Evaluating the Effect of Nuclear Power Plant Buildings on the Atmospheric Dispersion Behavior of Released Radioactive Materials

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ABSTRACT

One of the most important principles in air pollution is to minimize the release of pollutants to the atmosphere, deposition on the ground and promote sufficient dilution of released pollutants within the atmosphere. Building downwash describes the effect that wind flowing over or around buildings create a cavity of reticulating winds in the area near the buildings. These cavities cause increased vertical dispersion of plumes emitted from stacks on or near the buildings. Often it leads to elevated concentrations downwind of affected stacks.

The aim of this work is to evaluate the effect of the building downwash phenomena on the atmospheric dispersion behavior of released radioactive materials from NPP. In this study, a hypothetical scenario is presented involving a point source with varying stack parameters and rectangular shaped buildings (Milestone Nuclear Power Plant) using meteorological parameters of a chosen day.

The concentrations of assumed released radionuclides, taking into consideration the building downwash effect and without are calculated using the AERMOD Model taking into consideration the effect of the type of atmospheric stability class. Also the analysis includes the model predictions for the highest 1-hour cavity concentration.

The results show that the size of the cavity zone is not affected by the type of stability class, but is affected by the stack location and buildings shape. On other hand, the distance at which the plume touches the ground is affected by the type of stability class, the stack location and buildings shape. So, strategies for locating buildings need to be considered to maximize dispersion when planning for constructing several reactors and accessory buildings at a nuclear site.

Keywords: AERMOD, Building downwash, Cavity Zone, Milestone Nuclear Power Plant.

INTRODUCTION

The term building downwash describes the effect that wind flowing over or around buildings create a cavity of reticulating winds in the area near the buildings. These cavities cause increased vertical dispersion of plumes emitted from stacks on or near the buildings. Building downwash often leads to elevated concentrations downwind of affected stacks. The building concept is shown in fig (1), (a, b) (¹).
Figure (1 b) shows the effect of building downwash on a plume. In the figure, the stack on the left is located on top of a building and this structure impacts on the wind-flow which, in turn, impacts upon the plume dispersion, pulling it down into the cavity zone behind the building. The stack on the right is located far enough downwind of the building to be unaffected by the wake effects and is not as dispersed in the near field.

When the airflow meets a building (or other obstruction), it is forced up and over the building. On the lee side of the building, the flow separates, leaving a closed circulation containing lower wind speeds. Farther downwind, the air flows downward again. In addition, there is more shear and, as a result, more turbulence.

The severity of building downwash depends on several factors. This includes building shape, building orientation to the wind direction, ratio of stack height to building height, exhaust momentum or buoyancy, stack location relative to the building, and wind speed.

**MATERIALS AND METHODS**

The Gaussian dispersion code AERMOD incorporates the Plume Rise Model Enhancements (PRIME), [a comprehensive tool to simulate both plume and building downwash- (Schulman et al. 2000)] algorithms for estimating enhanced plume growth and restricted plume rise for plumes affected by building wakes and change in plume centerline due to streamline deflections from buildings, also to calculate recirculation within a cavity. (2)

PRIME calculates fields of turbulence intensity, wind speed, and the slopes of the mean streamlines as a function of the projected building dimensions.

It is common to use the following form of the Gaussian model to account for building downwash effect for short-term plume centerline calculations.

\[
x/Q = \frac{1}{(\pi \sigma_y \sigma_z + C \cdot A) \mu}
\]

Where

A= cross section area of the building normal to flow, and
C=shape factor to represent the fraction of A over which the plume is dispersed;
C=0.5 is a conservative value which is commonly used.
Regulatory guide 1.145 (3) indicates that the building wake correction should be used in the first 8h following release, with a shape factor C of 0.5 and the minimum cross-sectional of the reactor building only.

In case the effective height of release is less than twice the building height, IAEA has recommended the use of modified Sigma Method to account for building wakes (4).

In the presence of buildings in this study Airflow is affected by several factors such as the following as shown below:

- Source characteristics of the building such as building dimensions, stack height, stack diameter and gas exit velocity.
- Meteorological factors at the region such as atmospheric stability class, ambient temperature, wind direction and wind speed.
- Surface parameters as Monin-obukhov length (L), surface heat flux, mechanical mixing height and convective mixing height.

**PRIME Chart Components**
The chart is composed of the following components which describe figures (8) and (9).

<table>
<thead>
<tr>
<th>Stack Parameters:</th>
<th>At the top of the chart, the source name, the date and hour the profiles represent are displayed. Below this, the some of the stack properties are shown. Note that the stack properties are obtained directly from information within the .DAT input file and not from optional hourly emissions files.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plume centerLine</td>
<td>This is the plume centerline profile as a function of downwind distance from the source.</td>
</tr>
<tr>
<td>Plume Sig. Z</td>
<td>This is the plume centerline minus one Sigma Z. It describes the plume’s vertical size and shape out to a distance of one Sigma Z above the plume center-line.</td>
</tr>
<tr>
<td>Plume Sig. Z+</td>
<td>This is the plume centerline plus one Sigma Z. It describes the plume’s vertical size and shape out to a distance of one Sigma Z above the plume centerline.</td>
</tr>
<tr>
<td>Building wake</td>
<td>This line depicts the building wake profile directly under or above the plume centerline as computed by AERMOD.</td>
</tr>
<tr>
<td>Cavity zone</td>
<td>This line depicts the cavity zone vertical profile directly under or above the plume centerline, as computed by AERMOD.</td>
</tr>
<tr>
<td>Bld. Ht. x 2.5 (Wind)</td>
<td>This horizontal line indicates the height the stack would have to be to avoid the influences of building downwash (as computed by the model) for the current wind direction. If this line is not present, the height is the same as the Bld. Ht. X 2.5 height.</td>
</tr>
<tr>
<td>Bld. Ht. x 2.5</td>
<td>This horizontal line indicates the height the stack would have to be to avoid the influences of building downwash (as computed by the model) for all wind directions.</td>
</tr>
</tbody>
</table>
Case Study

Reactor Building downwash -Cavity zone

One day of meteorological data employed in the case study. January 18/ 2007 was selected due to the presence of all stability classes in that day, also the wind direction is towards the sector S-SSW in all chosen hours.

The ground level data included are: topography, temperature, friction velocity, sensible heat flux, specific humidity, and pollutant deposition velocity.

Emission temperatures were close to the ambient temperature, release velocities are close to 10m/s. 18/01/2007. Input data are presented in table (4-2).

The results for the highest first hour are tabulated for the AERMOD model run.

The analysis also includes the model predictions for the highest 1 hour cavity concentration.

Table (1): 18/01/2007 input data

<table>
<thead>
<tr>
<th>Hour</th>
<th>Wind speed</th>
<th>Wind direction</th>
<th>Stability class</th>
</tr>
</thead>
<tbody>
<tr>
<td>04</td>
<td>4.2</td>
<td>178</td>
<td>E Stable</td>
</tr>
<tr>
<td>08</td>
<td>3.4</td>
<td>181</td>
<td>C Unstable</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>182</td>
<td>B Unstable</td>
</tr>
<tr>
<td>11</td>
<td>3.5</td>
<td>190</td>
<td>A Unstable</td>
</tr>
<tr>
<td>16</td>
<td>4.9</td>
<td>181</td>
<td>D Stable</td>
</tr>
<tr>
<td>22</td>
<td>3.4</td>
<td>191</td>
<td>F Stable</td>
</tr>
</tbody>
</table>

A hypothetical scenario involves point source with varying stack parameters and rectangular shaped building (Milestone Nuclear Power Plant) (4). Reactor stack parameters are listed in table (2).

Table (2): Source characteristics

<table>
<thead>
<tr>
<th>Source name</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Stack height (m)</th>
<th>Effective Diameter (m)</th>
<th>Emission rate (g/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REAC</td>
<td>(0,0)</td>
<td>(-42.1,-16.4)</td>
<td>48.4</td>
<td>2.12</td>
<td>1</td>
</tr>
</tbody>
</table>

Receptor configuration and building dimensions

A gridded polar array of receptors is used in the flat terrain portion of the analysis; a Cartesian receptor grid extending out to 3 kilometers is used in the building downwash analysis.

The building dimensions are given in Table (3) - and their location relative to the modeled stacks are shown in Figure (2).
Fig. (2): the building and stack locations

Table (3): the building dimensions

<table>
<thead>
<tr>
<th>Building name</th>
<th>Length(m)</th>
<th>Width(m)</th>
<th>Height (m)</th>
<th>Angle(°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor1</td>
<td>45.6</td>
<td>35.4</td>
<td>41.6</td>
<td>344.8</td>
</tr>
<tr>
<td>Reactor2</td>
<td>47.8</td>
<td>47.8</td>
<td>44.7</td>
<td>344.2</td>
</tr>
<tr>
<td>Turbine1</td>
<td>92.4</td>
<td>36.7</td>
<td>27.6</td>
<td>344.3</td>
</tr>
<tr>
<td>Turbine2</td>
<td>91.2</td>
<td>35.4</td>
<td>27.6</td>
<td>344.8</td>
</tr>
</tbody>
</table>

Meteorological data analysis

The Wind Rose - Wind class frequency distribution for January 18/2007 – are shown in Figure (3).
Sensible heat flux (SHTF) and temperature Figure (4) shows the evolution of these parameters at the source location between hours 1 and 24 on 18 January-2007 (local time). The SHTF calculated by Meteorological data pre-processing (Night hours) shows low and negative values for the first seven hours, then at (hour 8) [Sunrise], the SHTF rises together with a slight temperature increase. During the last simulation hours, SHTF decreases again according to the expected tendency, in coherence with the [Sunset], which leads to the SHTF low and negative values. Variation of wind speed and direction at (10 m) is shown in figure (5).

Mixing height for AERMOD, Fig (6) shows the mixing layer heights processed by Meteorological data pre-processing. AERMET selects the mixing height values given by input instead of the values calculated internally, except for the hour 16, for which the mechanical mixing height calculated by the code is used. During the stable hours this is originated in the lowest value calculated for \( u^* \) and \( L \). During the unstable hours it is attributed to the higher values of SHTF.
RESULTS

Building Downwash Analysis

AERMOD model output Contours for release from Reactor for (stack locations 1, 2) are shown in Fig (7)

Fig. (6): Mixing Height, Hours 1-24

Fig. (7): AERMOD Contours for REAC
Cavity Zone analysis
Release from REAC (0, 0)

Fig. (8): release from REAC (0, 0)
Release from REC (-42.1, 16.2)

Fig. (9): release from REAC (-42.1, 16.4)
Plume to ground distance locations (1, 2) are presented in table (4).

Figures (10) and (11) show the plume centerline and Sigma Y for REAC-stacks.

**Table (4): Plume to ground distance**

<table>
<thead>
<tr>
<th>Hour</th>
<th>Wind speed</th>
<th>Wind direction</th>
<th>Stability class</th>
<th>Location 1</th>
<th>Location 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>04</td>
<td>4.2</td>
<td>178° E</td>
<td>Stable</td>
<td>275</td>
<td>380</td>
</tr>
<tr>
<td>08</td>
<td>3.4</td>
<td>181° C</td>
<td>Unstable</td>
<td>330</td>
<td>410</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>182° B</td>
<td>Unstable</td>
<td>256</td>
<td>290</td>
</tr>
<tr>
<td>11</td>
<td>3.5</td>
<td>190° A</td>
<td>Unstable</td>
<td>257</td>
<td>270</td>
</tr>
<tr>
<td>16</td>
<td>4.9</td>
<td>181° D</td>
<td>Unstable</td>
<td>270</td>
<td>290</td>
</tr>
<tr>
<td>22</td>
<td>3.4</td>
<td>191° F</td>
<td>Stable</td>
<td>290</td>
<td>390</td>
</tr>
</tbody>
</table>

**Fig. (10): Plume Centerline for REAC stacks**

**Fig. (11): Sigma-Y for REAC stacks**

Distance vs. Concentrations with and without building downwash for all stability classes are shown in the figure (12)
DISCUSSION AND CONCLUSIONS

The presence of buildings affects airflow by several factors such as:

- Source characteristics of the building such as building dimensions, stack height, stack diameter, and gas exit velocity.
- Meteorological factors at the region such as atmospheric stability class, ambient temperature, wind direction, and wind speed.

Fig. (12): distances vs. concentrations
An analysis of year 2007 data found that the most appropriate day for this study is January 18, 2007 as there is a narrow change in wind direction at about 13 degrees and wind speed of about 1.7 m/s and this day contains all stability class (7).

-From the analysis of the stack location at REAC (0, 0) which is located at the right side of reactor building 2 and has a 344.2 degree angle of inclination and because the wind is coming from the south, the building effect is very limited as shown in Fig (5-1), and the dispersion is towards the North (sea side). The downwash change in the distance comes mainly from changes in the stability of the air at different hours.

An increase after the descent of pollutants on ground were compared the situation of location1 as indicated in table (5-1), so pollutants reach the ground at distances further than that for the stack location 1.

-The nearest point at downwash (turbulent wake) distance for hour 11 is 240m (location 1) at which the plume follows the plume-looping concept, while (turbulent wake) distance for hour 16 is 240m (location2) at which the plume follows the coning plume concept, and this distance is clean from radioactive releases.

From the cavity zone analysis we got that the stack height at which the building wake has no effect is 111.75m

From figure (10) for building downwash the maximum concentration at stability class A is 18.8 ug/m3 and 2.45 ug/m3 at stability class D without building downwash.

REFERENCES


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(7) N.Nassar, "Assessment and Modeling of Radiation level over North Western Coast of Egypt", 2012.