Radiation Hazard Prediction of Egyptian Research Reactor for the Development of Emergency Decision Support System

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1. Introduction

One of the important issues on safety and security field is decision support systems (DSS) to support experts during the emergency planning operations in case of nuclear accidents. Accidents that have risk on the atmosphere and human health are increasing proportionally to the requirements of the energy of human society. DSS is important to ensure the right choice of safety precautions are selected, and to enhance the prevention phase that is essential in an emergency planning system [1]. One of the tools that support prompt action and accurate information during the nuclear emergency is HotSpot health physics codes, that provides a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials. The HotSpot program created by Lawrence Livermore National Laboratory (LLNL) to support emergency response personnel and planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material [2]. The aim of this study is applying the HotSpot code as one of DSS to simulate hypothesis radionuclides release accident on the second Egyptian research reactor (ETRR2). It has been operated since 1997 for the research purpose and produce radionuclides for medical and industrial. It has thermal power 22 MW. According to IAEA hazard categorization, ETRR2 belong to category number two. The description of category two is facilities, for which on-site events, events involving an atmospheric or aquatic release of radioactive material, or external exposure, i.e., to a loss of shielding or a criticality event, which originates from a location on the site, are postulated that could give rise to doses to people off the site [3]. In case of emergency, noble gases, halogen and alkali particles of radionuclides may release to the environment by ventilation system of reactors through stacks at 27 m height above the ground level [4]. Dispersion of radionuclides depends on several factors such as wind speed and atmospheric stability. In this study, we compared two accidental scenarios, the first scenario is the accident with average wind speed over two years; the second scenario is the accident occurred with worst wind speed (the wind speed is 95% value for the worst case greater the two-sigma from the average).

2. Methods and Results

There are several important input data shall enter to HotSpot code to simulate release of radionuclides to environment and calculate the total effective dose equivalent to human. The first parameter is type of your simulation. In this study, we used general plume to study the release of source term from ETRR2 to environment.

2.1 Source term

The selected scenario for this study is Core damage scenario. This scenario caused by more severe earthquake than reactor designed. Then station blackout, this mean the reactor total loss of AC power when both offsite and onsite AC power sources fail because of frequency fire is accompanying to severe earthquake. Rupture occurred in the Tangential beam (this beam used to neutron activation analysis and it is located at lowest point of reactor pool), therefore, large LOCA occurred and leading to uncovering of the core during few minutes. From probabilistic risk assessment point of view, this scenario has low probability but it has highly risk, one of goals of this study is assessment the worst case accident can occurred in the ETRR2 by HOTSPOT code.

The source term for fission product inventory inside the reactor core was defining on average 60% burnup by ORIGEN 2 code. It assumed that the reactor had operated on continuous for 160 days at its full power of 22 MW to achieve the Max burnup of 60%; the accident occurred in the end of nuclear fuel cycle which the rate radionuclide production become constant. Table I shows the representative important radionuclides in the reactor core at the time of accident, and the activity released to the atmosphere.

Table I: Source terms used in this study

Isotopes	Groups	Activity (Ci)
I-131	Halogen	1.07E+06
Xe-133	Noble gas	2.15E+06
Cs-137	Alkali metal	1.12E+04
Sr-89	Alkali earth	1.09E+06
Sr-90	Alkali earth	1.03E+04

2.2 Meteorological data

Meteorological condition of accident considered from historical meteorological data. This data was collected from Al Shorouk City weather station; it is the nearest weather station to ETRR2; the distance between this station and the ETRR2 is 32 km. The hourly data was analyzing to determine wind speed and wind direction, Fig. 1 explains the histogram graph for the wind speed over 2 years. From the graph, we can estimate the wind speed data over 2 years is not normally distributed and the data is skewed. Therefore, we used the median wind speed over two years of 2018 and 2019; it is more statistically significant than the average. The median value is 3.6 m/s (8 mph); this value was used for first scenario. For the worst-case scenario, we used the average of wind speed that greater than 95% value, these values are greater than two-sigma. The average value of wind speed greater than two-sigma is 10.2 m/s (22.7 mph). Wind direction determined by wind rose. Fig. 2(a) and 2(b) explain the north sector is predominate wind direction in the ETRR2 region in 2019 and 2018.

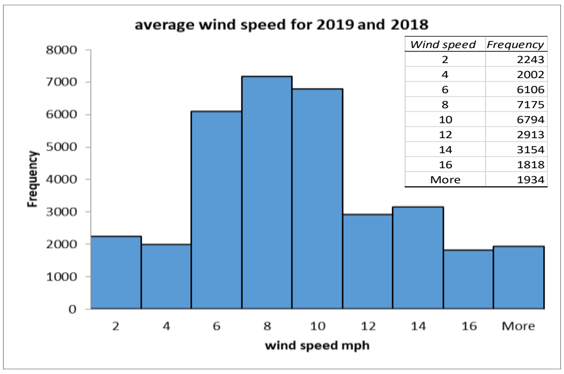


Fig. 1. Histogram of wind speed in 2019 and 2018

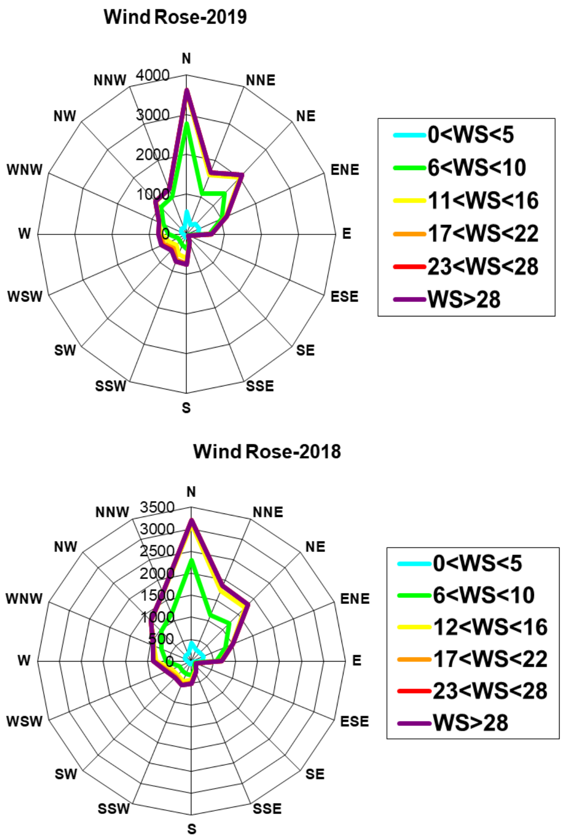


Fig. 2. Wind rose diagram in 2019 and 2018

In addition, Egyptian atomic energy authority modeled postulated accident release of $^{99}MoO_3$ powder from ETRR2 stack, and north wind direction used as predominate sector [4]. Table II shows the summary of input data used in HotSpot.

Table II: Summary of input data

Source term characteristics	Source material	Using representative radionuclide from each radionuclide group as shown in Table I
	Airborne Fraction	1
	Respirable Fraction	1
	Respirable Deposition Velocity (cm/sec)	0.3
	Non-resp. Deposition Velocity (cm/sec)	8
	Effective release height (m) [4]	27
	Damage ratio	1.0
	Leak path factor	1.0
Meteorological conditions	Wind speed	median = 3.6 m/s
		Max = 10.2
	Wind direction	North
	Weather stability	From A to F
Others	Receptor height	1.5 m
	Inversion layer height	None
	Breathing rate (m^3/s)	3.3×10^{-4}

2.3 Results

HotSpot outputs for the general plume scenarios are reported in Fig. 3 and Fig. 4 that show the graphical representations of the results for both the simulated scenarios, in terms of total effective dose equivalent (TEDE) and ground deposition, respectively. In Fig. 3 we can show in the first scenario (wind speed is 3.6 m/s) the dispersion of radioactive material is wide and for short distance, but for the worst scenario (wind speed is 10.2 m/s), the dispersion of radionuclide is narrow and for long distance.

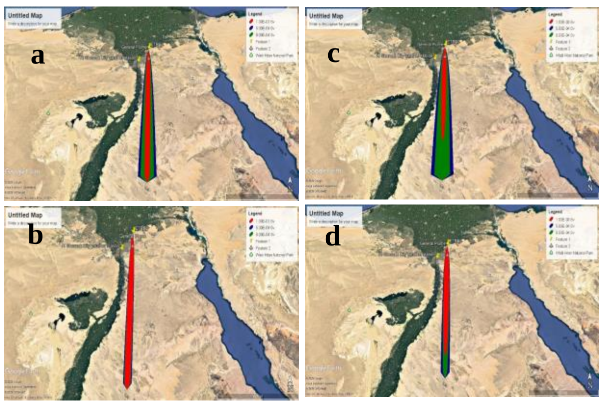
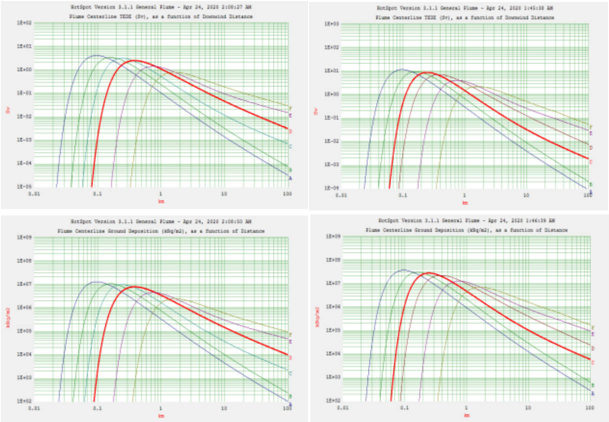


Fig. 3. a) Ground deposition for wind speed of 10.2 m/s, b) TEDE for 10.2 m/s, c) Ground deposition for 3.6 m/s, and d) TEDE for 3.6 m/s

Fig. 4. a) TEDE for wind speed of 10.2 m/s, b) Ground deposition for 10.2 m/s, c) TEDE for 3.6 m/s, and d) Ground deposition for 3.6 m/s



From Fig. 4 and Table II, we can observe for the first scenario (low wind speed is 3.6 m/s), maximum TEDE is 12 Sv at 95 m for stability class A. While in the second scenario (high wind speed is 10.6 m/s), maximum TEDE is 4.1 Sv at 95 m for stability class A.

Table III: Max TEDE for all stability classes for both scenarios

stability classes	Distance (km)	Max TEDE first scenario (Sv)	Max TEDE second scenario (Sv)
A	0.095	12	4.1
B	0.16	9.5	3.4
C	0.24	8.8	3.1
D	0.38	7.1	2.5
E	0.74	4	1.4
F	1.6	2.2	0.787
Select distance greater than the Max TEDE distance To see the effect of stability class for long distance			
A	10	3.90E-03	1.40E-03
B	10	9.00E-03	3.20E-03
C	10	3.20E-02	1.20E-02
D	10	1.30E-01	4.60E-02
E	10	2.60E-01	9.60E-02
F	10	5.10E-01	1.90E-01

From the previous Table, we can observe:

- At the same distance from the source term, the TEDE in first scenario (low wind speed) is greater than TEDE in the second scenario (high wind speed). For all stability classes. Therefore, first scenario is worse.
- In the short distance in first scenario, weather stability class A is the worst case of accident. The Max TEDE is 12 Sv at 95 m
- In the long distance in first scenario, weather stability class F is the worst case of accident. TEDE is 0.51 Sv at 10 km

According to ICRP 103, during emergencies, the residual dose to the public in emergency shall be in range 20 mSv to 100 mSv [5]. From this principle, for first scenario (wind speed is low), people who live at distance less than 10 km from the ETRR2 should be evacuated. While for the second scenario (wind speed is high), people who live at distance less than 20 km from the ETRR2 should be evacuated.

3. Conclusions

Hotspot is very useful tool for ETRR2 emergency that can be used to support decisions of experts for short time and short distance. If the accident occurs in normal meteorological condition (low wind speed), individuals whose are living very close to ETTR2 and worker would receive higher dose than from individuals whose are living far from ETRR2, and vice versa.

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