IN SITU RADIOLOGICAL ASSESSMENT of SOILS in CEA

AIEA - Meeting

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SUMMARY

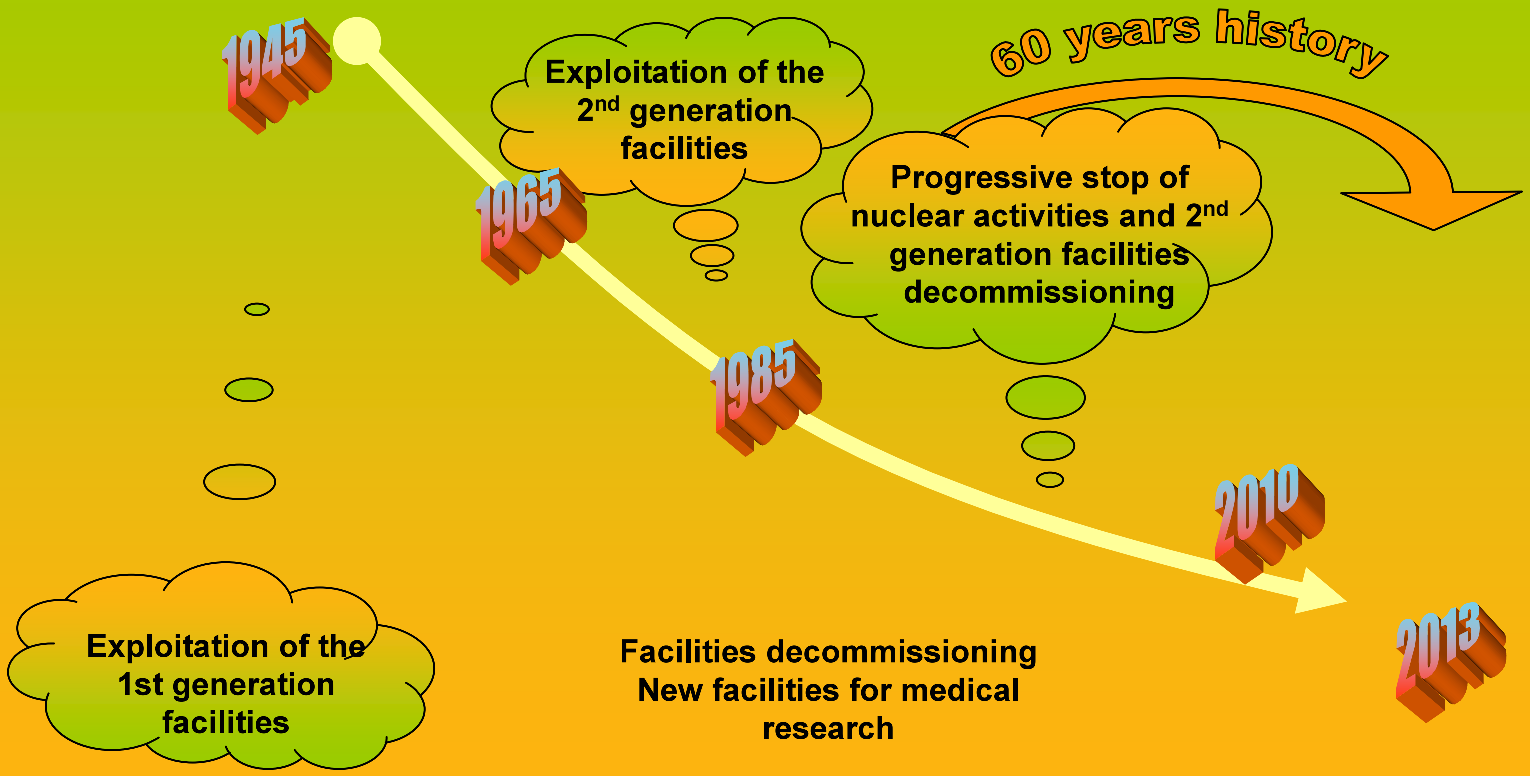
- Historical of CEA/Fontenay Centre
- Rules and clean up methodology
- Tools dedicated to the radiological characterization of contaminated sites
- Vehicle laboratory
  - Characterization with DSP and Spectrometry gamma in situ
  - Software developed by CEA Clean up Section
  - Sampling process and data processing by Geostatistical method
  - Optimized remediation and examples
  - Conclusions

The **CEA** of Fontenay-aux-Roses and the ***«CLEAN UP SECTION»***

CEA/FAR: 1st CEA Centre, created in 1945

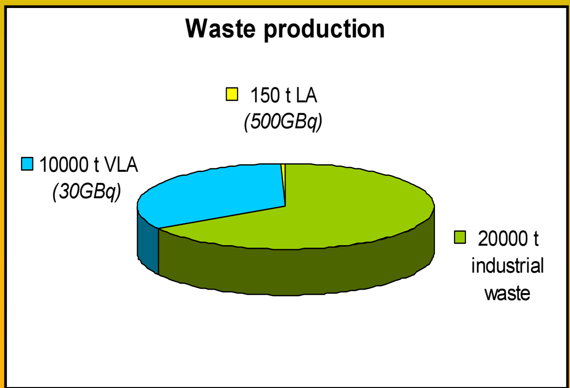
1999: Decision to clean up the site → Remediation Service: SAS

- Clean up of hazardous places done by 2012-2013
- Tools development dedicated to sites and soils remediation
- Expertise in French and foreign sites



METHODOLOGY

- **No remediation level in France for polluted site and sols**
- **No regulation for soil under and around nuclear facilities**
- **Optimizing the sanitary impact:**
  0,01 mSv/yr < Sanitary impact < 0,3mSv/yr
- **Necessity to have methods, procedures and reliable tools dedicated to sampling**



Clean up Process of CEA/FAR Site → 45 M€

Historical investigations

Area functional analysis
Data gathering

Radiological surface evaluation

Radiological in-depth evaluation
Chemical measures since 1998

Cost/advantages study

Optimized remediation

Final characterization

LABORATORY VEHICLE: LAMAS

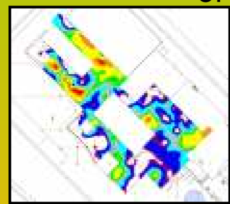
Weather measurements
Wind vane, anemometer, temperature sensor, pluviometer, relative humidity

Monitoring of radiological incidents
Wind scattering
Gas and aerosols activity measurements

Atmospheric measurements
Beacons to measure aerosols and ambient radiation.

Centralization of the measures in the front of the vehicle

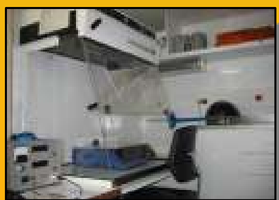
Differential GPS
with submetric accuracy



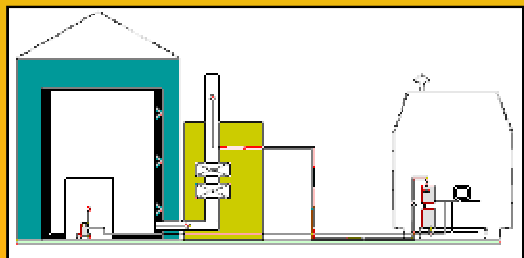
Data processing
through geostatistics

Gamma spectrometry *in situ*

Map making
Optimization of the sampling plan
Diffusion gradients



Samples treatment cell



Containment Room

Follow-up of the gamma environment.

Centralization and management of equipment and measurement operation

ACTINIDES MEASUREMENTS

Ground samples activity measured by in situ alpha spectrometry

Measurements are taken by a PERALS system, inside the convey.
It needs ventilation, a hotplate and centrifuge machine.

This alpha spectrometer has 3 characteristics:

The sample remains in liquid phase. No electrodeposition is necessary,

It uses a selective scintillating-extractant, reacting only with the targeted radioelement. There are different scintillating, according to the alpha transmitter to be measured,

Its output (> 99%) and the low background noise make it a good quality instrument for the search of actinide traces on the site.

Protocols of extraction (alpha totals, U+Pu, U or Pu), developed by BIII/DASE, allow to obtain, with sand or ground,
detection limits < 1 Bq/kg within < 24 hours.

Time needed for extraction:……………………………………………5 h
Counting time:………………………………………………………8 h

MESURING STRONTIUM-90

The Activity of samples of ground are measured by liquid scintillation

Strontium-90 is measured thanks to his descendant: yttrium 90, by liquid organically extraction. It requires a ventilated cupboard, a hotplate, a balance, a centrifuge and the Triathler (liquid scintillation measuring device).

The Sample is decontaminated beforehand by precipitating hydroxides with ammonia in chlorydric milieu. After regrowing from purified strontium-90, yttrium-90 is extracted in organical phase, then measured liquid scintillation.

The extraction protocol, for sand or dirt, gives detection limit of 30Bq/kg.

Manipulation time:…………………………………. 5 h
Time between the 2 extractions:……………….. 24 h
Counting time:……………………………………. 6 h

EXPERTISE VEHICLE: VEgAS

VEgAS is an expertise and investigation vehicle dedicated to radiological characterization of contaminated places

Vehicle

- 4WD vehicle
- Speed control system 2,6 ; 5 and 10km/h.
- Differential GPS with submetric accuracy.
- Dopler System

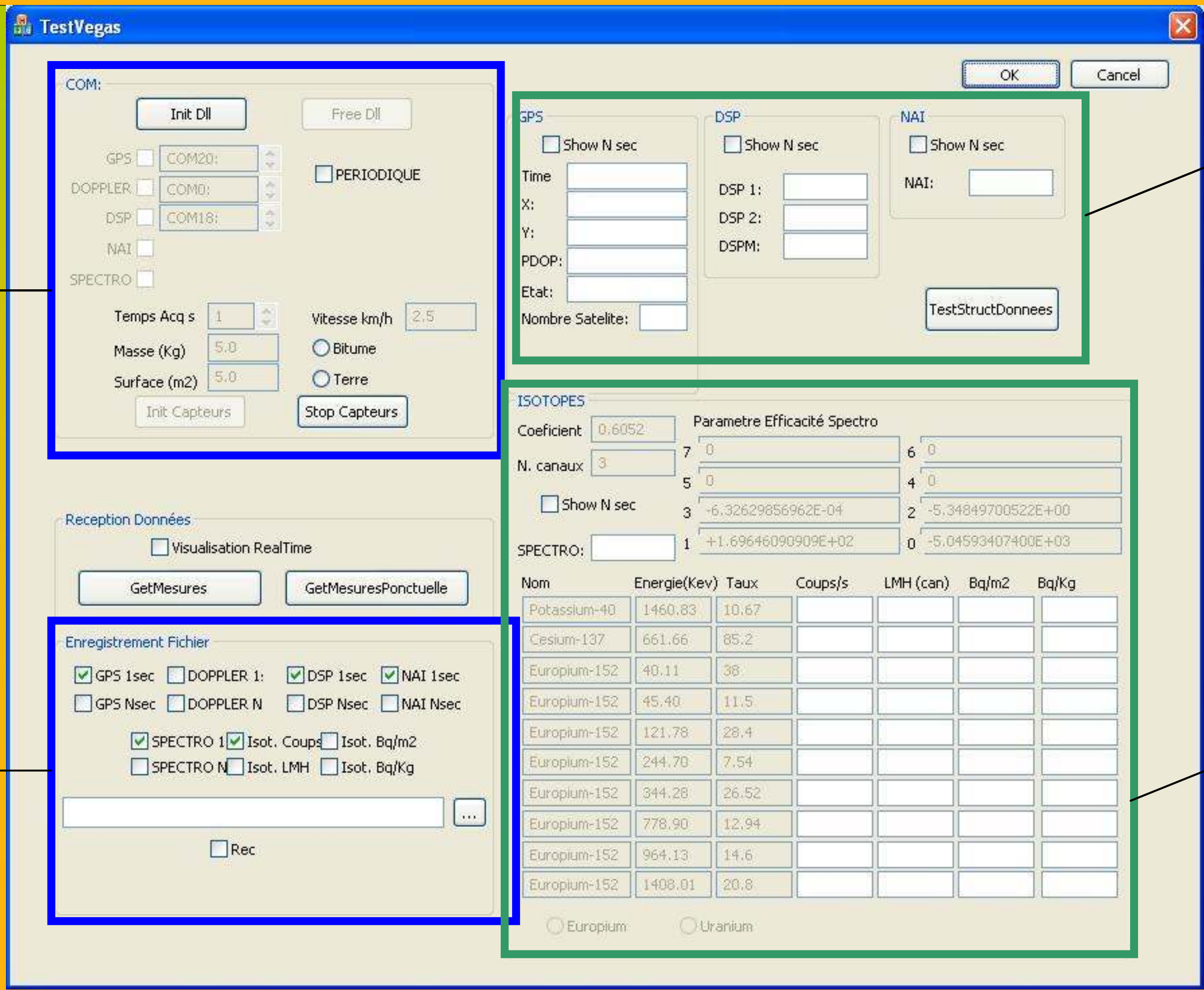
Instruments

- Hyper pure germanium detector, efficiency 30%
- NaI detector (crystal 2,4L)
- Two plastic scintillation detectors
- Centralization and supervision of the measures in the vehicle

REAL TIME ACQUISITION: COMPLETE CONFIGURATION

Choice of the instruments and measurement time. Initialization, reset…

Choice of the features for the data file



Displaying the data, each second

Displaying the cps of the selected isotopes measured by gamma spectrometry

REAL TIME ACQUISITION: FAST CONFIGURATION

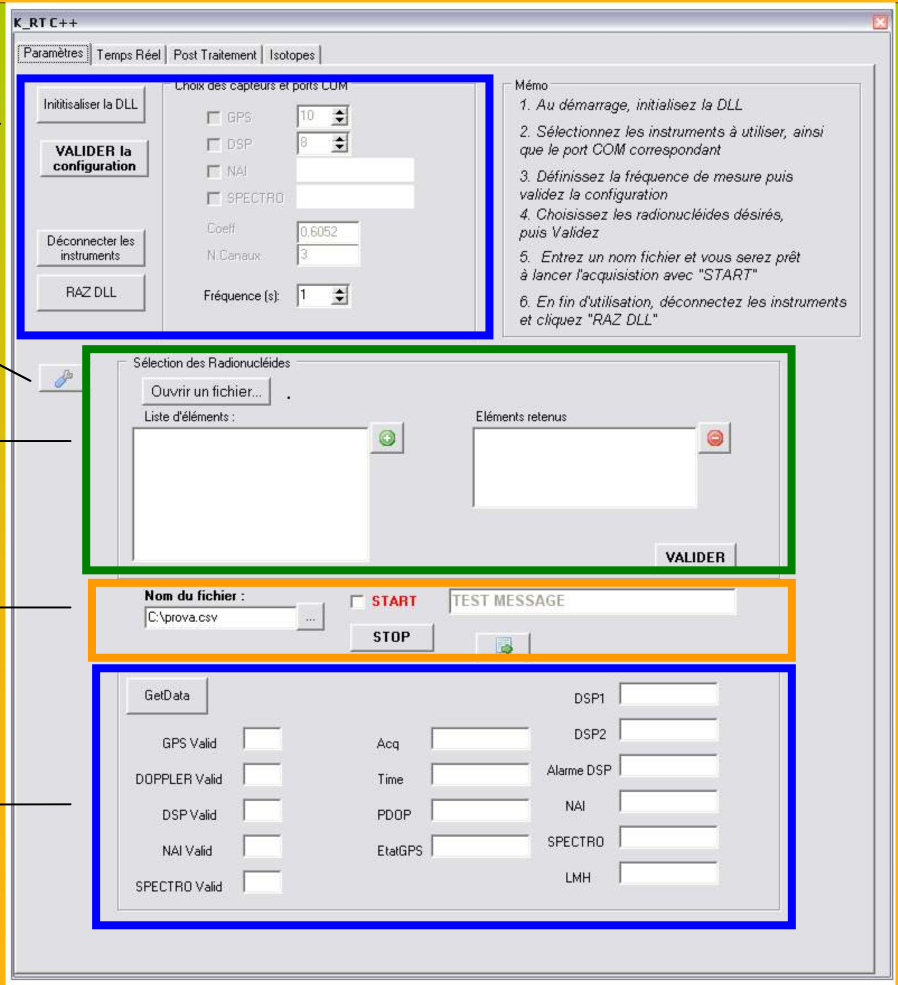
Choice of the instruments and measurement time.
Initialization, reset…

Automated
Configuration

Choice of the radionuclides to be measured

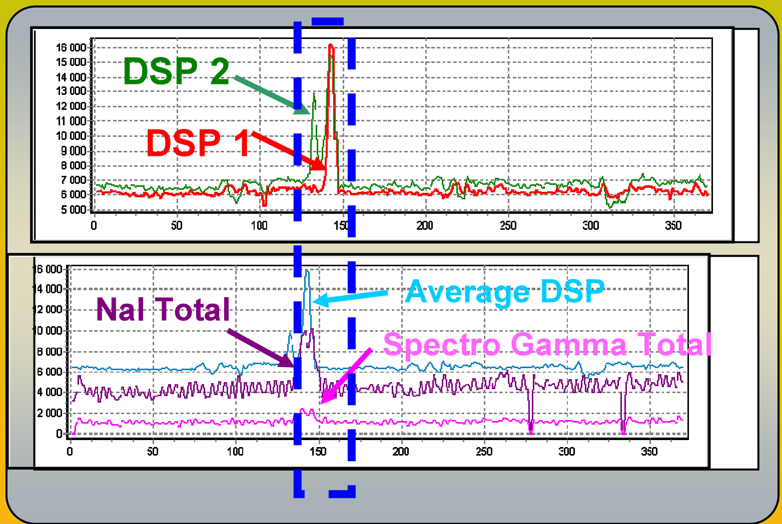
Choice of the file's name
Start the acquisition
Display of functioning messages

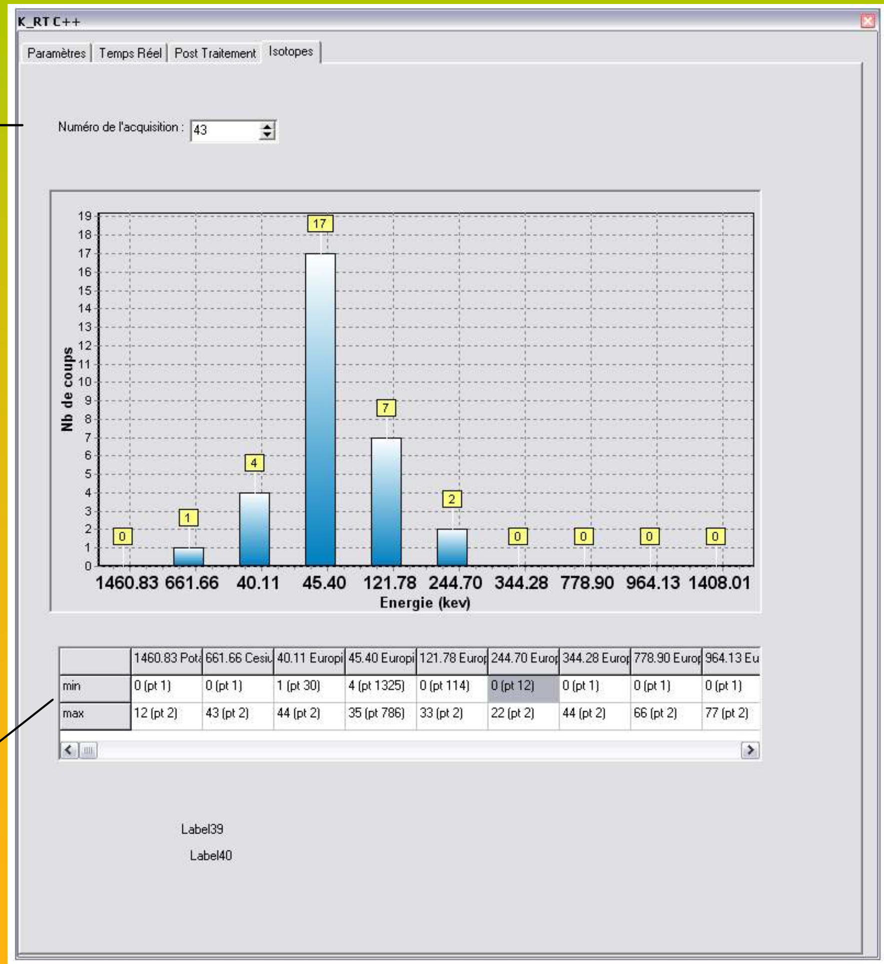
Validity of the devices
Data reception



REAL TIME ACQUISITION: IDENTIFYING the RADIONUCLIDES

For each n-second acquisition and for each radionuclide, we can observe how many cps were detected by the gamma spectrometry device

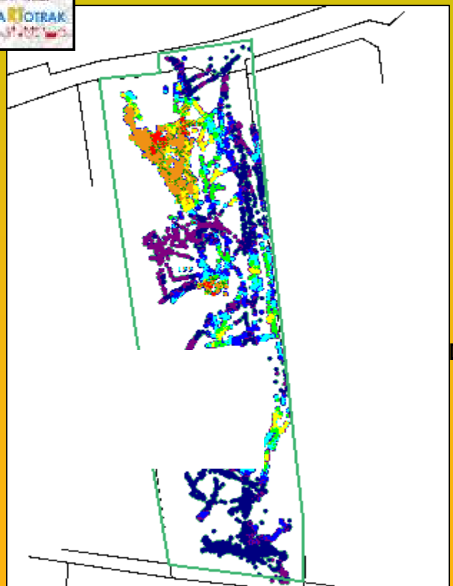




This table indicates the min & max values of each radionuclide

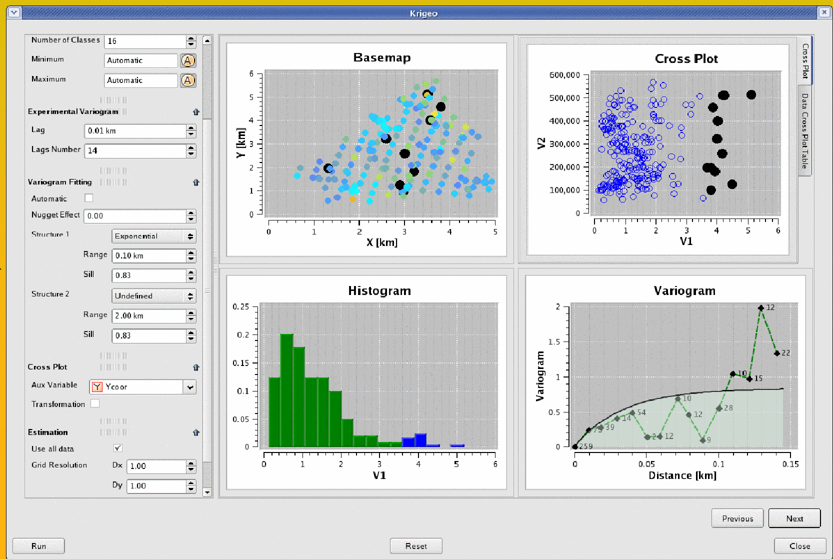
VEgAS:
ACQUISITION, TREATMENT
and CARTOGRAPHY

Kartotrak RT

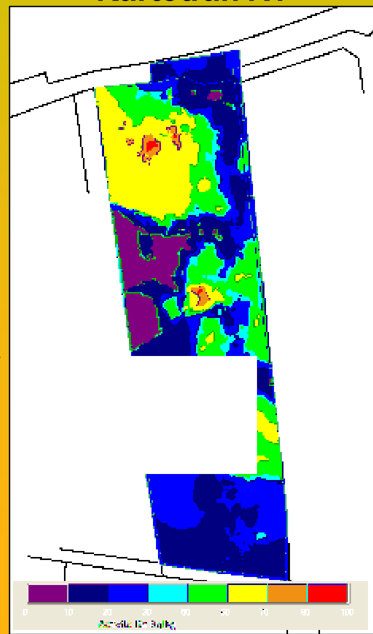


~ 4h acquisition (1s measure)

Krigéo



Kartotrak RT



VEgAS:
DSP DETECTION PERFORMANCES

Detection performances of a punctual source at 2.5km/h

LD	PUNCTUAL SOURCE	
	2,6 km/h	5 km/h
^{241}**Am** E=60 keV	37 kBq	58 kBq
^{137}**Cs** E=662 keV	1,8 kBq	2,8 kBq
^{57}**Co** E=124 keV	2,9 kBq	4,4 kBq
^{226}**Ra**$_{eq=60\%}$ Multi γ	0,30 kBq	0,47 kBq

When driving at 2.6 km/h, the detection limit for ^{137}Cs is approximately 1 Bq/g *(only with spectrometry gamma in situ)*

Factors and detection limits for 1 m² ground /tar pollutions

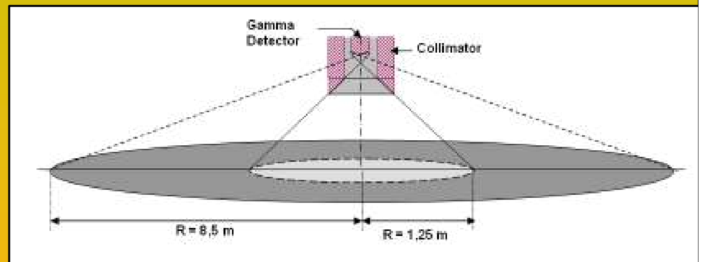
	TAR ROADS			GROUNDS		
Radionuclides	Detection Limits (Bq/kg)			Detection Limits (Bq/kg)		
	2,6 km/h	5 km/h	10 km/h	2,6 km/h	5 km/h	10 km/h
^{137}Cs	0,309	0,369	0,513	57,2	68,3	94,9
^{60}Co	0,162	0,193	0,268	30,1	35,9	49,9
^{152}Eu	0,210	0,251	0,349	38,5	45,9	63,8
^{226}Ra + descendants (FE=100 %)	0,168	0,201	0,279	30,7	36,7	50,9
^{226}Ra alone (FE=100 %)	0,0187	0,0223	0,0310	3,41	4,08	5,66
^{226}Ra alone (FE=60 %)	0,0312	0,0372	0,0517	5,69	6,79	9,43

IN SITU GAMMA SPECTROMETRY MEASUREMENTS

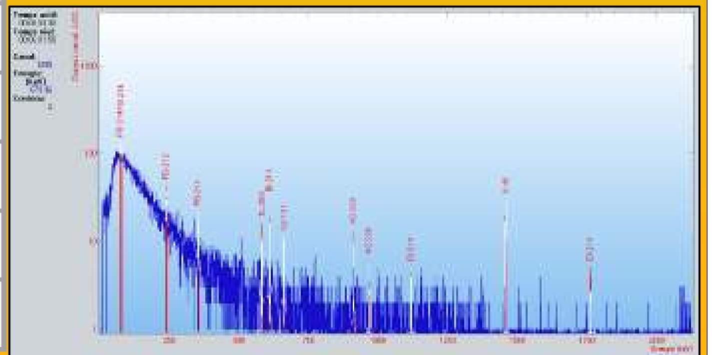
Hyper Pure Germanium Detector, 30% effectiveness

- Modeling 5 m²
- Measured thicknesses from 1mm to 100 cm

When driving at 2.6 km/h, the detection limit for ^{137}Cs is approximately 1 Bq/g

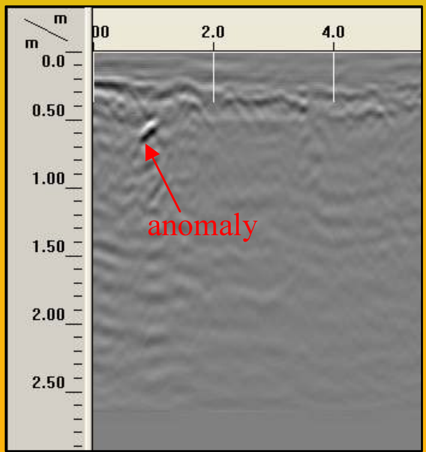


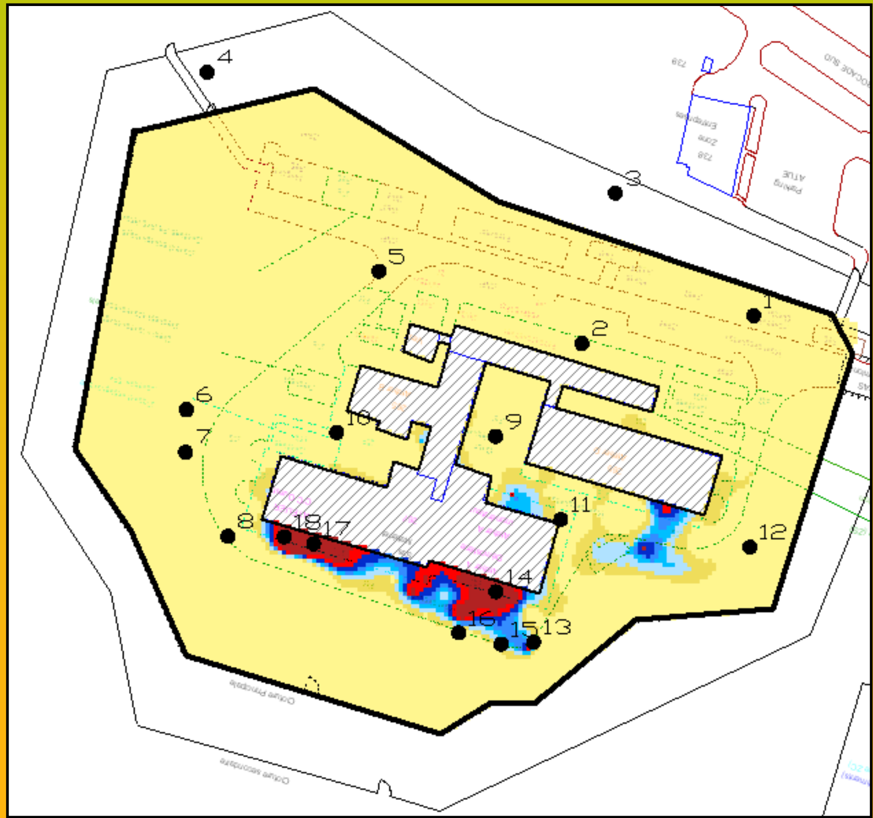
Detection limits obtained with a GeHP detector (Germanium Hyper Pure) 30 % effectiveness, 1 hour of acquisition				
Radionuclide	Surface measurement (Bq/m²)	Measure thickness 1 cm (Bq/kg)	Measure thickness 5 cm (Bq/kg)	Mass measurement thickness 10 cm (Bq/kg)
^{241}Am	66	9,7	5,1	4,4
^{228}Ac	75	7,9	2,9	2,2
^{137}Cs	24	2,8	1	0,8
^{60}Co	21	2	0,8	0,5
^{40}K	151	15	5,4	3,9



GEOPHYSICS INVESTIGATIONS

Confirm the position of drill holes by checking the absence of metallic parts or underground network near the drill holes.





SAMPLING TECHNIQUE

Drillings with auger or Geoprobe

- Depends on the field, maximal depth: 2m
- Simple and relatively cheap
- Unsuitable for chemical measures
- Unsuitable for containment

Drillings with ultrasonic device

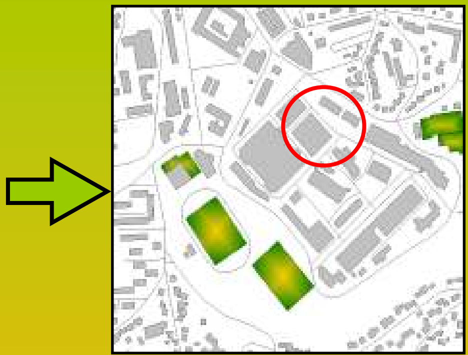
- Every type of soils
- Maximal depth 50 to 100m
- Suitable for containment
- Expensive technique

SOFTWARE DEVELOPMENT

RADIOLOGICAL CHARACTERIZATION for CONTAMINATED SITES through DATA PROCESSING *(Krigéo)* ASSOCIATED to a GIS *(KartotraK)*

OPTIMIZATION & DECISION making AID module *(STRATEGE)*

KARTOTRAK: GEOGRAPHIC INFORMATION SYSTEM



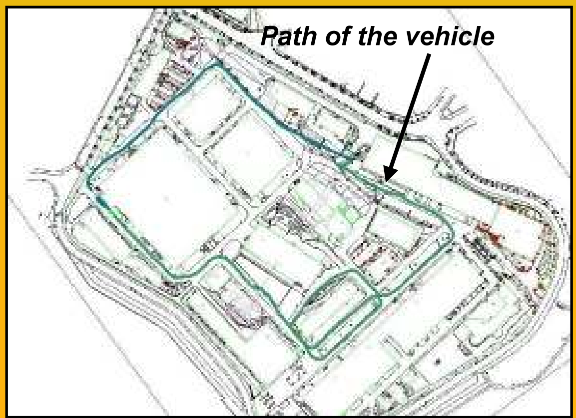
Vectorial Maps

→ No pixellisation effect when zooming in

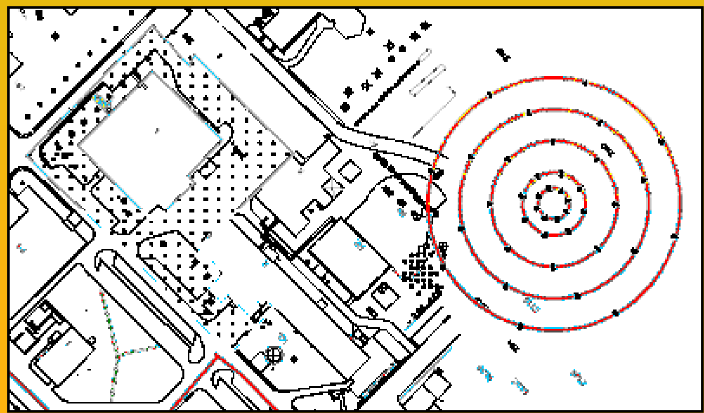
Different layers: vectorial + raster

Georeferenced maps

→ Used with a differential GPS + Doppler radar



Grid Editing

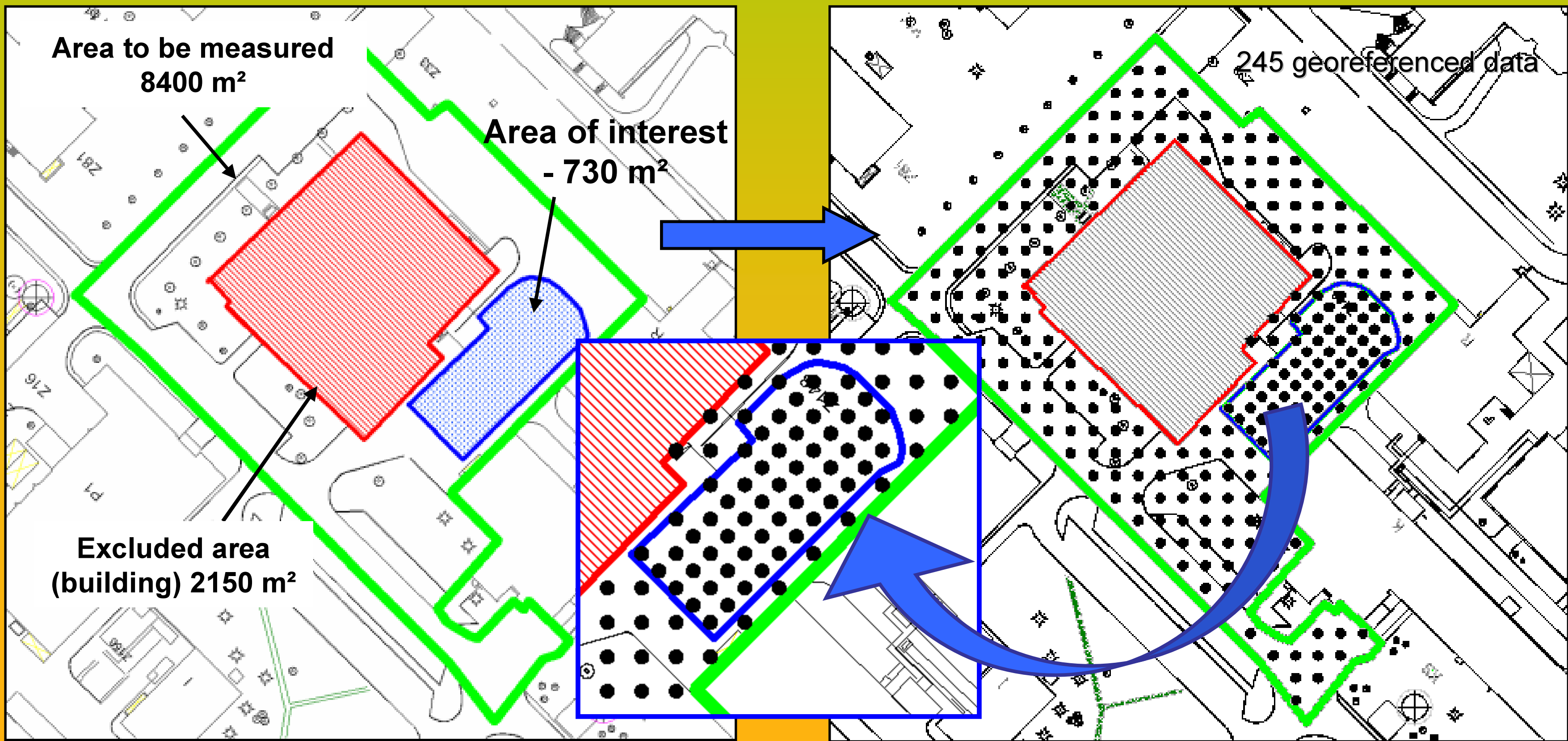


KARTOTRAK: GEOGRAPHIC INFORMATION SYSTEM

Different working processes: systematic mesh

→ Specify areas to be/not to be measured

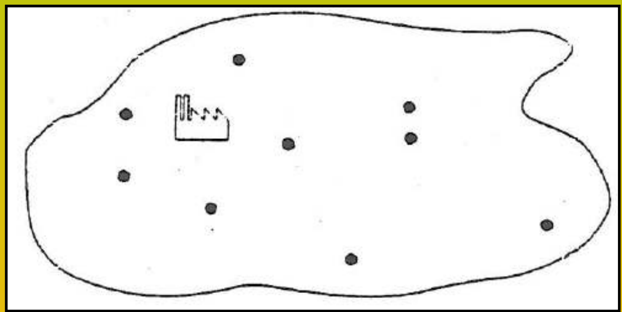
→ Specify areas with an historical interest *(known location of contamination)*



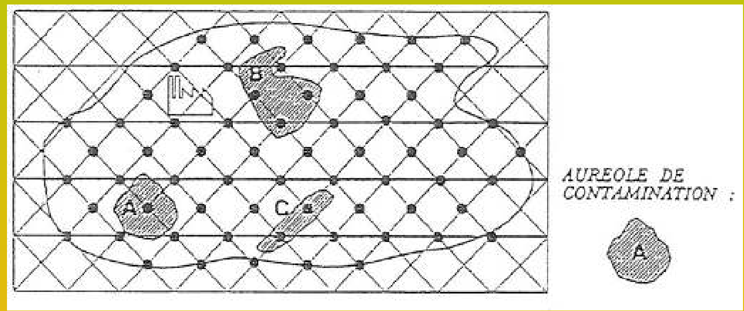
EVALUATION OBJECTIVES and SAMPLING: STRATEGE

Different sampling plans for different evaluations

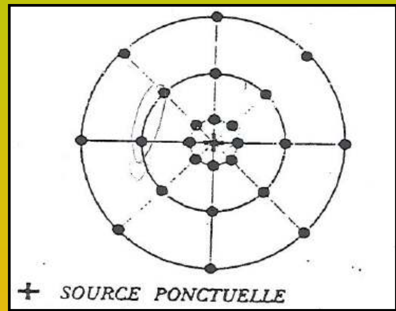
BRGM data



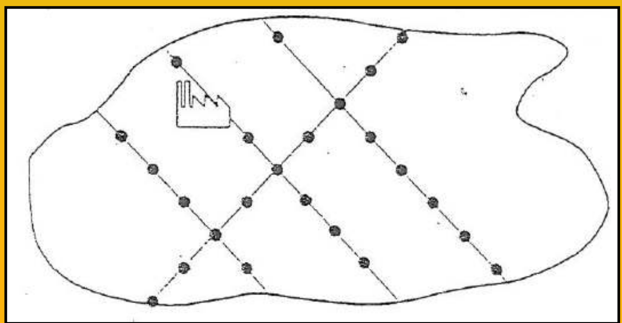
Random sampling



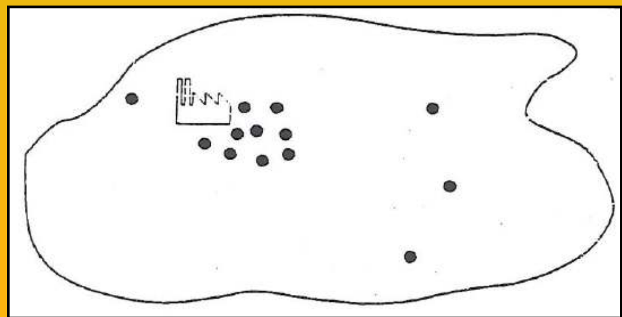
Specific search sampling



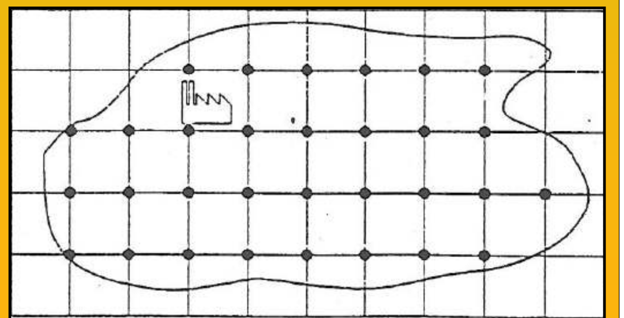
Circular grid sampling



Profile sampling

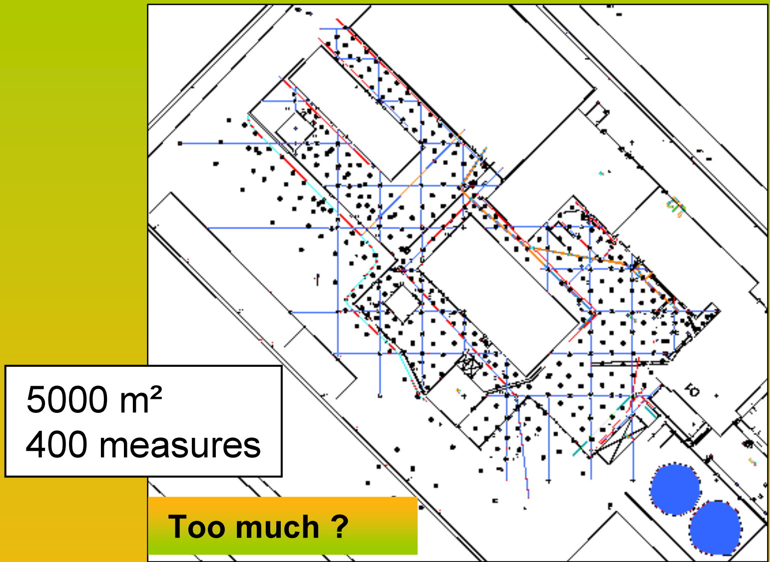


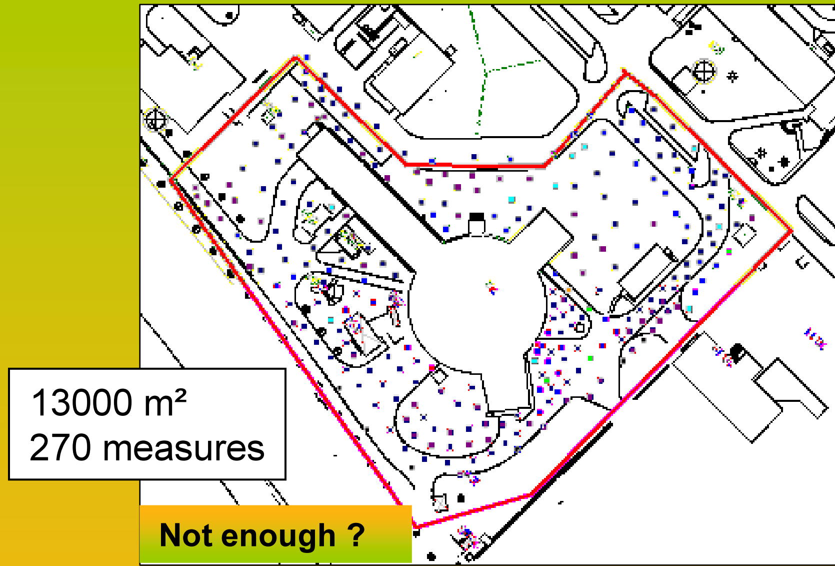
Appraisal sampling

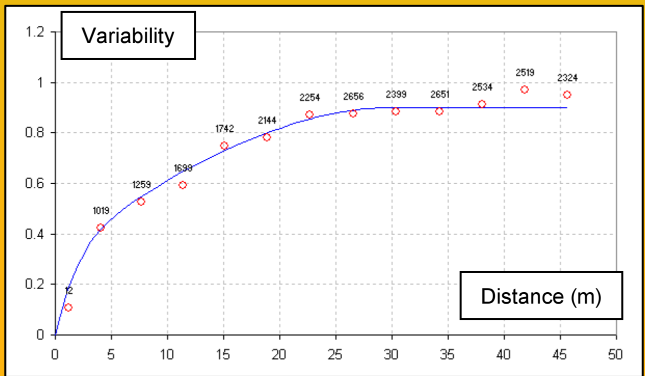


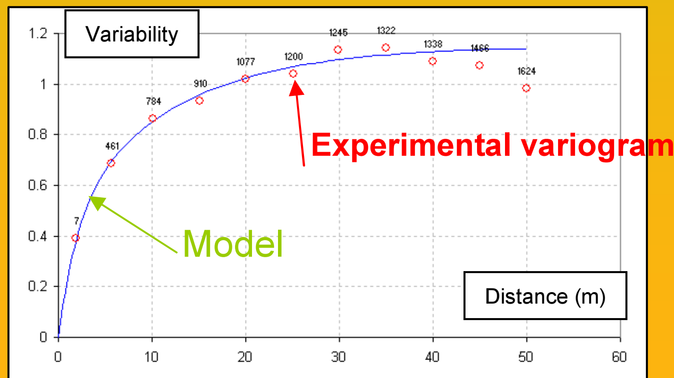
Regular sampling

STRATEGE: SAMPLING OPTIMIZATION





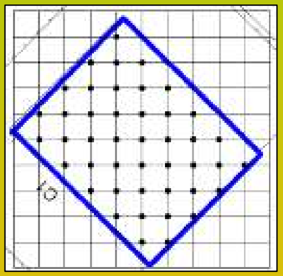




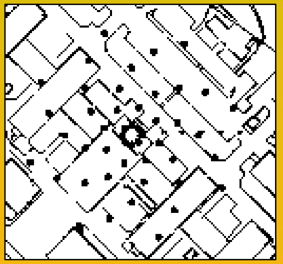
DECISION MAKING AID MODULE: STRATEGE

"**STRATEG**ies d'**E**chantillonnage"

Evaluation objective
- *Removal of doubt / Initial cartography*
- *Environmental diagnosis*
- *Radiological characterization*
- *End of remediation controls*

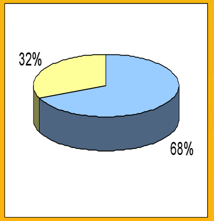


Determine and optimize the sampling plan
- *Optimized grid*
- *Circular grids*
- *Drillings distribution*
- *PESCAR, Wilks method*



Forecast measures performances

Estimating the projected budget

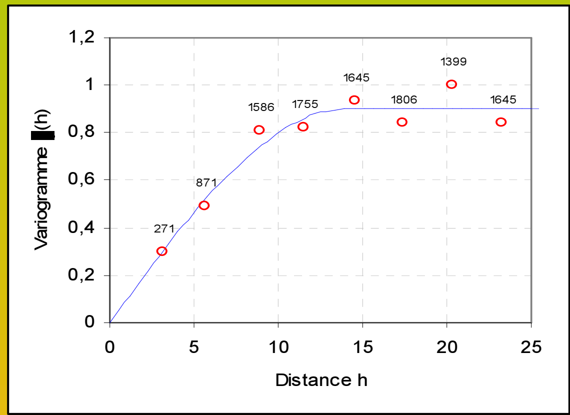


Editing a report of the evaluation preparation

STRATEGE:
SAMPLING OPTIMIZATION

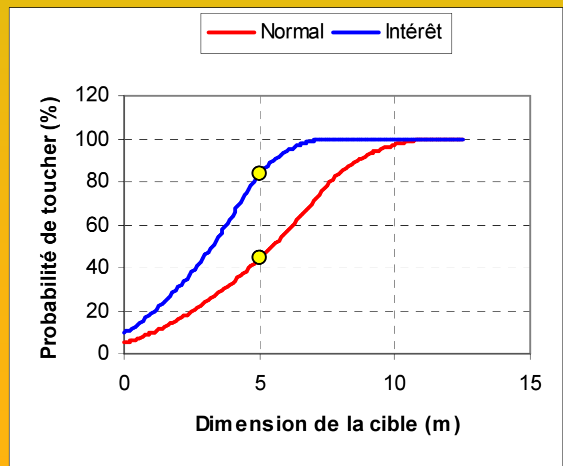
Analyzing the experience feedback

Optimizing the systematic grid
in order to use geostatistics
(highlight the spatial structure of the data)



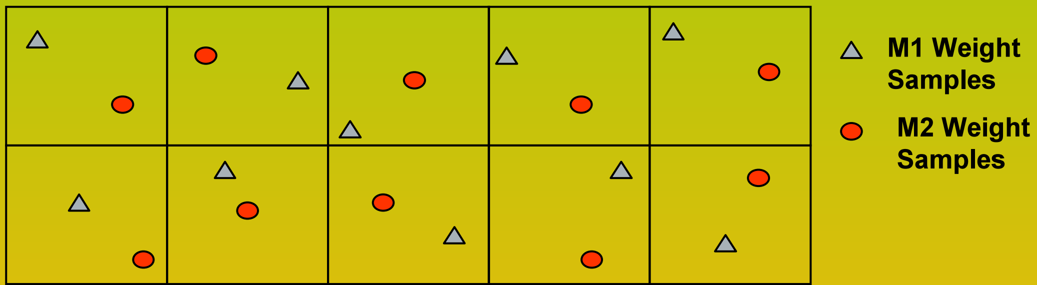
Considering the informations of the area *(historical, geology, topography)* **and the evaluation constraints**
(budget, performances…)

Graphic indicators:
- Probability of hitting a target
- Impact/relevance of extra measures



RADIOLOGICAL ASSESSMENT AFTER CLEAN-UP PROCESS FINAL CONTROLS

PESCAR: Assessment of the average remaining activity, in order to determine the sanitary impact of the cleanup.



Random Sampling of 2x10 samples

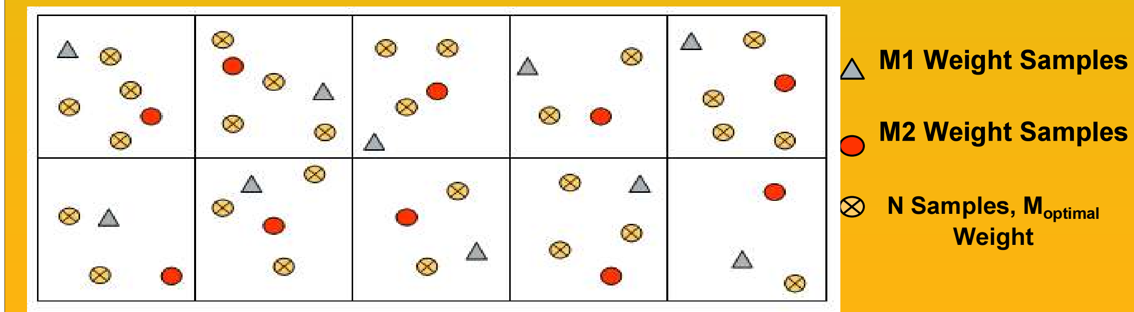
- Computing the homogeneity constant A
- Computing the segregation constant B
  - Computing the optimum mass M
  - Computing the optimum amount of samples for the last stage

$$A = \frac{M_1 M_2 (S_1^2 - S_2^2)}{M_2 - M_1}$$

$$B = S_1^2 - \frac{A}{M_1} = S_2^2 - \frac{A}{M_2}$$

$$M_{optimale} = A/B$$

$$N \geq \left[\frac{(Z_a + Z_b)}{D}\right]^2 + 0.5 Z_a^2$$



Random Sampling of N samples

RADIOLOGICAL ASSESSMENT AFTER CLEAN-UP PROCESS: FINAL CONTROLS

Wilks Formula: **using statistics with a few samples**

$$P\left[P\left(X \leq X_{\max}\right) \geq \alpha\right] \geq \beta$$

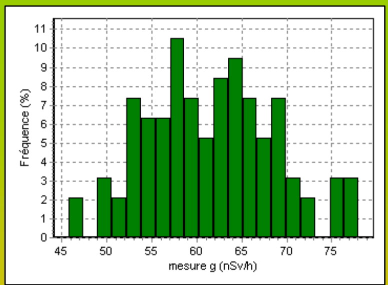
$$1-\alpha^{N}=\beta$$

α, proportion of the studied variable
β, confidence level
N, amount of measurement

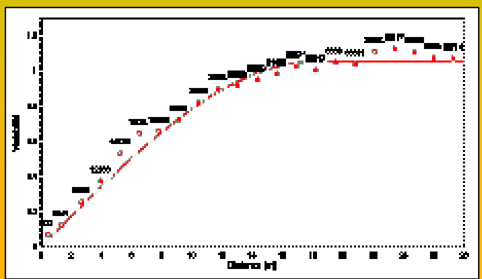
GEOSTATISTICS: BASICS

Kriging

Data Analysis

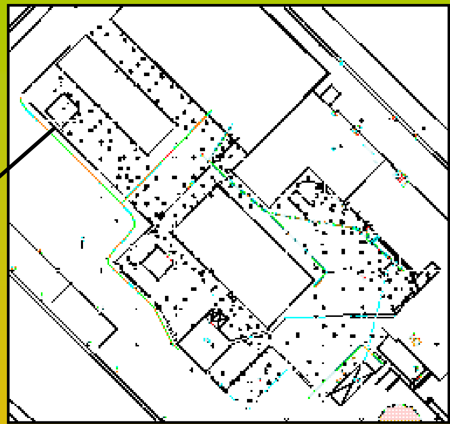


Histogram

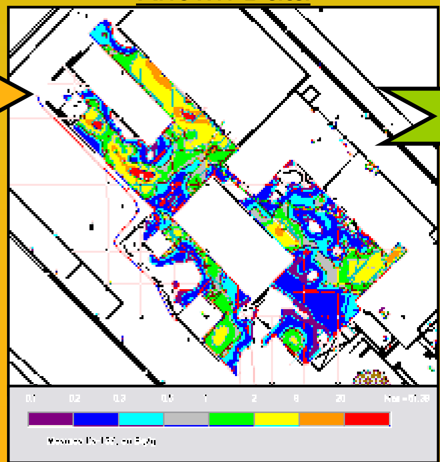


Experimental variogram and model

2D

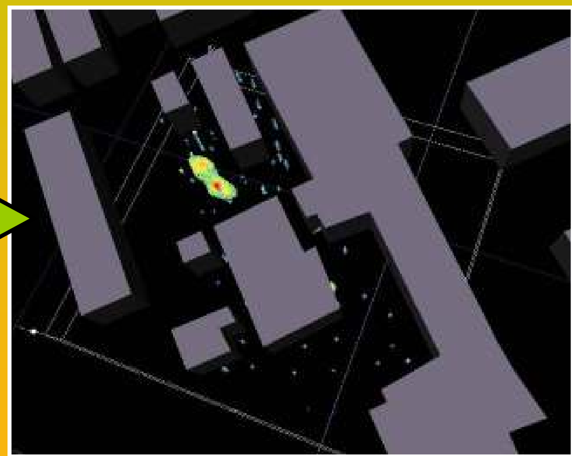


Known Data



2D Interpolation *(initial cartography)*

3D



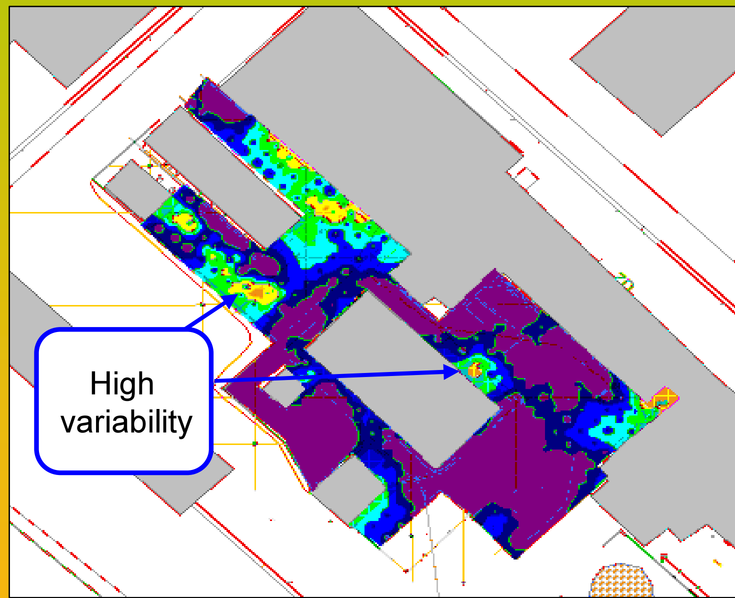
3D Interpolation *(with drillings)*

EXAMPLE of **INITIAL CARTOGRAPHY KRIGING** and **UNCERTAINTY MAP**

55 Drillholes
Resolution: 30 cm

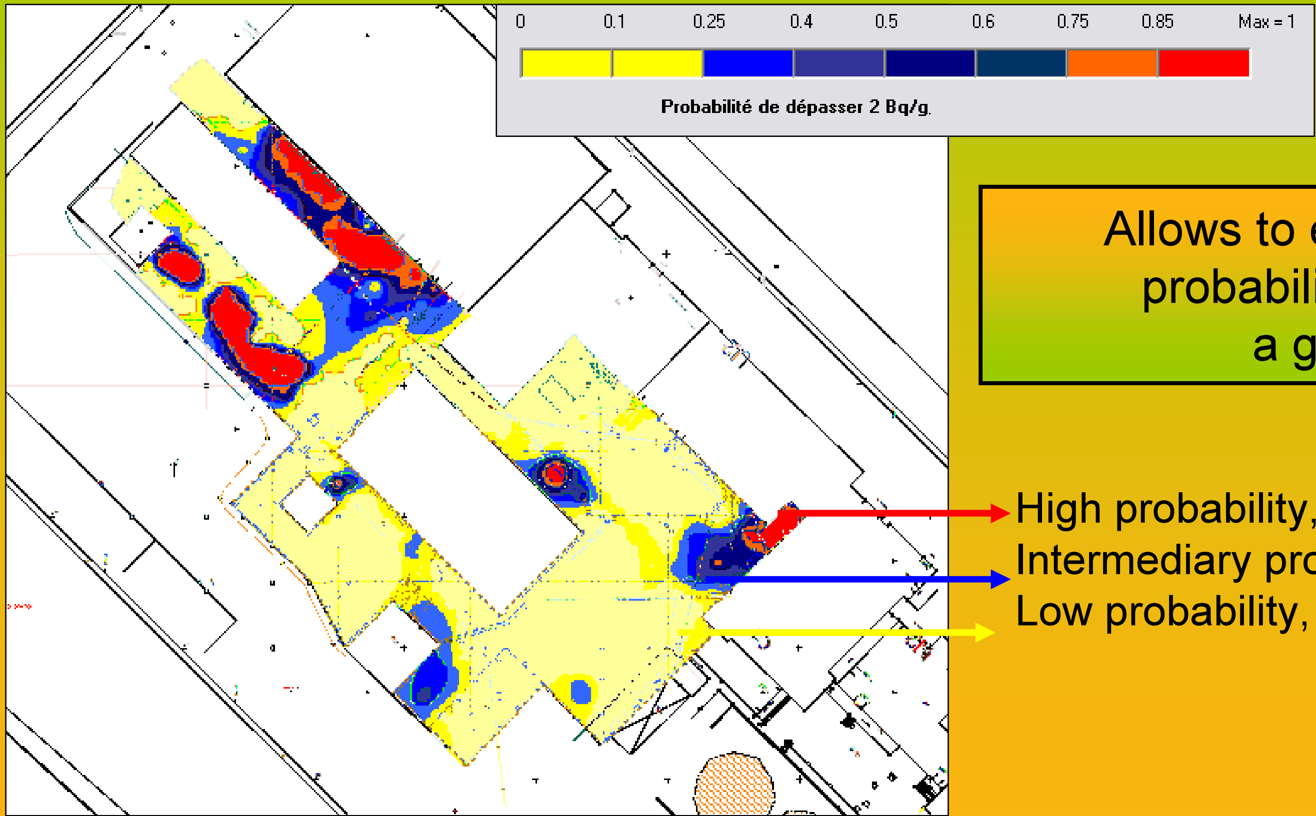
Kriged area: ≈ 5000 m²

Applicable to small and big surfaces



High uncertainty can be *«solved»* by collecting more measures if it's not due to a pure nugget effect.

RISK ANALYSIS
PROBABILITY MAPS

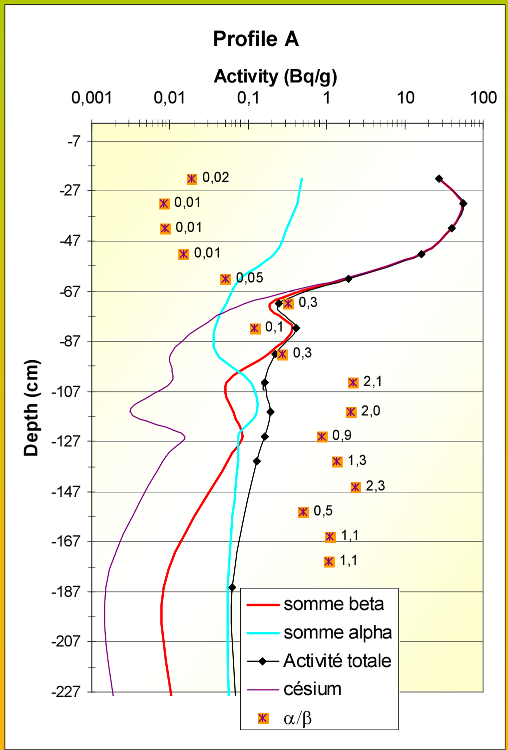


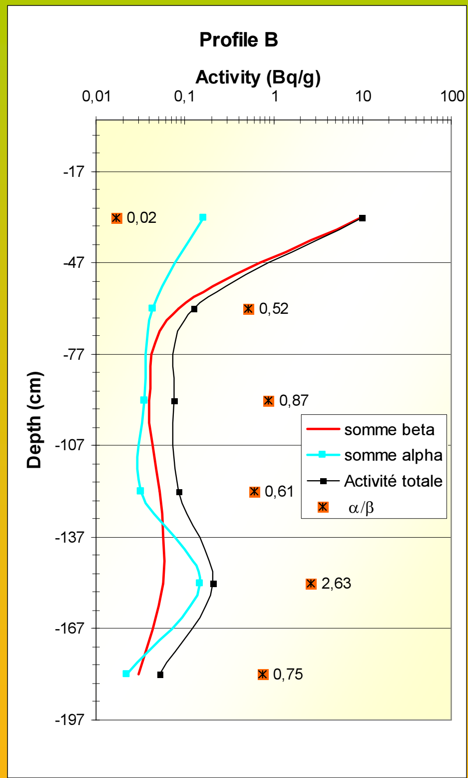
Allows to estimate the local probability of exceeding a given value

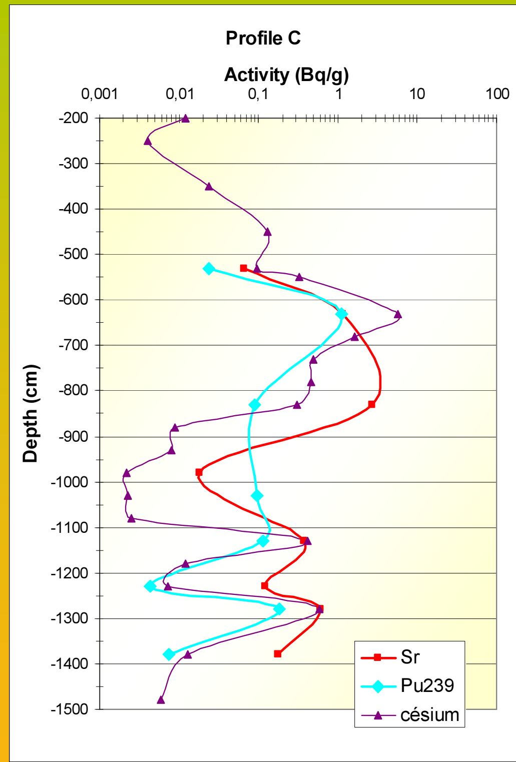
High probability, very likely
Intermediary probability, ***uncertainty***
Low probability, very likely

→ Complementary to the contaminated surface estimation *(through simulation)*
→ Helps to establish a relevant drilling positioning

MIGRATION PROFILES EXAMPLES (α, β, γ)







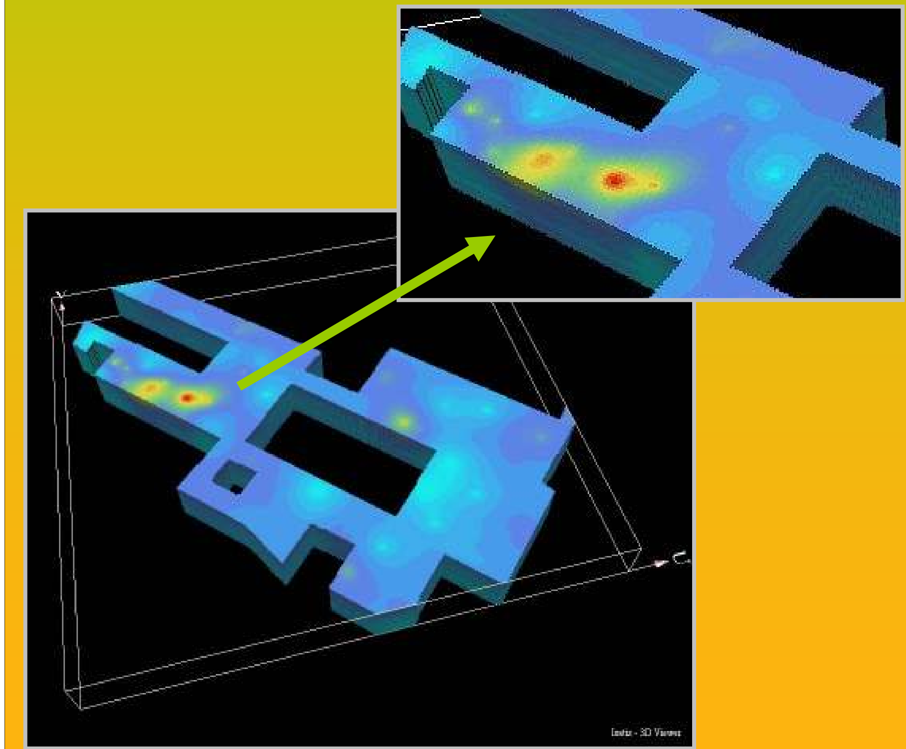
Sampling step: 10 cm
(2 m 30 core)

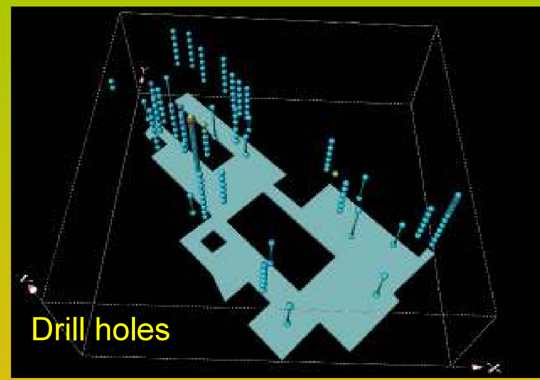
Sampling step: 30 cm
(2 m core)

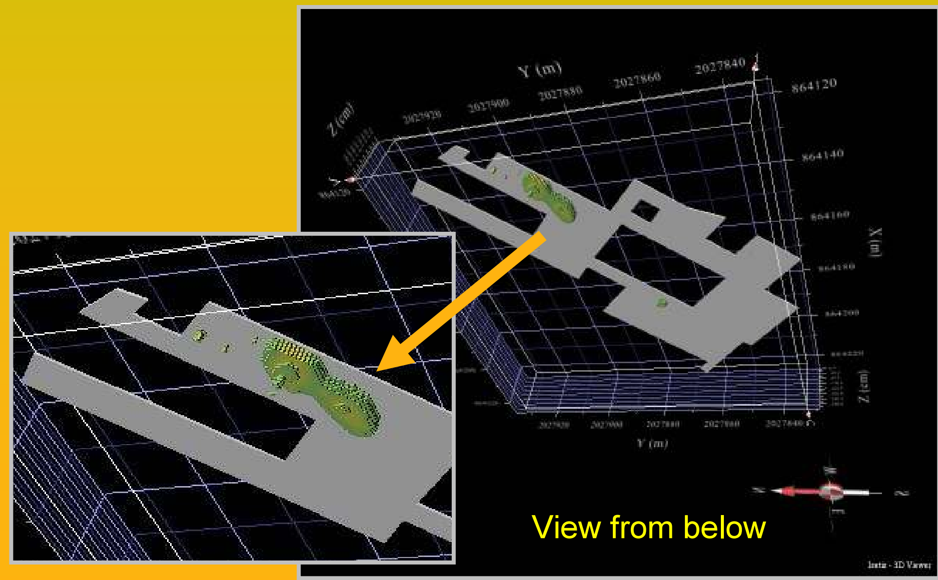
Sampling step: 1m
(15 m core)

FROM the **2D** to the **3D VIEWING**

The preliminary 2D mapping leads to a drill hole campaign processed in 3D







DEPTH EXCAVATION OPTIMIZATION

Drillings and samplings

↓

Analyses results

↓

Typical spectrum determination per zone

↓

In depth profile plotting

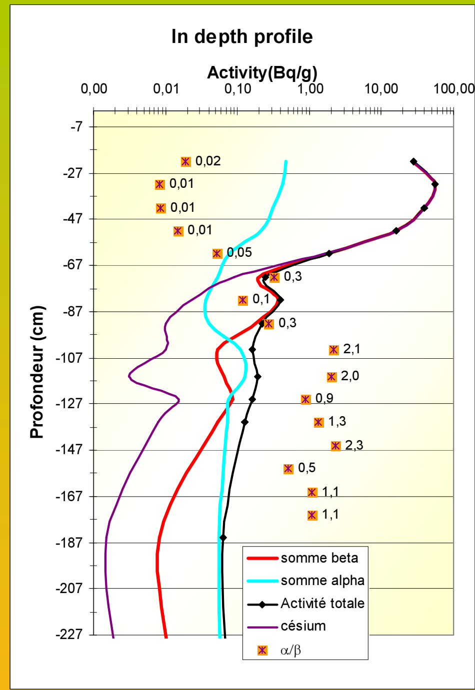
↓

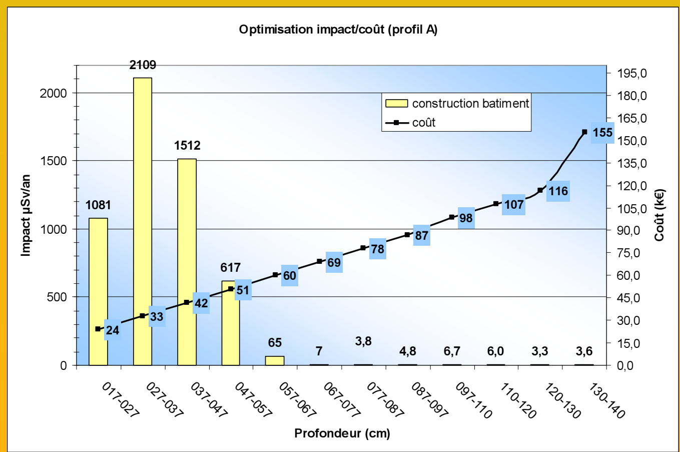
Optimization graph functions of a **remediation scenario** Cost/advantage study

↓

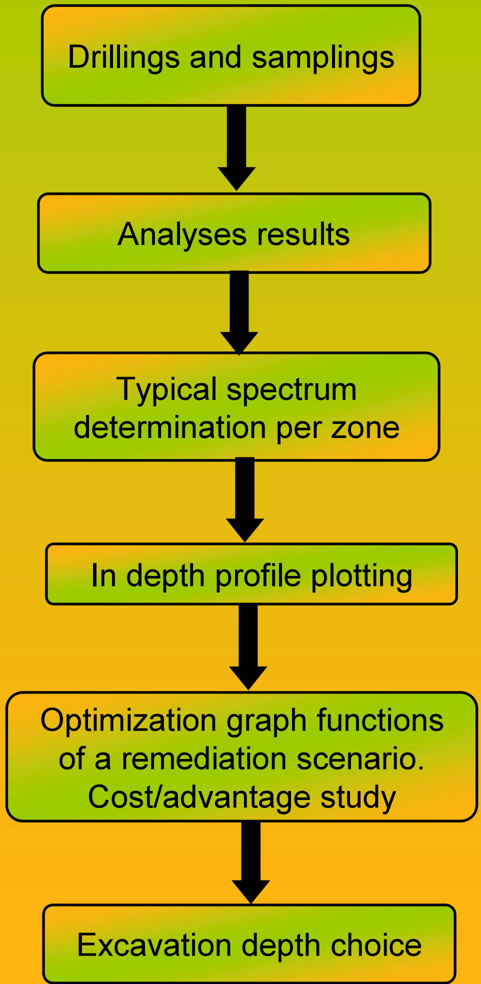
Excavation depth choice

	Ratio %
Cs137+	50,2
Co60	10,8
Sr90	4,0
U235+	1,5
U238+	9,5
Pu238	2,1
Pu239	1,9
Pu240	1,4
Am241	4,0
Pu241	14,6
TOTAL	100,0





DEPTH EXCAVATION OPTIMIZATION



Remediation scenarios come from IRSN methodology guide:

“ Industrial sites management potentially contaminated by radioactive substances ”

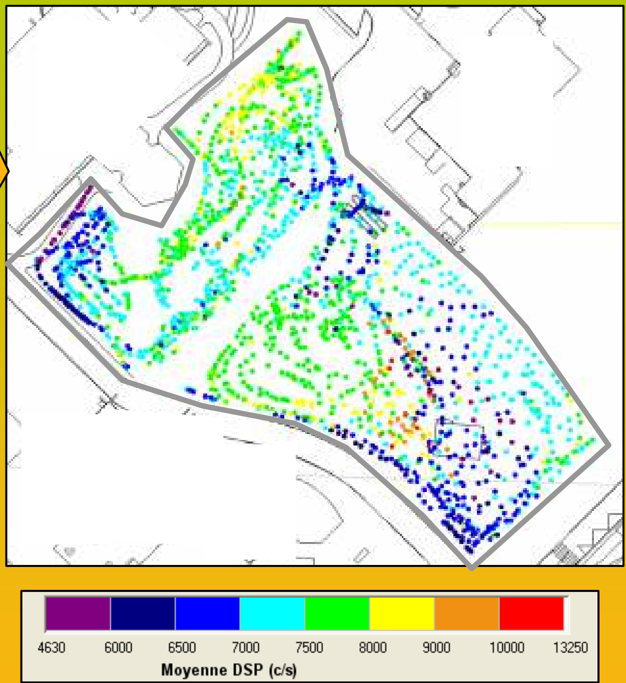
- Residence and playgrounds
- Primary school
- Market gardening
- Offices
- Public car park
- Waste land
- Building site
- Car park under construction



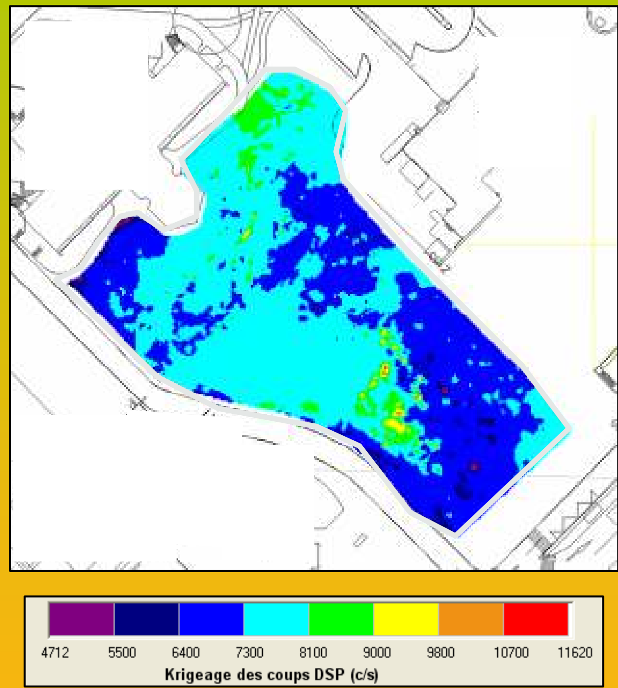


CASE 1: SURFACE CARTOGRAPHY

Highlighting 2800 m² of interest out of a 7050 m² zone → one day after

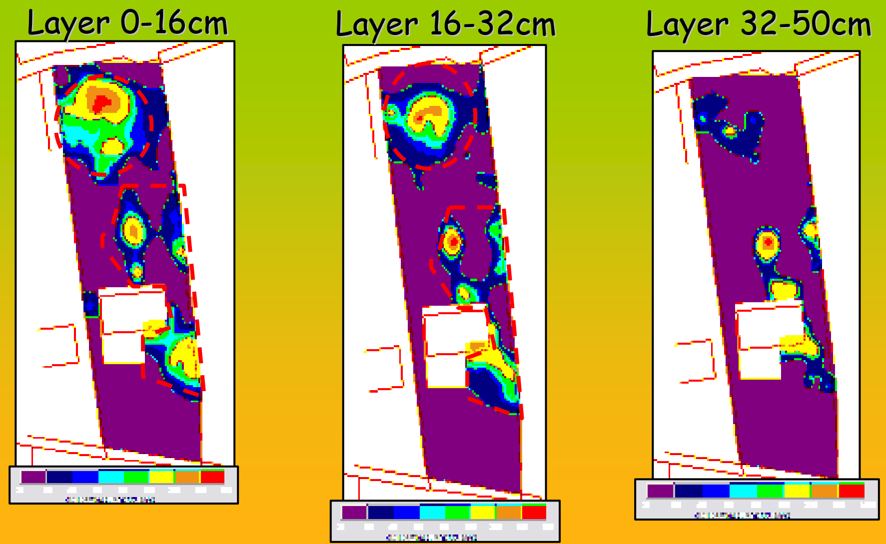


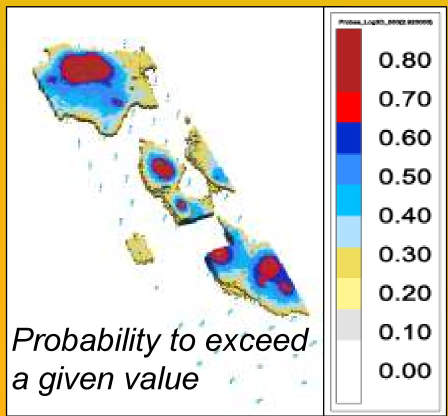
Real Time Measuring



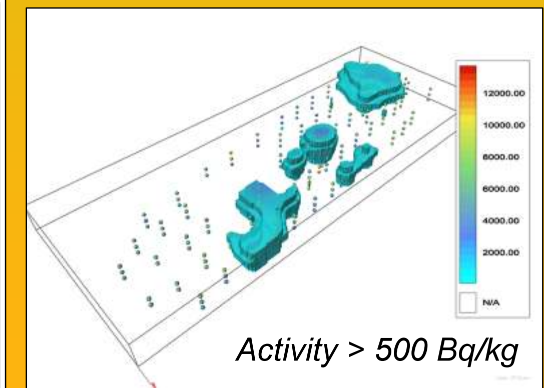
Identifying
the areas of interest

PROCESSING by 2D/3D LAYERS





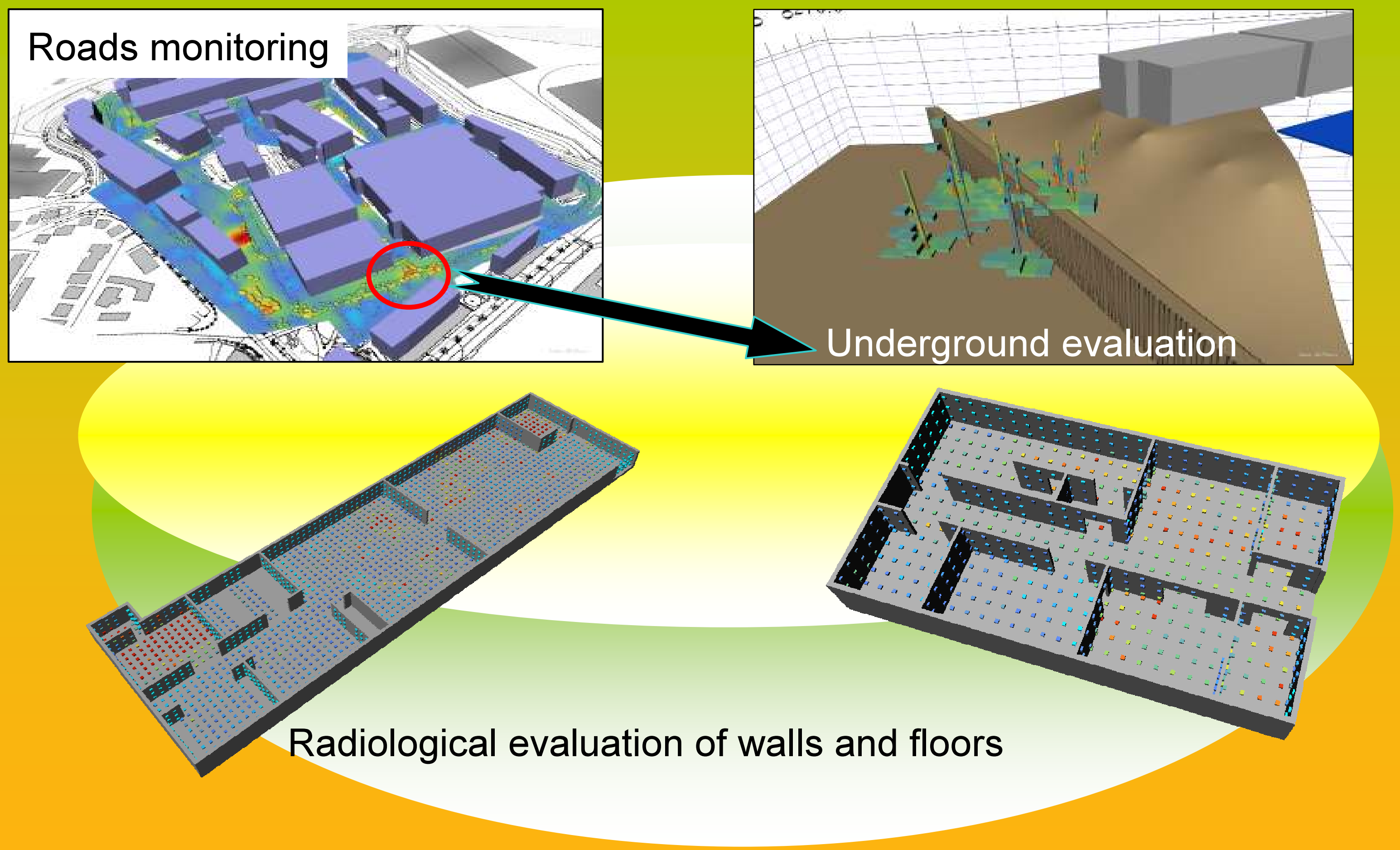
Probability to exceed a given value



Activity > 500 Bq/kg

3D

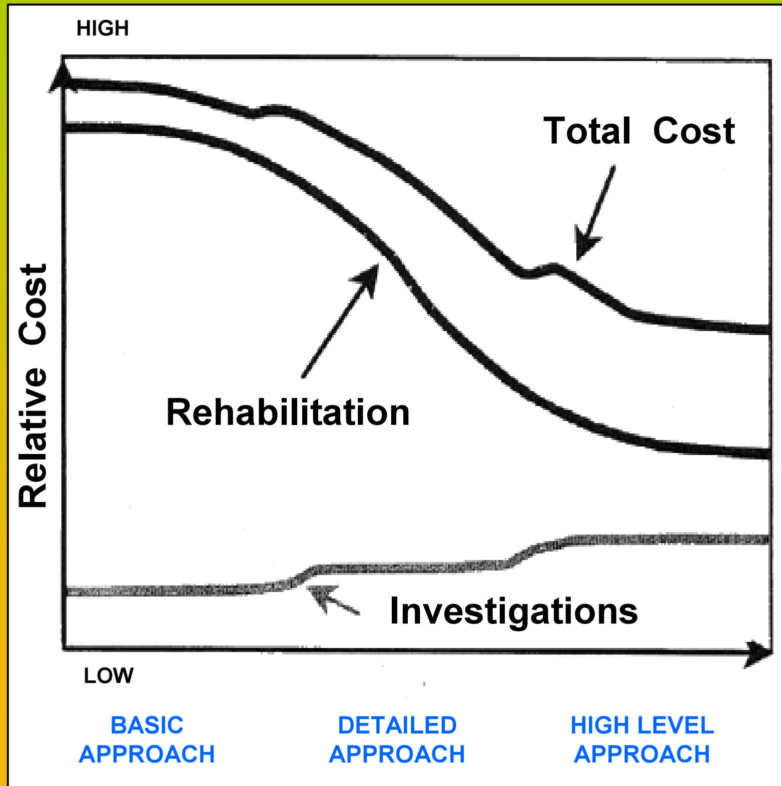
SUMMARY


Roads monitoring
Underground evaluation
Radiological evaluation of walls and floors

Conclusions

- **Sampling takes a critical place in our project management**
- **More than 120 sites characterized and permanent feedback**
- **Current industrialization of the software platform Kartotrak**
- **Cost/advantage study allows to optimize the remediation in function of the rehabilitation, to justify the remediation choices before the safety authority and to control cost and delays.**

The better you characterize upstream with surface and in-depth measures, the better you manage the remediation operations, respecting the projected cost and deadlines.



Edited by BRGM, D. Hubé

Scientific promotions, publications, seminars and collaborations :

Decommissioning Avignon 2008; SIEN Bucharest 2009; Statgis 2009, SFEN 2009, Intersol Paris 2010, DDR Idaho 2010, Environet program (AIEA), Collaboration with China, Russia and South Korea about contaminated sites and soils