

EFFECTS OF BUILDINGS AND COMPLEX TERRAIN ON RADIONUCLIDES ATMOSPHERIC DISPERSION

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Evaluation of atmospheric dispersion factors for nuclear power plant environmental impact assessment are usually based on the regulations of CNCAN, the regulatory body in Romania. However, the presence of tall buildings and for sites in complex terrain, especially for low wind speed and calm conditions, it is needed to evaluate the validity and conservation of atmospheric dispersion model and parameters. This paper aims to evaluate the effects of reactor building and site complex topography upon the dilution factor at Cernavodă NPP site.

Keywords: atmospheric dispersion, nuclear releases, ADMS, complex terrain

1. Introduction

Nuclear power plants can release radionuclides to the atmosphere under normal operating conditions or during abnormal events. As a consequence, atmospheric dispersion and radiation dose calculations for routine and accidental releases of radioactive materials are of great importance for licensing requirements [1]. The radiological dose evaluation implies estimating exposures to radiation through several pathways, e.g. external and internal exposure because of radionuclides from the plume or deposited on the ground. Currently, the procedure for licensing of nuclear power plants predominantly employs atmospheric dispersion calculations performed using Gaussian plume approach. The Gaussian models use the solution of the general advection-diffusion equation that describes pollutants transport in air assuming that the wind speed and turbulent diffusivity are constant. Frequently, several changes in the standard model regarding releases of radioactive pollutants, radioactive decay and dry/wet deposition are required by the regulatory bodies [2].

Gaussian models behave better for smooth-plane sites, and give best results for dispersion regions where there is only small variation of terrain elevation [3]. Thus, there is inherent inaccuracy if the environment around the

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pollutant source has a tall nearby buildings, variable surface roughness vegetation, or height variations not considered by the atmospheric dispersion model. In general, models tend to be reasonably accurate for flat areas, but less accurate for complex terrain. For flat terrain, the dispersion modeling presents uncertainties associated with meteorology data (air circulation, solar radiation, air temperature and precipitation rate), terrain specification, physical and chemical processes inside the plume, etc. Furthermore, presence of buildings near the source can disrupt the air streamlines. Selection of an adequate Gaussian model should consider the ratio between the height at which the effluent emission takes place and building height influencing the air movement near the point of emission.

Considering the above-mentioned aspects of dispersion over complex terrains, in this work we have performed an updated atmospheric dilution factor calculation for Cernavodă NPP site. The objective was to compare the flat-terrain dispersion factors (currently employed for radiation dose evaluation) with calculations performed considering the reactor building and the specific topography of the Cernavodă site. A new generation Gaussian model, ADMS5 [4] was used for three configurations; one takes into account the flat terrain hypothesis, and the other two consider the effects of the reactor containment and the surface elevation on the plume dispersion.

In the following section, the Cernavodă site and the specific meteorological conditions are presented. Some basic aspects of the ADMS model and the modeling assumptions are presented in Section 3. Calculations of dispersion factors results are presented and discussed in Section 4. Section 5 presents our conclusions.

2. Cernavodă NPP site characteristics

The Cernavodă NPP is located in Constanța county at about 2 km south-east from the limit of Cernavodă city, about 1.5 km north-east from the Cernavodă lock on the Danube – Black Sea Canal (see Fig. 1). The geographic coordinates of the Cernavodă city are (44°20'17"N; 28°02'01"E). Within a zone of 10 km radius around the Cernavodă NPP, there are the Cernavodă - Saligny industrial zone, the Cernavodă-harbor industrial zone, Cernavodă town and some villages.

Site characteristics include the topography around the site and representative weather data. The topography is not homogenous, that is, there are changes from buildings to rolling hills to valleys etc. However, in all previous calculations, it was assumed that from source to receptor the topography is homogenous. In this paper, the elevation datasets used for complex terrain model were obtained from Shuttle Radar Topography Mission (SRTM) database covering a 10 x10 km area around the NPP, with a 75 m grid step (see Fig. 2). As

one can observe the terrain shows a complex irregular pattern, the maximum elevation exceeding 100 m (southeast of NPP).



Fig. 1. Cernavodă site – Google Map view

Site meteorological characteristics dictate the rate at which the plume disperses and deposits, the degree of dispersion and the direction of plume travel. The meteorology is characterized by the prevailing wind speed, wind direction and trajectory, mixing layer heights, ambient air temperature, precipitation rate (if applicable) and atmospheric stability. The employed data are the meteorological studies elaborated by National Administration for Meteorology (ANM) on the basis of the recorded met data at Cernavodă during 1986 – 2002 [5].

Analyzing the wind frequency on 16 directions it is noticed that for Cernavodă area, the most frequent winds are from north and west with an annual frequency of 10.9 % and 8.8 % respectively, followed by the east winds (7.1 %), the annual frequencies for the other directions being between 1.7 - 5.8 % (see Table 1 and Fig. 3).

Table 1

Average annual wind frequency (%) on 16 directions (1986-2002)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSV	SV	VSV	V	VNV	NV	NNV
10.9	3	3.6	2.9	7.1	3.7	4.7	3.3	3.8	1.7	2.8	5.7	8.8	3.1	3.9	5.8

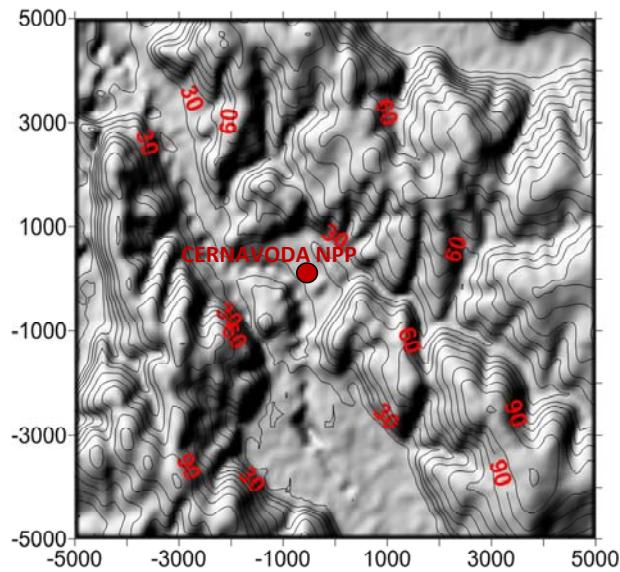


Fig. 2. Elevation isolines around Cernavodă NPP (10 x10 km grid)

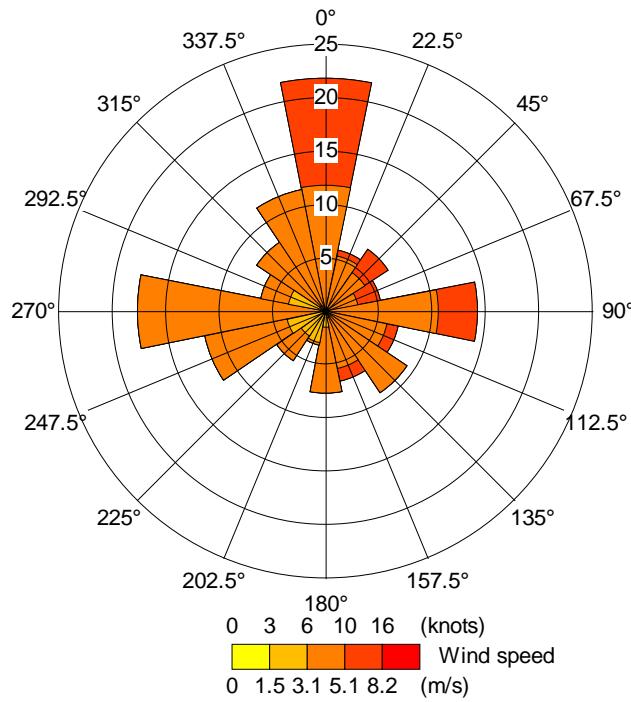


Fig. 3. Cernavodă wind rose for monthly averaged met data

For all release locations on site, the nearest building is assumed to be 20m away from the release point. The height of the nearby building is assumed to be 45 m (the height of the reactor building). The pollutant considered for transport in atmosphere is NO_x.

3. ADMS5 model

ADMS5 model developed by CERC [4] represents an advanced Gaussian dispersion model that uses the boundary layer height and the Monin-Obukhov length to characterize the atmospheric stability and the vertical wind, temperature and turbulence profiles. Several inter-correlated aspects of the plume dispersion may be considered by the ADMS modules:

- the effect of plume rise;
- the effect of buildings and hills (complex terrain) and spatial variation in surface roughness;
- the kinetics of the uptake of gases, and the thermodynamics and chemistry of the dissolution of gases in raindrops for wet deposition;
- dry deposition considering the deposition and terminal velocities;
- short-term fluctuations in concentration due to atmospheric turbulence;
- radioactive decay and gamma dose.

For stable and neutral atmospheric conditions, ADMS model uses the Gaussian distribution for pollutant concentration calculation (Eq. 1), while for unstable atmosphere a skewed distribution is employed.

$$C = \frac{Q_s}{2\pi\sigma_y\sigma_z U} e^{-y^2/2\sigma_y^2} \left(e^{-(z-z_s)^2/2\sigma_z^2} + e^{-(z+z_s)^2/2\sigma_z^2} + e^{-(z+2h-z_s)^2/2\sigma_z^2} + e^{-(z-2h+z_s)^2/2\sigma_z^2} + e^{-(z-2h-z_s)^2/2\sigma_z^2} \right) \quad (1)$$

where: Q_s is the source term, σ_y and σ_z are the spread parameters, U is the mean wind velocity, z_s is the source height, h represents the terrain roughness, and z is the vertical coordinate.

The building effects are considered in ADMS by entraining a part of the plume into the downstream cavity region near the building, bringing the plume at the ground level. The same concentration profile is employed but with modified plume height and spread parameters [6]. Further down the recirculation region, the concentrations are determined by summing up the ground level plume and the rest of the non-entrained plume (see Fig. 4). The equation used for plume concentration calculation is:

$$C = (Q/U) C_y(y, y_p, \sigma_y) C_z(z, z_p, \sigma_z, h) \quad (2)$$

where: Q is the plume strength, U is the mean wind velocity, C_y and C_z are profile functions, y_p and z_p are plume centerline coordinates, σ_y and σ_z are the spread parameters, and h is the boundary layer height.

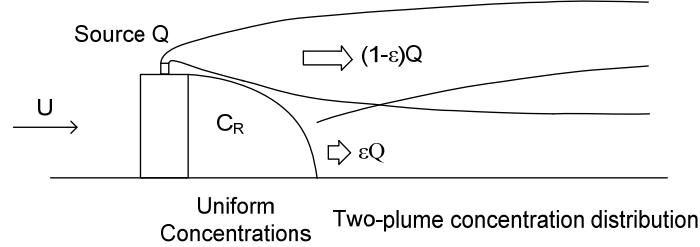


Fig. 4. Building effects in ADMS

When a variable terrain topography and roughness are considered in the model (complex terrain option), ADMS employs the FLOWSTAR algorithm to simulate wind flow and turbulence over complex flow [7]. The complex terrain option uses a three-dimensional flow and turbulence field to the dispersion modeling calculations. Also, the roughness can be introduced, modifying the wind speed vertical profile. Using the flat terrain dispersion parameters, the complex terrain module calculates the modified ones using two linear differential equations in order to consider for the mean wind and turbulence changes:

$$\frac{d\sigma_{yh}}{dx} = \frac{\left(1 + \frac{\Delta\sigma_y^2}{\sigma_{y0}^2}\right)^{1/2}}{\left(1 + \frac{\Delta u}{U_0}\right)} \frac{d\sigma_{yf}}{dx} \quad (3)$$

$$\frac{d\sigma_{zh}}{dx} = \frac{\left(1 + \frac{\Delta\sigma_w^2}{\sigma_{w0}^2}\right)^{1/2}}{\left(1 + \frac{\Delta u}{U_0}\right)} \frac{d\sigma_{zf}}{dx} \quad (4)$$

where: $\Delta u = U - U_0$, $\Delta\sigma_y^2 = \sigma_{yh}^2 - \sigma_{y0}^2$, $\Delta\sigma_w^2 = \sigma_{zh}^2 - \sigma_{w0}^2$, U_0 is the unperturbed wind speed, U is the terrain influenced wind component in the free stream direction, σ_{y0} and σ_{w0} are the unperturbed turbulence parameters, and suffices f and h refers to flat and complex terrain.

4. Results and discussion

The dilution factor obtained with the standard model currently used for derived release limits (DRL) calculation (no buildings and flat terrain considered)

is shown in Fig. 5. The maximum value is $0.46 [10^{-6} \text{ s/m}^3]$, while the 0.01 isoline is crossing through Cernavodă city. The results are in good agreement with ones given by the ANM report [5] (see Fig. 6), and it is noticed that the pollutant concentrations pattern follows the annual wind frequency chart.

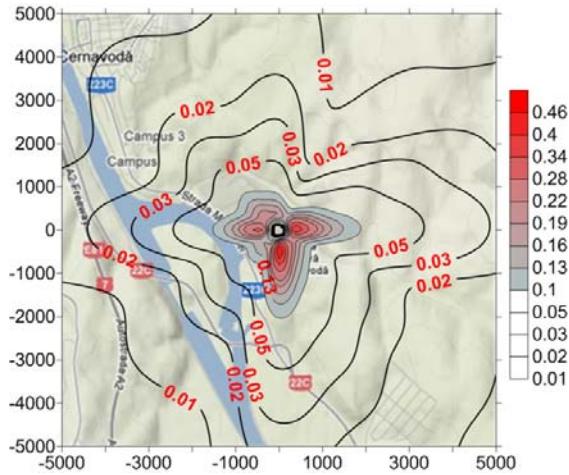


Fig. 5. Cernavodă dilution factor $[10^{-6} \text{ s/m}^3]$ for standard model (ADMS)

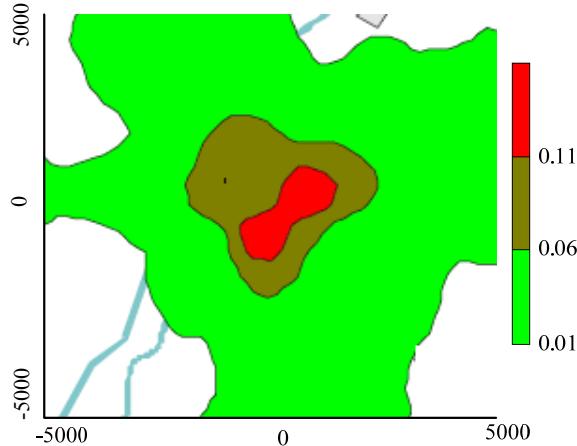


Fig. 6. Cernavodă dilution factor $[10^{-6} \text{ s/m}^3]$ (ANM calculation)

The next set of results presents the effect of reactor building upon the plume dispersion (see Fig. 7). The plume release take place from an elevated stack positioned at almost 40 m SW from the reactor containment axis. The building characteristics are $H_b = 42.3 \text{ m}$, $D_b = 30.6 \text{ m}$. The entrainment of plumes in building wakes being of major interest and represents a major factor in obtaining

acceptable derived release limits. The most important feature of building effect upon the dispersion studies is the plume entrainment in the building wake or its rapid downwash from elevated sources, since this generates higher near-field concentrations at the ground level. As one can observe from Fig. 7, the ground concentration on NW-SE direction is increased by almost $1.1[10^{-6} \text{ s/m}^3]$ relative to the standard model dilution factor. This downwash phenomena will further deplete the plume strength, the concentrations above Cernavodă city being decreased by more than 10%.

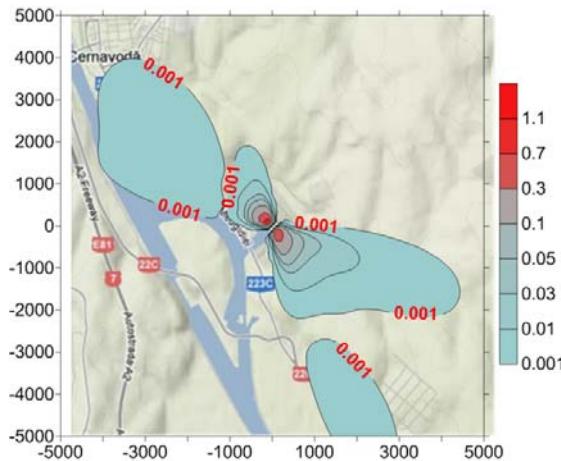


Fig. 7. Concentration difference [$10^{-6}\text{s}/\text{m}^3$] between standard and building models (absolute values)

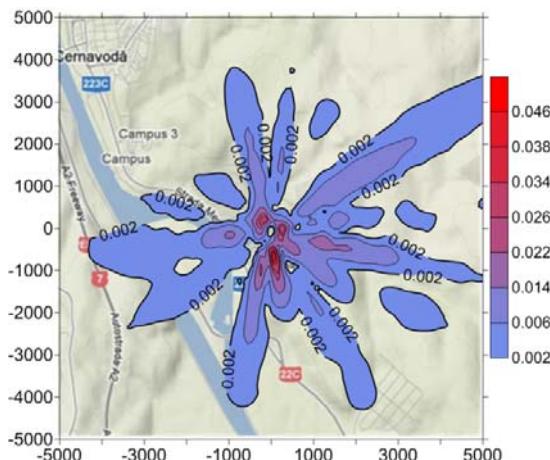


Fig.8. Concentration difference [10^{-6} s/m³] between standard and complex terrain models (absolute values)

Improvements in DRL calculations over complex terrain must determine beforehand the three-dimensional wind and turbulence fields. Using the FLOWSTAR module and the terrain file processed from the SRTM database, Cernavodă terrain topography influences on dispersion were calculated and are shown in Fig. 8. The concentration variations (up to $46[10^{-9} \text{ s/m}^3]$) are given by the perturbations in air velocity and direction over the hilly surface (see Fig. 9).

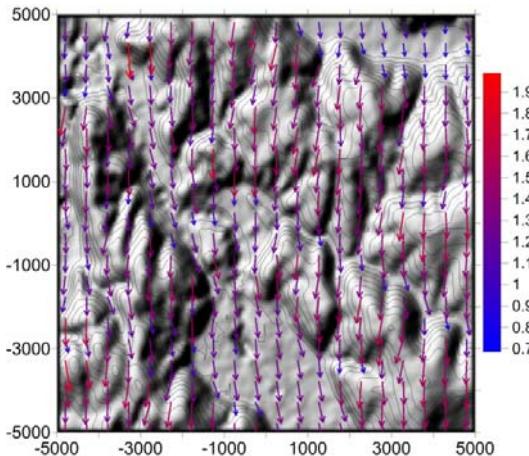


Fig.9. Friction velocity vectors [m/s] for north wind direction

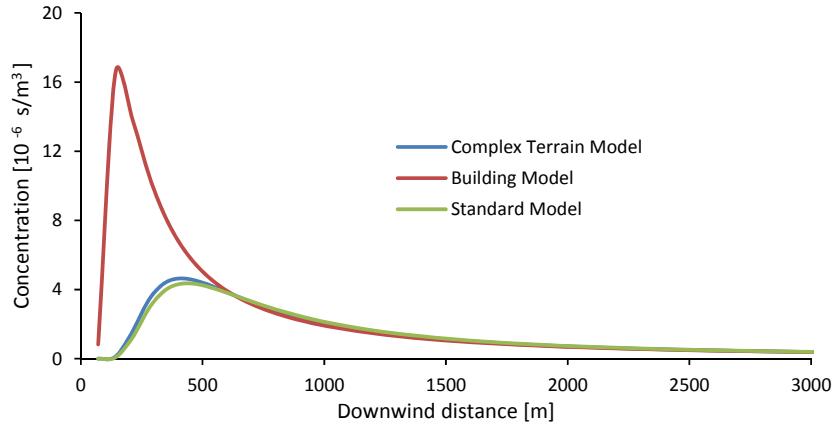


Fig.10. Ground concentrations vs. downwind distance for SE wind direction

The ground concentrations under the plume centerline (considering only the SE wind direction, meaning that the reactor building and the release stack are on the wind direction) for the three models employed in this paper are shown in Fig. 10. One can notice the light difference between the standard and complex

terrain models and the strong effect of the containment upon the near field concentrations (the building influence zone extends to almost 550 m).

5. Conclusions

The standard Gaussian models used to evaluate the atmospheric dispersion of radionuclides do not model the flow directly, and their applicability to study the interaction of the air flow with buildings and complex terrain topography is limited. In this paper the authors have considered the problem of dilution factor calculation over complex terrain at Cernavodă NPP site, in the frame of regulatory dispersion calculations.

The major conclusions are drawn as follows:

1. The presence of reactor containment in the ADMS model gives increased concentrations (by $1.1[10^{-6} \text{ s/m}^3]$ relative to the standard model) at close distance from the release point.
2. The hilly area around the NPP, even though very complex, affects the standard dilution factor only by $46[10^{-9} \text{ s/m}^3]$, the main reason for this being the small height of the hills (up to 100 m).

Acknowledgment

The work has been funded by the Sectorial Operational Programme Human Resources Development 2007–2013 of the Romanian Ministry of Labor, Family and Social Protection through the Financial Agreement POSDRU/107/1.5/S/76813.

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