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Applying IAEA Simplified Atmospheric Dispersion Model as a training tool for Technical Support Organization Capacity Building Courses

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ABSTRACT

In addition to its scientific and technical research duties, the Nuclear and Radiological Safety Research Center (NRSRC) is currently working hard to strengthen its role to become a technical support organization on the both national and international levels, in cooperation with the IAEA, in the fields of nuclear and radiation facilities as well other different energy sources. The Siting and Environmental department belonging to NRSRC, is interested to develop training programs suitable for new students and trainees to use airborne dispersion codes for both nuclear and radiation facilities and non-nuclear sources. This helps them understand how to deal with these issues and calculate, estimate, and assess the risks resulting from these facilities. Based on this principle, SCREEN 3 model-originally developed by the U.S. Environmental Protection Agency- for atmospheric dispersion industrial applications - was used to evaluate the atmospheric dispersion parameters, taking into account different scenarios in terms of (emission rate, stack height and inside diameter, stack exit velocity and exit temperature, ambient air temperature, receptor height and atmospheric stability) which are the necessary data to calculate the worst concentration of the released pollutants at the receptor points, taking into account the topography of the site surrounding the facility. The results showed that stable conditions (F) shifted peaks to larger distances (1737–7880 m) with lower concentrations, whereas unstable conditions (A) produced peak concentrations close to the source (500–1041 m).

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Introduction

The Nuclear and Radiation Safety Research Center is a unique center, which in addition to its research duties in the fields of nuclear and radiological safety, security and safeguards of nuclear, radiation facilities as well the environmental impact assessment, is considered one of the potential scientific and technical support organizations (TSOs) of the country's nuclear safety system. Through these efforts, the center aims to support the safe operation of these facilities, while minimizing risks to humans and the environment. This will be achieved through effective cooperation with the International Atomic Energy Agency (IAEA), ensuring the exchange of expertise and the adoption of international best practices in this vital field, which represent an important contribution for capacity building and improving the quality and credibility of the center as a potential TSO. The Siting and Environmental department, belonging to the center, is interested to develop specialized training programs for qualifying new students and trainees in the siting and environmental fields. The dispersion of effluents from nuclear, radiation, as well as industrial facilities is important element for assessment of environmental impacts and emergency planning (Damara *et al.*, 2017). These programs focus on teaching how to use airborne dispersion codes for nuclear and radiation facilities, as well as non-nuclear sources (Bijad *et al.*, 2016 and Aristodemou *et al.*, 2020). Through these codes, the trainees understand the mechanisms of airborne pollutants transport and assess the impact of emissions on the surrounding environment, which is critical for environmental emergency planning and safety decision-making. Based on this approach, SCREEN3 model was adopted as one of the scientific tools to assess atmospheric dispersion parameters (Damara *et al.*, 2017 and Afzali *et al.*, 2022). Although the model is mainly designed for industrial applications, the principle is the same for nuclear energy facilities and other radiation sources. Therefore, the approach adopted is based on the idea of getting benefit from the simplicity of the model for training purposes, even in nuclear facilities, and to gradually use more specialized programs at a later training phase. This model is considered a simplified model, yet it is effective in providing preliminary estimates of the concentration of pollutants in the air resulting from emissions from specific sources, such as nuclear, radiation and industrial facilities (Wandasundari *et al.*, 2024 and Ruhiat *et al.*, 2008). Using this model allows researchers and trainees to understand how to calculate the extent of dispersion of radioactive or other polluting materials and estimate risk levels in different environments according to weather and topographic conditions, where the purpose of this study is to assess the viability of using the SCREEN3 model as a training tool in technical support organizations' capacity-building programs by examining several hypothetical scenarios that show how weather conditions and source characteristics affect air pollution spread (Ruhiat *et al.*, 2016 and Rai *et al.*, 2011).

Theoretical Background

The atmospheric stability influences how pollutants spread in the environment, which in turn influences air pollution dispersion. Pollutants concentrations at ground level are frequently predicted using the Gaussian Plume Model (GPM) under various stability scenarios. Wind speed, emission rate, and atmospheric stability classes (A to F) are among the variables taken into account in this model (El-Kilani *et al.*, 2010; Sankaran *et al.*, 2012 and Narayanachari *et al.*, 2014). The areas where pollutants build up the greatest before dispersing have the worst concentrations at ground level. This differs according to the stability class, which regulates both horizontal and vertical mixing. Assessments of environmental health, industrial emissions control, and air quality management all benefit from an understanding of dispersion behavior (EPA-454/B-95- 004, 1995 and Flori *et al.*, 2020). For the most severe pollution situations, precise forecasts are made by using atmospheric dispersion models. Modeling atmospheric dispersion for the release of radioactive gases and volatiles is a significant contribution for different stages in the nuclear technology safety criteria because atmospheric dispersion is a very important process in air pollution (Khaniabadia *et al.*, 2018 and Peszko *et al.*, 2023), as illustrated in figs. (1,2). The effluents are carried by wind and dispersed by atmospheric turbulence (Tingting *et al.*, 2020 and Karl *et al.*, 2000). According to Equation (1), the SCREEN3 model employs a Gaussian plume model. The estimation of pollutant concentration from continuous sources takes into account both climatic and source-related parameters. When the pollutant is being transported from the source, it is expected that no chemical reactions will occur and that no additional removal procedures, such as wet or dry deposition, will affect the plume (Zareba *et al.*, 2024; Ciobanu *et al.*, 2021 and Shikhovtsev *et al.*, 2024). The origin of the source's coordinate system is positioned at the ground surface at the base of the stack for every source. The z axis extends vertically, the y axis is crosswind (normal) to the x axis, and the x axis is positive in the downwind direction. The original purpose of the SCREEN3 source code is to determine ground-level concentrations at the wind blow direction beneath the plume centerline (Fojcíková *et al.*, 2019 and Rääf *et al.*, 2019).

$$X(x,y,z)=\frac{Q}{2\Pi\,\sigma_y\,\sigma_z\,U}\exp\left[-\left(\frac{Y^2}{2\sigma_y^2}\right)\right]\left(\exp\left[-\left(\frac{-(z-h)^2}{2\sigma_z^2}\right)\right]+\exp\left[-\left(\frac{-(z+h)^2}{2\sigma_z^2}\right)\right]\right) \quad \textbf{(1)}$$

Where:-

X (x, y, z): air concentration (Bq.m-3) at a point with coordinates x, y, z,

x: downwind distance(m), y: crosswind distance (m),z:

height above the ground (m), Q: release rate (Bq. s-1), U: mean wind speed (m.s-1) h: effective release height (m) $\sigma_y\ \sigma_z$: Diffusion parameters (m), which are a function of downwind distance, and atmospheric stability.

Equation (1) is the fundamental formula for simulating the impacts of point, flare, and volume releases on plumes in SCREEN3 model, which uses a virtual point source for volume releases and a numerical integration approach for calculating impacts from area releases.

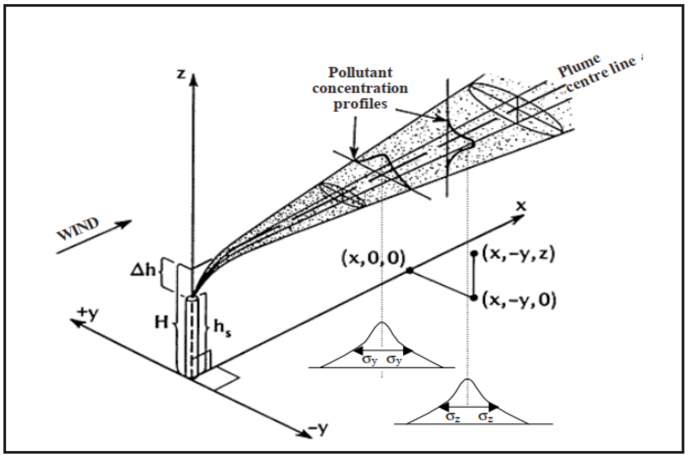


Figure (1): Gaussian Dispersion Model

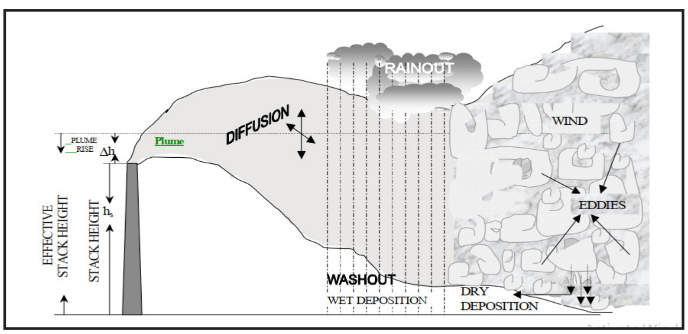


Figure (2): Behavior of effluents released to the atmosphere

For a steadystate Gaussian plume, the hourly concentration at downwind distance x (meters) and crosswind distance y (meters) is given spatially by Eq (2):

$$X = \frac{QSVD}{2\Pi\,\sigma_y\,\sigma_z\,U}\exp\left[-0.5\left(\frac{Y^2}{\sigma_y^2}\right)\right] \quad (2)$$

Where:
Q:- the pollutant emission rate (mass per unit time);
S:- a scaling constant that converts estimated concentrations to desired units (the default value is 106 for Q in g/s and concentration in µg/m3)
V:- term of vertical,
D:- term of decay
U:- the average wind speed (m/s) at release height.
σ_y ,σ_z :- The standard deviation of lateral and vertical concentration distribution (m) IN case (nuclear facility), concentration of pollutant ($Bqlm^3$), thus convert concentration from ($\mu g/m^3$) to ($\mu\ Bqlm^3$) as equations (3, 4) (Knoll, 2010): -

$$\mu Bqlm^3 = X(\mu g/m^3) * As(Bq/g) \quad (3)$$

$$As = \frac{0.693.NA}{(T_{\frac{1}{2}}).M} \quad (4)$$

Where :- X:- concentration of mass
As:- specific of isotope for CS-137 equal $3.2*10^{12}$
M:- molar mass
NA:- Avogadro's number

Methodology

The dispersion of pollutants released from a hypothetical point source (industrial facility) was investigated using the SCREEN3 model, because contaminants show a dispersion pattern while accounting for radioactive units, this program is equally appropriate for nuclear facilities. The atmospheric conditions and source attributes were represented by a set of hypothetical data from NOAA www.ready.noaa.gov/archives.php. The model inputs included the following parameters:
Emission rate: 500 g/s
Stack height: 100 m
Stack exit Gas velocity : 20 m/s
Stack Gas exit temperature: 400 K
Ambient air temperature: 293 K
Three different scenarios for industrial facility, that show differences in a few source attributes were examined:
Case 1: Chimney diameter 3 m, receiver height 0 m
Case 2: Chimney diameter 6 m, receiver height 0 m
Case 3: Chimney diameter 3 m, receiver height 200 m
The results were analyzed for both rural and urban environments under three atmospheric stability conditions: A: Unstable case, D: Neutral stability, F: Stable stability.

Results and Discussion

Figs (3), (4) and table (1) related to scenario (1) for rural region gives a maximum 1-hr concentration at specific distance for different stability classes: A maximum one-hour concentration is 538.2 ug/m3 at a distance of 739 meters in unstable class (A). Because of the substantial mixing in unstable conditions, the peak occurs near the source with a high concentration, A maximum one hour concentration is 111.5 ug/m3 at a distance of 5313 meters in neutral stability class (D). Since there is substantial mixing under neutral conditions, the peak appears farther away and has a lower concentration. A maximum one-hour concentration is 3.972 ug/m3 at a distance of 7880 meters in stable class (F). Since there is little mixing under stable conditions, the peak appears far away and has a very low concentration. Fig (5) scenario (2) and table (1) for rural region gives a maximum one-hour concentration of 218.7 ug/m3 at a distance of 1041 meters in unstable class (A). Because of the substantial mixing in unstable conditions, the peak occurs near the source with a high concentration, A maximum one hour concentration is 6.304 ug/m3 at a distance of 7880 meters in neutral case (D). Since there is substantial mixing under neutral conditions, the peak appears farther away and has a lower concentration. A maximum of one hour concentration is 0.8946 ug/m3 at a distance of 7880 meters in stable class (F), Since there is little mixing under stable conditions. Figs (6), (7) and (8) scenario (3) and table (1) for rural region gives a maximum of one hour concentration of 1197 ug/m3 at a distance of 500 meters in unstable class (A), because of the substantial mixing in unstable conditions, the peak occurs near the source with a high concentration. A maximum of one hour concentration is 2936 ug/m3 at a distance of 555 meters in neutral case (D). Since there is substantial mixing under neutral conditions, the peak appears farther away and has a lower concentration. A maximum of one hour concentration is 1041 ug/m3 at a distance of 1737 meters in stable case (F), since there is little mixing under stable conditions.

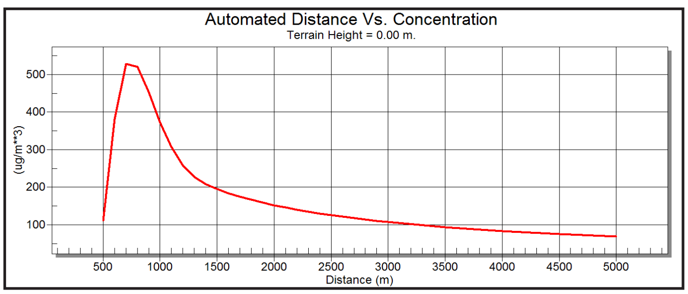


Figure (3): Maximum 1-hr concentration of 538.2 ug/m3 at a distance 739 of meters for unstable case.

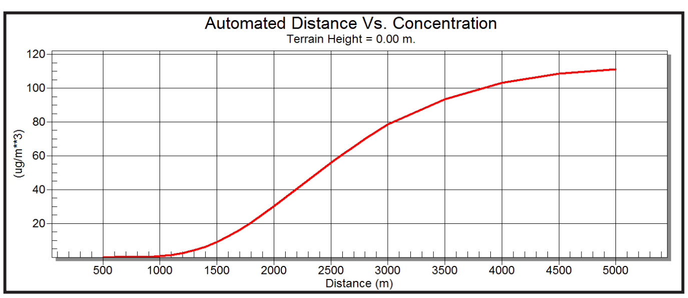


Figure (4): Maximum 1-hr concentration of 111.5 ug/m3 at a distance of 5313 meters for neutral case.

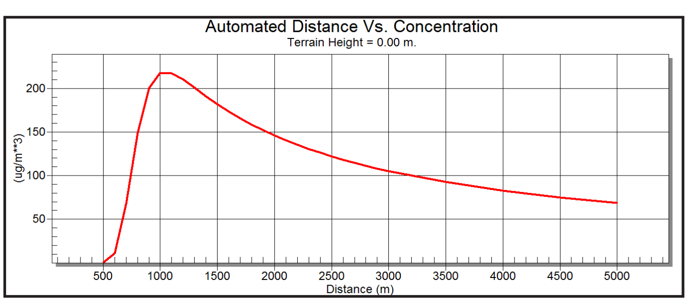


Figure (5): Maximum 1-hr concentration of 218.7 ug/m3 at a distance of 1041 meters for unstable case.

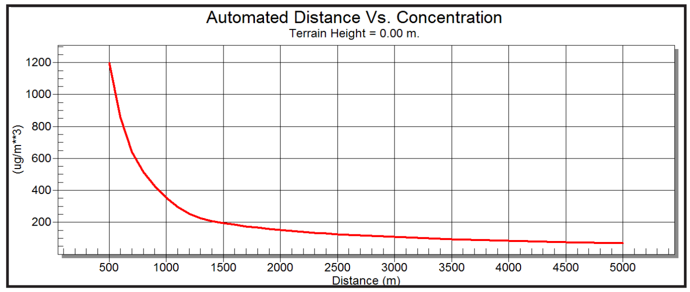


Figure (6): Maximum 1-hr concentration of 1197 ug/m3 at a distance of 500 meters for unstable case.

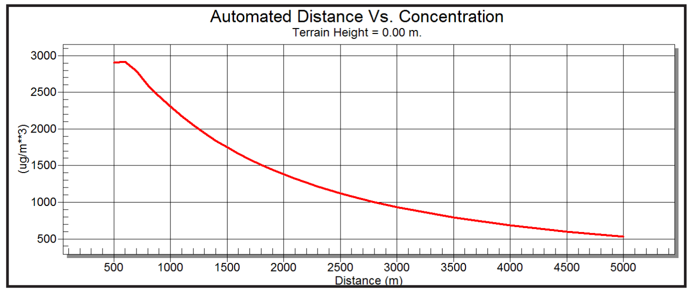


Figure (7): Maximum 1-hr concentration of 2936 ug/m3 at a distance of 555 meters for neutral case.

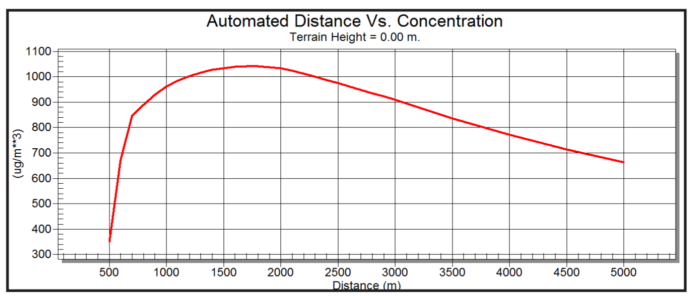


Figure (8): Maximum 1-hr concentration of 1041 ug/m3 at a distance of 1737 meters for stable case.

Figs (9 - 11) and table (1) related to scenario (1) for urban region gives a maximum 1-hr concentration at specific distance for different stability classes: A maximum concentration of one hour is 433 ug/m3 at a distance of 628 meters in unstable case (A), a maximum of one hour concentration is 391.5 ug/m3 at a distance of 1331 meters in neutral case (D) and a maximum one-hour concentration is 320.6 ug/m3 at a distance of 3360 meters in stable case (F), respectively. Figs (12-14) and table (1) related to scenario (2) for urban region gives a maximum 1-hr concentration at specific distance for different stability classes: A maximum of one hour concentration is 155.5 ug/m3 at a distance of 1027 meters in unstable case (A), a maximum of one hour concentration is 134.5 ug/m3 at a distance of 2527 meters in neutral case (D) and a maximum of one hour concentration is 203.2 ug/m3 at a distance of 40793 meters in stable case (F), respectively. Figs (15),(16) and (17) and table (1) related to scenario (3) for urban region gives a maximum 1-hr concentration at specific distance for different stability classes: A maximum of one hour concentration is 776.4 ug/m3 at a distance of 500 meters in unstable case (A), a maximum of one hour concentration is 2532 ug/m3 at a distance 500 meters in neutral case (D) and a maximum one hour concentration is 4481 ug/m3 at a distance 500 of meters in stable case (F), respectively. It is observed from table (1) that the Maximum Pollutant Concentration for an Unstable Case decrease in Urban Areas compared to Rural Areas. Strong turbulence in unstable atmospheric circumstances causes contaminants to diffuse more which may be due to variations in surface roughness, thermal effects, and mechanical turbulence. Urban areas have lower maximum pollutant concentrations than rural areas under unstable conditions. This is because urban areas have stronger mixing from buildings, heat islands, mechanical turbulence. Pollutant dispersion is more constrained in neutral and stable air conditions.

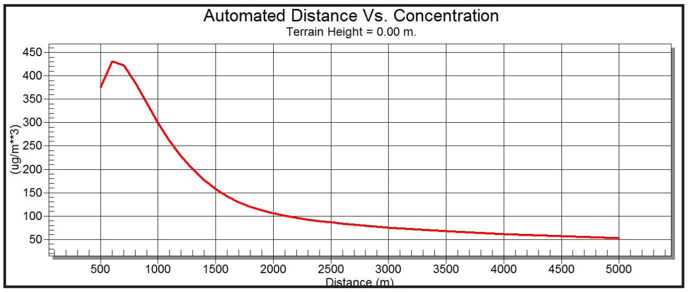


Figure (9): Maximum 1-hr concentration of 433 ug/m3 at a distance of 628 meters for unstable case.

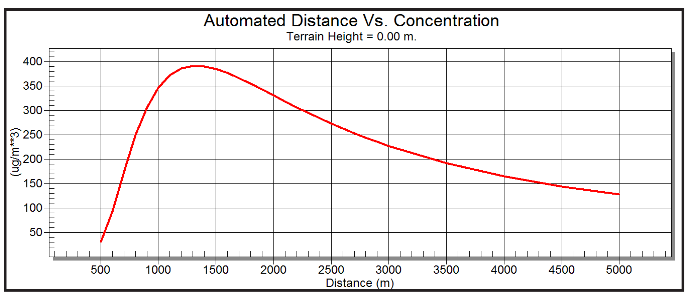


Figure (10): Maximum 1-hr concentration of 391.5 ug/m3 at a distance of 1331 meters for neutral case.

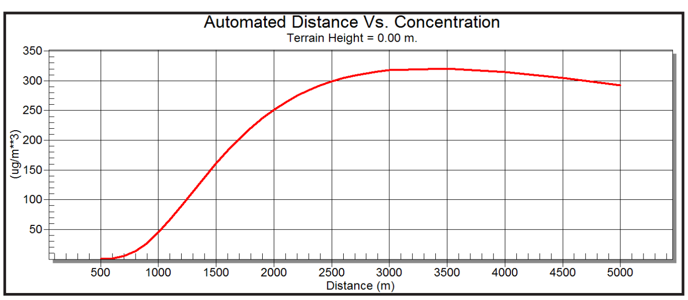


Figure (11): Maximum 1-hr concentration of 320.6 ug/m3 at a distance of 3360 meters for stable case.

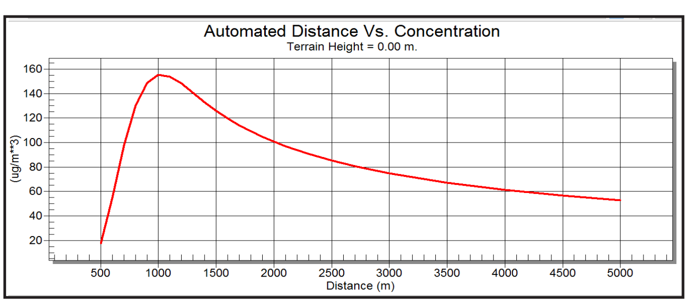


Figure (12): Maximum 1-hr concentration of 155.5 ug/m3 at a distance of 1027 meters for unstable case.

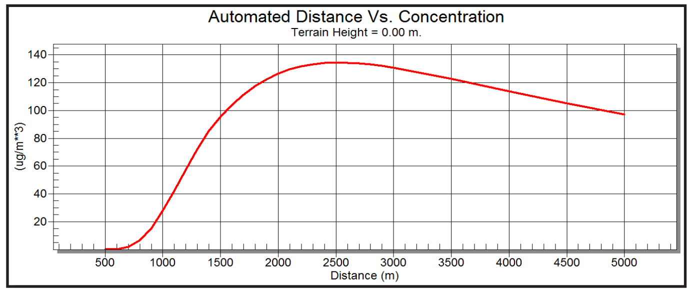


Figure (13): Maximum 1-hr concentration of 134.5 ug/m3 at a distance of 2527 meters for neutral case.

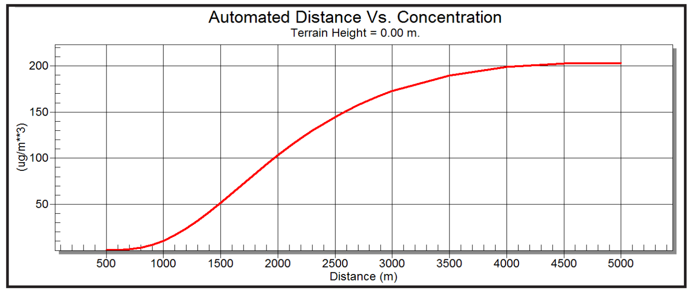


Figure (14): Maximum 1-hr concentration of 203.2 ug/m3 at a distance of 4793 meters for stable case.

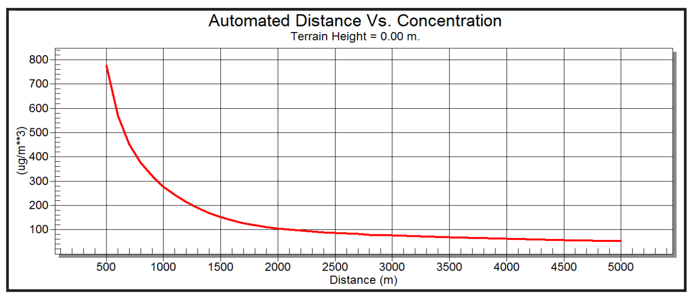


Figure (15): Maximum 1-hr concentration of 776.4 ug/m3 at a distance of 500 meters for unstable case.

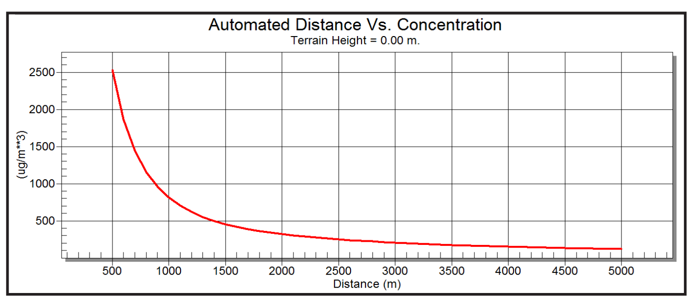


Figure (16): Maximum 1-hr concentration of 2532ug/m3 at a distance of 500 meters for neutral case.

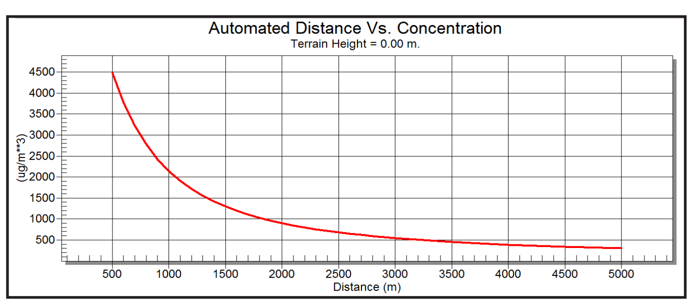


Figure (17): Maximum 1-hr concentration of 4481ug/m3 at a distance of 500 meters for stable case.

Table 1. Maximum concentration(ug/m3)^(uBq/m3) for different stability classes at rural and urban area

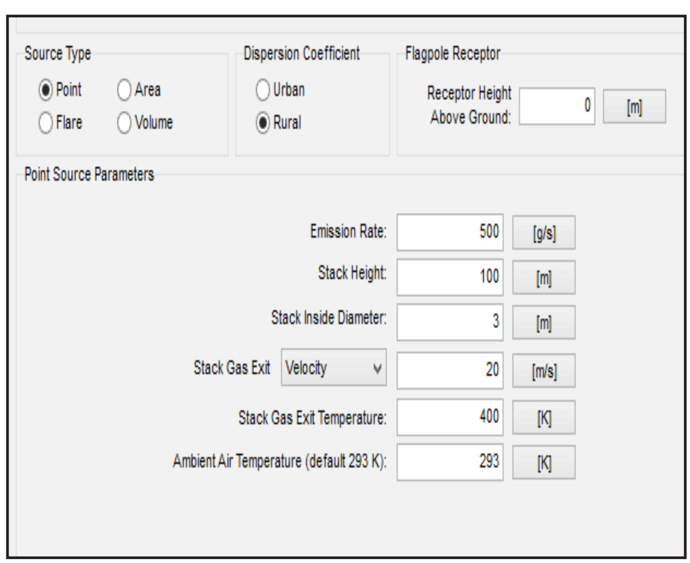
Scenario	Condition	Stability class	Type of area	Maximum concentration (ug/m3)	Maximum concentration (ubqlm3)	Distances (m)	Type of area	Maximum concentration (ug/m3)	Maximum concentration (ubqlm3)	Distances (m)
Scenario (1)	emission rate (g/s)= 500 stack height (m)= 100	unstable	**rural**	538.2	1.72E+15	739	urban	433	1.39E+15	628
	stk inside diam (m) = 3 stk exit velocity (m/s)= 20	neutral		111.5	3.57E+14	5313		391.5	1.25E+15	1331
	stk gas exit temp (k)= 400 ambient air temp (k)= 293 receptor height (m) = 0	stable		3.972	1.27E+13	7880		320.6	1.03E+15	3360
Scenario (2)	emission rate (g/s)= 500 stack height (m)= 100	unstable		218.7	7E+14	1041		155.5	4.98E+14	1027
	stk inside diam (m= 6 stk exit velocity (m/s)= 20 stk gas exit temp (k)= 400	neutral		6.304	2.02E+13	7880		134.5	4.3E+14	2527
	ambient air temp (k)= 293 receptor height (m)= 0	stable		0.8946	2.86E+12	7880		203.2	6.5E+14	4793
Scenario (3)	emission rate (g/s) = 500 stack height (m)= 100	unstable		1197	3.83E+15	500		776.4	2.48E+15	500
	stk inside diam (m)= 3 stk exit velocity (m/s)= 20 stk gas exit temp (k)= 400	neutral		2936	9.4E+15	555		2532	8.1E+15	500
	ambient air temp (k)= 293 receptor height (m)= 0	stable		1041	3.33E+15	1737		4481	1.43E+16	500

Finally, the results of the first scenario in rural areas revealed that, under atmospheric instability, the highest pollutant concentration reached about 538 micrograms per cubic meter at a distance of about 739 meters. This is explained by increased atmospheric turbulence, which causes pollutants in the lower layers of the atmosphere to mix quickly. In contrast, under neutral atmospheric stability, the highest concentration value was observed at a greater distance of about 5313 meters because of lower mixing rates than in the instability scenario. The greatest concentration values were found at even farther distances—roughly 7880 meters—in strong atmospheric stability. This is because contaminants can travel farther before dispersing due to inadequate vertical air mixing.

Changes in the parameters of the released gas flow and its impact on cloud height and dispersion caused a decrease in the maximum concentration values in the second scenario, where the chimney diameter was increased. A notable rise in the reported concentration levels was noted in the third scenario, where the receiver height was raised to 200 meters. This is explained by the receiver's proximity to the cloud axis, which has higher pollutant concentrations than the ground. Additionally, a comparison of urban and rural settings showed that during atmospheric instability, urban regions frequently record lower concentrations because of increased mechanical turbulence brought on by structures and rougher surfaces, which increases atmospheric dispersion and mixing.

As a result, the movement of radioactive materials in the atmosphere following nuclear accidents or radioactive leaks can be estimated using the results of atmospheric diffusion models. The resulting air concentrations can be used to determine the possible radiation doses for the population by expressing the emission rate in radioactivity units.

During nuclear emergencies, these computations play a critical role in decision support systems by assisting in the identification of regions that could need protective measures like building shelter or evacuation. Also, the literature reviews (Wang *et al.*, 2019; Rai *et al.*, 2011; El-Kilani *et al.*, 2010 and Shikhovtsev *et al.*, 2024) make it abundantly evident that air diffusion models are essential to nuclear emergency response and decision support systems. However, in order for these models to be used effectively, specialists working in organizations that support nuclear regulatory bodies (TSOs) need particular training and capacity building. In order to help trainees, grasp the fundamentals of atmospheric diffusion modeling before advancing to the more sophisticated models used in evaluating the radiological effects of nuclear accidents, this research focuses on using the SCREEN3 model as a simplified training tool.



Run Screen Models for Point Source
SCREEN3 MODEL RUN
SOURCE TYPE : POINT
EMISSION RATE (G/S) = 500
STACK HEIGHT (M) = 100
STK INSIDE DIAM (M) = 3
STK EXIT VELOCITY (M/S)= 20
STK GAS EXIT TEMP (K) = 400
AMBIENT AIR TEMP (K) = 293
RECEPTOR HEIGHT (M) = 0
URBAN/RURAL OPTION = RURAL
Buoy. Flux= 118.042 m^4/s^3; mom. Flux = 659.250 m^4/s^2
STABILITY CLASS 1 ONLY
ANEMOMETER HEIGHT WIND SPEED OF 3 m/s
Terrain height of 0. M above stack base used for following distances
DIST CONC U10M USTK MIX HT PLUME SIGMA SIGMA
(M) (UG/M^3) STAB (M/S) (M/S) (M) HT (M) Y (M) Z (M) DWASH
------- ---------- ---- ----- ----- ------ ------ ------ ------ -----
500. 112.0 1 3.0 3.5 960.0 292.28 119.93 112.06 NO
600. 381.6 1 3.0 3.5 960.0 292.28 140.37 160.45 NO
700. 528.0 1 3.0 3.5 960.0 292.28 160.35 219.14 NO
800. 520.6 1 3.0 3.5 960.0 292.28 179.95 288.27 NO
900. 452.5 1 3.0 3.5 960.0 292.28 197.96 367.26 NO
1000. 373.9 1 3.0 3.5 960.0 292.28 215.82 457.16 NO
1100. 307.1 1 3.0 3.5 960.0 292.28 233.55 558.01 NO
1200. 259.2 1 3.0 3.5 960.0 292.28 251.14 669.84 NO
1300. 228.2 1 3.0 3.5 960.0 292.28 268.61 792.74 NO
1400. 208.5 1 3.0 3.5 960.0 292.28 285.95 926.77 NO
1500. 194.9 1 3.0 3.5 960.0 292.28 303.17 1072.01 NO
1600. 184.1 1 3.0 3.5 960.0 292.28 320.27 1228.53 NO
1700. 174.8 1 3.0 3.5 960.0 292.28 337.25 1396.42 NO
1800. 166.5 1 3.0 3.5 960.0 292.28 354.11 1575.75 NO
1900. 158.9 1 3.0 3.5 960.0 292.28 370.87 1766.58 NO
2000. 152.1 1 3.0 3.5 960.0 292.28 387.53 1968.98 NO
2100. 145.9 1 3.0 3.5 960.0 292.28 404.09 2183.03 NO
2200. 140.2 1 3.0 3.5 960.0 292.28 420.55 2408.78 NO
2300. 134.9 1 3.0 3.5 960.0 292.28 436.91 2646.30 NO
2400. 130.1 1 3.0 3.5 960.0 292.28 453.19 2895.65 NO
2500. 125.6 1 3.0 3.5 960.0 292.28 469.38 3156.88 NO
2600. 121.4 1 3.0 3.5 960.0 292.28 485.48 3430.05 NO
2700. 117.5 1 3.0 3.5 960.0 292.28 501.51 3715.22 NO
2800. 113.9 1 3.0 3.5 960.0 292.28 517.45 4012.43 NO
2900. 110.5 1 3.0 3.5 960.0 292.28 533.33 4321.74 NO
3000. 107.4 1 3.0 3.5 960.0 292.28 549.12 4643.20 NO
3500. 94.01 1 3.0 3.5 960.0 292.28 627.08 5000.00 NO
4000. 83.80 1 3.0 3.5 960.0 292.28 703.48 5000.00 NO
4500. 75.72 1 3.0 3.5 960.0 292.28 778.51 5000.00 NO
5000. 69.16 1 3.0 3.5 960.0 292.28 852.32 5000.00 NO
MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 500. M:
739. 538.2 1 3.0 3.5 960.0 292.28 168.24 245.53 NO
CALCULATION MAX CONC (UG/M3) DIST TO MAX (M) TERRAIN HT (M)**
SIMPLE TERRAIN 538.2 739. 0.

Conclusions

This study proves the successful use of simplified Screen 3 model, originally designed for industrial applications, in developing a training program for atmospheric dispersion of pollutants, which also includes nuclear power generation and other radiation facilities. The detailed training program is now under development. This can either a standalone program specially tailored for trainees to be specialized in the areas or part of another basic training course or advanced professional ones arranged in cooperation with the IAEA, Arab Atomic Energy Agency and other International Technical Support Organizations. The Nuclear and Radiological Safety Research Center and the Siting and Environmental Department possess the key highly qualified personnel and physical facilities for training, also in coordination with facilities available in the Central training umbrella of the Atomic Energy Authority. The financial assessment of each program is to be assessed according to the requirement of the customer. Needless to say, that the cooperation is highly recommended with other groups within the Center, the department, and the Egyptian Atomic Energy Authority. This interdisciplinary approach for capacity building will lead to the efficient use of the available limited resources and will benefit all the stakeholders, the results showed the importance of source characteristics and atmospheric stability conditions in influencing the locations and amounts of peak pollutants. Before advancing to the more sophisticated models used in evaluating the radiological effects of nuclear accidents, this kind of model might be employed in the early phases of training.

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