LOCAL ATMOSPHERIC DISPERSION MODELLING OF TRACE CONSTITUENTS ISSUED FROM A NUCLEAR POWER PLANT : A COMPARISON USING A CFD CODE AND ADMS WITH WIND TUNNEL DATA

Emmanuel Demael and Bertrand Carissimo
Research and Teaching Center in Atmospheric Environment (CEREA, ENPC / EDF R&D), Champs-sur-Marne, France

INTRODUCTION

In order to evaluate the impact of emission of pollutants on the environment, it has become important to develop models capable to predict accurately the dispersion processes in complex situations involving buildings in close proximity and topography that both may have a strong influence on the flow and pollutant concentration distribution. Such models are necessary to better estimate and then control the impact of industrial releases issued from its power plant on their local environment.

For this purpose, Computational Fluid Dynamics (CFD) can simulate pollutant dispersion in such geometrically complex situations and can be considered as an appropriate alternative to integral Gaussian-type dispersion models such as ADMS (*Di Sabatino, S. and al,* 2006 – *Riddle, A. and al,* 2003).

This work proposes a comparison for the modelling of flow and dispersion on the built up area of a nuclear power plant through the study of two types of releases. A CFD model developed by CEREA / EDF R&D is compared to ADMS simulations against wind-tunnel measurements.

WIND TUNNEL EXPERIMENTAL SET-UP

A wind tunnel experiment conducted in collaboration by the French Institute for Radioprotection and Nuclear Safety (IRSN) and the Fluid Mechanics and Acoustic Laboratory (LMFA) has been realized . It consists in two accidental releases on a power plant located along the Rhone river, in France (Fig. 1). One is a stack release and the other is occurs through one of the reactors buildings. For this purpose, the whole built-up area of a nuclear plant was taken into account with detailed buildings configurations and the topography. The scaling factor used is 1:500 and the size of the domain corresponds in reality to a rectangle of 5 by 2 km. A neutral boundary layer was simulated and measurements were performed using Laser Doppler Anemometer (LDA) for the velocity and turbulence fields and Flame Ionisation Detector (FID) gas sampling system for the concentrations and their fluctuation. These measures were taken both within the built-up area and more downstream at different height levels and distances from the source. They have been used for the comparison of the results of the computational simulation and the evaluation of models.

NUMERICAL STUDY

CFD Mercure_Saturne simulations

Mercure_Saturne is a three-dimensional CFD model adapted to atmospheric flow and pollutant dispersion. The numerical solver is based on a finite-volume technique on unstructured grids. In our simulations, a RANS approach with a k-ε (and its RNG modification) turbulence closure is used. Both concentrations and variances of concentration fluctuations are predicted using appropriate transport equations.

Based on the set-up used in the wind-tunnel experiment, the computational domain was selected as $H_d \times W_d \times L_d = 0.3 \times 2 \times 5$ km and account for both the buildings and the topography. The unstructured mesh consists in hexahedrons with a slight proportion of pentahedrons and contains about 1 million of cells.

The releases are modelled by volumic sources terms technique with appropriate cells defined for the two distinct release. For the stack release, a large zone is refined around to capture the plume rise (Fig. 1).

Neutral conditions are assumed and experimental profiles of velocity and turbulent variables are applied as inlet conditions. The ground is specified with a surface roughness of about 0.1 m, atmospheric wall-laws being applied. The same treatment is used for the buildings with their own roughness (about 0.01 m).

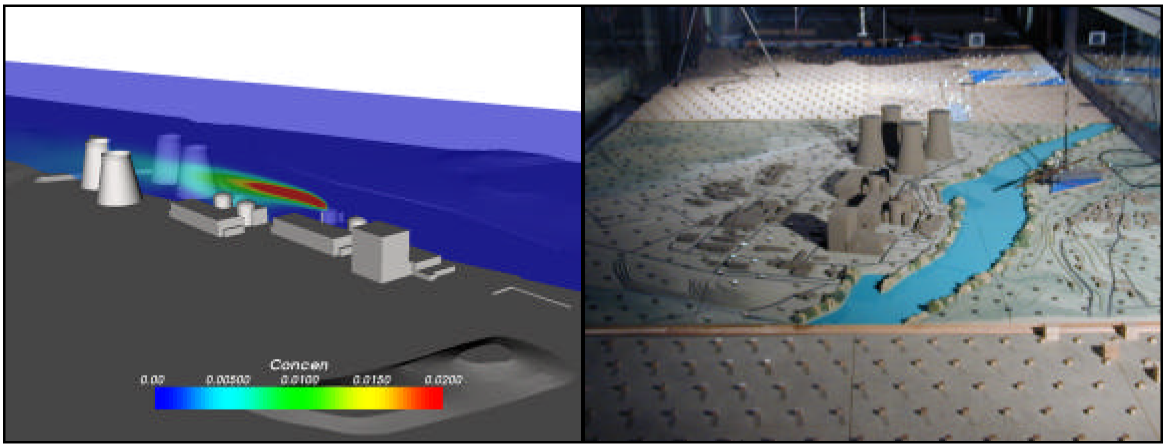

*Fig. 1; L*eft: Mercure_Saturne modelling of the stack release. Right: experimental model.

ADMS simulations

ADMS 3.0 short term dispersion simulations are performed for the same conditions as previously, i.e. a same computational domain and the same flow and releases features. A neutrally stratified atmosphere is calculated through the logarithmic law for a wind speed reference of 3.7 $m.s^{-1}$ at a reference height of 50 m. The boundary layer height is taken as 800 m and the same surface roughness is the same as those used in Mercure_Saturne's run. The simulation of a passive tracer is done using point source for the release on the chimney and a volume source for the other with the same emission rate. Thanks to the building effect module (*Robins, A.G.*, 2005), a configuration with very simplified buildings of the nuclear plan was considered, the cooling towers assuming the main part in the dispersion process downstream. The results are obtained for a time averaging of 10 min.

MEAN RESULTS AND DISCUSSION

Flow analyses

As ADMS does not give detailed flow in this area, only Mercure_Saturne's flow results are here compared with LDA measures in term of velocity components and longitudinal velocity fluctuation u'. Wind tunnel experiment and numerical simulations show different three-dimensional structures of the flow. Indeed, the built-up area leads to complex flow structures that are globally captured in the same way by the CFD code and wind tunnel data. This concerns both the global wake effect induced by the whole built-up area and the several recirculations or deflexions occurring between or around the buildings (e.g. around cooling towers, see Fig. 2). However, we can note a discrepancy behind the cooling towers concerning both the average wind speed in the lower part of the boundary layer and the longitudinal fluctuation of velocity u' (see Fig. 3). Indeed, we observe a clear under-estimation by Mercure_Saturne of the wind speed under 130 m, -corresponding to the height of cooling towers-, and lower values of u', especially near the ground. Thus, Mercure_Saturne overestimates the slow done effect of cooling towers in the wake. These differences tend to weaken more downstream in parallel with the wake effect.

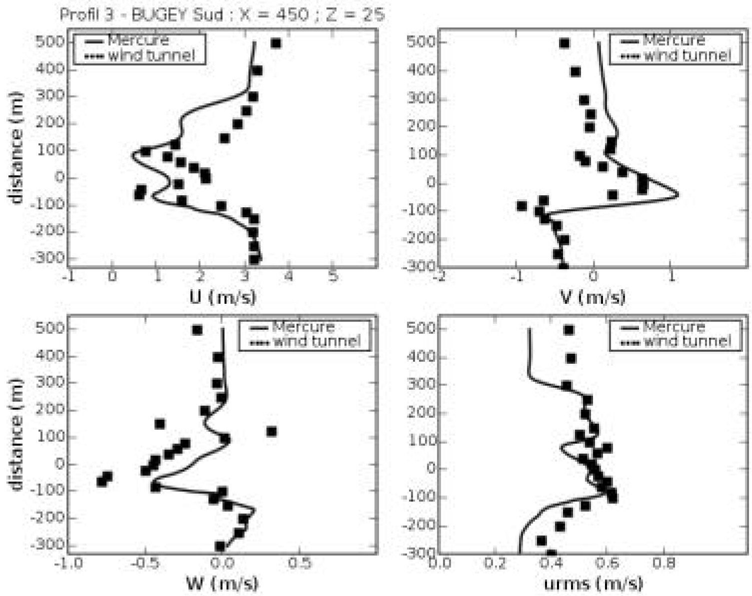

Fig. 2; Cross-wind profile of wind components and rms longitudinal wind fluctuation predicted by CFD Mercure_Saturne and wind-tunnel experiment at the level z = 25 m, located just upstream of the first cooling tower.

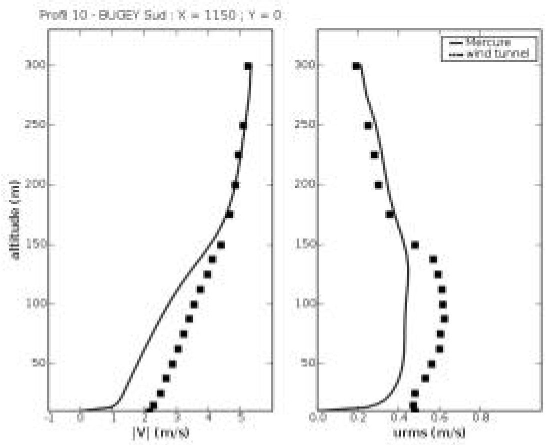

Fig. 3; Vertical profile of wind magnitude and rms longitudinal wind fluctuation predicted by CFD Mercure_Saturne and wind-tunnel experiment located 350 m behind the cooling towers, where the differences are maximum.

Dispersion Analyses

Mercure_Saturne and ADMS dispersion results are compared here with FID measures in term of mean concentration and fluctuations. Fig. 4 displays the concentration contours of passive tracer on the ground for the stack release. At first, we observe that the plume predicted by ADMS does not impact the ground into the build-up area but only further downstream of the cooling towers, contrary to Mercure_Saturne's results and wind tunnel data which are here in relatively good agreement, as seen in Fig 5. These observations highlight the inability of ADMS to really account for the effect of buildings on the dispersion processes, especially in a case of several interacting buildings. On the other hand, we can note also on Fig. 4 that maximum of ground level concentration occurs just behind the last cooling towers for Mercure_Saturne whereas it is located just after the recirculation zone evaluated by ADMS.

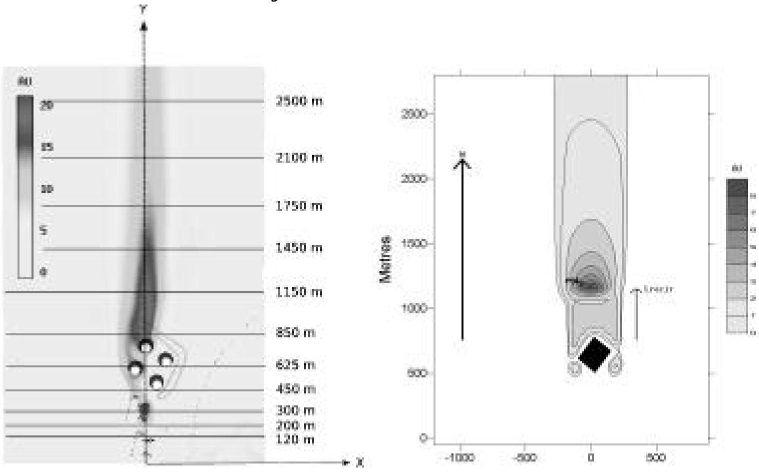

Fig. 4; Predicted ground level concentration in arbitrary units for the stack release, respectively for Mercure_Saturne (left) and ADMS (right).

For this type of release, both models are within a factor of two from the experimental measurements downstream of the built-up area and the cooling towers but with an underestimation by ADMS and an overestimation by Mercure_Saturne (see Fig 5.).
Turbulent mixing is indeed much more important in ADMS simulations than in Mercure_Saturne's simulations and also greater than those observed in the wind tunnel study. Mercure_Saturne's results show less vertical mixing and a weaker lateral spread connected to a slight lack of diffusivity. Similar observations can be made for the other type of release.

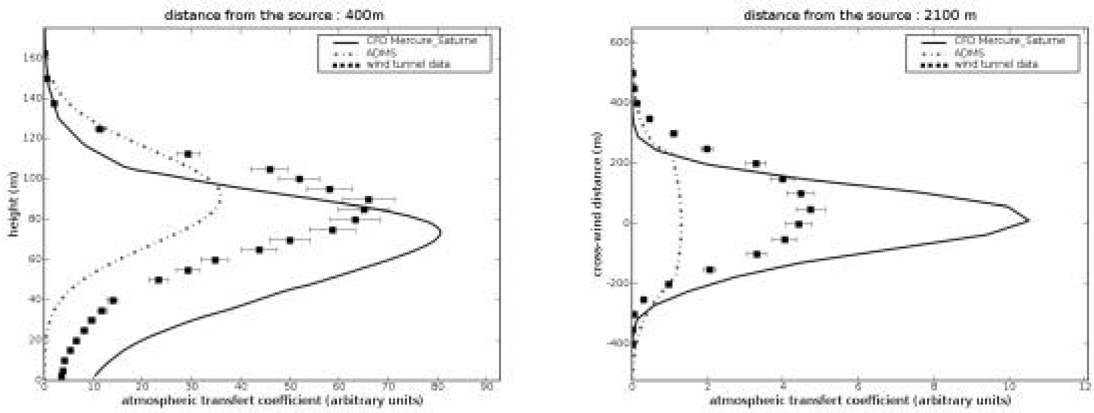

Fig. 5; predicted ground level concentration in arbitrary units for the stack release, respectively for Mercure_Saturne (left) and ADMS (right).

CONCLUSION
A preliminary comparison of the concentration distribution predicted by an atmospheric CFD code and ADMS 3.0 with wind tunnel data is presented for releases on a nuclear power plant. This study highlights the differences between two types of modelling used in risk assessment. Resolving in details the mean flow, Mercure_Saturne's simulation give more accurate

concentration distribution compared to ADMS in the built-up area, especially for the south wind direction with buildings downstream of the release. However, for the both releases, we can note that downstream of the built-up area and the cooling towers, both models are within a factor of two from the measurements and that the plume width is much closer to observations for both models. The over-estimation of maximum ground level concentrations shown by Mercure_Saturne can be directly related to the over-estimation of the slow-done in the wake if we have in mind that the concentration is inversely proportional to the mean wind. Thus, only more detailed models could provide more accurate simulation of wind fields and then a better prediction of the concentration values.

REFERENCES

Andronopoulos, S., D. Grigoriadis, A. Robins, A. Venetsanos, S. Rafailidis and J.G. Bartzis, 2002: Three-Dimensional Modelling of Concentration fluctuations in Complicated Geometry. Environmental Fluid Mechanics, **1**, 415-440.

Di Sabatino S., R. Buccolieri, B. Pulvirenti and R.E. Britter, 2006: Flow and Poluttant dispersion in Street Canyons using FLUENT and ADMS-Urban. Environmental Modeling and Assessmen, in press.

Riddle, A., D. Carruthers, A. Sharpe, C. McHugh and J. Stocker, 2003: Comparisons between FLUENT and ADMS for atmospheric dispersion modelling. Atmospheric Environment, **38**, 1029-1038.

Robins A.G., 2005: Modelling of buildings effects in ADMS, Technical Review of ADMS 3.