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VALIDATION OF THE GAUSSIAN PUFF MODEL PX USING NEAR-FIELD KRYPTON-85 MEASUREMENTS AROUND THE AREVA NC LA HAGUE REPROCESSING PLANT: COMPARISON OF DISPERSION SCHEMES

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Abstract: In case of an accidental release of radionuclides in the atmosphere, atmospheric dispersion models are used by IRSN to assess the sanitary and environmental consequences, and infer mitigation actions. Several tools are comprised in the C3X operational platform (Tombette et al. (2014)), including various models and levels of complexity. Among them, the Gaussian puff model pX is used for local scale. Gaussian models are indeed widely used in a crisis context, due to their simple approach, low computational burden, and fair performance at short distance in most situations. However, many dispersion schemes can be used, from a crude, discrete representation of the atmospheric stability, to more physical parameterizations. Besides, most schemes are not well adapted to very stable situations. Thus, model-to-data validation is crucial to determine the model's performance and limitations, and the best dispersion scheme for each meteorological situation.

The AREVA NC La Hague site is one of the world's largest fuel reprocessing plant. During reprocessing operations, the plant's 100-m height stacks emit krypton-85 that can be measured in the environment. IRSN carried out several experimental campaigns, measuring ^{85}Kr air concentration activities (Connan et al, 2013, Connan et al, 2014). A fixed measurement device is now continuously registering air concentrations in the courtyard of IRSN's laboratory of Cherbourg (LRC), 18 kilometers from the source. These measurements were used with the pX model, along with near-field measurements (1-5 km) conducted during stable situations. These field data are particularly relevant for studying local-scale dispersion from an elevated release, in a topographically complex area (near the ocean and cliffs). In particular, near-field measurements raise the matter of effective release height, taking into account the effect of neighboring buildings. Several dispersion schemes and ways of determining atmospheric stability were compared. Various meteorological data were also used (10-m and 30-m on-site anemometers, 100-m measurements from SODAR profiles), highlighting the complexity of wind fields in this area, and the issue of measurement representativeness.

Key words: *Gaussian model, model validation, Kr-85, atmospheric dispersion, stable cases, elevated release*

INTRODUCTION

The Gaussian puff model pX is used at IRSN (the French Institute of Radiation Protection and Nuclear Safety) to model dispersion up to a few tens of kilometers in case of an accidental release of radionuclides in the atmosphere. The results are then used to infer mitigation actions, to take countermeasures for the protection of populations, and to help design measurement strategies. Thus, model-to-data validation is crucial to determine the model's performance and limitations. The pX model was already validated on classic field experiments with passive tracers, such as those contained in the Model Validation Kit (Olesen (2001), Olesen (2005)), or the Prairie Grass experiment. However, there is a need for more experiments in very stable, low-wind conditions, where models are less accurate.

While local-scale (up to a few kilometers) or large scale (from 100 to 1000 km) field experiments have been conducted in the past, there is clearly a gap in the literature, between 10 to 50 kilometers, which are the distances of interest for our applications. At such distances, ^{85}Kr can be used as a tracer. Krypton-85 (^{85}Kr) is a β^- and γ emitting radioactive noble gas with a half-life of 10.7 year. As such, it is particularly interesting for tracer experiments, since it does not undergo deposition processes, and its half-life is large enough for radioactive decay to be neglected during the experiment. Its main source of emission is anthropogenic, mainly from the reprocessing of spent nuclear fuel.

Here, IRSN's field measurements of ^{85}Kr around AREVA NC La Hague, one of the world's largest reprocessing plants, are used. Two case studies are shown:

- Continuous measurements of ^{85}Kr in the courtyard of IRSN's laboratory of Cherbourg (LRC), 18 kilometers from the source (Connan et al. (2013)),
- Near-field (1-5 km) measurements in stable situations (Connan et al. (2014)).

FIELD EXPERIMENTS

The releases of ^{85}Kr occur at the site of AREVA NC La Hague, from the 100-m high stack of the production unit. The plant is located in a coastal area, near cliffs. It contains two production units with high stacks and many buildings (Figure 1). The time series of the release were provided by AREVA NC.

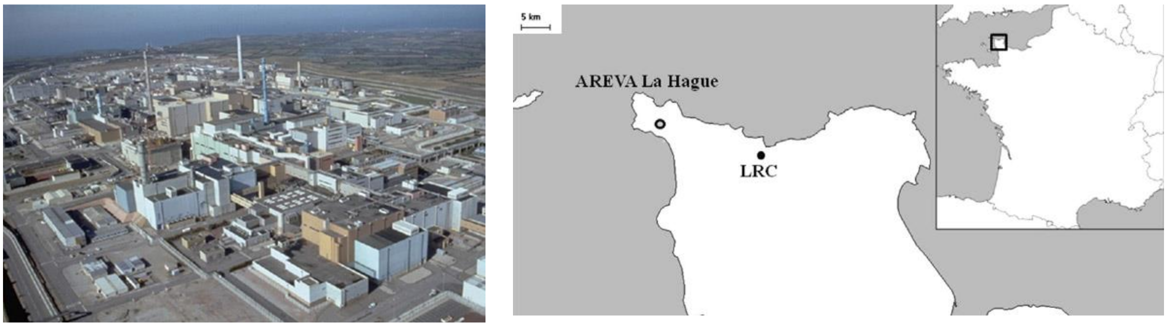

Figure 1. Aerial view of the AREVA NC La Hague reprocessing plant (left), geographical situation of the plant and IRSN's laboratory (LRC) (right).

The meteorological observations were obtained from several sources: (1) 30-meters wind measurements (sonic anemometer) located on AREVA NC site, near the release point (for 2012-2013 cases), (2) 6-meters wind measurements at a site located 2 kilometers from AREVA NC (available since 2014), (3) SODAR wind profile measurements at the AREVA NC site. In addition, meteorological measurements were also available at IRSN's laboratory. The meteorological measurement frequency is 1 minute, and variables are then averaged over 10 minutes. The wind standard deviations (σ_v, σ_w) are also calculated, so as to induce stability parameters, such as Monin-Obukhov length or Pasquill stability class.

Figure 2. Beta counting proportional counter (Berthold-LB123) (left), air sampler VEGA (middle), and 6-m sonic anemometer for wind measurement (right).

Close to the discharge point i.e. less than 20 km, ^{85}Kr concentrations are usually sufficiently high to allow real-time measurements (Figure 2). In these conditions, the activity concentration in the air sample may be determined by β counting in a Berthold-LB123 gas proportional counter (Connan et al. (2013)). The detection limit is about 500 Bq.m^3. In addition, for integrated measurement, air samples are collected in tedlar bag (20-L) and measured by γ spectrometry. Then, the detection limit depends on the counting time duration.

RESULTS AT LRC

Continuous measurements of ^{85}Kr are made in LRC's courtyard. Each time the wind direction is such that peaks are detected, the corresponding release amounts are given by AREVA to IRSN and simulations are made. Here, six one-month periods between 2012 and 2014 were studied. Each time, several peaks were detected, of relatively short duration (Figure 3). The simulations were carried out with pX, using several meteorological data, and three Gaussian standard deviations: Pasquill (1978), Doury (1976) and formulas based on similarity theory (Hanna et al. (1982), Hanna and Paine (1989), Irwin (1979)).

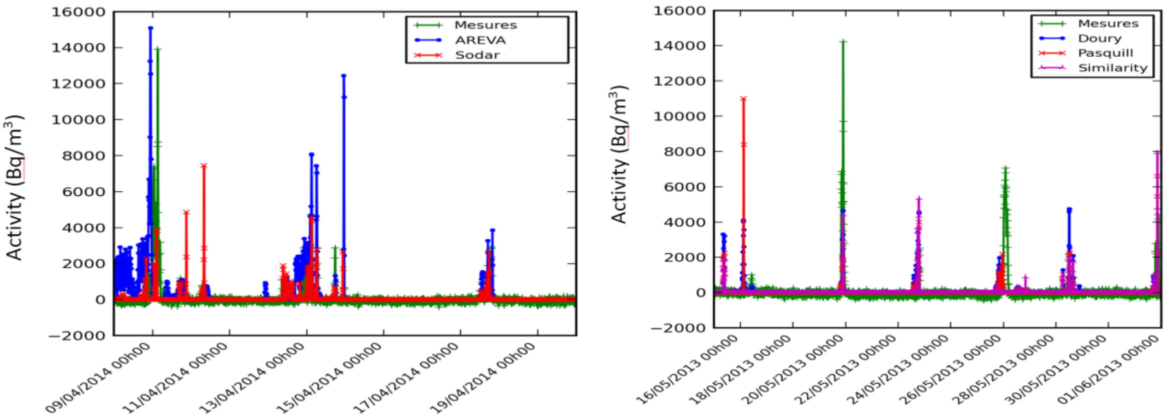

Figure 3. Examples of ^{85}Kr measurements at LRC site, for April, 2014 (left) and May, 2013 (right). Observations are in green. On the left, results with Pasquill parameterization are compared using two different wind data: 6-m anemometer observations (blue) and 100-m SODAR data (red). On the right, 3 Gaussian standard deviations are shown (Doury, Pasquill and Similarity) with 6-m wind data.

Contrary to usual dispersion experiments, which include several measurement points recording time-averaged values, here, the measurement frequency is high (1 minute) but we only have a single measurement point. Thus, results are very sensitive to wind direction measurements uncertainties: even at this distance, a shift of a few degrees in wind direction can result in a missing peak, or a false alarm. Since the stack is 100-meter high, and the measurement device is a few meters above the ground, it is difficult to determine the adequate wind measurement height. In Figure 3 (left), for instance, the 6-meter wind measurement (in blue) shows a lot of peaks at the beginning of the time series (on April 8th), whereas the SODAR and measurements don't. This comes from the wind direction, which blows towards LRC according to the 6-m anemometer, while the 100-m direction differs by a few degrees. Besides, the source and receptors are 18 kilometers apart, in a complex orography, and the representativeness of meteorological observations can be questioned.

To get an overview of the model's performance, statistical indicators were designed. Traditional indicators used in dispersion validation, such as bias or correlation, did not seem well adapted to this kind of measurements. Instead, we decided to use indicators based on peak detection: a peak is detected each time a value (observed or simulated) is above a given threshold. If both observations and simulations detect a peak at the same time, it is a *hit*. If the peak is observed, but not simulated, it is a *miss*, and the reverse is a *false alarm*. Then, three indicators can be based on the number of *hit*, *miss* and *fa*:

- The probability of detection: $pod = hit / (hit + miss)$
- The false alarm rate: $far = fa / (fa + hit)$
- The measure of effectiveness: $moe = hit / (hit + 1.5*miss + 0.5*fa)$

Table 1: Statistical indicators (POD, FAR and MOE) computed over the six case studies at LRC for several configurations: 3 Gaussian standard deviations (Pasquill, Doury, Similarity) and two meteorological data (AREVA anemometer and wind at 100-m from SODAR profile).

Configuration (1-h average, threshold 200 Bq/m^3)	**Probability of detection (POD)**	**False alarm rate (FAR)**	**Measure of effectiveness (MOE)**
Pasquill – AREVA anemometer	0.83	0.30	0.66
Doury – AREVA anemometer	0.80	0.34	0.61
Similarity – AREVA anemometer	0.78	0.36	0.59
Pasquill – SODAR 100m	0.72	0.37	0.53
Doury – SODAR 100m	0.69	0.41	0.50
Similarity – SODAR 100m	0.72	0.40	0.52

A perfect model would have *pod* = 1, *far* = 0 and *moe* = 1. The *moe* is designed so as to be more penalizing for a model that would miss a peak than for one that would falsely detect one. Table 1 summarizes the model's performance with several configurations. Between 70 and 80% of the observed peaks are detected, but about 30 to 40% of simulated peaks are false alarm. The *moe* is between 50% and 66%. Results are clearly better when using the 6-m wind measurements than using 100-m SODAR data. However, for some cases, 100-m observations give better results, as shown Figure 3. Results in terms of peak detection are not very sensitive to standard deviations, but the Pasquill parameterization gives the best performance. The peak intensities, however, are clearly dependent on the chosen parameterization and on the stability diagnosis (Figure 3, right).

NEAR-FIELD MEASUREMENTS IN STABLE SITUATIONS

Twenty-two measurement campaigns were conducted in stable situations, during nighttime, between 2010 and 2013 (Connan et al. (2014)). Sensors were positioned downwind from the source, at distances varying from 1 to 5 kilometers. Results were integrated over 30 minutes. In this preliminary study, eight cases have been simulated with the pX model, using on-site meteorological measurements (30-meter sonic anemometer). Simulations were made with three Gaussian standard deviations (Doury, Pasquill and similarity) and three release heights: 100 meters (stack height), 50 meters and ground release, in order to take into account building downwash due to the high number of buildings close to the source (Figure 1, left).

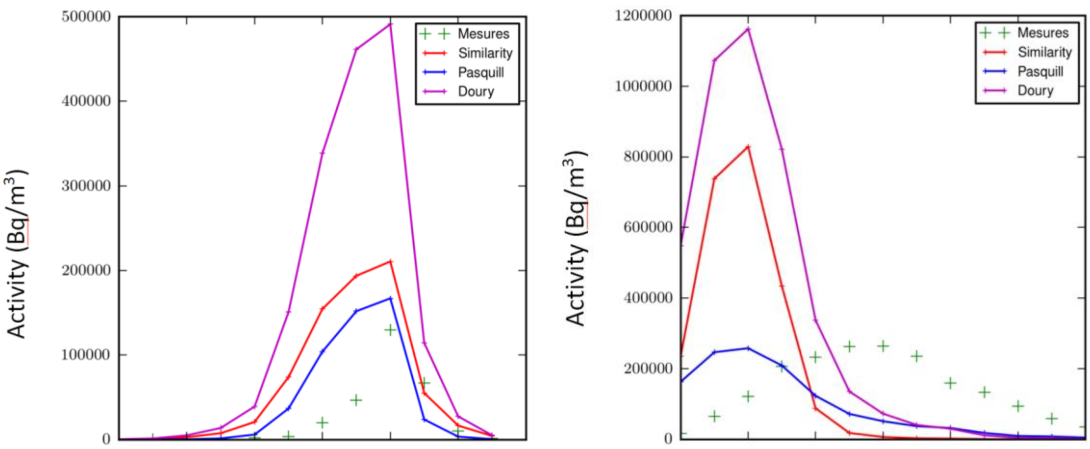

Figure 4. Crosswind ^{85}Kr activity for two cases (February, 19th and 20th, 2013). Simulations are made with a ground release, and 3 Gaussian standard deviations are shown (Doury, Pasquill and Similarity).

Figure 4 shows two examples of crosswind concentrations obtained for a ground release. While there is an overestimation with some parameterizations, simulations are in good agreement with observations, especially with Pasquill standard deviations. However, with 50-m and 100-m releases, which are more realistic, concentrations are highly underestimated, and there is often no simulated plume close to the ground at these distances. This shows the crucial importance of taking into account the effect of buildings in the simulations. Also, in several cases, there is no simulated plume at all, no matter the source height or the parameterization. This comes from a discrepancy between the wind direction used in the model and the "real" wind direction responsible for the plume transport.

CONCLUSION

We presented model-to-data comparisons to ^{85}Kr measurements in the vicinity of AREVA NC La Hague reprocessing plants. The continuous measurements at the LRC laboratory, located 18 kilometers from the plant, allowed us to carry out comparisons between several configurations and meteorological data. They raised the issue of meteorological representativeness in such a complex area, with a 100-m release and several surrounding buildings. The near-field measurements in stable situations highlighted the issue of building downwash, and the difficulty to model dispersion in some cases. Again, the question of meteorological data representativeness was raised. In the future, more experiments will be added to our dataset, and 3D meteorological fields at fine resolutions will be tested, and compared to observations.

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