SMART USE OF THE VARIOGRAM TO EXPLORE SPATIAL DATA, TO BREAK DOWN VARIANCE CONTRIBUTIONS AND TO MODEL RADIOLOGICAL CONTAMINATIONS

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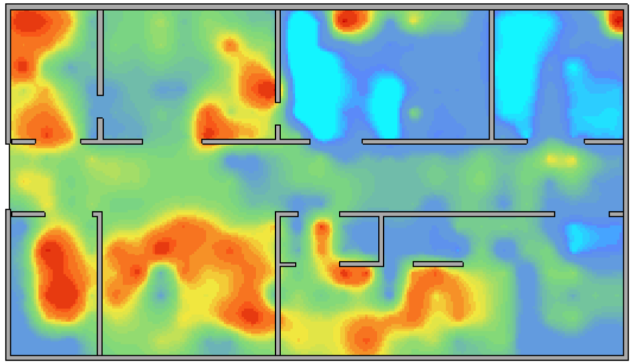
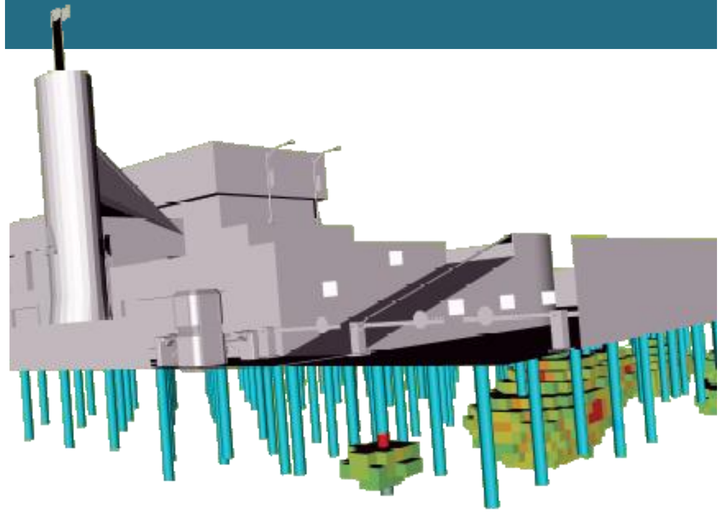
Several characterisation stages

Surface mapping



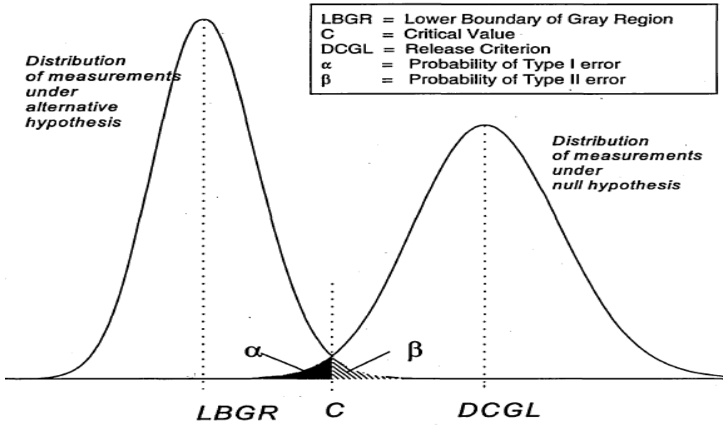
- Hot spot identification
- Zone priorisation
- Radiation protection
- Doubt removal

Volume categorisation



- Operational waste zoning: radiological thresholds, migration profiles
- Source term: scaling factors, average activity

Final control



- Compliance with clearance level
- Residual average activity for impact assessment

To introduce geostatistics

Exploratory data analysis

- Cleaning and consolidation
- Spatial and statistical analysis

Spatial structure (variography)

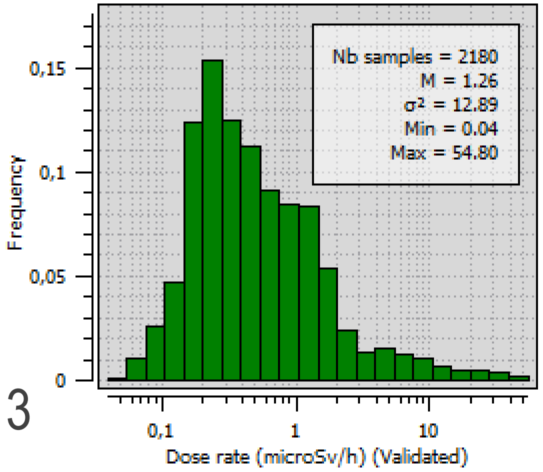
- Spatial continuity interpretation
- Integration of auxiliary data

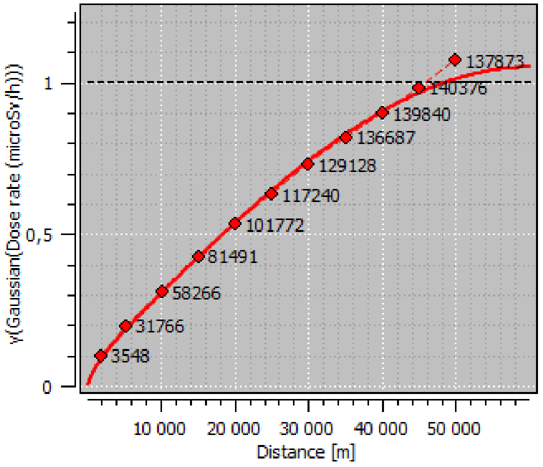
Interpolation (kriging estimates)

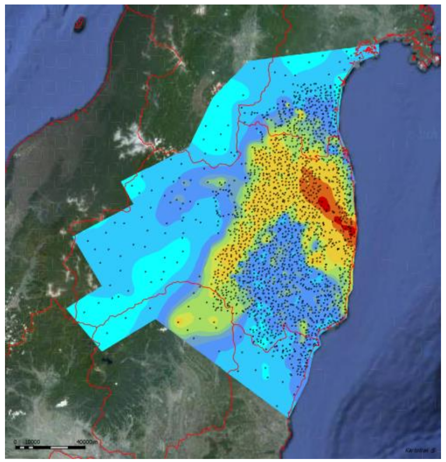
- 2D or 3D maps of the contamination
- Visual representation

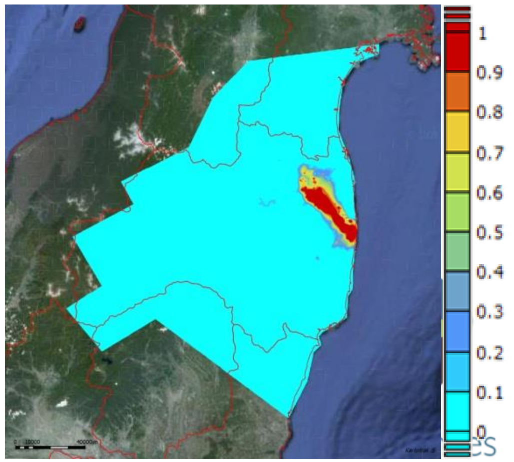
Risk analysis (uncertainty)

- Area or volume categorisation
- Estimation of the source term
- Decision making









Smart use of the variogram to explore spatial data, to break down variance contributions and to model radiological contaminations

Geovariances
Where no one has gone before

Classical formula for the statistical variance

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(z_i - m)^2 \; avec \; m = \frac{1}{N}\sum_{i=1}^{N} z_i$$

Geovariances

Alternative formula for the statistical variance

So we can take benefit from the distance between point i and point j

$$\sigma^2 = \frac{1}{N^2} \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{1}{2} \left(z_i - z_j\right)^2$$

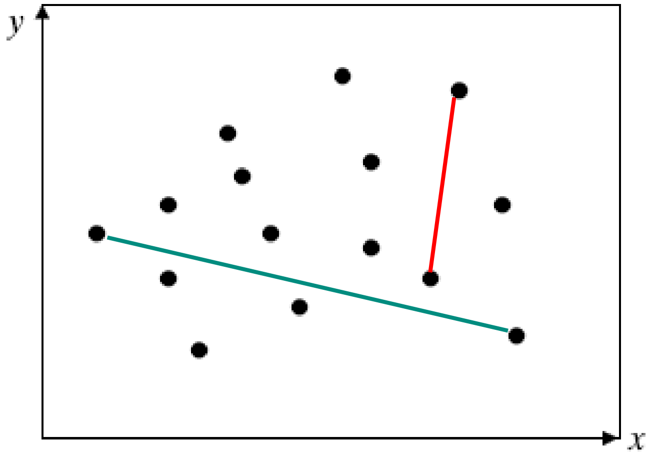
Calculating the mean

of variabilities between each pair of points

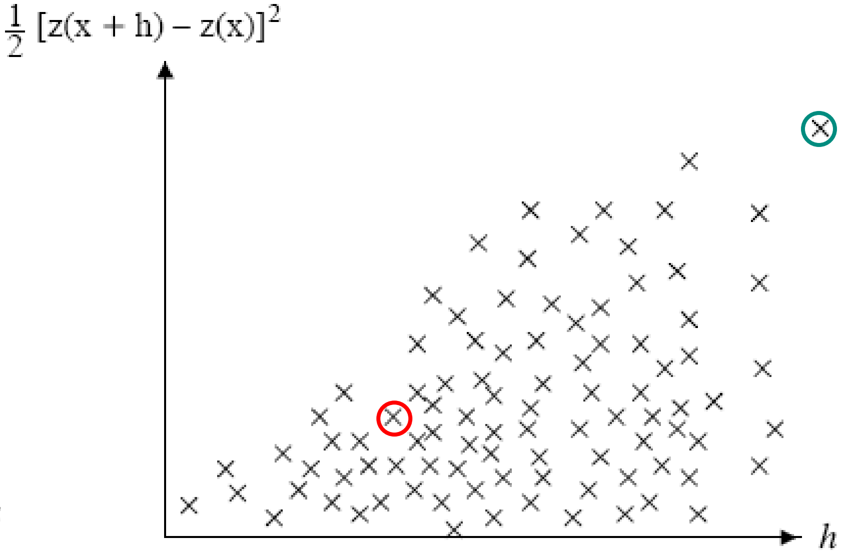
Geovariances

Key tool in geostatistics

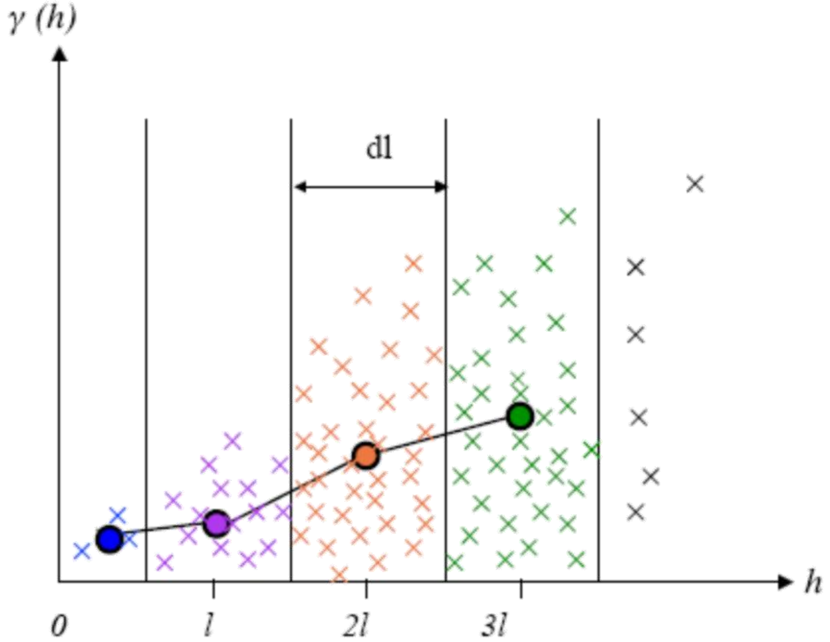
Base map



Variogram cloud



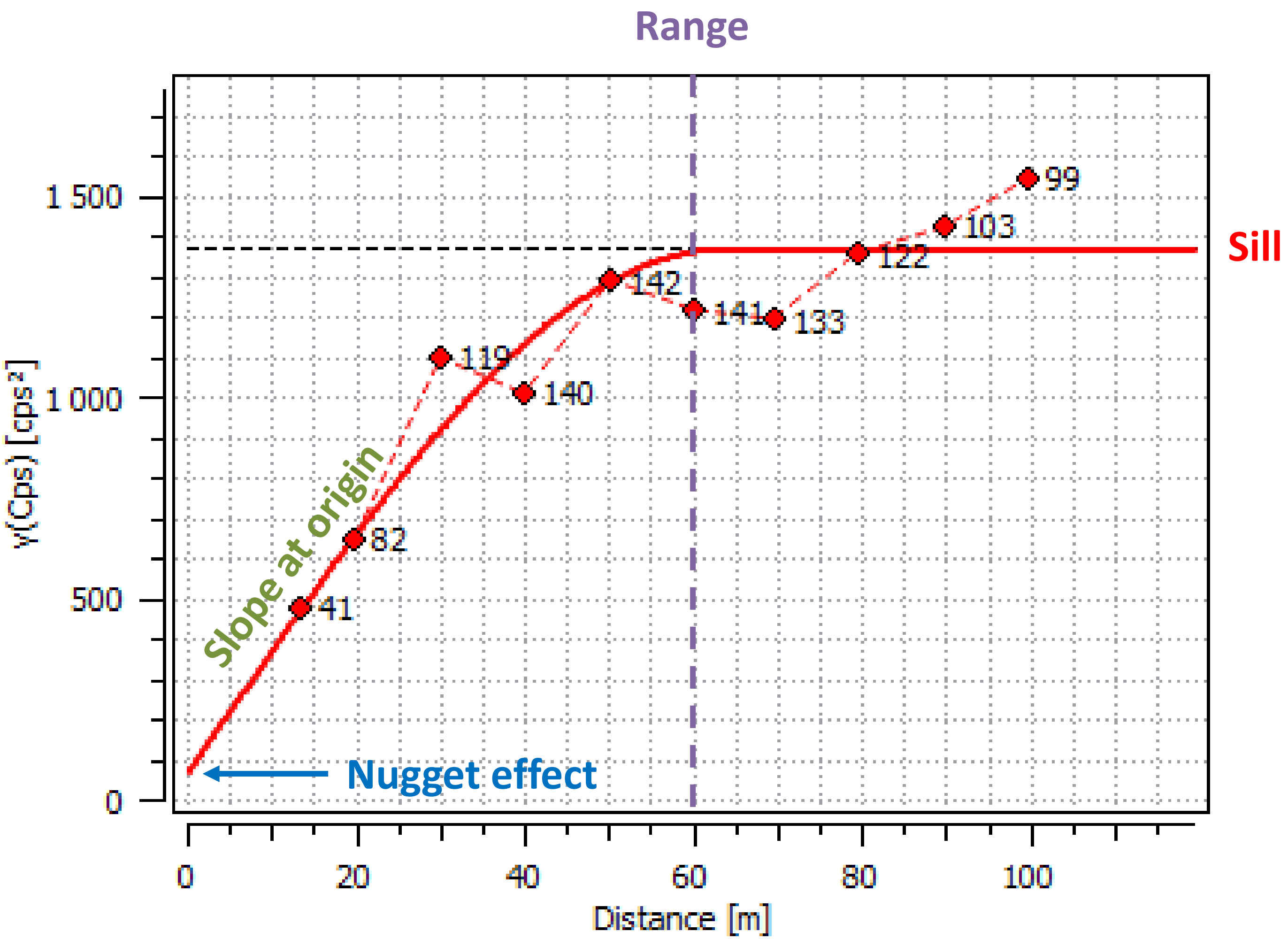
Variogram



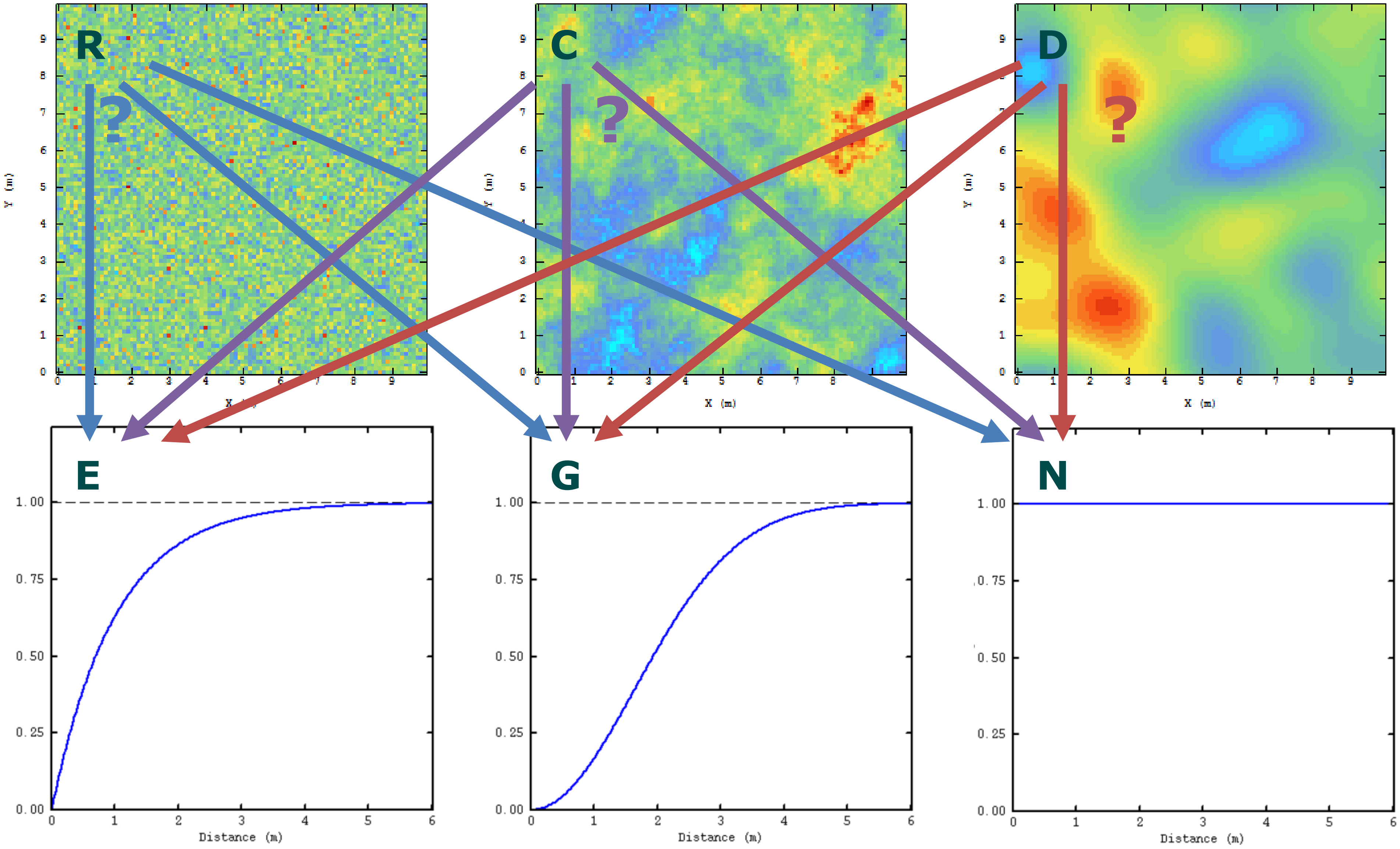
Spatial variability to be interpeted and fitted

Geovariances

Variogram key points

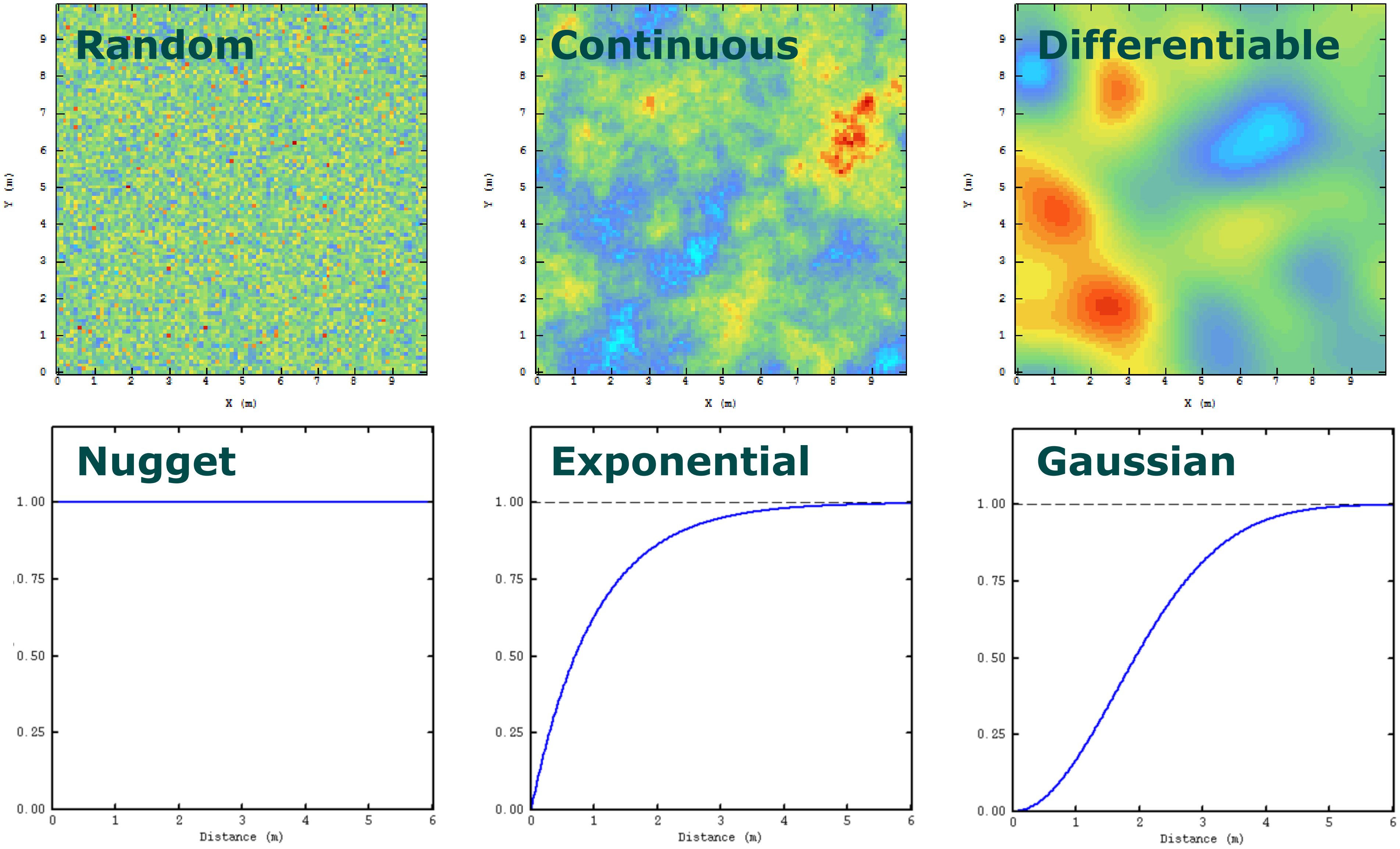


Three spatial signatures...



Geovariances

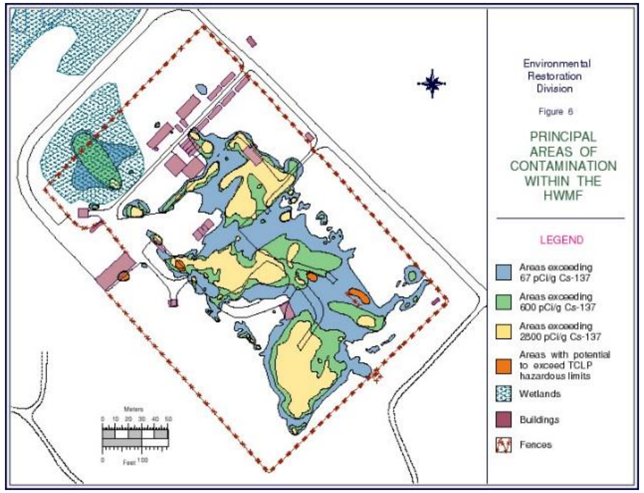
Three spatial signatures…



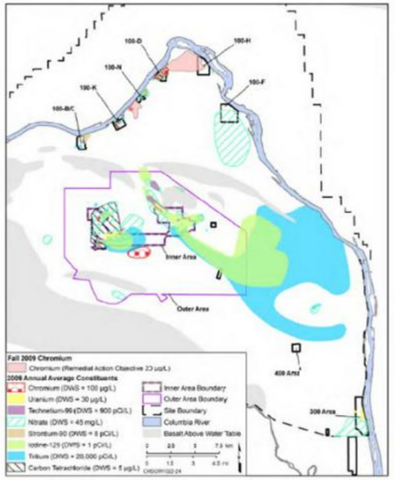
Geovariances

…in the nuclear context (environment)

Waste in a trench



Contaminated soils



Plume in groundwater

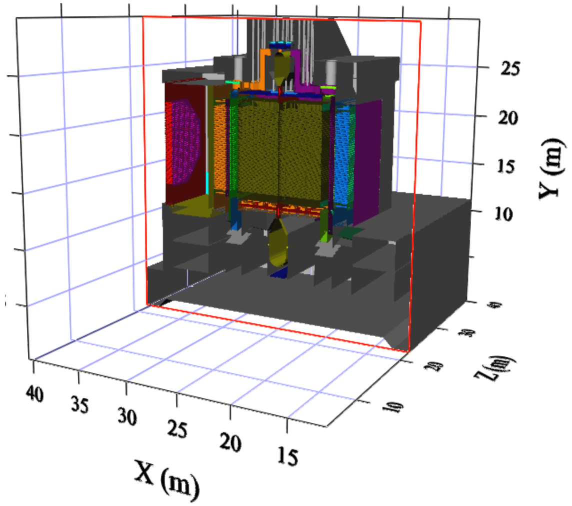
More and more continuous behaviour

Geovariances

...in the nuclear context (buildings)

Waste packages

Building structures

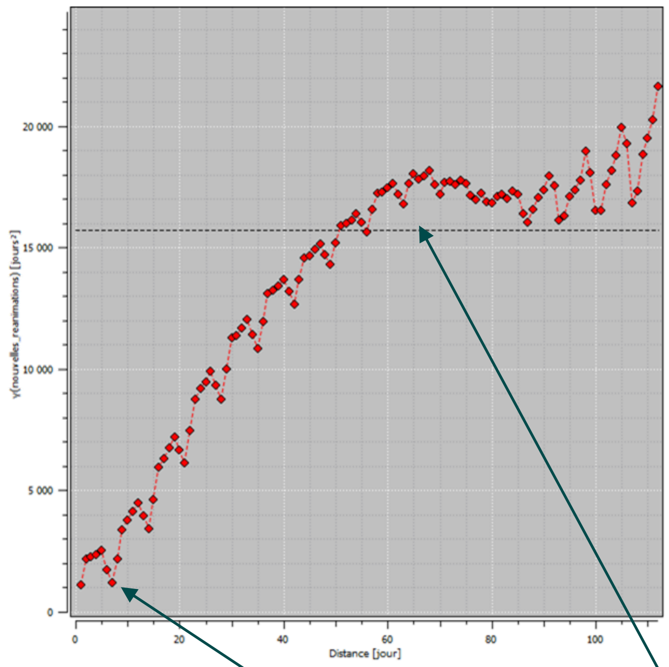


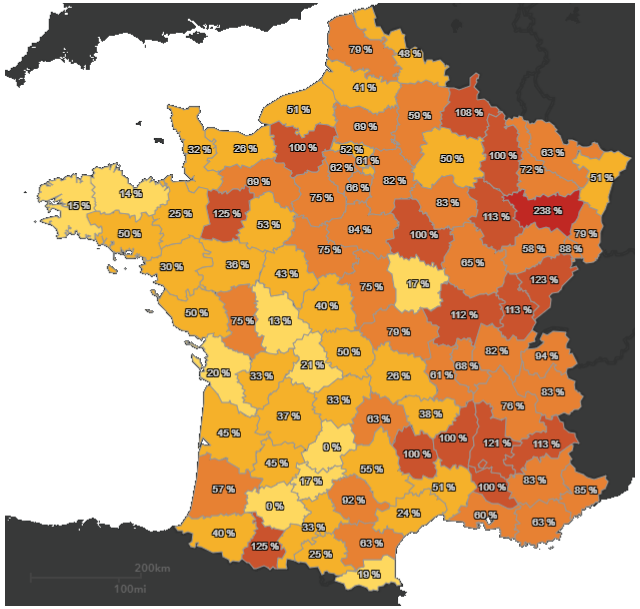
Activation

More and more continuous behaviour

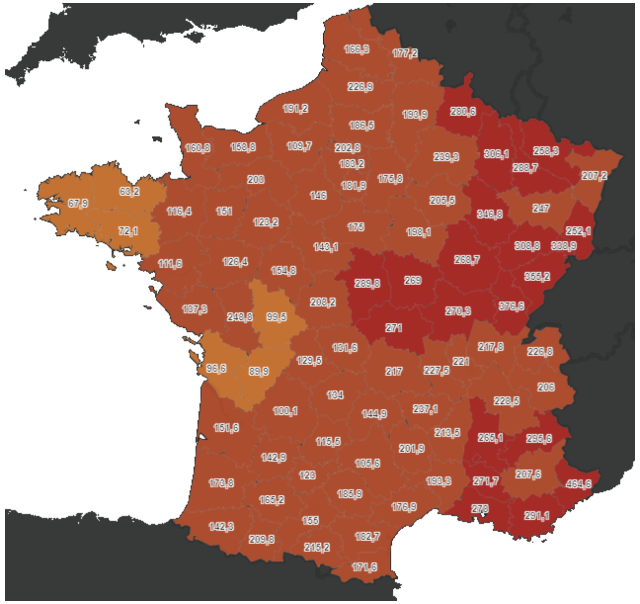
Geovariances

…for temporal variations (Covid-19)

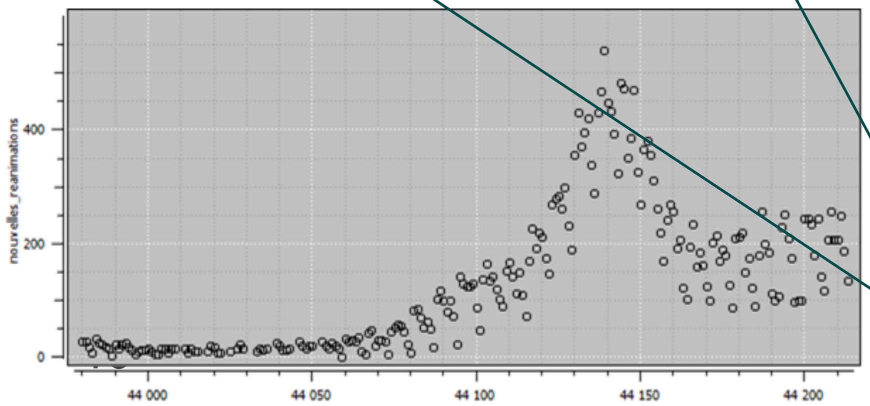




Hospital capacities



Incidence rate



Temporal fluctuations of reanimation entries

- Long-term range (60 days)
- Weekly variations (7 days)

Geovariances

Smart use of the variogram to explore spatial data, to break down variance contributions and to model radiological contaminations

Geovariances
Where no one has gone before

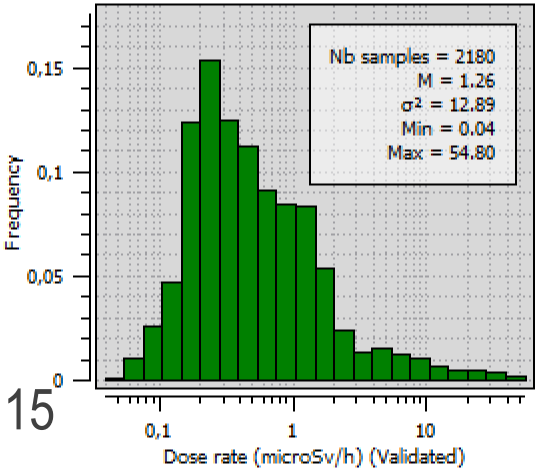
Geostatistics workflow on Fukushima (large scale)

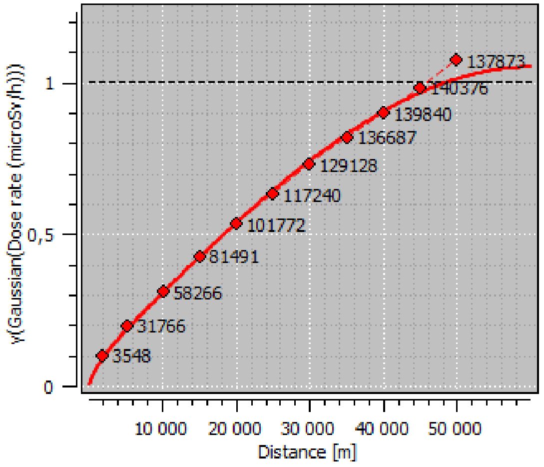
Exploratory data analysis
- Cleaning and consolidation
- Spatial and statistical analysis

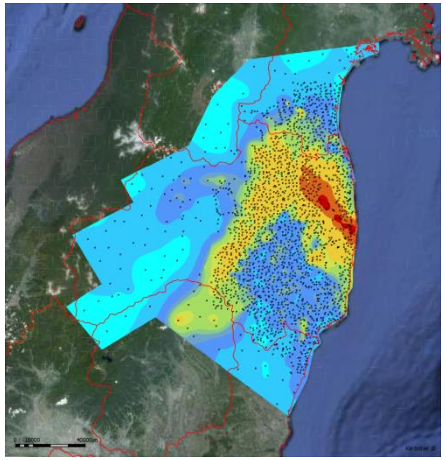
Spatial structure (variography)
- Spatial continuity interpretation
- Integration of auxiliary data

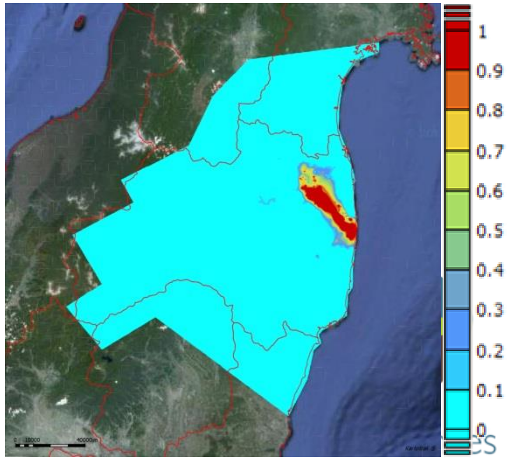
Interpolation (kriging estimates)
- 2D or 3D maps of the contamination
- Visual representation

Risk analysis (uncertainty)
- Area or volume categorisation
- Estimation of the source term
- Decision making

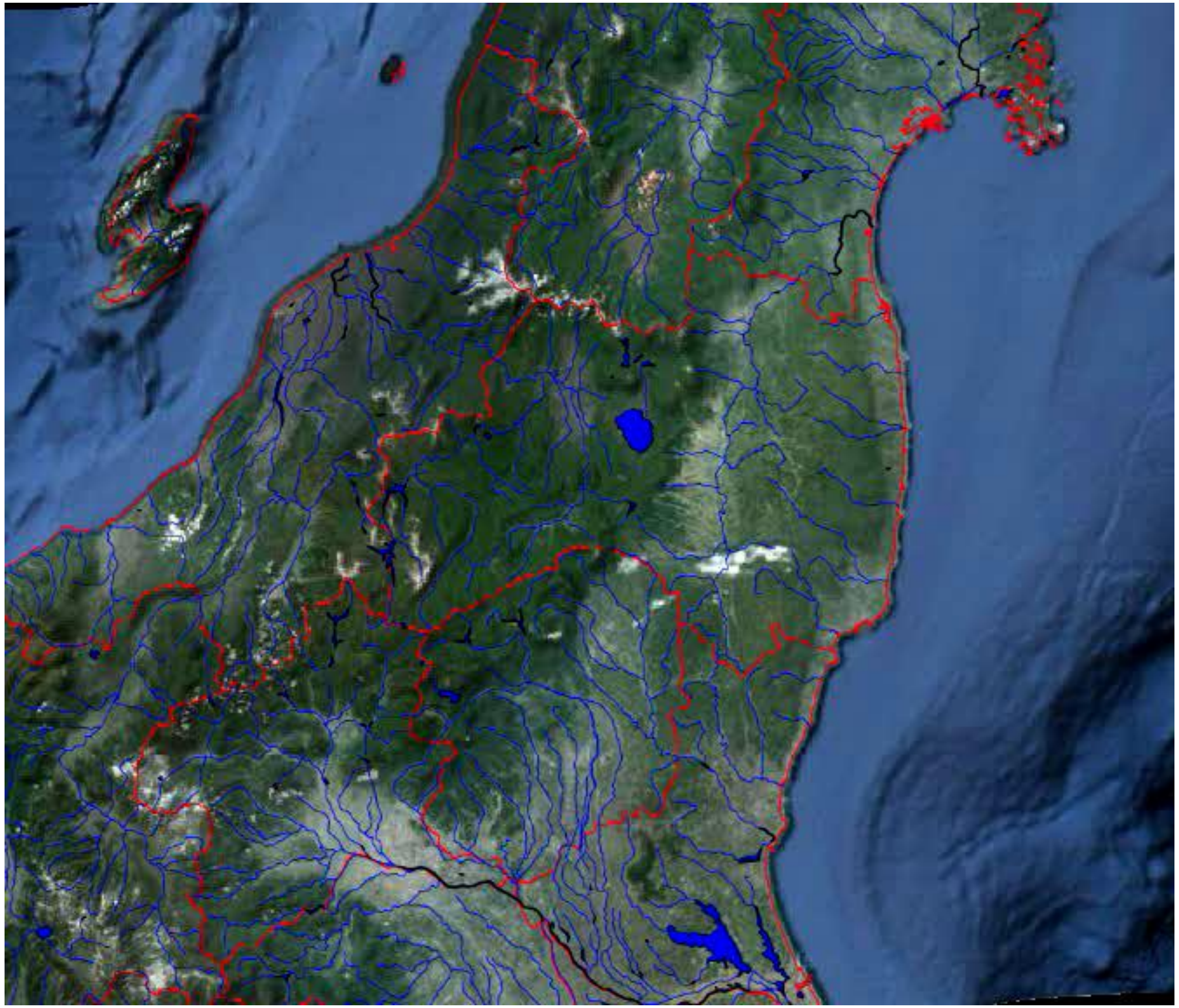




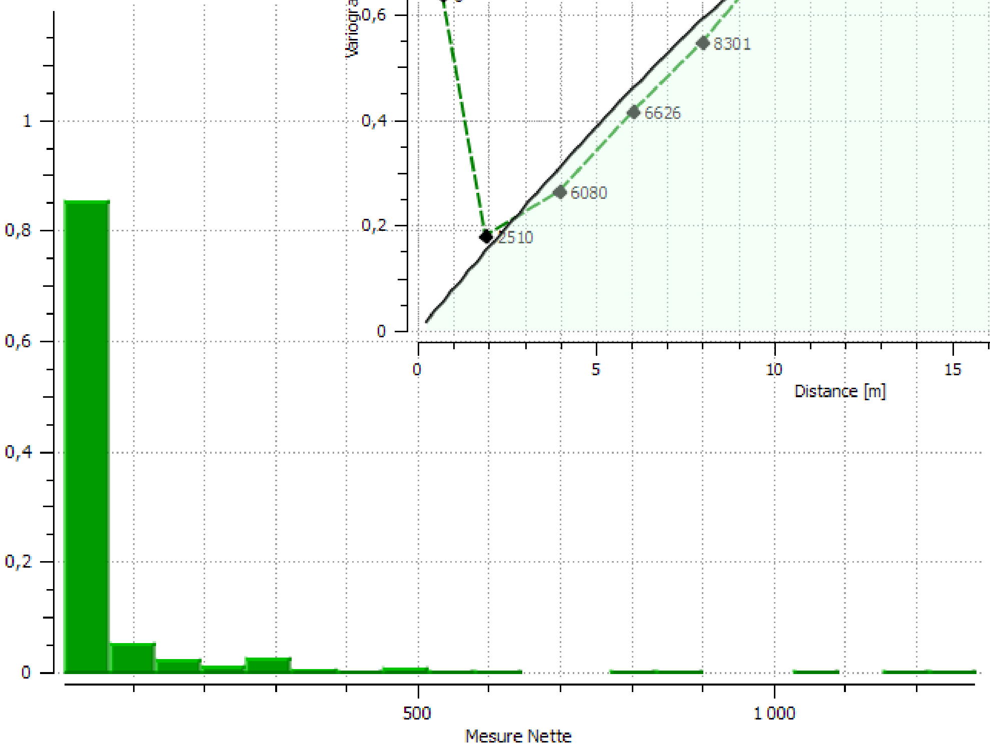


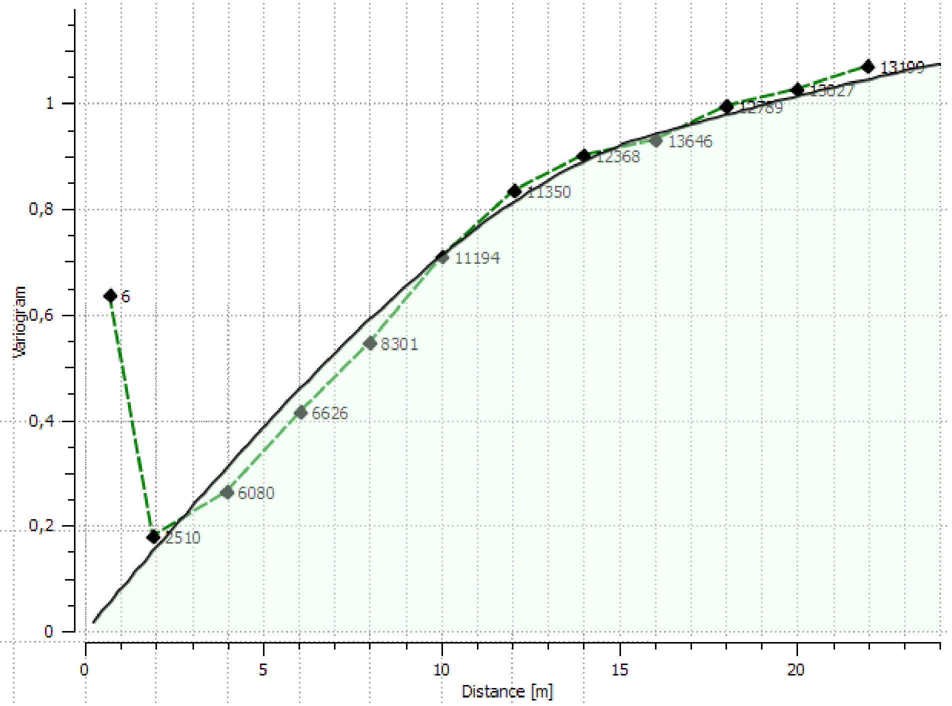


Application case: Fukushima



Application case: RM2 facility

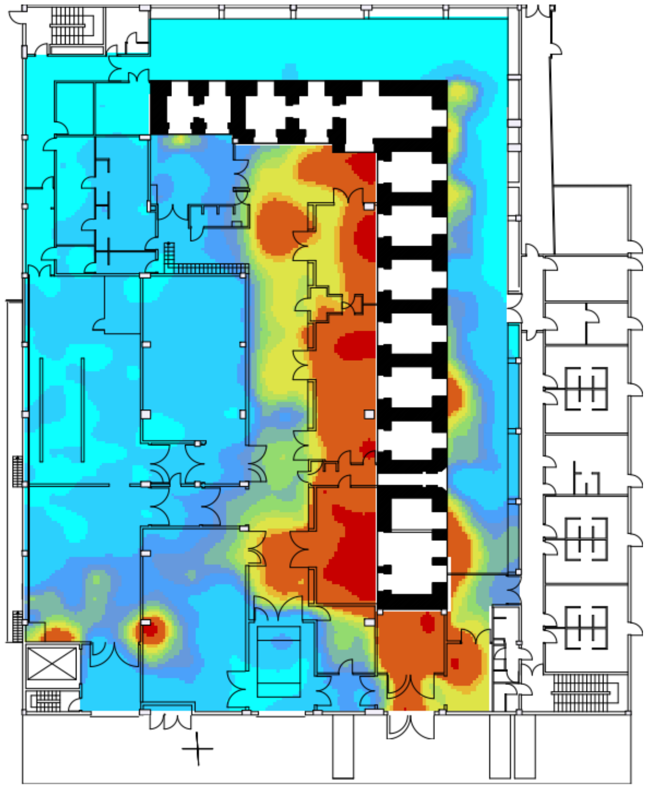


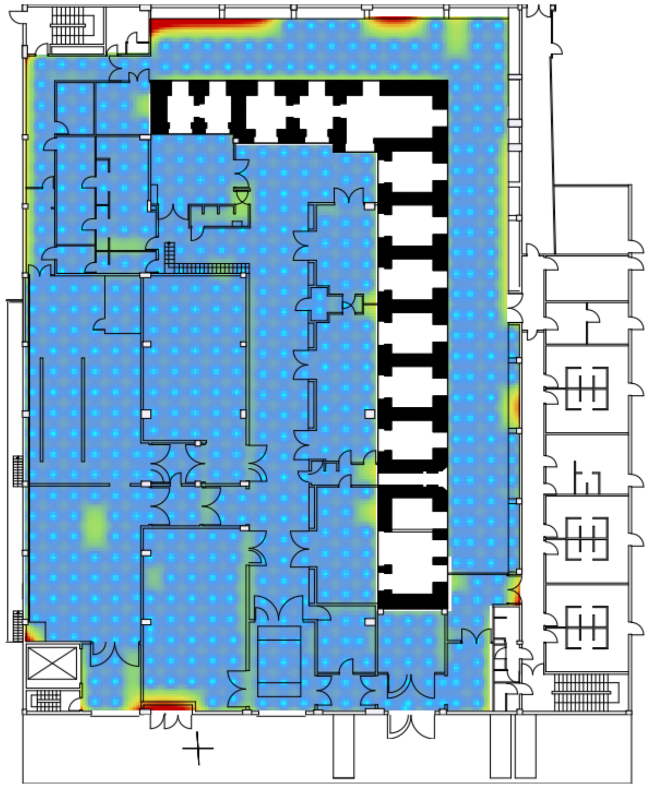


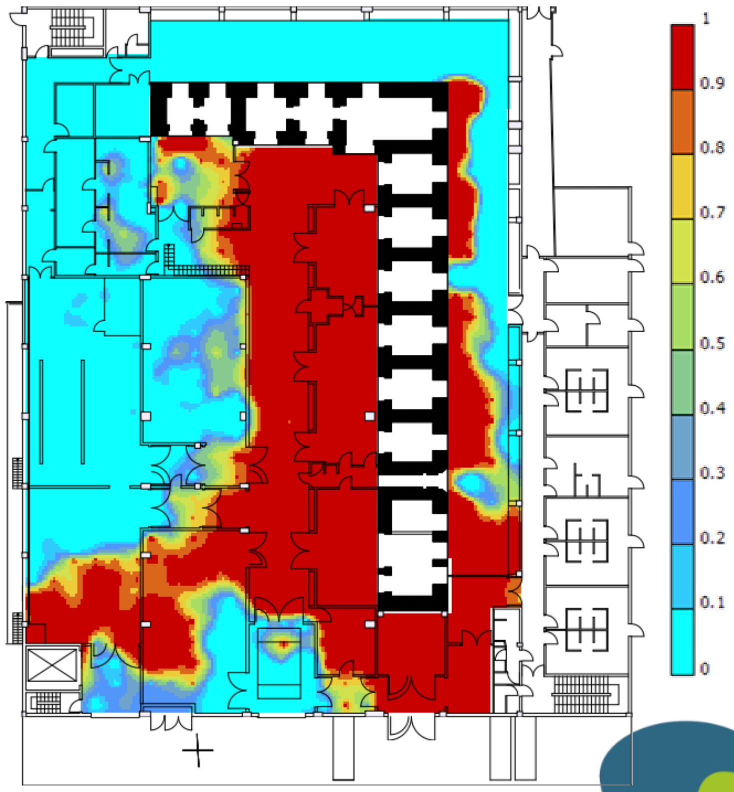
Geovariances

Application case: RM2 facility

Interpolation + Uncertainty = Classification



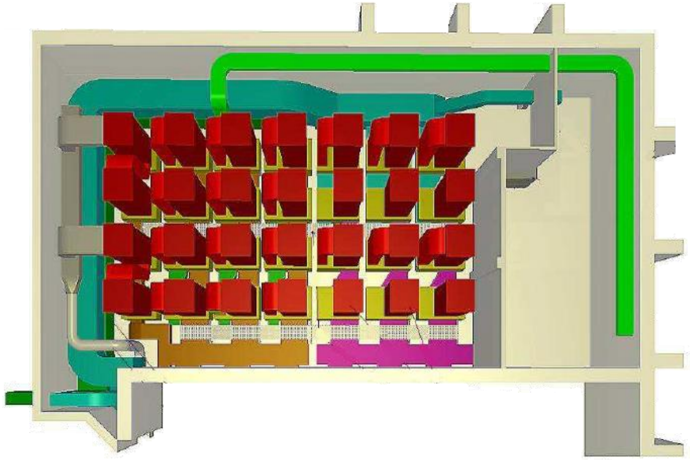




Geovariances

Filter room MAR200 (CEA Marcoule)

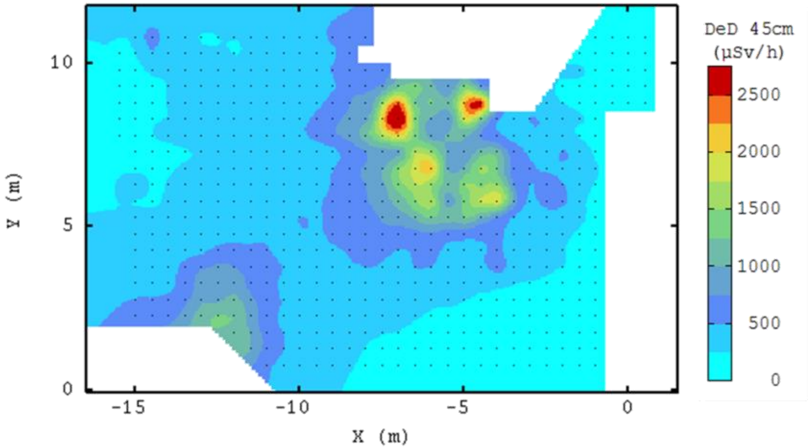
Historical



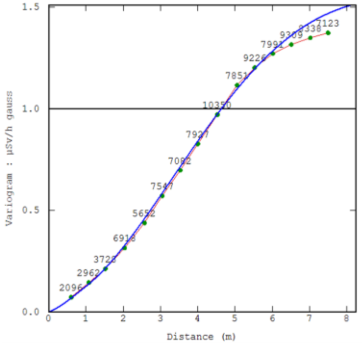
170 m², concrete slab
30 cm thickness

Two major events of contamination

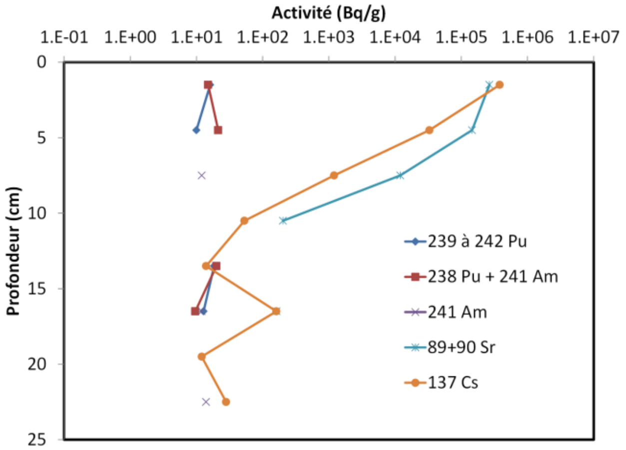
Dose rate



545 measures, remotely
(50 cm mesh)



Samples



13 points in 3 phases

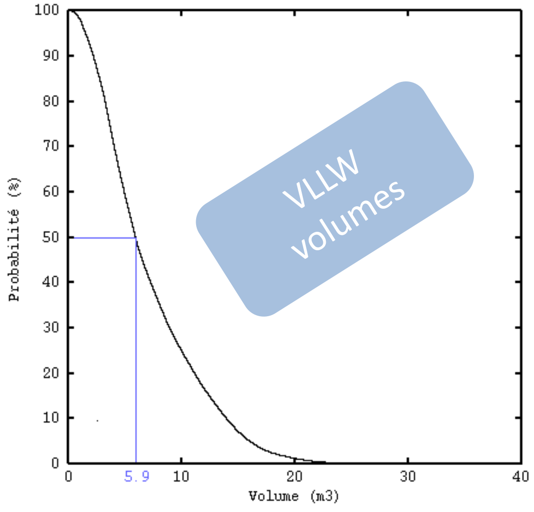
Migration profiles

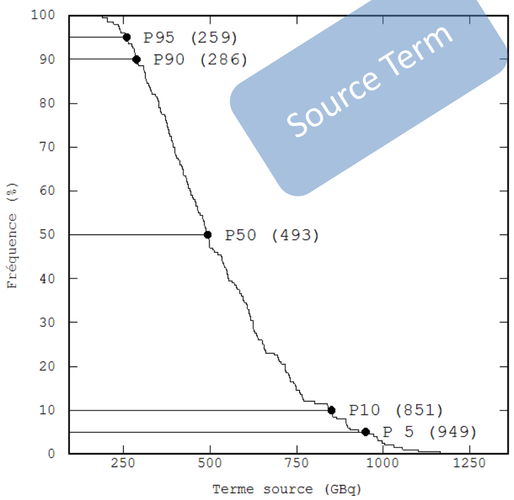
Correlation between nuclides

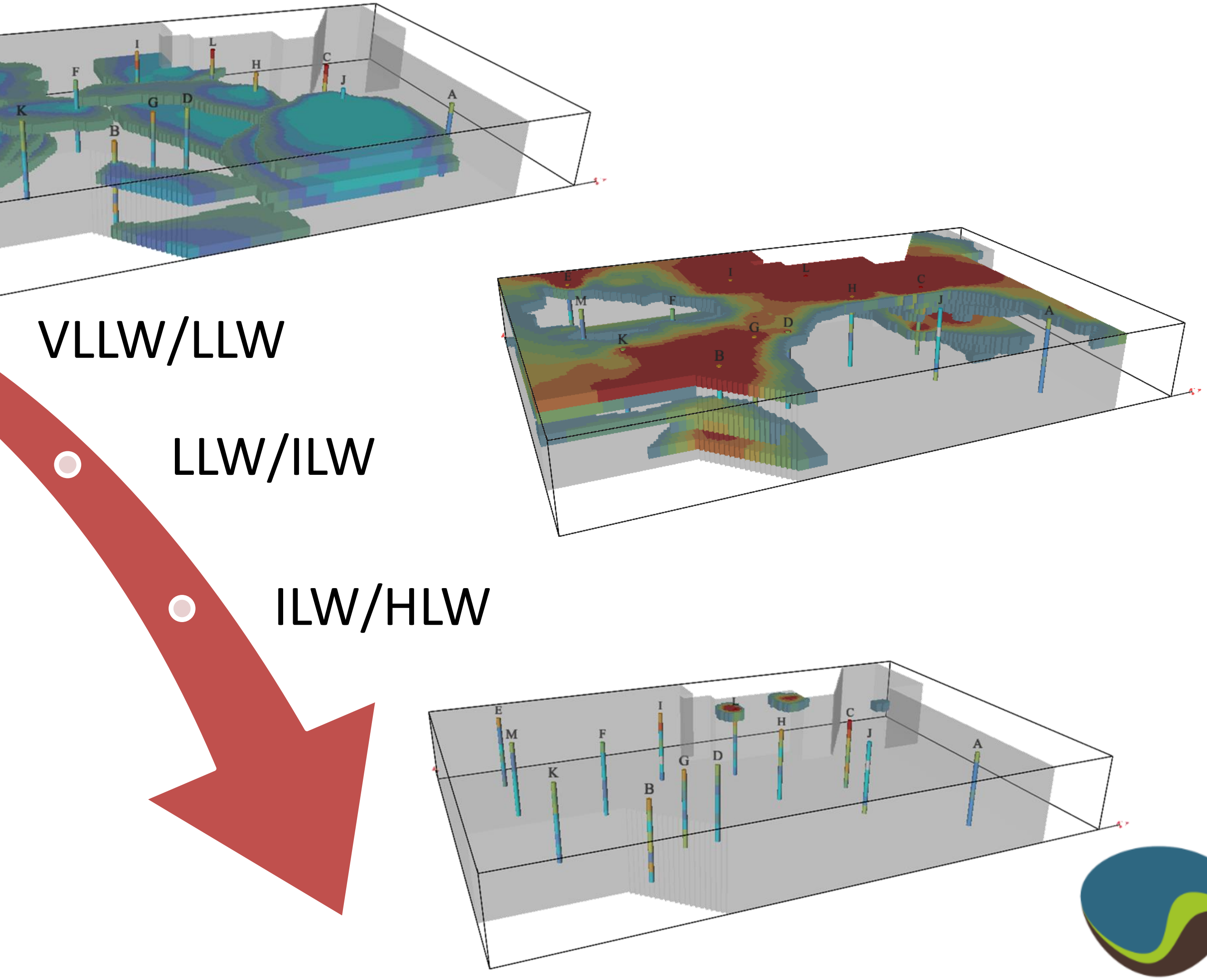
Geovariances

Filter room MAR200 (CEA Marcoule)

Waste categorisation



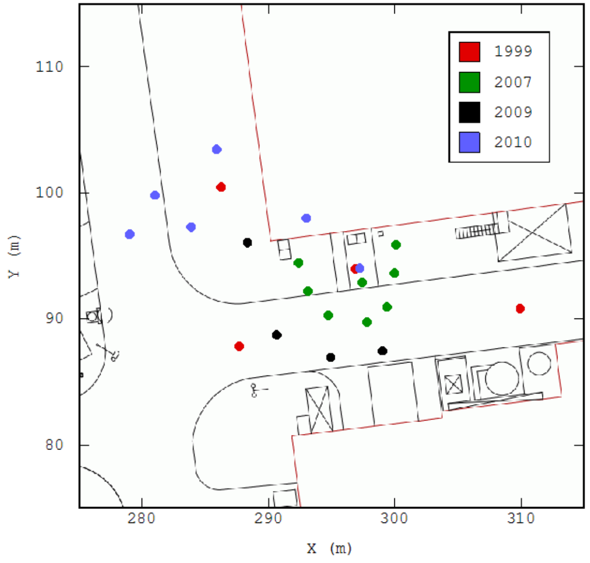




Geovariances

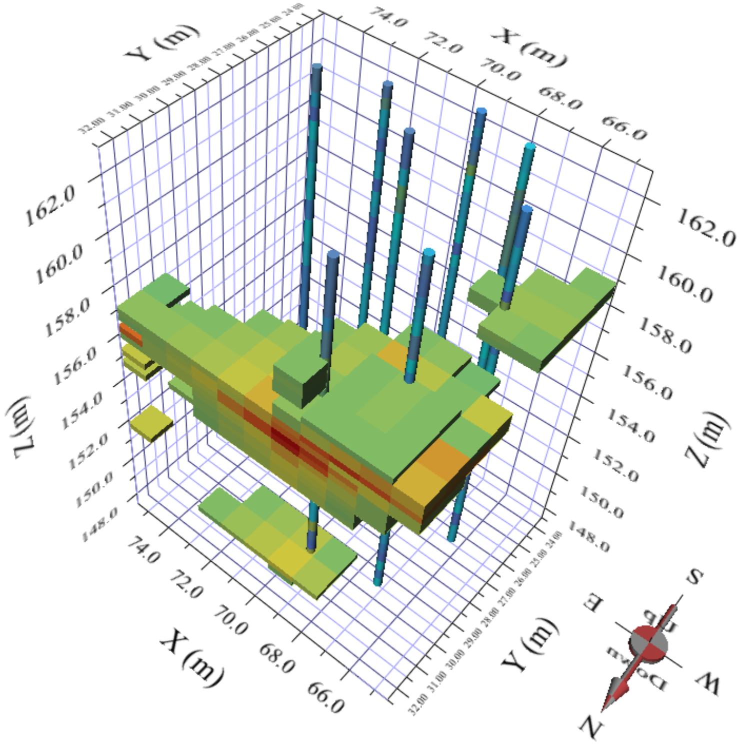
Former moat (CEA Fontenay-aux-Roses)

Historical



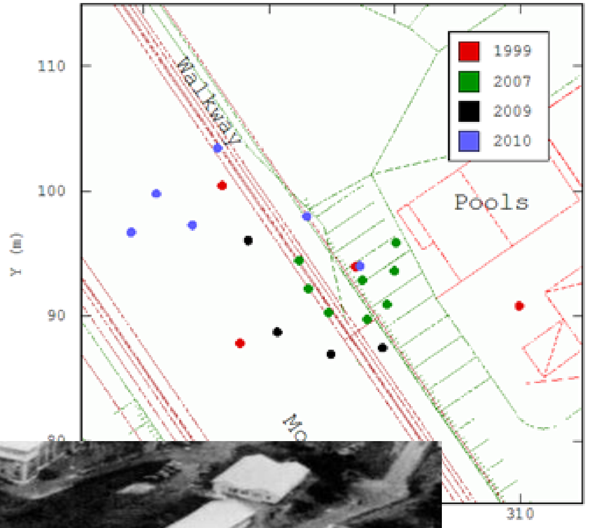
Presence of Cs-137
at 3-4 m depth in 1999

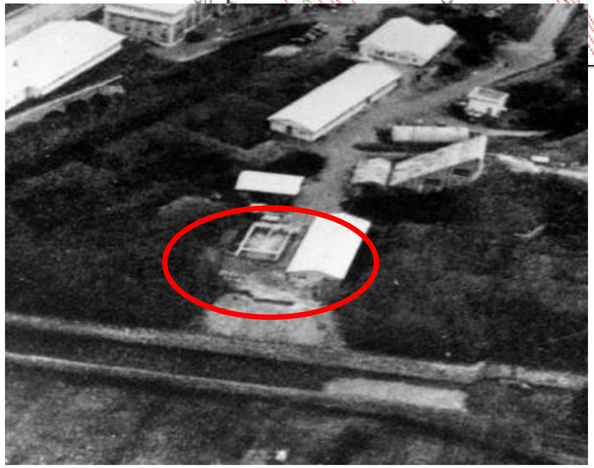
Investigations



Volumes with
existing data in 2007

Historical (bis)



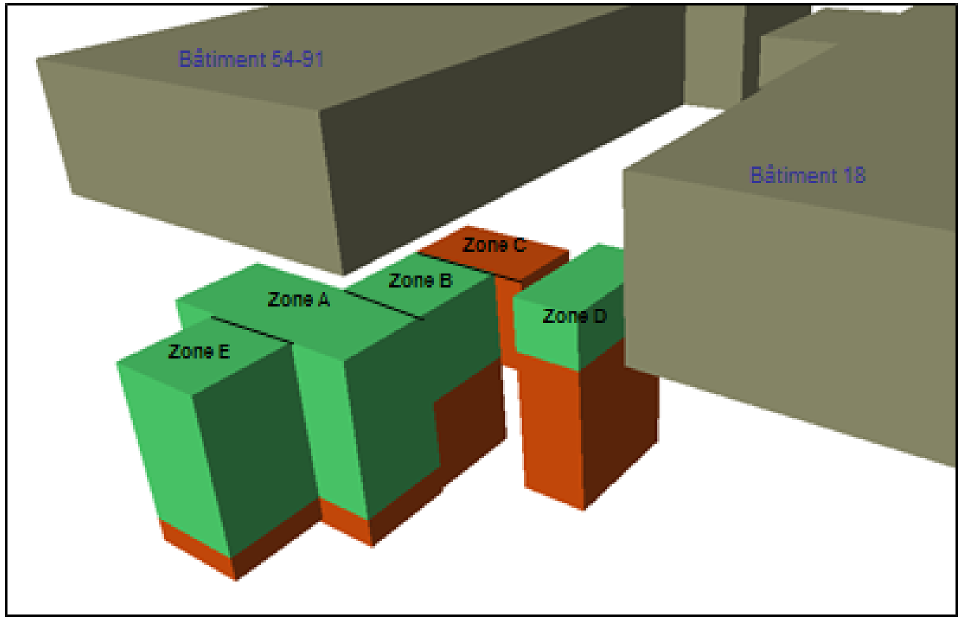


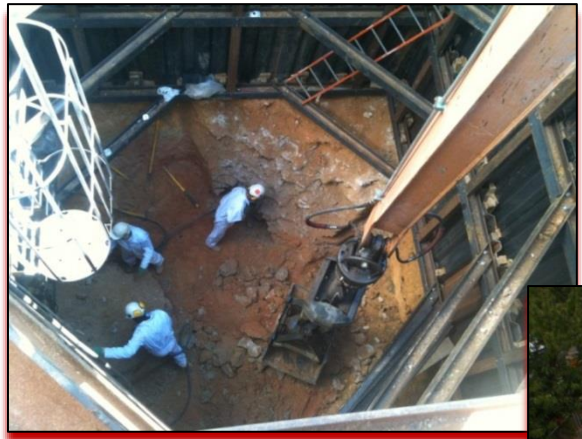
Geovariances

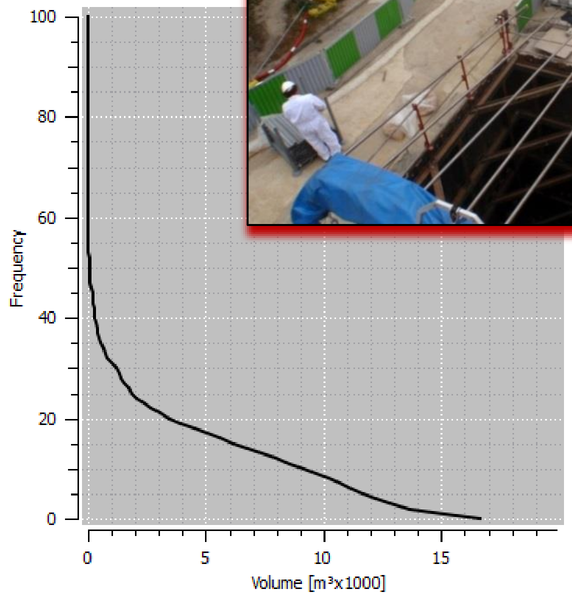
Former moat (CEA Fontenay-aux-Roses)

Geovariances

Former moat (CEA Fontenay-aux-Roses)





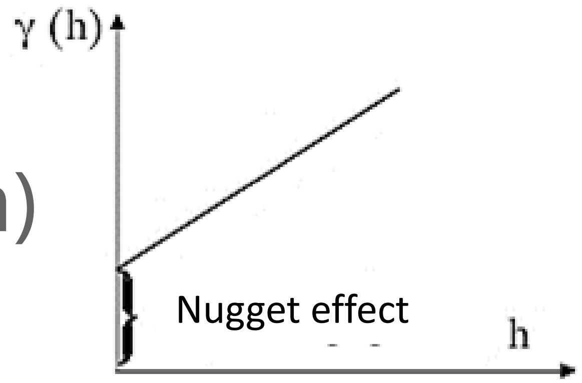


- 2000 m^3 of conventional waste
- 2000 m^3 of Very-Low-Level waste

Smart use of the variogram to explore spatial data, to break down variance contributions and to model radiological contaminations

Geovariances
Where no one has gone before

Precisions on nugget effect



Random contribution (no spatialisation)

Possible origins of nugget effect

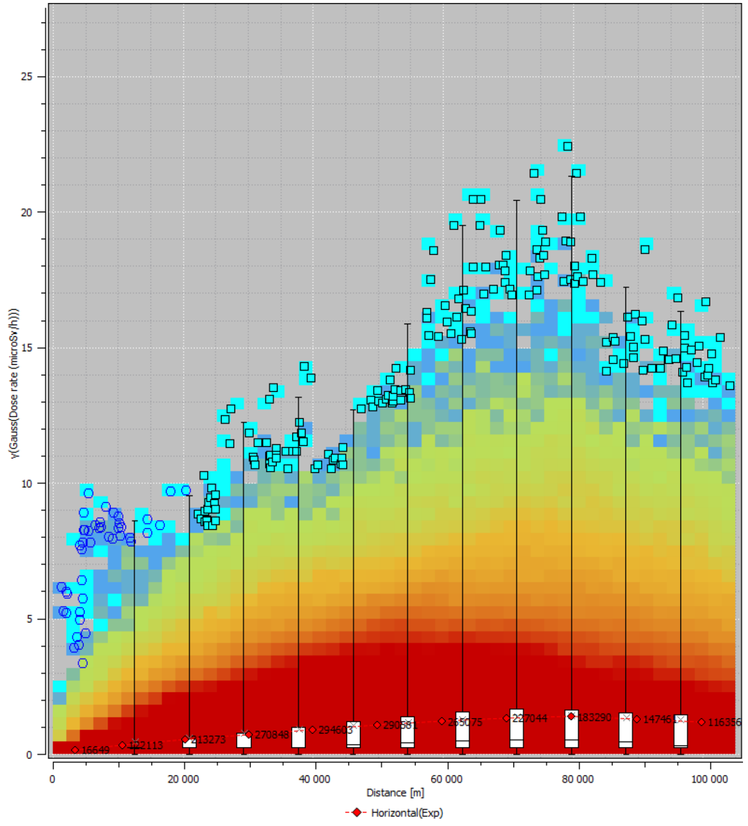
Phenomena
- Huge heterogeneity at small scale
- Perturbation of the environment during the sampling

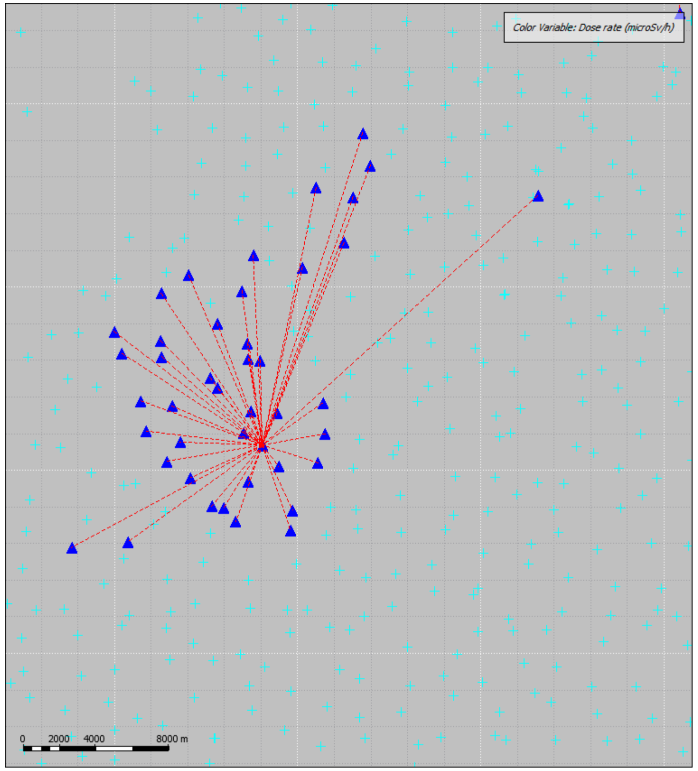
Metrology
- Measurement uncertainty or laboratory uncertainty
- Successive measurements are not identical (temporal fluctuation for dose rate for instance)

Location
- Errors and uncertainties of positioning (GPS)
- Height variation, matrix…

Identification of spatial outliers

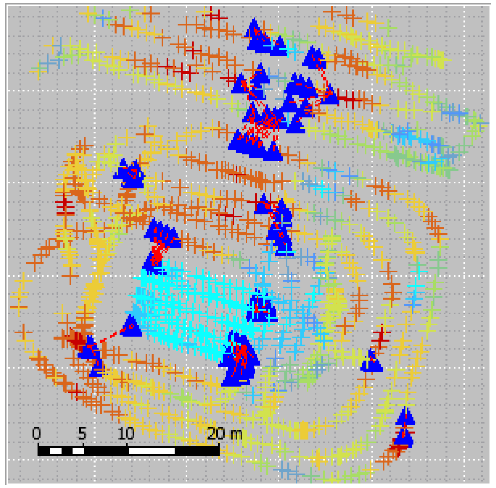
Spatialy close pairs of points but with high variability on the variogram cloud

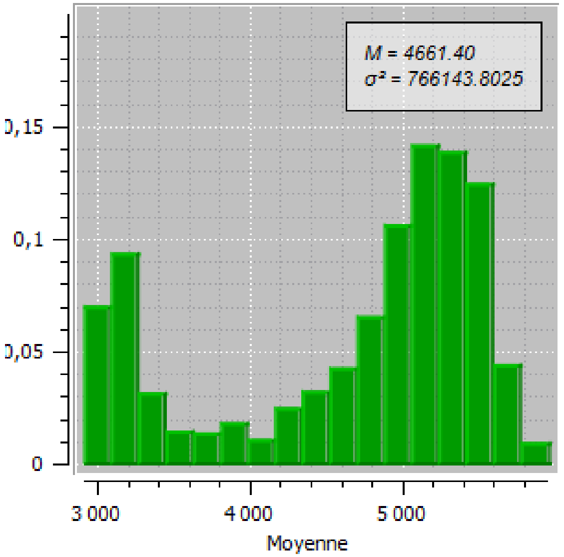


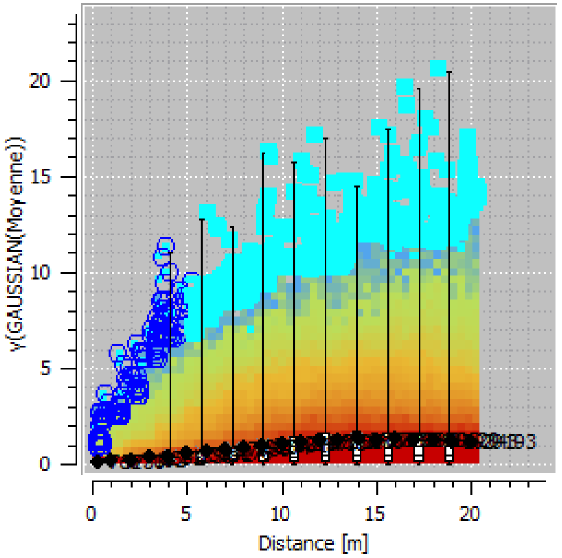


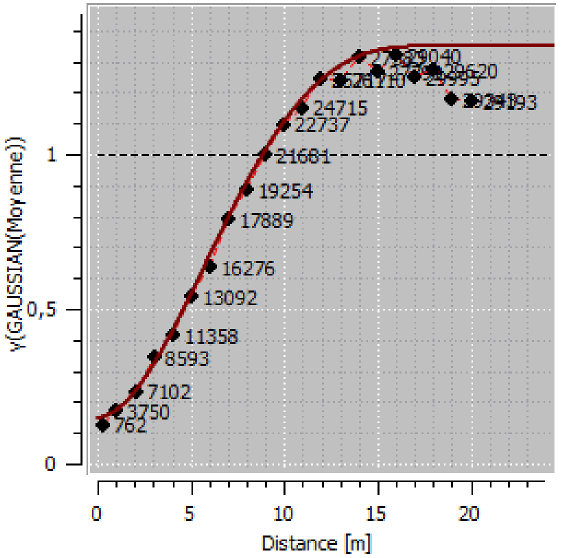
Back to exploratory data analysis

Soil composition
and GPS issues



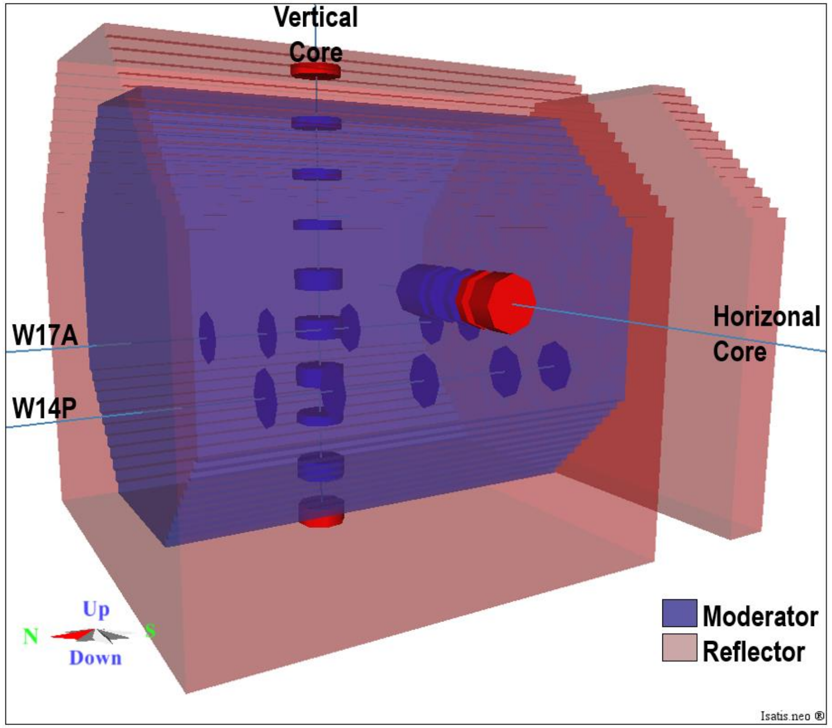


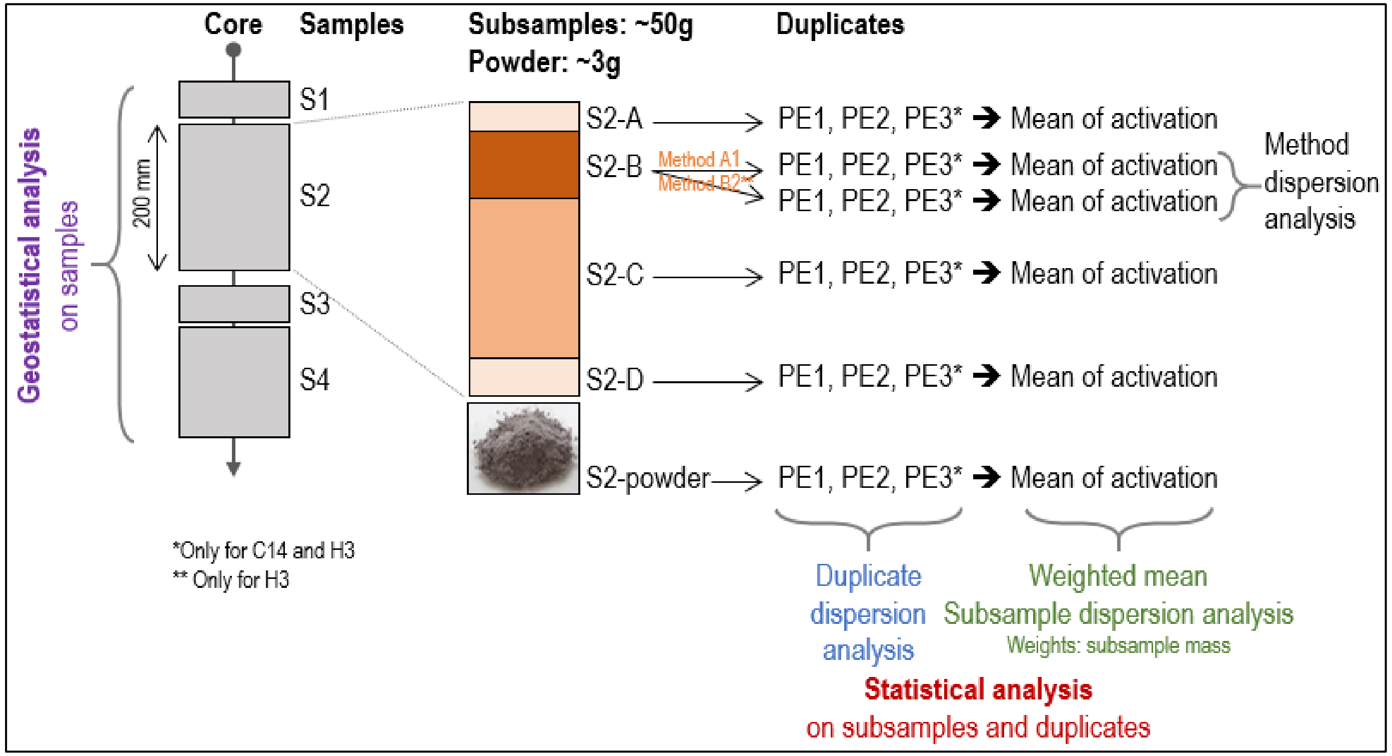




Geovariances

Variance decomposition (CEA G2 dataset)





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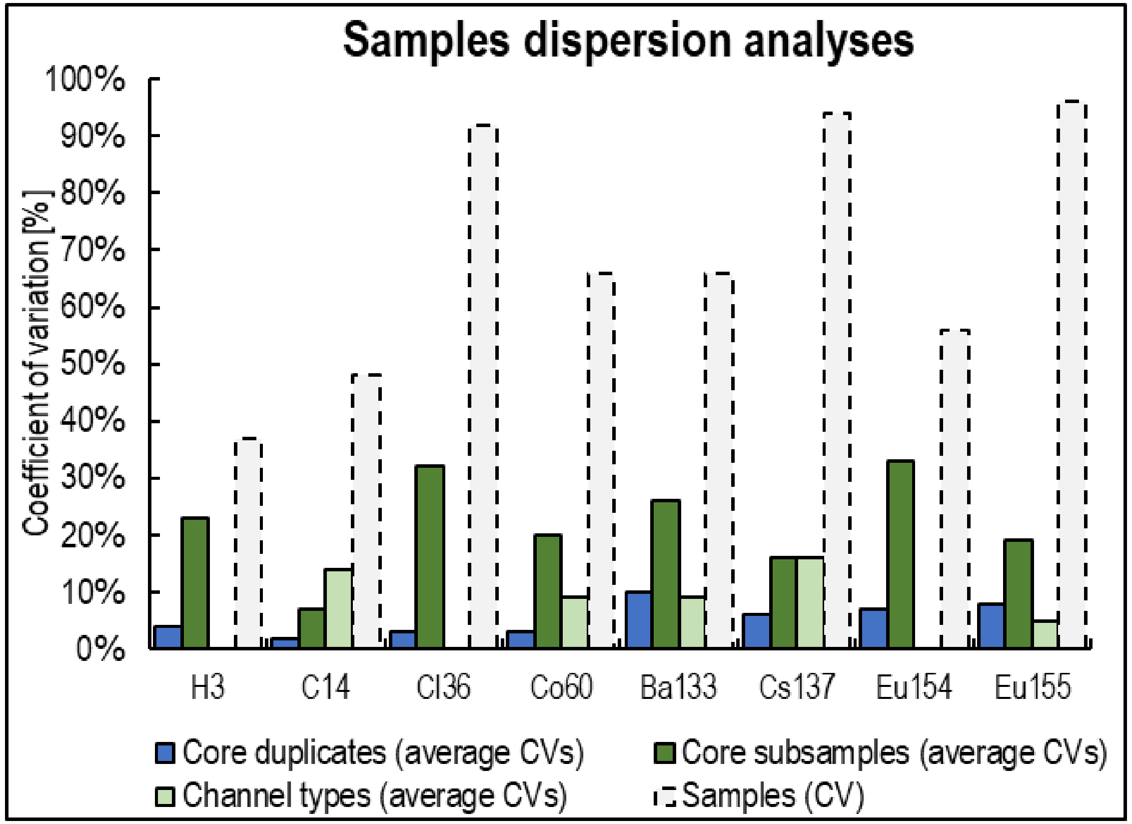
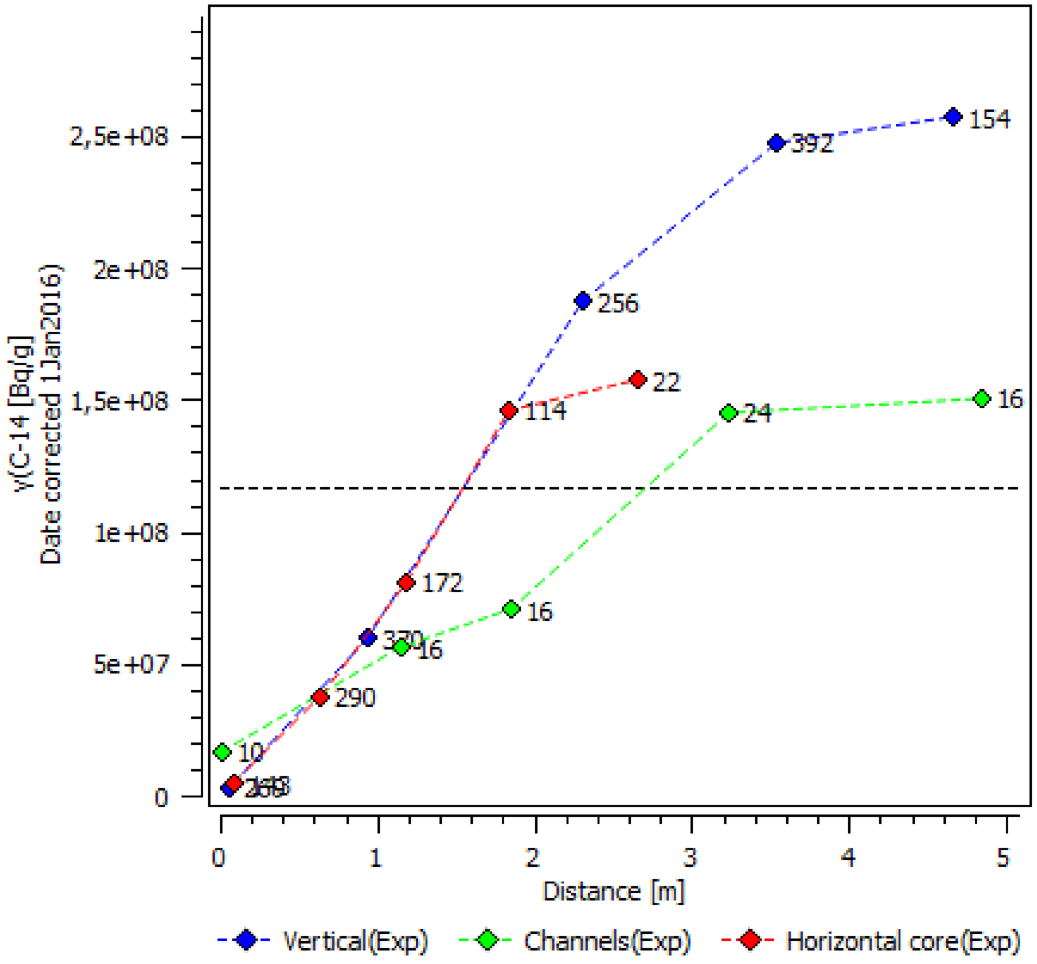
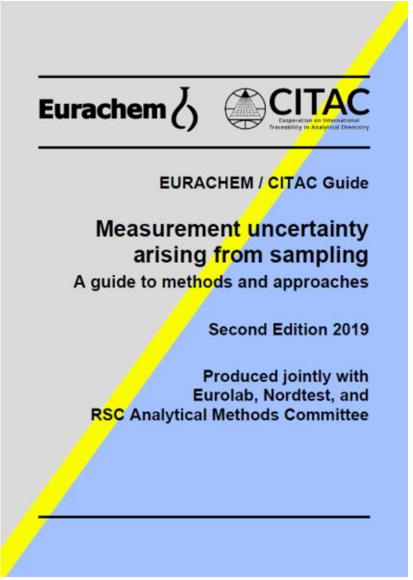




Variance decomposition (Eurachem dataset)



100 Samples (p45)

Table A2.1: Measured lead concentrations at each target on the sampling grid (mg kg^{-1}), shown by the actual coordinates used in the regular sampling grid (spacing 30 m) [56]. They show a high degree of variability between-locations of roughly a factor of 10. The variability within 10 of these locations selected at random (i.e. A4, B7, C1, D9, E8, F7, G7, H5, I9 and J5) was used for the estimation of uncertainty from sampling (Table A2.2). This within-target variation is substantial (e.g. a factor of 2) but substantially less than the between-target variability.

Row	A	B	C	D	E	F	G	H	I	J
1	474	287	250	338	212	458	713	125	77	168
2	378	3590	260	152	197	711	165	69	206	126
3	327	197	240	159	327	264	105	137	131	102
4	787	207	197	87	254	1840	78	102	71	107
5	395	165	188	344	314	302	284	89	87	83
6	453	371	155	462	258	245	237	173	152	83
7	72	470	194	82.5	162	441	199	326	290	164
8	71	101	108	521	218	327	540	132	258	246
9	72	188	104	463	482	228	135	285	181	146
10	89	366	495	779	60	206	56	135	137	149

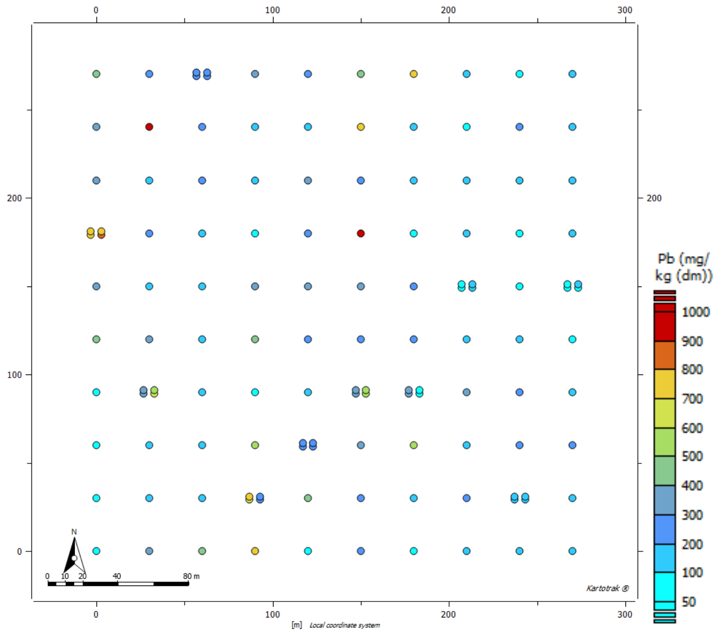
2x2x10 Replicates (p46)

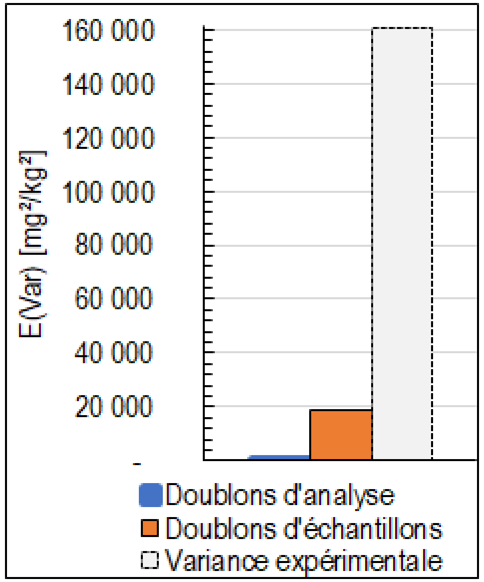
Table A2.2: Measurements of the concentration (mg kg^{-1}) of a lead on 10 duplicated samples from the total of 100 targets in a survey of contaminated land (Table A2.1) [56]. The duplicate samples are labelled S1 and S2. Likewise, duplicate analyses are labelled A1 and A2. Hence, D9S1A2 (value 702 mg kg^{-1}) is analysis 2, from sample 1 from sampling target D9. Values shown are rounded for clarity, and used for subsequent calculations, but generally un-rounded values are preferable for these calculations.

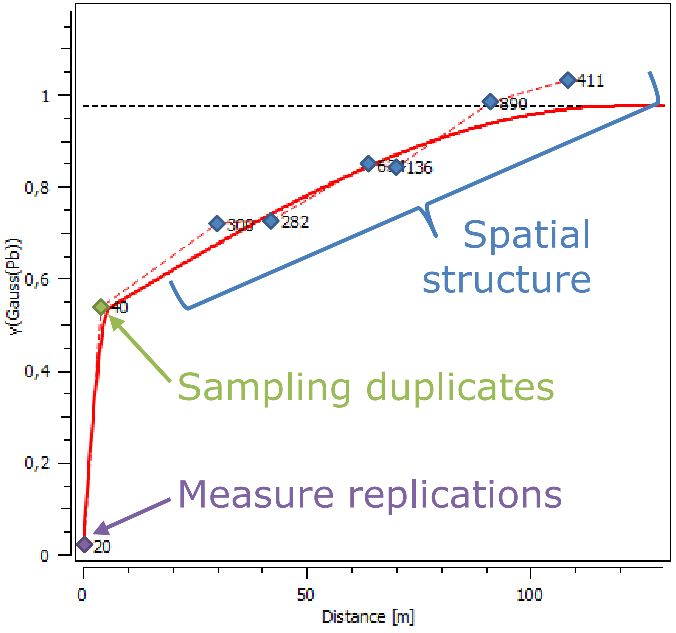
Sample target	S1A1	S1A2	S2A1	S2A2
A4	787	769	811	780
B7	338	327	651	563
C1	289	297	211	204
D9	662	702	238	246
E8	229	215	208	218
F7	346	374	525	520
G7	324	321	77	73
H5	56	61	116	120
I9	189	189	176	168
J5	61	61	91	119

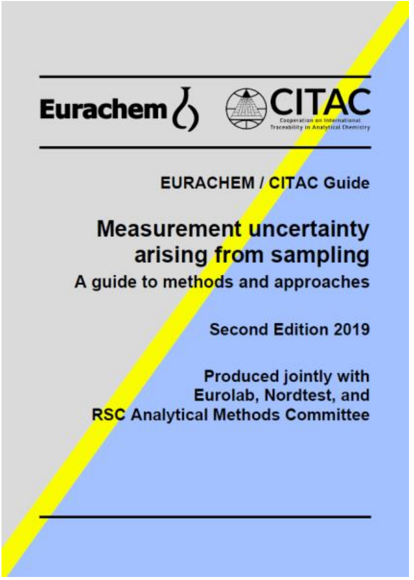
Geovariances

Variance decomposition (Eurachem dataset)



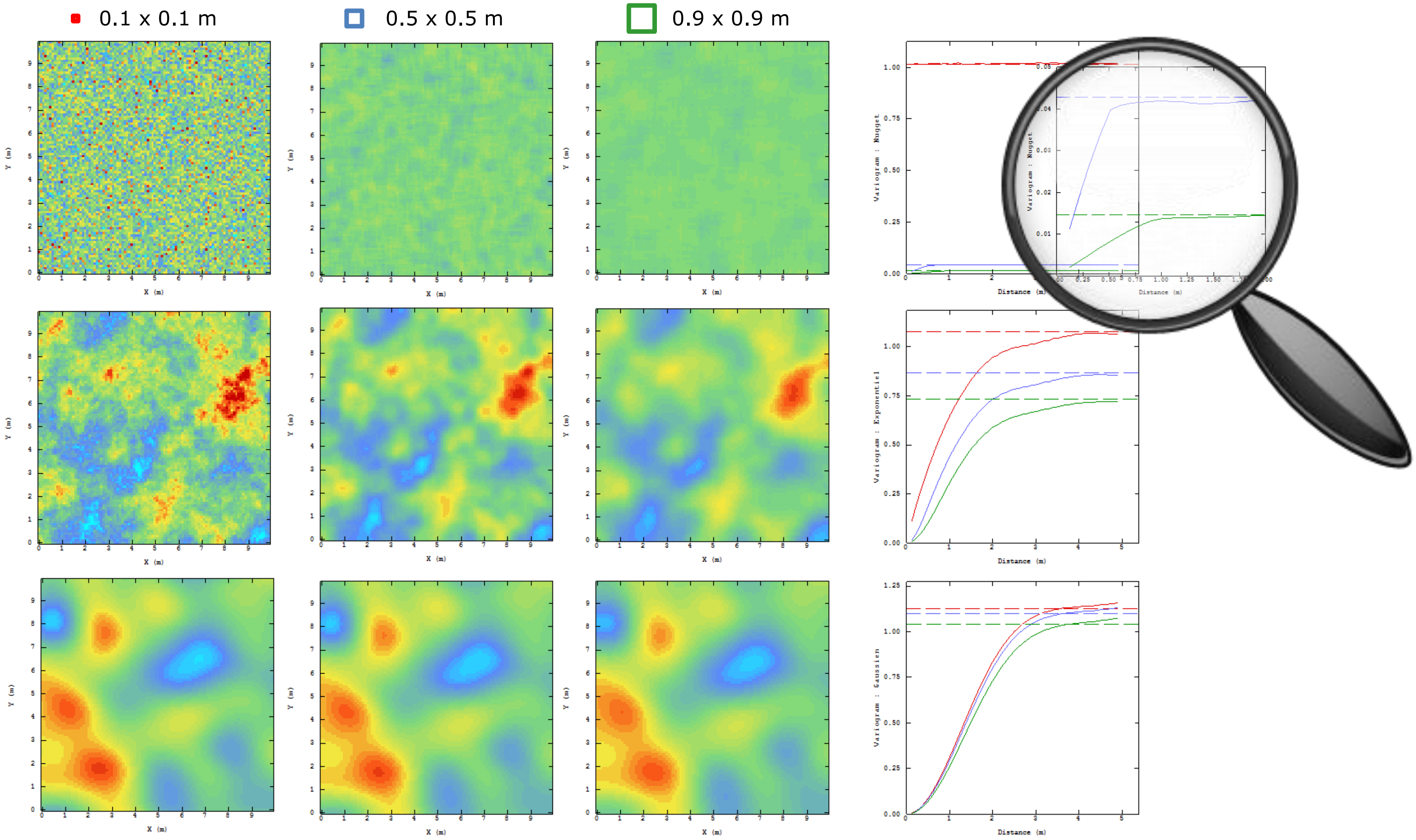






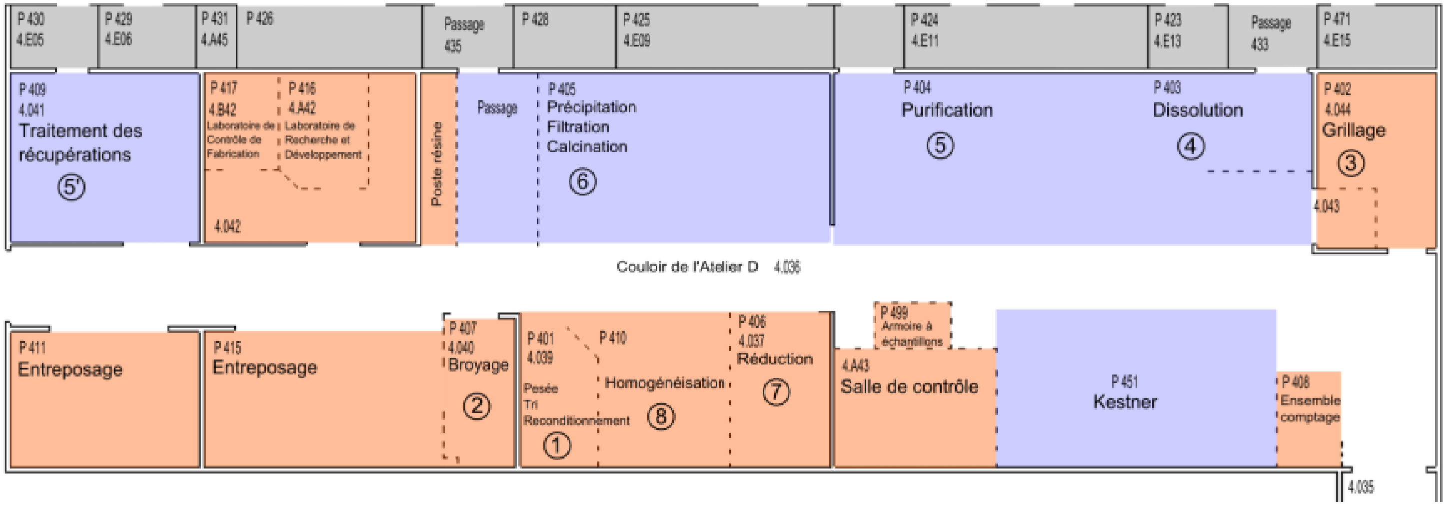
Geovariances

Support effect and spatial structure



Multivariate geostatistics: Case presentation

Workshop D of ATUE facility (CEA Cadarache)
Historical and functionnal analysis



Production of metallic uranium, then uranium oxides

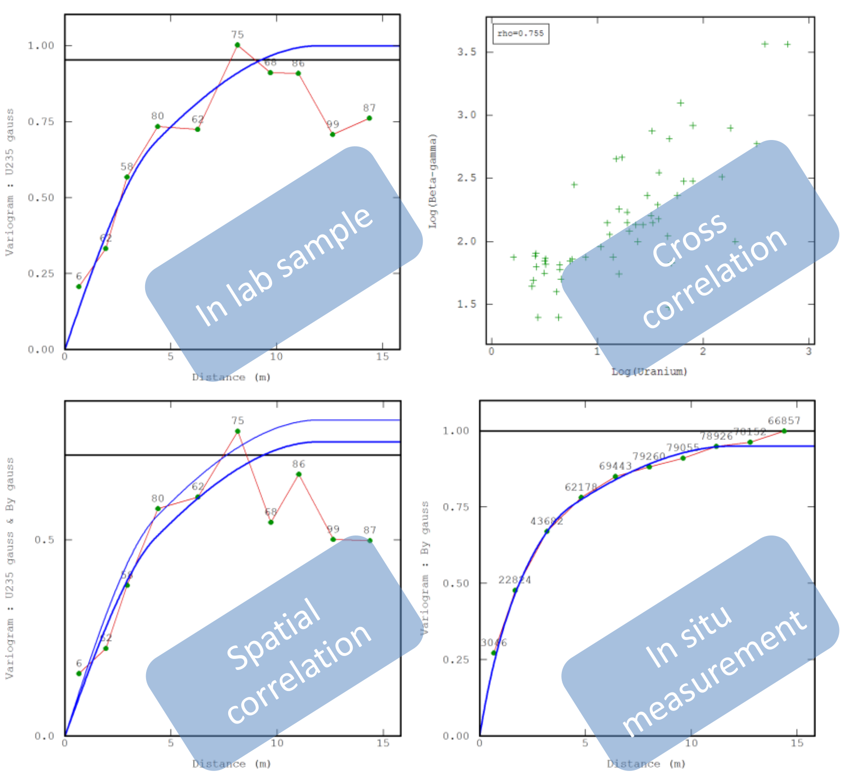
Two physical states of uranium : dry way / wet way

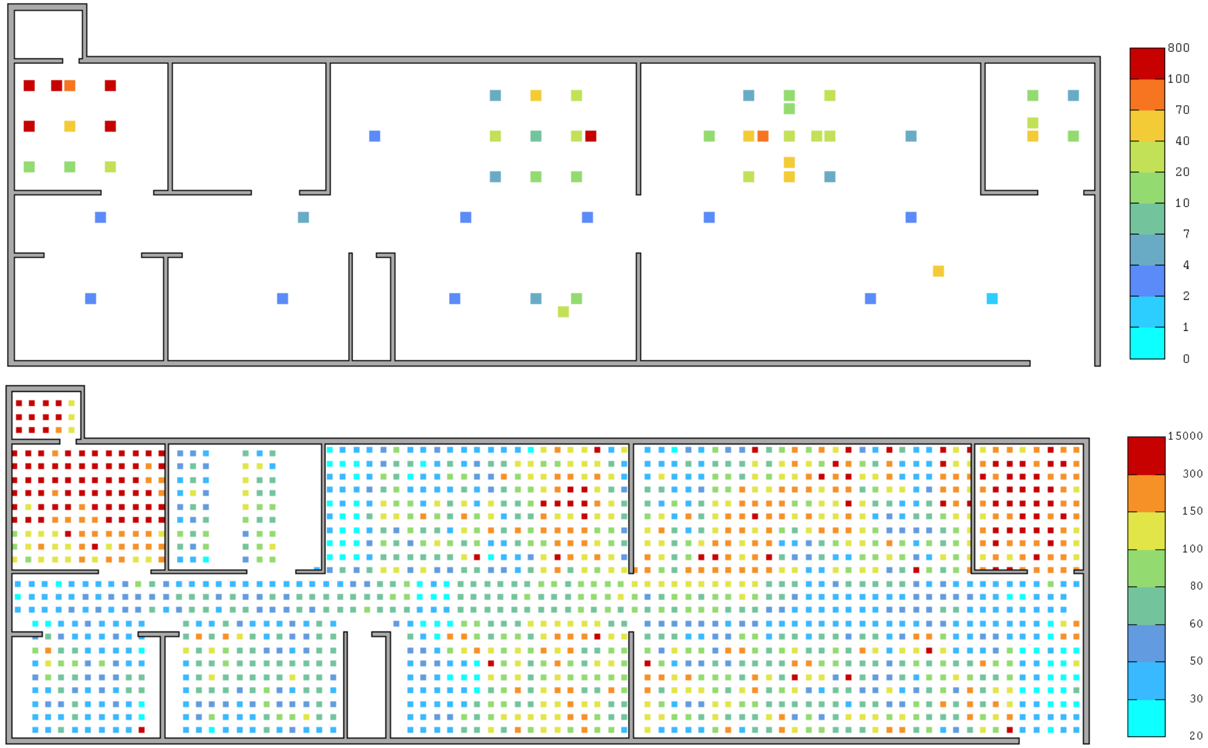
800 m²

Multivariate geostatistics: Variography analysis

Coupling between different radiological investigations

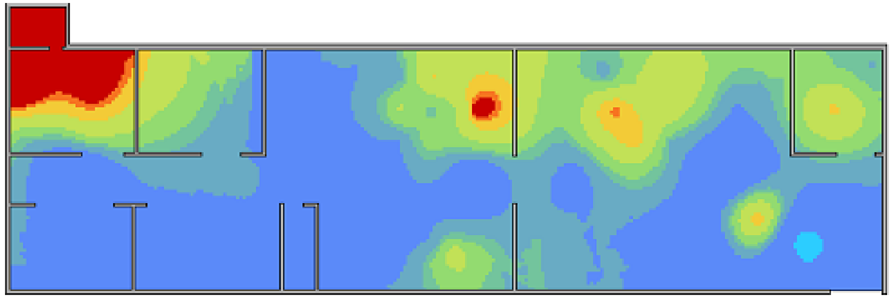
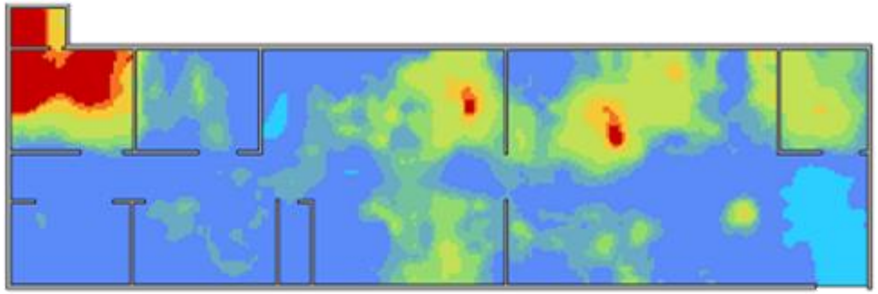
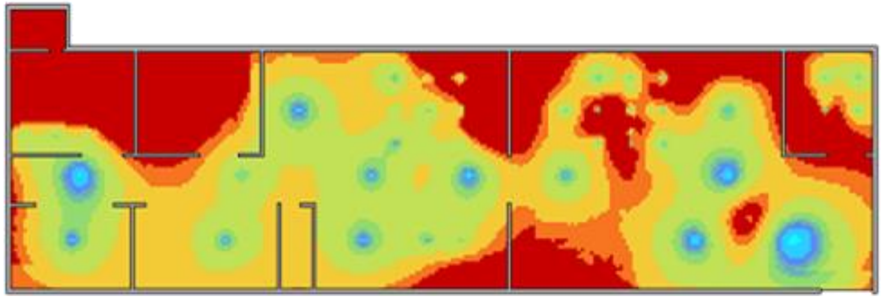
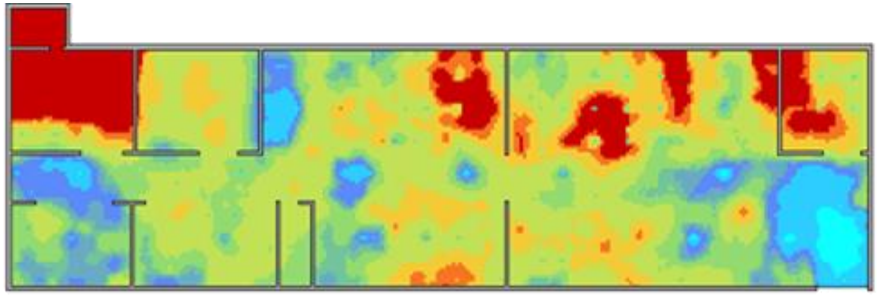
Cross-variogram: $$\gamma_{z_1 z_2}(h) = \frac{1}{2} E\{[z_1(x+h) - z_1(x)][z_2(x+h) - z_2(x)]\}$$

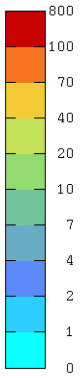




Geovariances

Multivariate geostatistics: Mapping comparison

	0 In lab data	+ In situ data
Z*		
[..]		



Geovariances

Smart use of the variogram to explore spatial data, to break down variance contributions and to model radiological contaminations

Geovariances
Where no one has gone before

Investigation optimisation

Initial mesh determination

- Geometrical context
- Historical analysis
- Feedback on spatial structures
- Target size

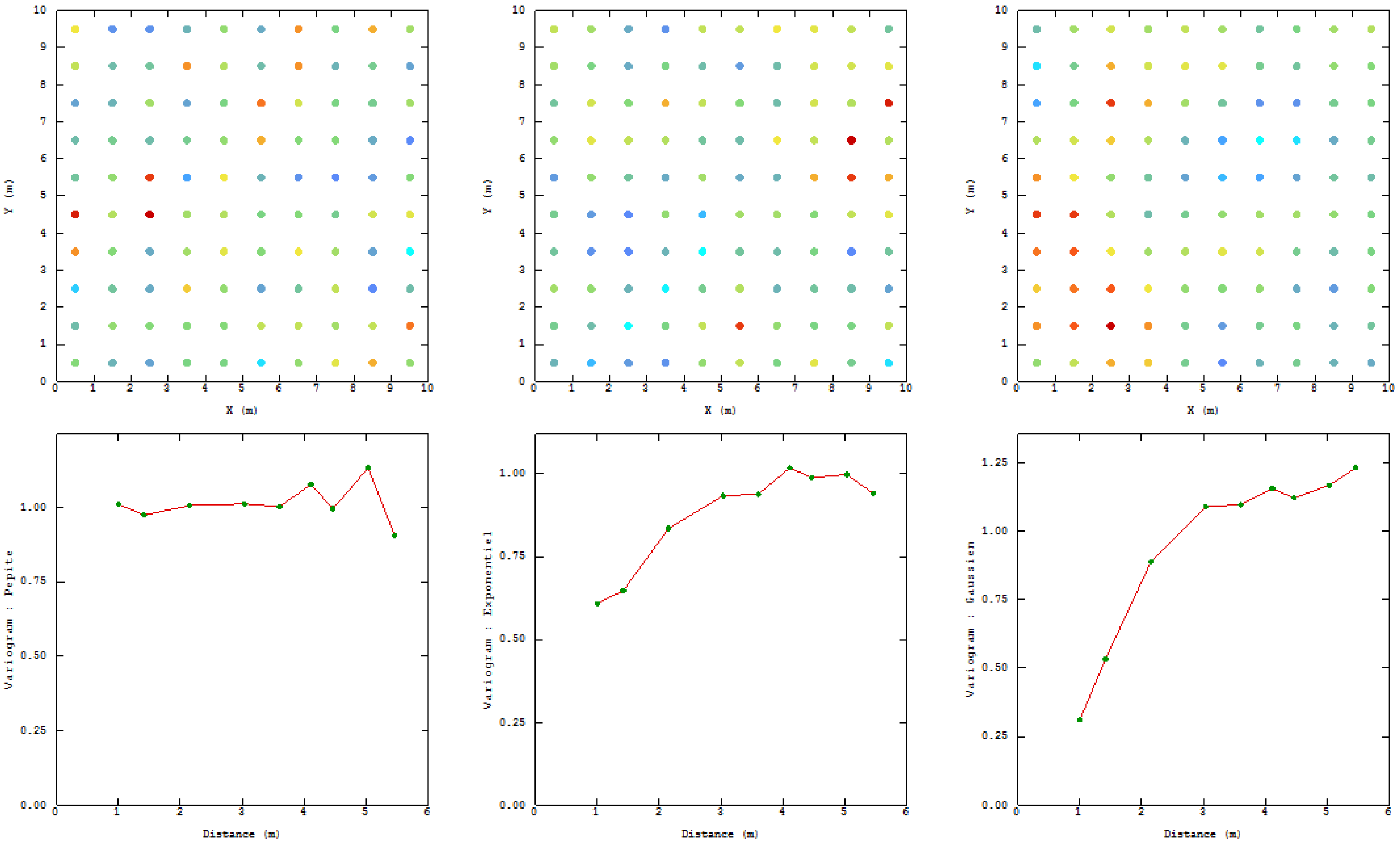
Adding extra measurements

- Uncertainty reduction
- Manual approach
- Automatic algorithm

Positioning of destructive samples

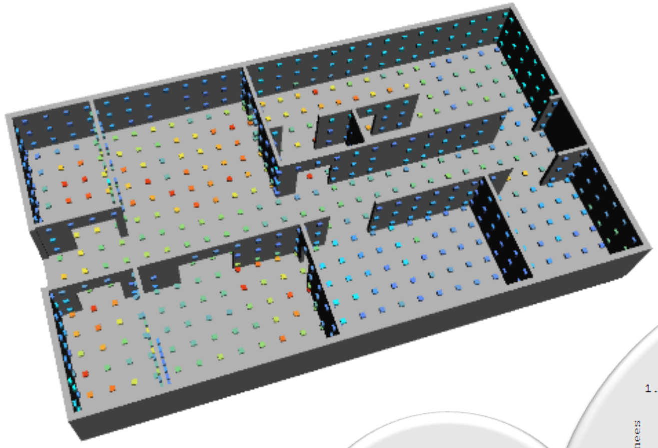
- Correlation with surface maps
- Specific vertical recommendations
- Feedback on migration profiles

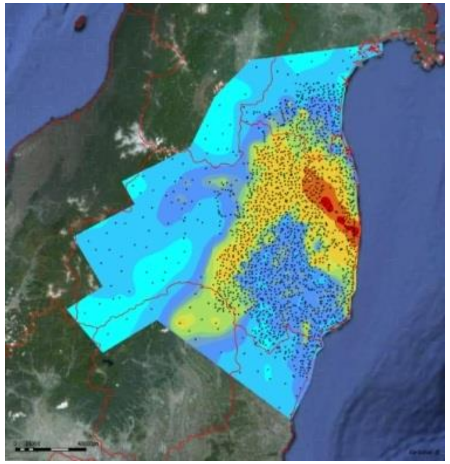
Experimental variograms with 1 m mesh

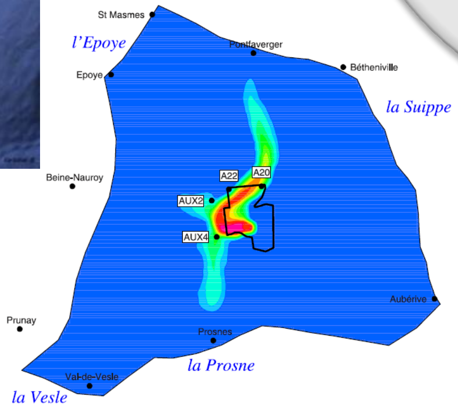


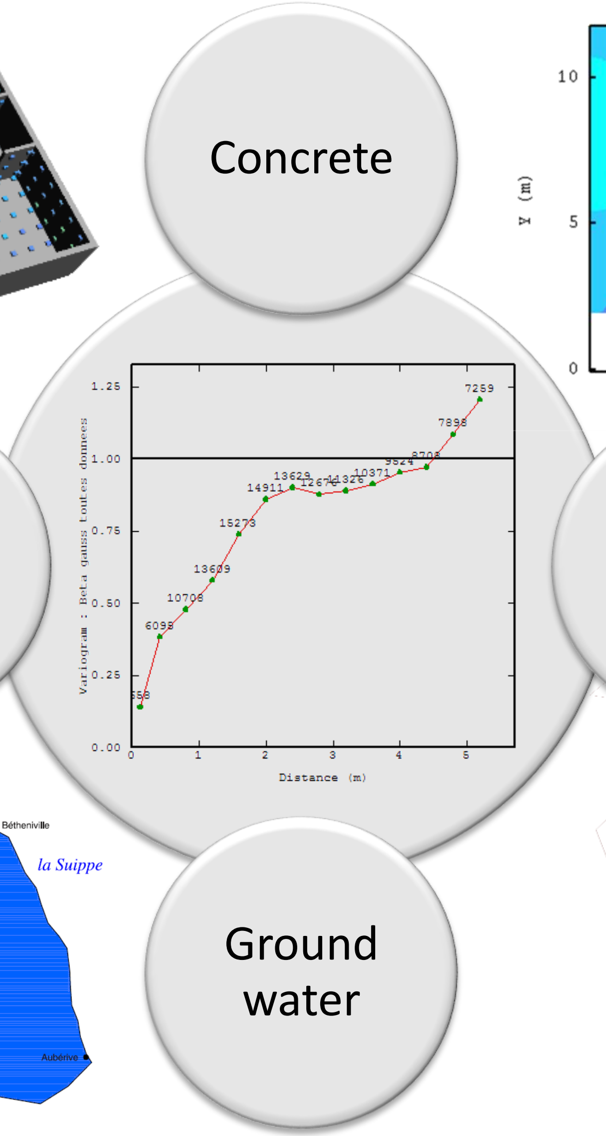
Geovariances

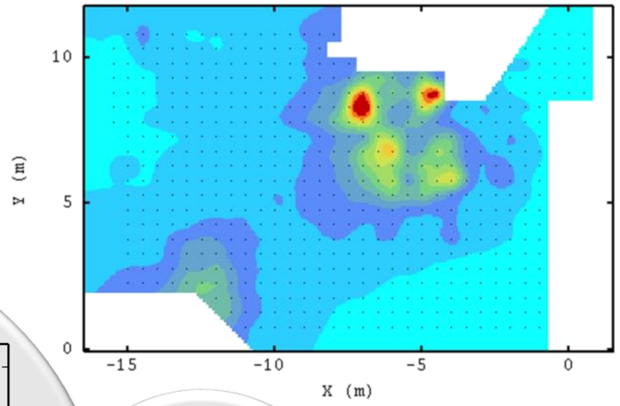
Geostatistics point of view

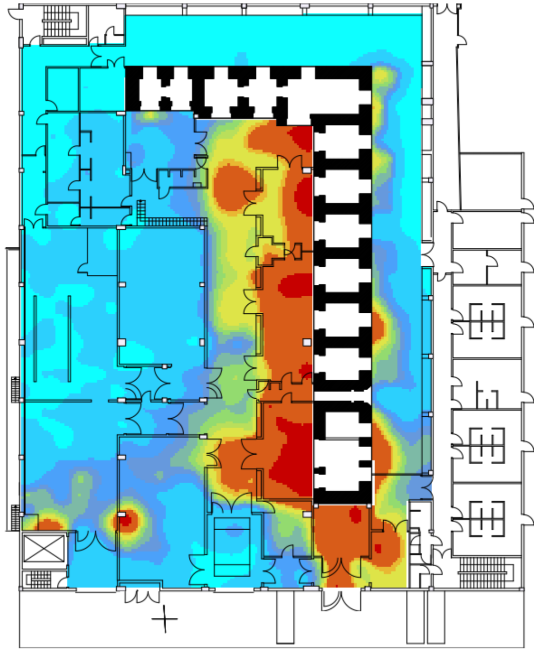


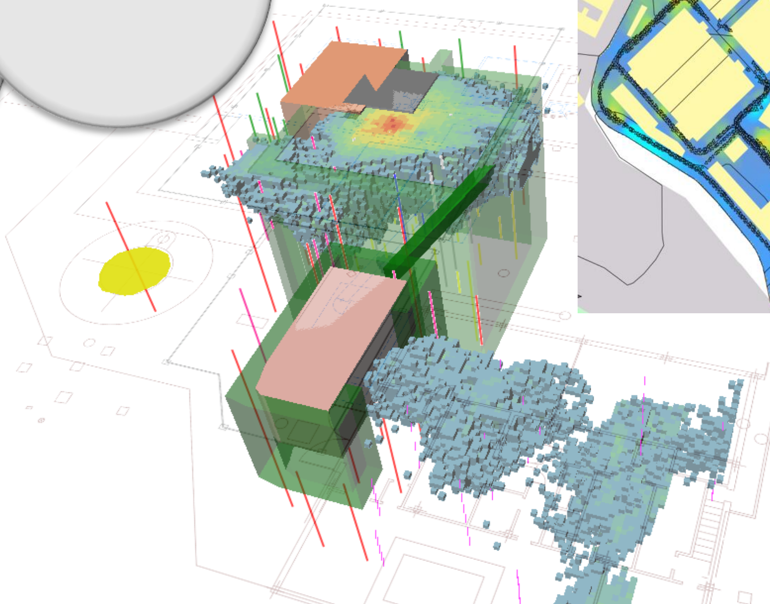


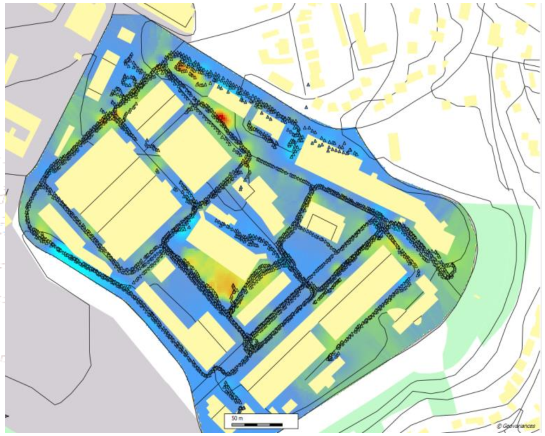








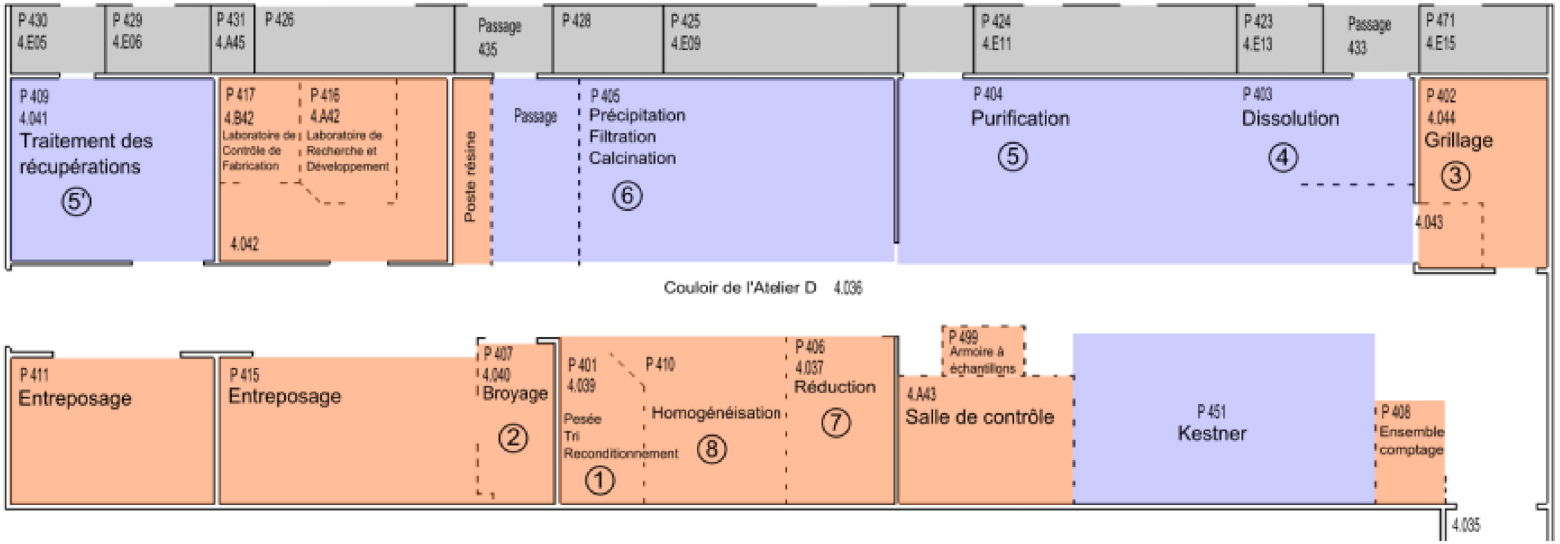




Geovariances

Narrative arc: Workshop D (ATUE – CEA Marcoule)

Historical and functionnal analysis



Production of metallic uranium, then uranium oxides

Two physical states of uranium : dry way / wet way

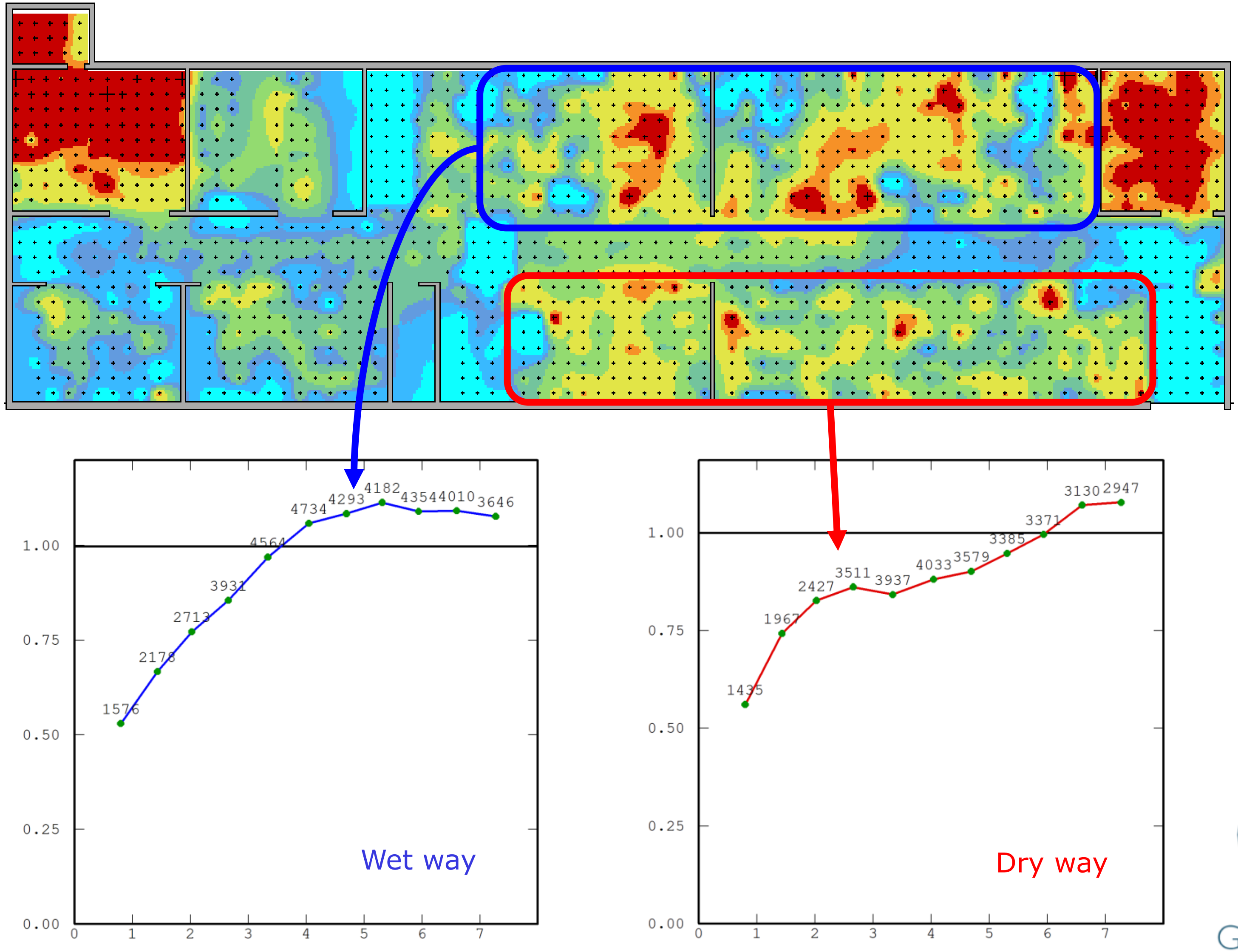
≈800 m² (54 m by 15 m)

Geovariances

Historical context

Different processes

Consequences on the sampling optimisation

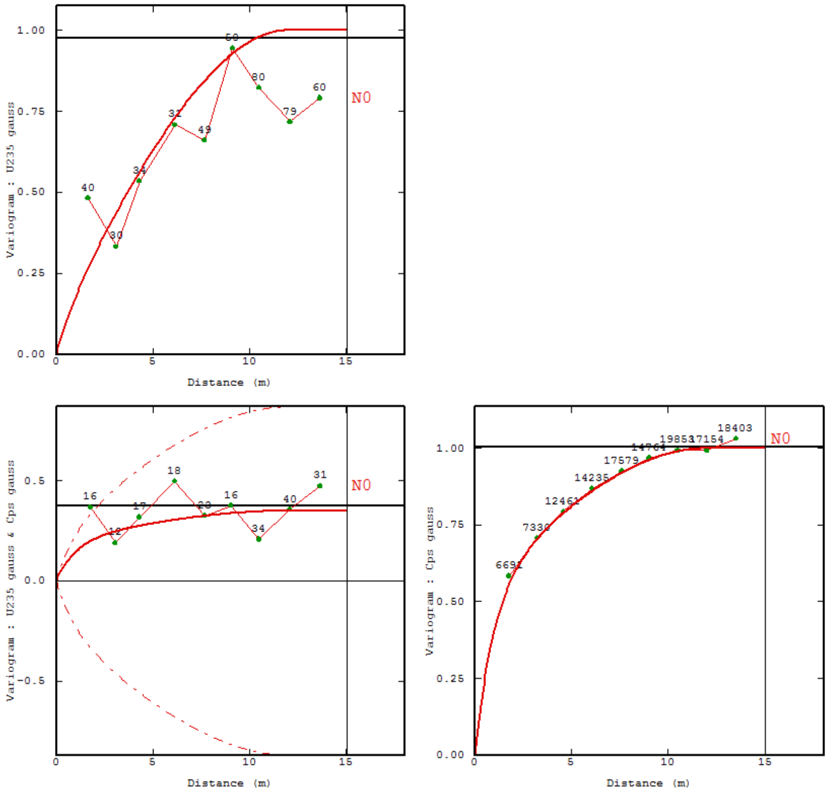


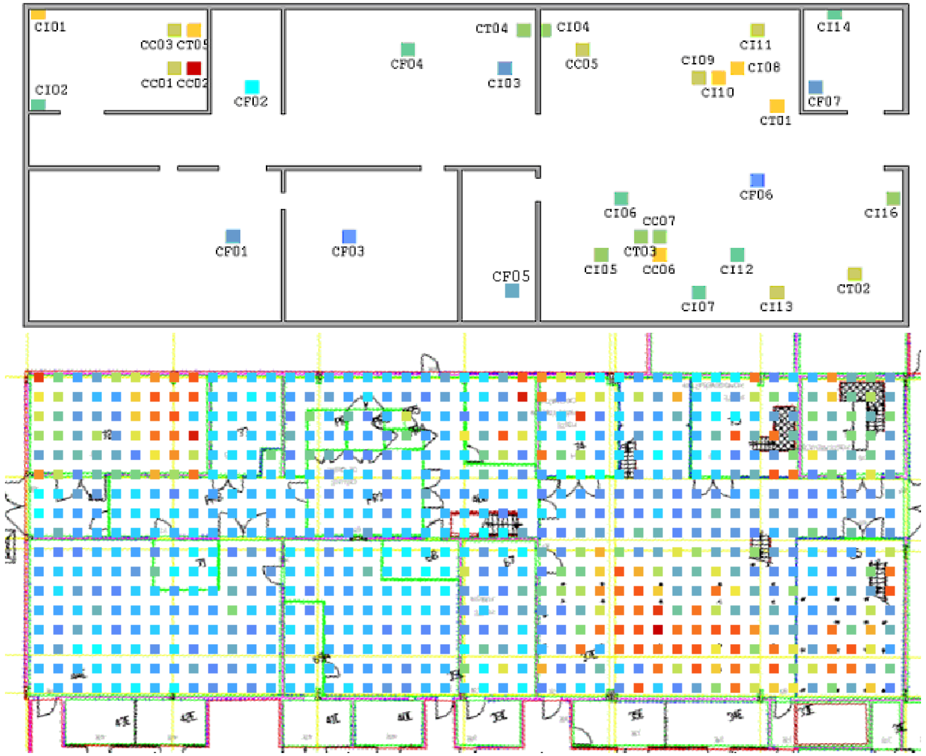
Geovariances

Positioning of destructive samples

Prior knowledge (incidents…)

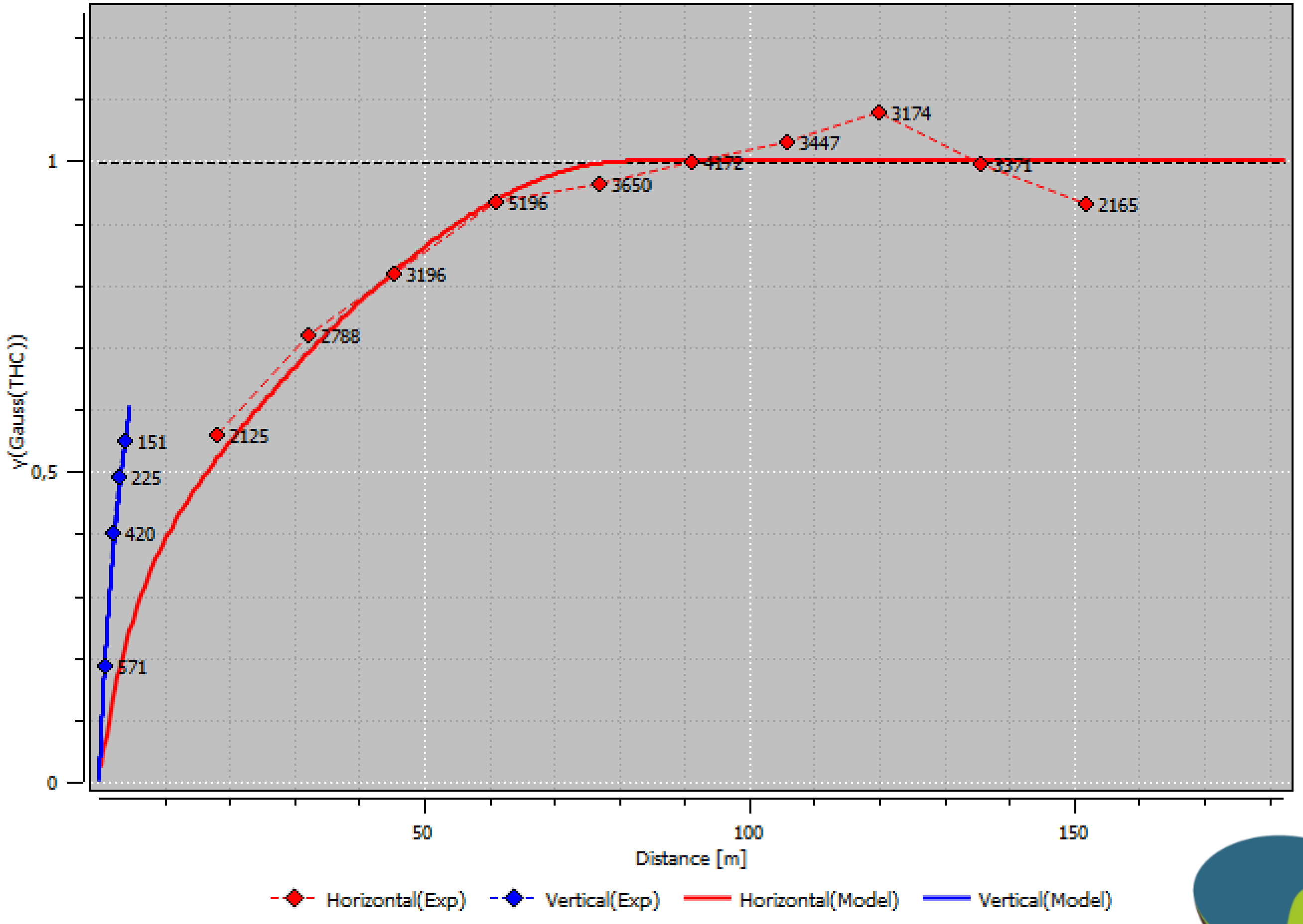
Multivariate with in situ mapping





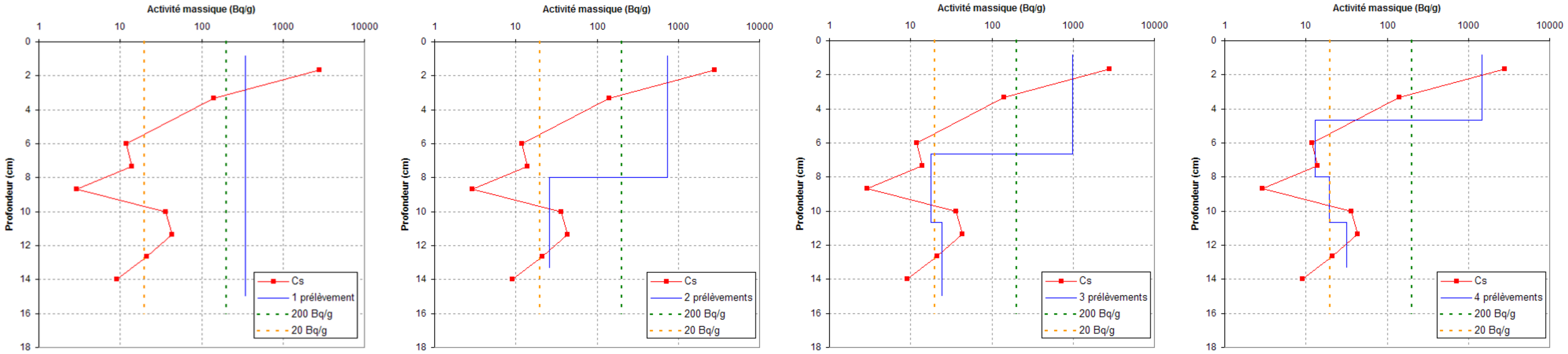
3D variogram and anisotropy

Generaly, the
vertical variability
(along-borehole)
is higher than the
horizontal one
(between-boreholes)



Additional comments

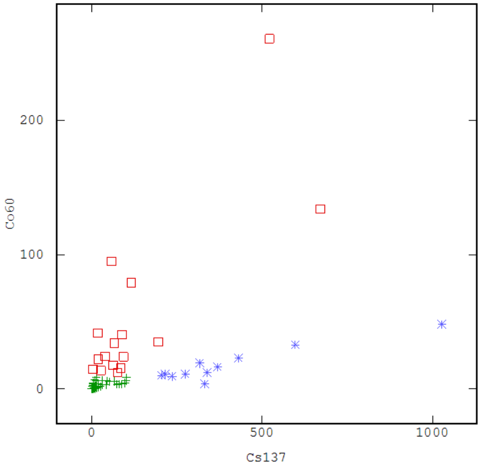
Migration profiles and vertical resolution



In lab analyses

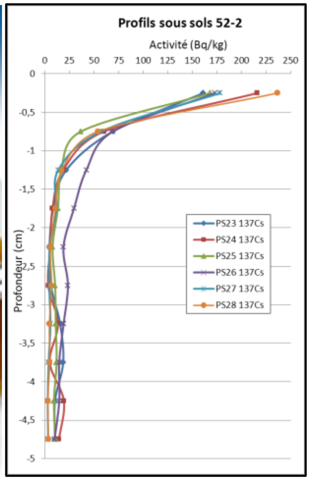
- Dose | Gamma | Beta | Alpha

Ratio variation
(both laterally and vertically)



Examples of vertical profiles

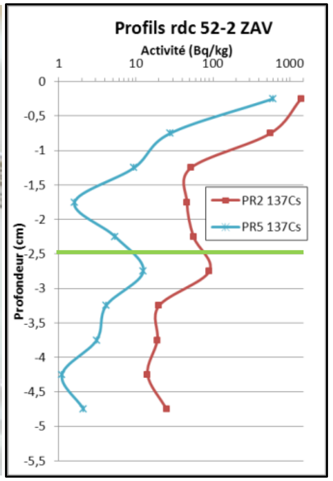
« Classical » shape



First mm (even cm) in concrete

A few tens of cm in soils

Several peaks



Lithology impact

Difference of concrete quality

Older contamination…

Geovariances

Smart use of the variogram to explore spatial data, to break down variance contributions and to model radiological contaminations

Geovariances
Where no one has gone before

Variogram, the smart tool

- To explore spatial data
  - Data errors, coordinates uncertainty
  - Quantification of the spatial correlation

- To break down variance contributions
  - Phenomenon, metrology, sampling issues
  - As regards spatial correlation

- To model radiological contaminations
  - 2D and 3D maps, along with estimation uncertainty
  - Taking spatial correlation into account

THANK YOU

Smart use of the variogram
to explore spatial data,
to break down variance contributions
and to model radiological contaminations

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Geovariances
Where no one has gone before