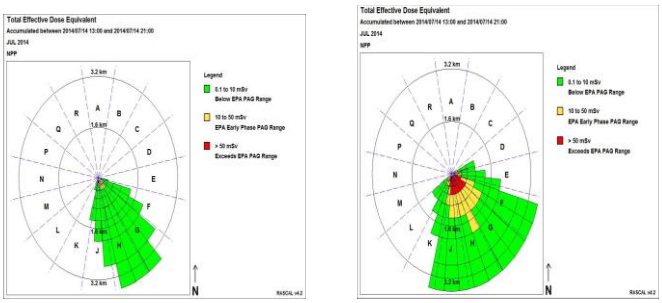
Figure 4 Total Effective Dose Equivalent for spring

Leakage scenario: The results showed that for LOCA postulated accident at 1200PWR-MWe, lead to evacuation countermeasures on public for spring scenario to area 0.6 Km. From the results we found that the maximum evacuation and sheltering zones are respectively 0.16Km and0.32 Km.

Bypass scenario: The results showed that for LOCA postulated accident, lead to evacuation countermeasures on public for spring scenario to area 4.8 Km because the dose was 62mSv (≥ 50 mSv). The sheltering shall be to area 23.5 Km the dose was 12mSv.

4.3. Results for Summer Scenarios

The metrological data for summer 14th July 2014 used for RASCAL calculations are summarized: Wind speed 12 m/s, stability class A , there is no rains and wind direction is 330.We run the code with selected source term time is uncovered. The reactor shutdown at time 10:00, the core uncovered at 13:00 and the core is not recovered. The release pathway option to be used in the calculations for the total effective dose (TEDE) is the containment leakage and bypass failure.



Leakage **Bypass**

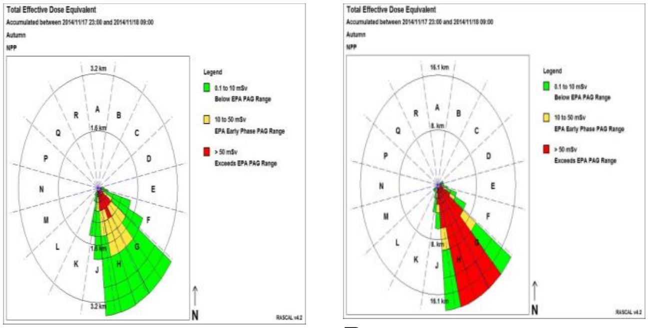
Figure5.Total Effective Dose Equivalent for summer

Leakage scenario: Results show that there are no evacuation countermeasure will be taken based on the regulation of emergency. Evacuation shall be taken if the dose to the public is ≥ 50 mSv. The total collective dose for summer is 1.1E-02 man Sv. The results showed that for LOCA postulated accident, does not lead to evacuation of the public countermeasures for Leakage failure summer scenario.

Bypass scenario: The result showed that the evacuation and sheltering zones are respectively 0.3Km and1.6Km.

4.4 Results for Autumn Scenarios

The metrological data for autumn 17th November 2014 used for RASCAL calculations are summarized: Wind speed 1.5 m/s, stability class F, there is no rain and wind direction is 330.Thereactor shutdown at time 21:00, the core uncovered at 23:00 and the core is not recovered. The release pathway option to be used in the calculations for the total effective dose (TEDE) is the containment leakage failure and bypass.



Leakage **Bypass**

Figure 6.Total Effective Dose Equivalent for autumn

Leakage scenario: The total collective dose for autumn obtained from leakage failure of Containment is 9.2E-02 man Sv. The results showed that for LOCA postulated accident, the maximum evacuation and sheltering zones respectively are 0.8Km and1.6Km.

Bypass scenario: The total collective dose for autumn obtained from bypass of Containment is 9.2E-02 man Sv. The results showed that for LOCA postulated accident at, the maximum evacuation and sheltering zones are respectively 38Km and 46.9Km.During autumn, the TEDE obtained from bypass of Containment was the highest dose for all scenarios.

5. CONCLUSION

From the previous discussions it can conclude that:

Site evaluation report (SER) and the environmental impact assessment of any new NPP contains a prediction about the radiation analysis consequences of a hypothetical accident. These consequences analysis is used to determine the protection or mitigation actions (evacuation, sheltering and administering potassium iodide (KI)).

The meteorological parameters like; wind speed, effluent temperature, stability class and type of accident have a significant impact on plume dispersion and radiation doses and need to be handled carefully.

The stability class of the atmosphere during the accident has a significant effect on the radiation dose to the public and the emergency preparedness.

Evaluation of the mitigation actions for the different seasons of the year indicate that the time of accident is a major factor for adopting a specific action.

A comparison between total effective doses equivalent (TEDE) for each scenario and season revealed that bypass accident scenario gave highest (TEDE) for autumn season.

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