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

- **Exploitation of the 1st generation facilities**
- **Exploitation of the 2nd generation facilities**
- **Progressive stop of nuclear activities and 2nd generation facilities decommissioning**
- **Facilities decommissioning**
- **New facilities for medical research**

60 years history
No remediation level in France for polluted site and soils

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

METHODOLOGY

Historical investigations

Data gathering

Radiological surface evaluation

Radiological in-depth evaluation

Chemical measures since 1998

Cost/advantages study

Optimized remediation

Final characterization

Clean up Process of CEA/FAR Site → 45 M€
LABORATORY VEHICLE: LAMAS

Atmospheric measurements
Beacons to measure aerosols and ambient radiation.

Differential GPS
with submetric accuracy

Gamma spectrometry
in situ

Samples treatment cell

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

Monitoring of radiological incidents
Wind scattering
Gas and aerosols activity measurements

Centralization of the measures in the front of the vehicle

Data processing through geostatistics

Map making
Optimization of the sampling plan
Diffusion gradients

Containment Room
Follow-up of the gamma environment.
Centralization and management of equipment and measurement operation

LABORATORY VEHICLE: LAMAS
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
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

~ 4h acquisition (1s measure)
VEgAS: DSP DETECTION PERFORMANCES

Detection performances of a punctual source at 2.5km/h

<table>
<thead>
<tr>
<th>LD</th>
<th>PUNCTUAL SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,6 km/h</td>
<td>5 km/h</td>
</tr>
<tr>
<td>$^{241}$Am $E=60$ keV</td>
<td>37 kBq</td>
</tr>
<tr>
<td>$^{137}$Cs $E=662$ keV</td>
<td>1,8 kBq</td>
</tr>
<tr>
<td>$^{57}$Co $E=124$ keV</td>
<td>2,9 kBq</td>
</tr>
<tr>
<td>$^{226}$Ra$_{eq=60%}$ Multi $\gamma$</td>
<td>0,30 kBq</td>
</tr>
</tbody>
</table>

Factors and detection limits for 1 m² ground/tar pollutions

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

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Surface measurement (Bq/m²)</th>
<th>Measure thickness 1 cm (Bq/kg)</th>
<th>Measure thickness 5 cm (Bq/kg)</th>
<th>Mass measurement thickness 10 cm (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}$Am</td>
<td>66</td>
<td>9,7</td>
<td>5,1</td>
<td>4,4</td>
</tr>
<tr>
<td>$^{228}$Ac</td>
<td>75</td>
<td>7,9</td>
<td>2,9</td>
<td>2,2</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>24</td>
<td>2,8</td>
<td>1</td>
<td>0,8</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>21</td>
<td>2</td>
<td>0,8</td>
<td>0,5</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>151</td>
<td>15</td>
<td>5,4</td>
<td>3,9</td>
</tr>
</tbody>
</table>
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)
DSV/FAR/USLT/SPRE

Section Assainissement du Site

5-9 JULY 2010

SOFTWARES dedicated to the GEOGRAPHIC representation of the MEASURES in the DIFFERENT STAGES of the CLEAN-UP process

- Preparing the sampling plan
- Observing the extension of the pollution
- Establishing the theoretical mesh
- Validating the clean-up objective
- Calculation of the projected impact
- Interaction of the different softwares
- Real-time data acquisition
- Data processing through Geostatistics
KARTOTRAK: GEOGRAPHIC INFORMATION SYSTEM

Vectorial Maps
→ No pixellisation effect when zooming in

Georeferenced maps
→ Used with a differential GPS + Doppler radar

Different layers: vectorial + raster

Path of the vehicle

Grid Editing
Different working processes: systematic mesh
- Specify areas to be/not to be measured
- Specify areas with an historical interest (*known location of contamination*)

Area to be measured: 8400 m²
Area of interest: 730 m²
Excluded area (building): 2150 m²
EVALUATION OBJECTIVES
and SAMPLING: STRATEGE

Different sampling plans for different evaluations

- Random sampling
- Specific search sampling
- Circular grid sampling
- Profile sampling
- Appraisal sampling
- Regular sampling

BRGM data
Section Assainissement du Site

STRATEGIE: SAMPLING OPTIMIZATION

5000 m²
400 measures

Too much?

13000 m²
270 measures

Not enough?

Variability

Distance (m)

Experimental variogram

Model
DECISION MAKING AID MODULE: STRATEGIE

“STRATEGies d’Echantillonnage”

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
STRATEGIE: 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.

- 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

\[
A = \frac{M_1M_2(S_1^2 - S_2^2)}{M_2 - M_1}
\]

\[
B = \frac{A}{M_1} = \frac{S_2^2 - A}{M_2}
\]

\[
M_{\text{optimal}} = \frac{A}{B}
\]

\[
N \geq \left[ \frac{(Z_{y} + Z_{x})^2}{D} \right] + 0.5Z_{x}^2
\]

Random Sampling of 2x10 samples

Random Sampling of $N$ samples
RADIOLOGICAL ASSESSMENT AFTER CLEAN-UP PROCESS: FINAL CONTROLS

Wilks Formula: using statistics with a few samples

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

\[ 1 - \alpha^N = \beta \]

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

Kriging

Data Analysis

Histogram

Experimental variogram and model

2D Interpolation (initial cartography)

Known Data

3D Interpolation (with drillings)

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EXAMPLE of INITIAL CARTOGRAPHY KRIGING and UNCERTAINTY MAP

55 Drillholes
Resolution: 30 cm
Kriged area: ≈ 5000 m²
Applicable to small and big surfaces

High variability

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 ($\alpha, \beta, \gamma$)

Profile A

Profile B

Profile C

Sampling step: 10 cm (2 m 30 core)

Sampling step: 30 cm (2 m core)

Sampling step: 1m (15 m core)
The preliminary 2D mapping leads to a drill hole campaign processed in 3D.

FROM the 2D to the 3D VIEWING
DEVELOPMENT EXCAVATION OPTIMIZATION

- Drilling 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

### Typical Spectrum

<table>
<thead>
<tr>
<th>Activity</th>
<th>Ratio %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs137+</td>
<td>50.2</td>
</tr>
<tr>
<td>Co60</td>
<td>16.8</td>
</tr>
<tr>
<td>Sr90</td>
<td>4.0</td>
</tr>
<tr>
<td>U235+</td>
<td>1.5</td>
</tr>
<tr>
<td>U238+</td>
<td>9.5</td>
</tr>
<tr>
<td>Pu238</td>
<td>2.1</td>
</tr>
<tr>
<td>Pu239</td>
<td>1.0</td>
</tr>
<tr>
<td>Pu240</td>
<td>1.4</td>
</tr>
<tr>
<td>Am241</td>
<td>4.0</td>
</tr>
<tr>
<td>Pu244</td>
<td>14.6</td>
</tr>
</tbody>
</table>

TOTAL: 100.0

### In depth profile

- **Profondeur (cm)**
- **Impact µSv/an**
- **Coût (k€)**

### Optimisation impact/Coût (profil A)

- **Construction bâtiment**
- **Coût**

### Activity (Bq/g)

- somme beta
- somme alpha
- Activité totale
- Césium / α/β

### Construction bâtiment

- **Profondeur (cm)**
- **Somme beta**
- **Somme alpha**
- **Activité totale**
- **Césium**
- **α/β**
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

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

Layer 0-16cm
Layer 16-32cm
Layer 32-50cm

Probability to exceed a given value
Activity > 500 Bq/kg
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 Kartotrax
- 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.

Scientific promotions, publications, seminars and collaborations:
- Internal Report 2010, EUR debate 2010, Emulation program (AIEA)
- Collaboration with China, Russia and South Korea about contaminated sites and soils

Edited by BRGM, D. Hubé