Validation of the French-German model for the treatment of atmospheric dispersion in accidental release situations with experimental data

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1 Introduction

Some years ago the French-German Commission for the Safety Problems of Nuclear Installations studied the results given by the atmospheric dispersion models used in French and Germany in case of an accidental release of radioactive substances from a nuclear power plant located near the border. For some meteorological conditions, the predicted concentration distributions differ substantially leading to different countermeasures to be considered in each country for the surrounding population protection.

In a first step a comparison of the corresponding dispersion models used in France and Germany has been carried out. Currently in both countries, Gaussian type models are in operation in emergency situations. In France the dispersion parameters used are those proposed by Doury [1]. They are based on an evaluation of the results of many different dispersion experiments. The so-called Doury parameters calculate dispersion parameters σ_y and σ_z for two stability classes (stable and non-stable stratification) depending upon travel time. The parameterisation is independent from release height and site roughness length. In Germany the parameterisation scheme used is based on the Pasquill-Gifford scheme with six stability classes. The source-height dependent diffusion parameters were derived from a serie of experiments performed at the Jülich and Karlsruhe research centres.

The comparison of both schemes for different meteorological and release conditions showed partly substantial differences. From this, the French-German Commission has decided to develop a common dispersion model for use during accidental releases from a nuclear power plant [0]. The performance of the common dispersion model should be higher as compared with the currently used approaches, this new model should be operational, i.e. the necessary input data should meet the available data basis concerning meteorology and release data. In addition the model should be practicable with respect to computer time and operator skills.

The French-German Commission selected a Gaussian puff model that is able to deal with time dependent meteorology and release data (see [3]).

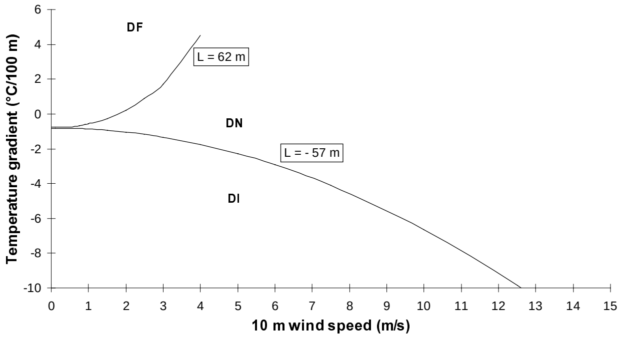
2 Comparison of theoritical and experimental results

2.1 Selected experiments

In order to check the ability of the French-German standard deviations [0] to simulate the dispersion of passive pollutants in the atmosphere, about thirty experiments of atmospheric tracing have been selected [4, 5, 6] and the in-site measurements compared to results obtained with a Gaussian puff model based on the French-German parameters.

The selected experiments come from various tracing campaigns. Tests carried out under rather extreme wind or atmospheric stability conditions (extremely low or extremely high wind speed, or very stable atmosphere) were selected as it is known that, under current weather conditions, all calculation methods give similar results. More than one third of the selected tests were made by wind speed lower than 2 m/s.

To return to the concept of weather classes of conditions, 3 atmospheric stability classes were defined: weak diffusion (noted DF), normal diffusion (noted DN), unstable diffusion (noted DI). Each stability class corresponds to a typical value of Monin-Obukhov length. Each diffusion class can be characterized by a couple of values, vertical temperature gradient and wind speed at 10 m height.



Atmospheric stability conditions were determined from the vertical temperature gradient and the measured wind speed. For some experiments where temperature gradient is missing, stability is estimated from observed parameters: cloud cover, sun ...

2.2 Method and comparison criterions

Only the maximum values of gas samplings at a given distance, corresponding to the points located in the supposed axis of the wind, were selected for comparison. The results are compared in terms of average concentration over atmospheric sampling duration or atmospheric of transfer coefficient (ATC) over the same duration.

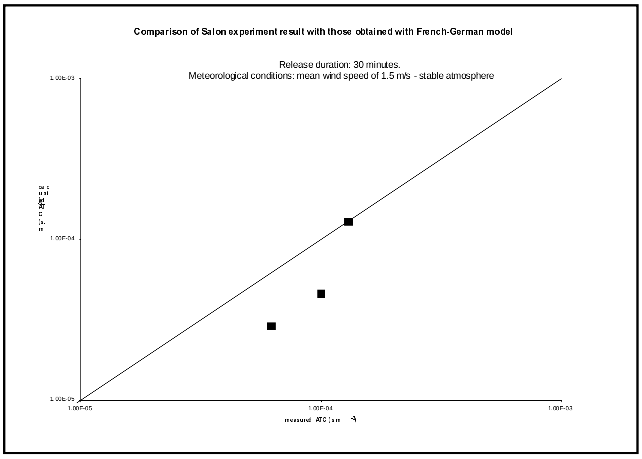
$$ATC(x,y,z) = \frac{\int_{T_0}^{T_1} \chi(x,y,z,t)dt}{Q}$$

with:

- χ (x, y, z, t) concentration at the point of co-ordinates x, y, z at the instant T;
- Q total quantity of emitted gas;
- T_0 and T_1 instants of beginning and end of samplings.

Standard deviations and concentrations results depend on the sampling time, which is an input data for the French-German model. Indeed, gas sampling duration conditions the importance of low frequency turbulences intervening in diffusion process. These turbulences result in wind direction variations during observation, which increase the horizontal standard deviation and decrease the average concentrations along the average wind axis.

One gives, for the whole of the tests, the model success frequency F according to the relationship R between measured values and computed values, i.e. the number of points of measurement, brought back to the total number of points, where this ratio lies between 1/R and R. This presentation helps to quantify the realism of the models: for a given R ratio, larger the frequency F is, better the model is. IPSN retained like comparison criterion of the models the value of F for R = 3. It is considered that a model is correct if its rate of success, i.e. the value of F for R = 3, is higher than 0.5. The value of F is called "success rate" here-after.



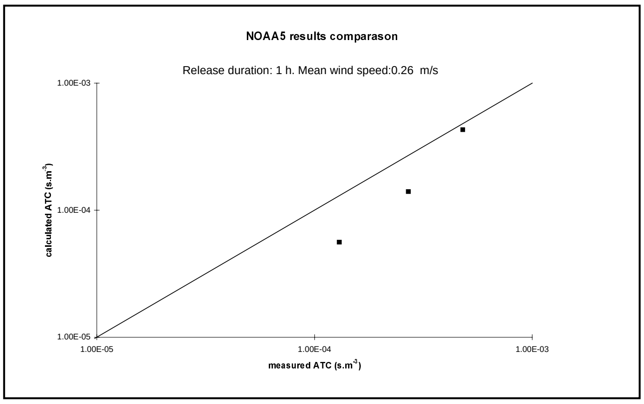
2.3 Tests Salon de Provence [4]

Some trials were led in order to study atmospheric dispersion under low wind speeds situations, particularly in stable atmosphere. Emissions generally lasted 1 hour and atmospheric samplings carried out up to 2 km of the source were sequenced per 10 or 20 minutes periods. Experimental results are expressed in terms of atmospheric transfer coefficients integrated over all the experiment duration.

It is noted that the French-German model give good results, rather close to experiments.

2.4 NOAA experiments [0, 4]

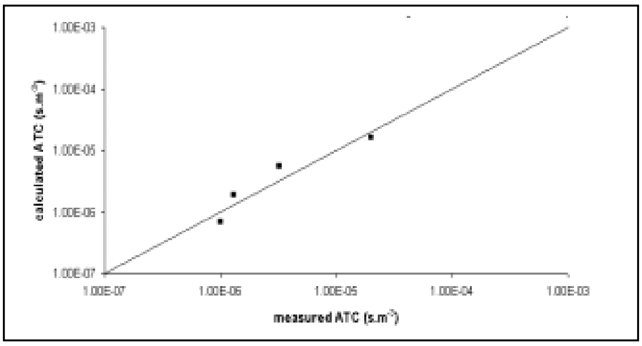
During 1976, Oak Ridge National Laboratory carried out experiments by very low wind speed (<0,5 m/s) and stable atmosphere in Tennessee, USA. The emissions duration were about 1 hour and the atmospheric samplings results were integrated over all the plume travel time, the points being distributed on 360° around the source, up to 400 m from the emission point.



For 2 m emissions height tests, the French-German model gives results close to the experiment. For high release height test in stable atmosphere, the model underestimates the results at short distance. This result is not very significant; it translates simply a little too small vertical standard deviation: in these situations, ground level results are extremely sensitive to the vertical standard deviation value. The model success rate is higher than 0.6.

2.5 Karun experiments [4]

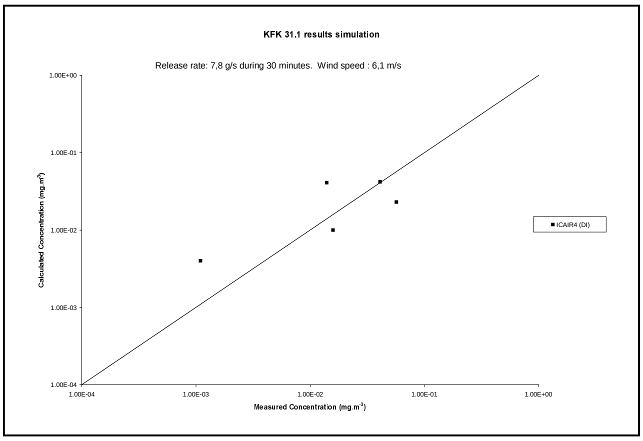
Two tests were carried out in 1977 at the edge of the Persian Gulf, in Iran, on the site where the establishment of a nuclear power plant was projected. This is a flat desert site with a very slightly rough. These tests (emission duration of 1h30, atmospheric samplings of 3h) are characterized by extremely strong wind speeds (17 m/s on average).



One can see that French-German model gives results close to reality.

2.6 Tests KFK [0, 4, 6]

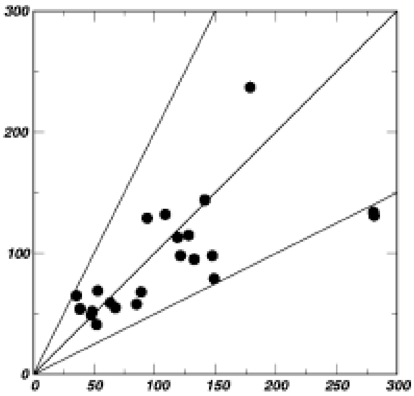
Several tracing campaigns were carried out on Karlsruhe site in Germany between 1975 and 1980. This site characterized by a high roughness length (strongly built and surrounded by forests of high coniferous trees site). The releases were done with high emission height, in order to simulate those resulting from power plants stacks (60 to 160 m above ground-level). Atmospheric samplings were carried out during 30 minutes, up to 6 km from the source. Atmospheric conditions were primarily unstable; some experiments were carried out in neutral or stable atmosphere. The French-German model results, taking into account site roughness length and the increase in turbulence that follows, are close to reality. The success rate is 0.6.



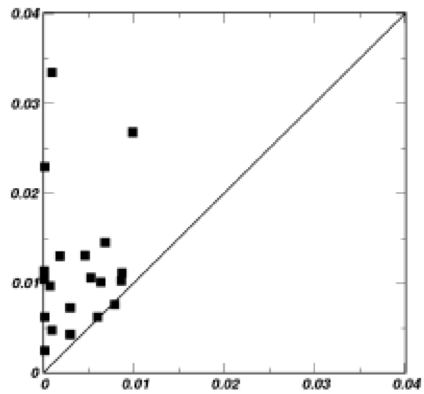
2.7 Lillestrøm tests, Norway [5]

Atmospheric tracing experiments were carried out on the site of Lillestrøm (Norway), on a flat site (0.5 m roughness length). Each experiment consisted of 2 sequences of 15 minutes emission at 36 m high. Concentrations sensors were placed on arcs of circle up to 900 m from the emission point. For each distance, the maximum concentration (µg/m^3), integrated concentrations perpendicular to the wind axis (µg/m^2) as well as horizontal standard deviations (σ_y) are given.

During the majority of these tests, a temperature inversion was observed in the surface layer 0-100 m. The horizontal (σ_v) and vertical (σ_W) wind fluctuations standard deviations were measured at 10 m height. The Monin-Obukhov length estimated by Turner's method was indicated in [5]. However, as this value was not coherent with temperature gradient (for example, negative value, i.e. unstable diffusion, whereas a temperature inversion – corresponding to a stable atmosphere – can be observed), before dispersion calculations, the Monin-Obukhov length was estimated with the French-German model from temperature gradient and wind speed measurements.



σ_y predicted(x)/observed (y)

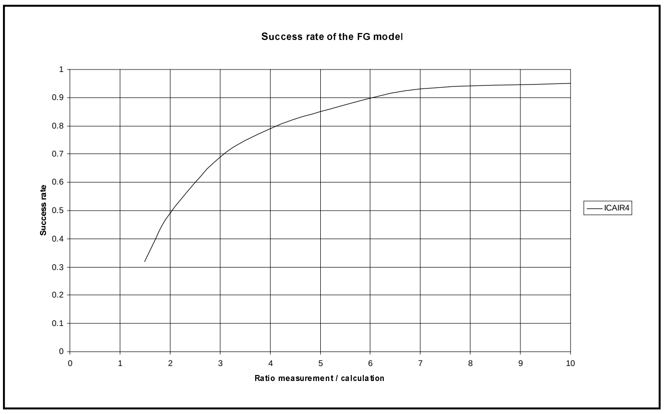


C_y/Q predicted(x)/ observed (y)
(Cross wind integrated concentration normalized by emission)

A rather good agreement between the calculated and measured horizontal standard deviation (σ_y) has been obtained, regarding the difficult dispersion regime. The ratio between simulated results and measurements is close to 1 for wind speeds higher or equal to 1 m/s. One notes a slight overestimation of the model for light wind (i.e < 1 m/s) with a ratio over a factor of 2. The ratio between the measured and calculated standard deviations of vertical wind direction fluctuations (σ_W) is generally less than 2, with a tendency of under-prediction. In the same way, the ratio between the measured and calculated wind horizontal fluctuations standard deviations (σ_v) is always less than 2, the model having tendency to slightly over-estimating the measure for low wind speeds.

3 Conclusion

The comparisons presented above confirm that by various different meteorological situations (low or high wind speeds, strongly unstable atmospheres), the French-German model gives rather correct results (it is pointed out that the comparisons made here relate to concentrations or Atmospheric Transfer Coefficients in the wind supposed axis and not the whole of the concentration field which is complex and description would require complementary approaches). On the whole of the comparisons carried out, for a measurement / calculation ratio ranging between 1/3 and 3, the success rate is 0.70; one obtains a success rate of 80% for a ratio R of about 4.



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