EMULATORS FOR THE RAPID PREDICTION OF CONSEQUENCES IN CASE OF NUCLEAR HAZARD

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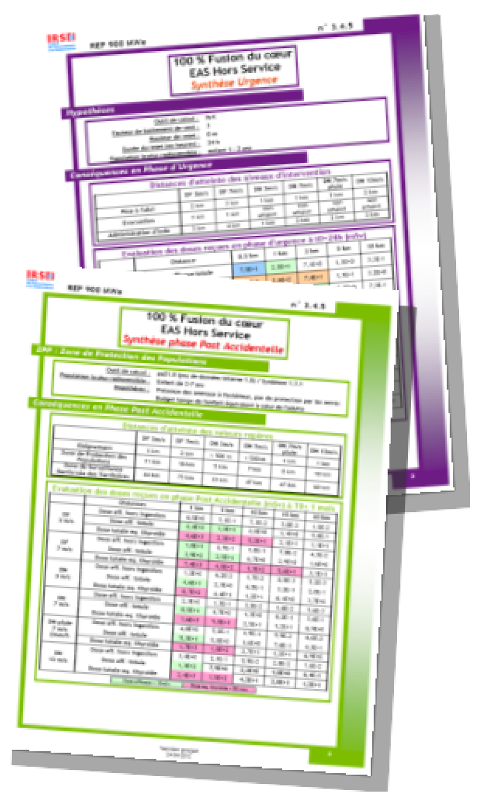
CONTEXT

In case of accidental releases of radioactivity in the atmosphere, the French Institute of Radiation protection and Nuclear Safety, IRSN, recommends protective actions to be taken on the basis of the predicted maximum distances of dose threshold exceedance, as well as the angular apertures of the territory likely to be concerned. These values are estimated on the basis of the current meteorological situation and a source term assessment. For this purpose, IRSN develops and uses a Gaussian puff model, pX, to perform these calculations. The pX model is embedded within IRSN's operational platform for emergency response C3X. For the whole calculation chain (including pre- and post-processing), five to ten minutes may be required, depending on the configuration.



Pre-calculated sheets for accident scenarios

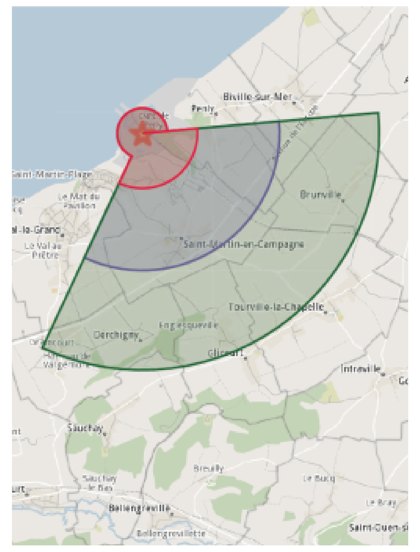
In the graded approach applied by the IRSN's emergency center, the first response generally relies on pre-calculated scenarios gathered in "Accident Type Sheet" (called FAT in french, for "Fiche Accident Type"). This database has been constructed in the preparedness phase. It relies on calculations made for accidental scenarios and simple weather situations, described by a few parameters assumed to be constant and homogeneous over the simulation domain.

However, all possible meteorological situations cannot be covered in a single operational sheet. Other release and dispersion parameters may also vary from the calculation assumptions made in the FAT. Thus, calculations may be required to adjust these parameters to the current situation.

Emergency protection zones after a nuclear accident

Three emergency protection zones are considered in this study :

- A **sheltering area**, where the simulated total effective dose over 24 hours is greater than 10 mSv,
- An **evacuation area**, where the simulated total effective dose over 24 hours is greater than 50 mSv,
- A **stable iodine prophylaxis area**, where the simulated equivalent dose to the thyroid due to inhalation over 24 hours is greater than 50 mSv.



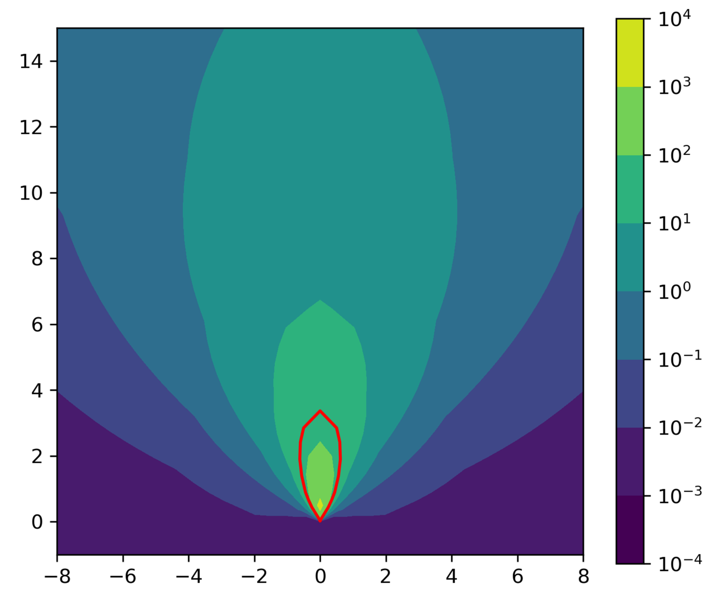
Emulators

Emulators are surrogate models for the original computational model, used to approximate some of its scalar responses. They are statistical functions built from a large number of simulations, with the aim of predicting new responses with a negligible evaluation time. The objective of this study is to use emulators to be able to predict quickly the three emergency protection zones in an operational context.

METHOD

Building the emulators

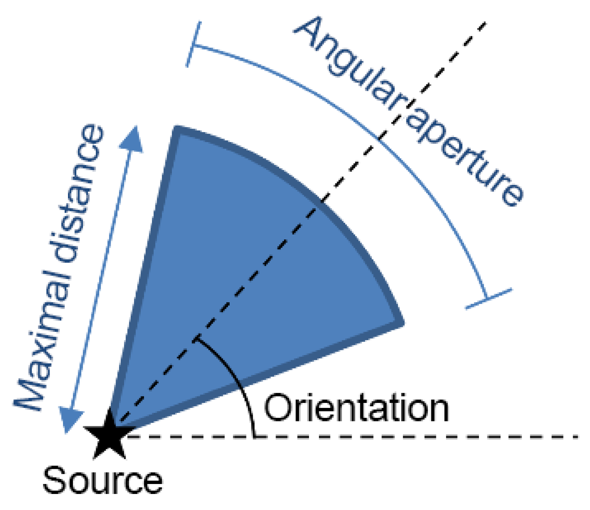
The construction of emulators relies on the simulation of thousands cases to cover a wide range of hypotheses. For each input variable, a draw is made over its range of variation (see table below), in order to make the emulators reliable over the entire space of possibilities. For this study, 2048 points were drawn in a five-dimensions space. For each point, a simulation was performed. These 2048 simulations were used as training sample to build the emulator.



Example of inhalation dose map (mSv) obtained by simulation. The red isoline correspond to the threshold exceedance of 50 mSv.

The maximum distances of threshold exceedance as well as the angular apertures corresponding to the three emergency protection zones were computed from the results of these simulations. These quantities were then used in the construction of three emulators (one for each protection zone), with Gaussian processes (or kriging), a form of "interpolation" that takes into account the distances between the data.

Input variable	Range of variation	Unit
Release height	[0, 100]	m
Wind module	[0, 10]	m/s
Wind direction	[0, 360]	deg
Rain intensity	[0, 10]	mm/h
Meandering wind factor	[1, 3]	
Source term magnitude	[10, 100]	%



Classification

The distances of threshold exceedance of protective action guide levels may be all zero for some values of the input variables and that creates a discontinuity that is difficult for emulators to reconstruct. To avoid this problem, we used a classification method to determine, prior to emulation, whether or not the distances are going to be zero, using a nearest k-neighbor method. For a given dose threshold, the input space of the model can be divided into two subspaces. The purpose of the classification is to estimate whether a point P in the space is located in one or the other of these subspaces.

Objectives of the emulators

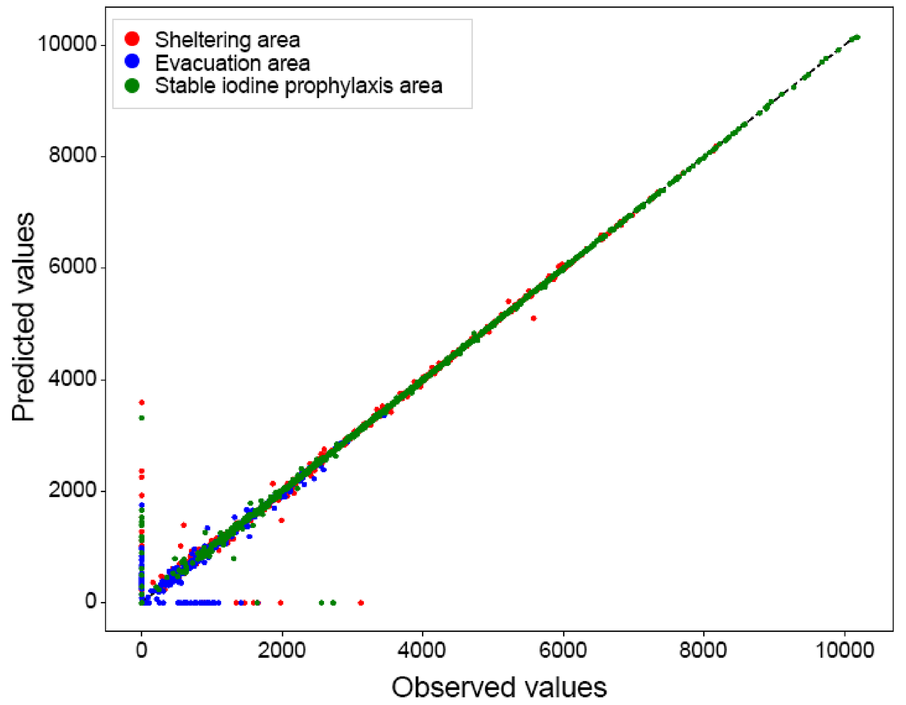
- **To obtain near-instantaneous results** in cases where the meteorological assumptions are not exactly the same as those given by the FAT,
- **To obtain a tool for sensitivity studies and training purposes**, which would allow to vary some parameters in order to observe their influence on the consequences,
- **Be able to estimate uncertainties quickly** (in the longer term) using a set of simulations.

RESULTS

Evaluating the emulators

To evaluate the results of this emulation, we used an uniform test sample of 1000 points to estimate the number of false positives and false negatives predicted by classification and to estimate the error made by the emulator.

There are still some false positive or negative cases (between 1.8 and 8.0%), but these numbers are much lower than without classification (between 3.7 and 46.0%).



Stability	Area	Mean error	Q95% of the error	False positive	False negative	Error rate
Normal diffusion	Sheltering	53 m	142 m	11	9	2.0 %
	Evacuation	60 m	78 m	45	35	8.0 %
	Iodine prophylaxis	42 m	230 m	50	4	1.8 %
Low diffusion	Sheltering	101 m	646 m	18	26	4.4 %
	Evacuation	414 m	222 m	20	27	4.7 %
	Iodine prophylaxis	67 m	492 m	18	25	4.3 %

It is important to identify which errors are acceptable or not in this context. An error of a few hundred meters over a maximum distance of 1 km may seem less acceptable than an identical error over a maximum distance of 15 km, but in terms of surface, the area of the zone where the emulator gives a bad prediction will be much smaller in the first. In practice, these values are not used as exact values, but as an order of magnitude that determines the actual areas over which actions will be carried out (often over administrative entities). Therefore, the error committed on the estimation of distances must be smaller than the margins that are taken by decision-makers for safety reasons.

OPERATIONAL USE

In an operational context, the emulators can predict the emergency protection zones. A Graphical User Interface (GUI) can be used to obtain useful charts which allows users to see the effect of each input on the zones. They can also be used for probabilistic approaches where hundred results must be obtained quickly.