Comparison of the local-scale atmospheric dispersion model CEDRAT with ^{85}Kr measurements

M. Rennesson[1], D. Maro[2], M.L. Fitamant[3] and E. Prian[4]

[1]*AREVA Reprocessing, 2 rue Paul Dautier, BP. 4, 78141 Vélizy Cedex, France*
[2]*Radioprotection and Nuclear Safety Institute (IRSN), Cherbourg Radioecological Laboratory, BP. 10, rue Max-Pol Fouchet, 50130 Cherbourg-Octeville, France*
[3]*AREVA Reprocessing, 50444 Beaumont Hague, France*
[4]*AREVA Engineering, 1 rue des Hérons, Montigny Le Bretonneux, 78182 Saint Quentin en Yvelines, France*

Abstract. An accurate model of atmospheric dispersion of radionuclides over the complex terrain of La Hague reprocessing plant (North Cotentin, France) has been developed by COGEMA, in partnership with Paris VI University, and has been yet adapted for an other industrial site (Marcoule). This model, called CEDRAT, takes into account areas typically outside the validity range of Gaussian models: topography and building influence, short-distance (beyond 500 m from the release point) and various atmospheric stability conditions. CEDRAT allows to reach an effective compromise between rapidity (30 min on a 6000 nodes grid, on a standard PC), robustness and accuracy, coupled with a user-friendly interface. The validation process consisted first of a comparison with the 3D reference model MERCURE**,** developed by EDF, and then, results of both models were compared on release scenarios thanks to tracer data (Krypton-85, an inert gas released from a height of 100 m) collected at five monitoring stations around the site. Then a second level of comparison, presented here, was made in collaboration with the IRSN Cherbourg Radioecological Laboratory, on ground and altitude (collected with a tethered balloon) field data.

1. INTRODUCTION

In order to improve the environmental survey program in the neighbourhood of La Hague nuclear reprocessing plant, and to enhance knowledge of dispersion mechanisms in the near field, a combined program was launched in 2001 between COGEMA and IRSN. COGEMA is in charge of the setting up of an accurate operational modelling tool, and IRSN, responsible for the experimental studies and their analysis. Until now, atmospheric dispersion of radioactive gaseous releases from high stacks which is relevant here was solved by operational tools based on gaussian models.

As a result of this collaboration, the validation program of COGEMA modelling tool called CEDRAT v1 (Code d'Evaluation de la Dispersion des Rejets ATmospheriques) [1] has been completed with comparisons of tracer concentrations of krypton 85 (^{85}Kr), sampled in a wide range of directions and distances from the release point, and to the higher altitudes through tethered balloon campaigns [2].

The atmospheric stability classes ranging from moderately unstable (Pasquill B class) to neutral (Pasquill D class) are covered in this study.

2. EQUIPMENT AND METHOD

IRSN has developed an original experimental device, of great interest considering the validation stage of the operational model.

2.1 Experimental campaigns

The IRSN conducted fieldwork using radioactive gas, [85]Kr, released in La Hague gaseous emissions, to trace atmospheric dispersion [2]. Bearing in mind that as a result of how COGEMA's La Hague plant operates, [85]Kr releases and kinetics are sequential, the Atmospheric Transfer Coefficients (ATC) for a given location during each shearing/dissolution of a fuel element in a bucket can be derived. By calculating the integrated [85]Kr concentration ratio to corresponding total emission quantity, over the whole period taken by the plume to reach the monitoring point, we derive the ATC (1):

$$ATC = \frac{\int_{t0}^{t1} X(M,t).dt}{\int_{t'0}^{t'1} q(t).dt} \qquad (1)$$

where: - $X(M,t)$: Radioactivity concentration at measuring point (M) at instant t (Bq.m^{-3}),
  - $q(t)$: Flow of the source activity (Bq.s^{-1}),
  - t'_0, t'_1: Instant of the beginning and end of source emission,
  - t_0, t_1: Instant of the beginning and end of measurement.

2.1.1 Ground samples

Sets of ground-level readings (Figure 1) are used to calculate the ATCs and determine horizontal distribution according to the distance from the source and meteorological conditions, essentially atmospheric turbulence. The campaigns took place during the daytime (in the time slot from one hour after sunrise to one hour before sunset), namely for atmospheric stability situations forecast to range from neutral (Pasquill class D) to slightly unstable conditions (Pasquill class C).
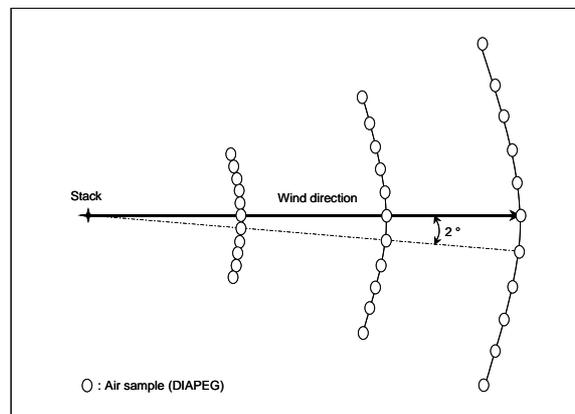

Figure 1. Position of air sample points regarding the discharge point and the average wind direction.

2.1.2 Tethered balloon campaigns

The device is composed of a tethered balloon and a laboratory truck equipped with a specific instrumentation. Measures can be performed until a height of 500 m. A nacelle, fixed under the balloon, loads a nuclear detector, meteorological sensors (air temperature, atmospheric pressure, air relative humidity) and a differential GPS. Data are sent to the ground through a radio emitter in real-time (1Hz frequency), to be treated in the laboratory truck. Measures are spaced out from about 30 minutes each and taken at altitudes between 4 and 150 meters.

2.2 Operational model

The project started in 1999 with a collaboration between COGEMA and a research laboratory in Paris VI University (Numerical Analysis Laboratory): considering existing models, the goal was to find the best compromise between gaussian and 3D complex models, in terms of accuracy, rapid computation, robustness and simplicity of use in operational conditions.

To gain in computation time, it has appeared acceptable to consider that the average wind flow is two-dimensional. The reference vertical section, in which the computation is carried out, is chosen to be that of the prevailing wind. The relief in this section is then extruded in the third dimension. Indeed, in view of the major atmospheric conditions (and to some extent to the topography), this approach seems to be justified.

Starting from the topographical definition into the main vertical section, a triangular un-structured mesh is automatically generated by the pre-processor of the solver FreeFem+, developed by Paris VI University and INRIA [1] [4] [5] [6].

FreeFem+ then solves Navier-Stokes equations under Boussinesq hypothesis (linear density approximation, depending only on temperature), heat and transport-diffusion equations, with a finite elements method using a conjugate gradient algorithm through a weak variational formulation.

The model specificity relies also on two strong assumptions:

- To solve the turbulent phenomena, the eddy viscosity has been assumed to depend only on the vertical component. The validation step is of great importance to confirm this hypothesis.
- The lateral dispersion is treated such that the final degree of modelling is of 2.5 D. Indeed concentrations are also computed in an adaptable number of vertical sections, carrying the same relief than in the main section, and communicating together though a finite differences method. Then the global mass preservation has been checked.
Physical phenomena such as aerosol deposit in wet or dry conditions, and transitory releases were also taken into account.

The PV-Wave visual software operates results visualisation in terms of ATCs, wind and concentration fields on the vertical or cross sections.

Depending on the atmospheric stability conditions and the mesh size (3000 to 12000 nodes), the required time to simulate a release scenario takes between 20 and 90 minutes on a standard PC.

2.3 Validation steps

The program, carried out by SGN, consisted of two successive parts:
- A theoretical step, as illustrated in Figure 2, which goal is to compare the results with an other validated model or existing analytical solutions (for initial comparison with academic cases), in order to check the good physical consistency of the outputs. The chosen tool was the 3D complex model MERCURE [7] developed by EDF.
- A physical step, where results of both models were compared to field data, collected at five monitoring stations around the industrial site. An example is given in Figure 3, for a monitoring station 2.6 km away from the release point.

These two parts were completed in September 2002. In the first part, a very good consistency was derived, so that the first assumption was confirmed; in the second one, a maximum deviation of 50% in 80% of the situations (for all Pasquill classes tested) was reached, which validated the second assumption.
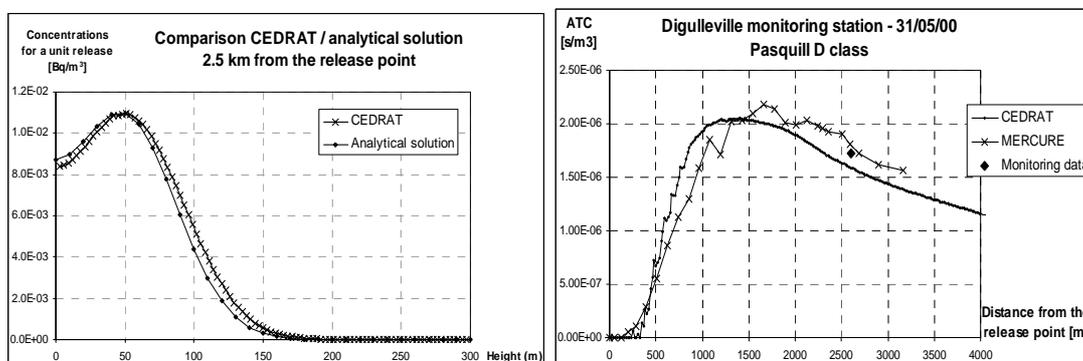
Figures 2 and 3. Extracts from the theoretical (left) and physical (right) validation program.

2.4 Comparison scenarios

2.4.1 Ground samples

Nine measurement campaigns were conducted between 21/05/01 and 15/11/01 for distances ranging from 500 – 3000 m from the discharge point (Table 1) to determine the ATCs and shape of the plume at ground level on either side of the wind axis.

The horizontal wind speeds, measured at a height of 100 m from the La Hague plateau are spread between 5.1 and 13.6 m.s^{-1}. The meteorological diffusion conditions throughout the samplings are of the "normal diffusion" type according to Doury's classification [3] and of "neutral or slightly unstable" (classes C and D) type according to Pasquill [8].

Table 1. Ground-level measurement campaigns.

Name	Date	Distance from release point (m)	Wind speed at 100 m (m.s^{-1})	Wind direction at 100 m (degrees)	Atmospheric stability according to Doury	Atmospheric stability according to Pasquill
DIAPEG1.1	21/05/01	1000	12.2	64.8	Normal diffusion	D class
DIAPEG3.1	20/06/01	1300	5.1	253.3	Normal diffusion	C class
DIAPEG4.2	26/06/01	2200	6.8	255.5	Normal diffusion	D class
DIAPEG5.1	27/06/01	3000	7.1	260.7	Normal diffusion	C class
DIAPEG6.1	18/09/01	1950	13.6	7.0	Normal diffusion	D class
DIAPEG7.1	19/09/01	625	13.6	332.2	Normal diffusion	D class
DIAPEG9.2	14/11/01	500	9.7	16.6	Normal diffusion	D class
DIAPEG10.1	15/11/01	660	9.3	66.4	Normal diffusion	D class
DIAPEG10.2	15/11/01	2500	8.2	61.2	Normal diffusion	D class

2.4.2 Tethered balloon campaigns

Twelve flights were carried out since 2000, to perfect equipment and to measure ^{85}Kr in altitude. All in all six upper-level measurements campaigns took place between 15/06/00 and 23/08/01 for distances ranging from 300 to 1800 m (Table 2) from the release point. The horizontal wind speeds, measured at a

height of 100 m from the La Hague plateau, are spread between 2.6 and 7.7 m.s^{-1}. The meteorological diffusion conditions throughout the sampling are of the "normal diffusion" type according to Doury's classification or of "neutral or unstable" type according to Pasquill (classes B, C and D).

Table 2. High-level measurement campaigns.

Name	Date	Distance from release point (m)	Wind speed at 100 m (m.s^{-1})	Wind direction at 100 m (°)	Atmospheric stability according to Doury	Atmospheric stability according to Pasquill
BIPV4	15/06/00	1800	4.1	274.2	Normal diffusion	Class C
BIPV6	01/02/01	600	6.3	149.2	Normal diffusion	Class D
BIPV8	16/02/01	300	7.7	10.8	Normal diffusion	Class D
BIPV10	18/06/01	300	2.6	42.8	Normal diffusion	Class B
BIPV11	03/07/01	600	3.4	159.0	Normal diffusion	Class C
BIPV12	23/08/01	600	5.2	191.7	Normal diffusion	Class C

3. RESULTS AND DISCUSSION

A comparison between experimental data and model results is presented on Figures 4 and 5, in terms of ATCs measured in the centre of the plume (ATC max) or at different heights for the balloon campaigns, and ATCs calculated in the same conditions with CEDRAT and two gaussian models [3] [8].
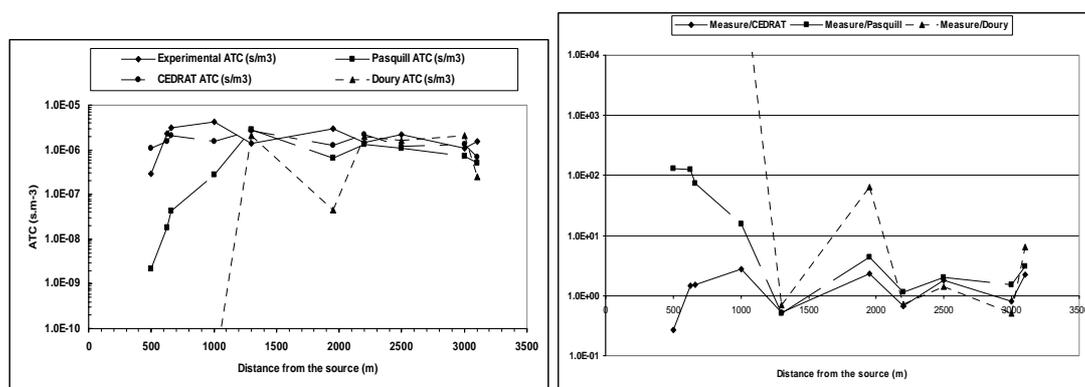
Figures 4 and 5. Max ATC function of the distance from the release point - ground campaigns.

The global observations show that a real consistency between CEDRAT and the experimental data can be derived, much better than those obtained with Pasquill or Doury theoretical data.

The mean deviation observation/model (Figure 5) is of 1.4 for CEDRAT, 36 for Pasquill and several decades for Doury. Convergence between Pasquill and CEDRAT is reached beyond 1500 m and Doury beyond 2000 m for these neutral or slightly unstable conditions.

This led us to the conclusion that there is a real improvement in the wind axis through site topography integration, for an optimal mesh of 12000 nodes in this study (domain size: 8.5 km long x 1 km high).

A slight deviation with experimental data is observed on the horizontal standard deviations (Figure 6). This leads to the assumption that the plume is vertically too developed and local subsidence phenomena appear. A further investigation is planned, to improve the spreading of the parallel lateral sections, using a gaussian distribution instead of a regular distribution.
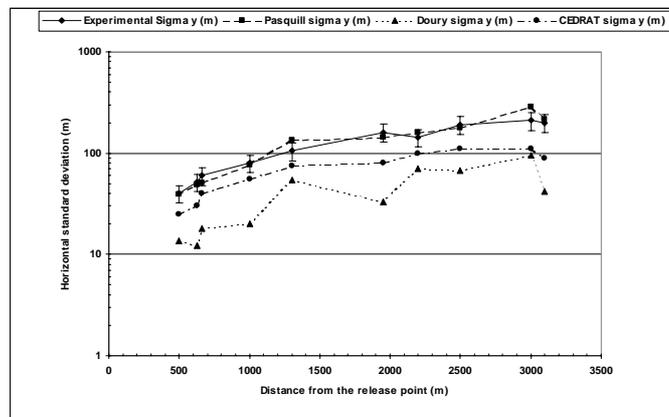
Figure 6. Horizontal standard deviations from ground campaigns, Doury, Pasquill and CEDRAT models.

The altitude cases (Figure 7) comparisons show a mean ratio (experimental data/model) of 2.1 for CEDRAT, most of the time under-predicting (ratio of 6 of maximum under-prediction, of 3.3 over-prediction), whereas Pasquill gives 13.4 and Doury, several decades.

Considering the vertical standard deviation, these experiments confirm that the model emphasizes the size of the plume vertically, narrowing its development horizontally. The concentrations computed at ground level are then often less than those expected.
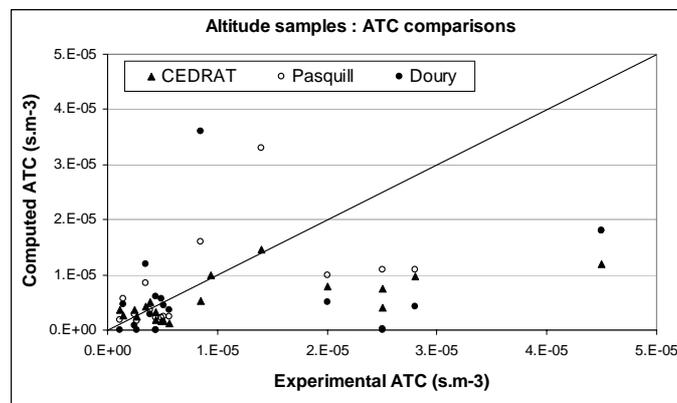

Figure 7. Computed vs. observed ATC for the tethered balloons campaigns.

4. CONCLUSION

Among the various models compared with IRSN experimental campaigns, CEDRAT gives the best answer in terms of concentrations or ATCs, and gives a more accurate answer for short distances from the release point than other operational models checked.

Future prospects will put the emphasis on the model description in the lateral direction, to improve the numerical modelling of the lateral diffusion.

A following research axis will be extreme stability conditions (15% of the time), for which few data have been collected, and which need further investigations, especially for the night-time period. Nocturnal campaigns are therefore to be worked on.

Acknowledgements

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