Radiological characterization for decommissioning – methodology, approach and example of a nuclear facility

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INTRODUCTION

Nowadays, nuclear industry is facing a crucial need in establishing radiological characterization for the appraisal and the monitoring of any remediation work. Regarding its experience in this domain, the French Atomic Energy Commission (CEA) of Fontenay-aux-Roses, established an important feedback and developed a sound methodology for radiological characterization. This approach is based on several steps:

- historical investigations and functional analysis
- assumption and confirmation of the contamination
- surface characterization
- in-depth characterization
- rehabilitation objectives
- remediation process

The amount of measures, samples and analysis is optimized for data processing through geostatistics. Geostatistics allow to understand if the pollution phenomenon is structured or not and quantify uncertainties regarding to the characterization.
This innovative approach, first developed for soils characterization, is now also used to characterize civil engineering of facilities.

According to feedbacks concerning facilities structures characterization, it appears that the perfect command of the initial state is a crucial step to carry out an efficient decommissioning strategy. Indeed it is essential to know the thickness of floor and wall to remove in order to take the right decision. For instance, a wall removal of 5 centimetres could be impossible without weakening the structure or could involve underpinning or important work. In this context the initial characterization is a decisive step which involves efficient methods, tools and optimization.

FOCUS ON THE NUCLEAR FACILITY

The nuclear facility located in the building 52 in Fontenay-aux-Roses CEA Centre is going through dismantling. The purpose of this facility was to carry out radio-metallurgic experiments on irradiated fuel. The nuclear facility started up in 1968 and shut down in 1982. Since then, preliminary work as material removal or partial decontamination has been performed. Today, in order to define a full decommissioning scenario and a remediation strategy, a sound methodology is needed.

Facility map
The study concerns the basement (except the filters room) and the ground floor of the facility (Figure 1 and Figure 2).

Figure 1 : basement map

Figure 2 : ground floor map
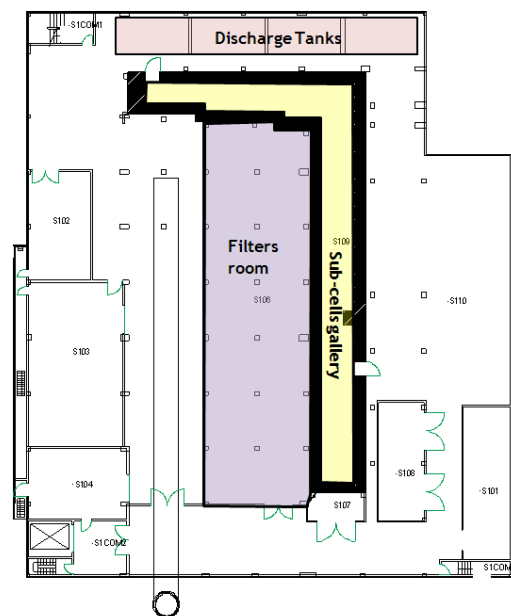
The facility is structured around a set of shielded cells arranged in two rows of unequal length in the shape of "L". The longer leg of the L is called "mainline". Cells have a front zone (FZ) which is the normal working area and a rear zone (RZ) disposed within the branches of L where it is possible to enter the cells for intervention. This rear zone consists mainly of a material corridor and five rear cells.

The basement includes a technical sub-cells gallery allowed to host cells gravity easements as discharge, the very high efficiency filters room, and the active and uncertain radioactive discharge tanks.

GENERAL METHODOLOGY

The aim of the characterization is to improve the knowledge of the building's radiological state in order to propose a sound and viable dismantling strategy.

The approach is based on several steps:

- Historical background and functional analysis

Understanding the radiological past of the facility is fundamental to orientate the subsequent characterization. This includes gathering information from archives, operational characteristics, materials handled, measurement results, incidents and records about former characterization or remediation.

- Former characterization

Measures and partial characterization were carried out during the facility life. Important information can be collected. Indeed, it often happens that measurements are not used to their fair value and it is essential, before planning new characterization, to process the existing data.

- Surface mapping

A detailed map of the floor radiological activity has to be established thanks to surface measurements (in situ gamma counting, gamma spectrometry). Surface measurements are generally easy to implement, and relatively inexpensive comparatively to samples. As a result, this step should be as complete as possible in order to save money during the in-depth characterization.

- In-depth characterization

Once areas of interest are identified thanks to the initial mapping, it is necessary to collect concrete samples at different depths to observe the migration of the pollution. This step provides information concerning the radiological activity, the radionuclides and the average pollution migration depth.

- Singularity investigation

Singularities as cracks, expansion joints, have to be investigated. There are preferential paths for the contamination. When singularities go through the entire slab, pollution can be found in soils. A global treatment should be defined for singularities.

- Soils characterization under the facility

Soils pollution under the slab has to be considered. Two cases are studied: the migration of the pollution through the slab until the ground or historical pollution coming from former facilities. A campaign of drill holes indicates the contamination depth in the soils. Any potential transfer towards the groundwater has to be considered.

According to this methodology, the following part presents the main steps of the facility characterization.

SURFACE MAPPING

Measurements have been performed with a 3'' NaI detector (Figure 3).

Figure 3 : surface measurement device (NaI)

The acquisition time for each measurement is 30 seconds with a regular mesh of 1.5 meters. The table ensures the reproducibility of measurements by setting the distance sensor / ground at 70 cm. The detector is equipped with a collimator lead. To

take into account the background noise component, the measurements are made for each point with and without the lead shield. Subtracting the two measures provides the "net data" that will be analyzed and processed (Figure 4 and Figure 6).

1000 m² have been characterized in the basement and 1500 m² at the ground floor for a total amount of more than 1200 surface measurements. In-situ measurements campaign is easy to implement and carried out in few days for a low cost.

Cartographies are made through kriging which is a data interpolation method using geostatistics. This method captures the spatial structure of the pollution and, according to measurements points, predicts a likely value on each map point while also quantifying the associated uncertainty. All geostatistical calculations and cartographies are performed using Kartotrak ® software (Figure 5 and Figure 7).
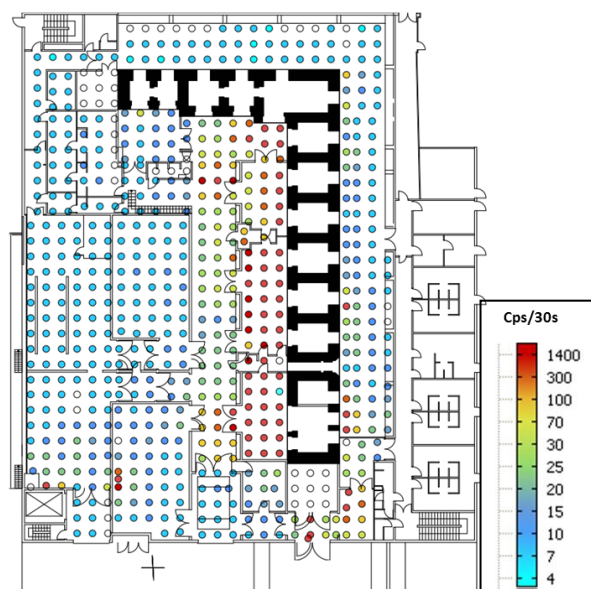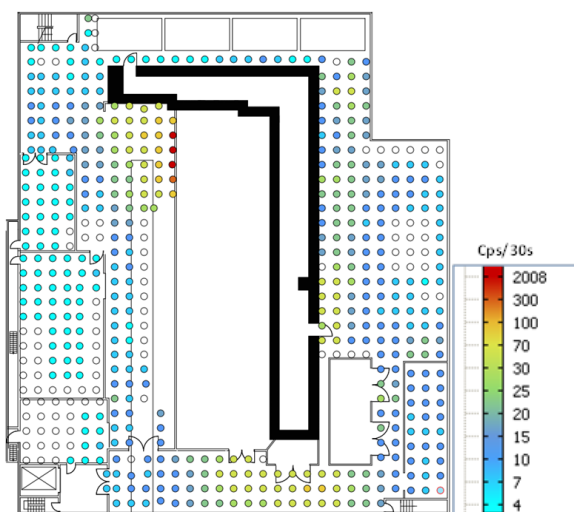

Figure 4 : basement data location

Figure 5 : basement surface cartography

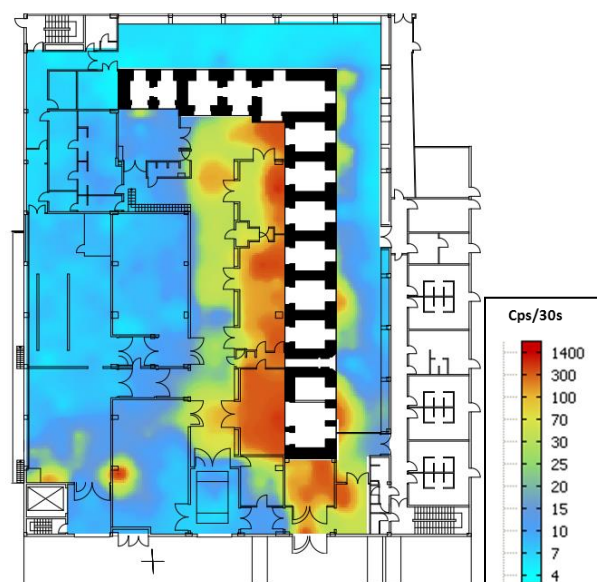**Figure 6 : ground floor data location**

Figure 7 : ground floor surface cartography

The surface characterization brings to light several areas which showed a significant rise of the global count rate. In the basement, areas of contamination are large and rather homogeneous. On the ground floor, areas of contamination are less continuous and more independent.

IN-DEPTH CHARACTERIZATION

These surface cartographies are used to define the samples position. 28 samples have been placed (22 on the ground floor and 6 on the basement): few of them in the most contaminated area to get the highest activity, few of them in the low counting
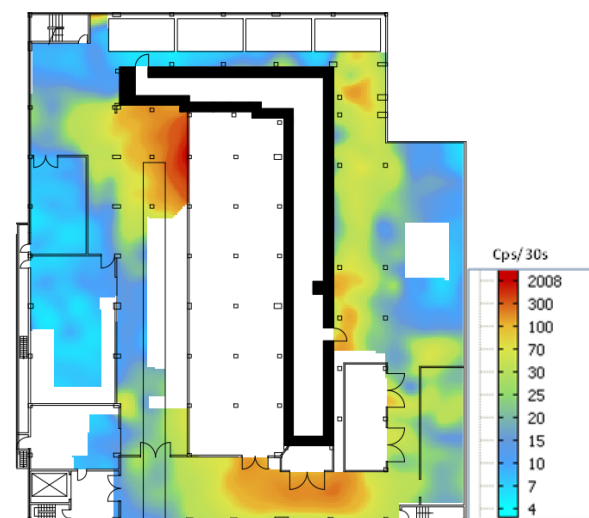
area in order to confirm the non-contamination and most of them are placed in intermediate areas where a doubt subsists as regards contamination.

Technical constraints as feasibility, accessibility or personal exposure should also be taken into account in the samples layout presented on the maps below (Figure 8 and Figure 9)
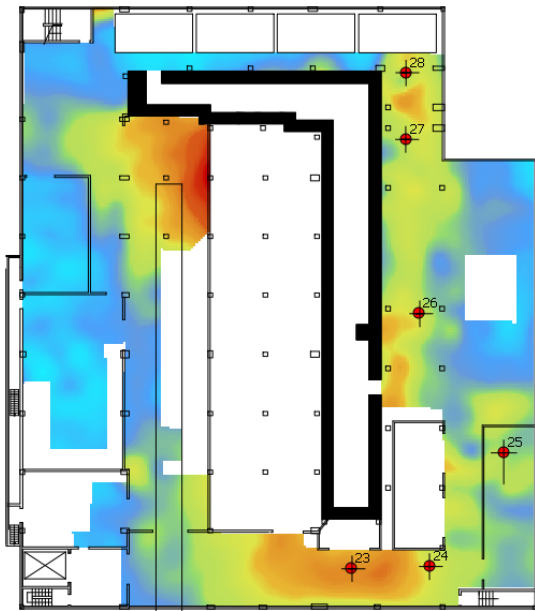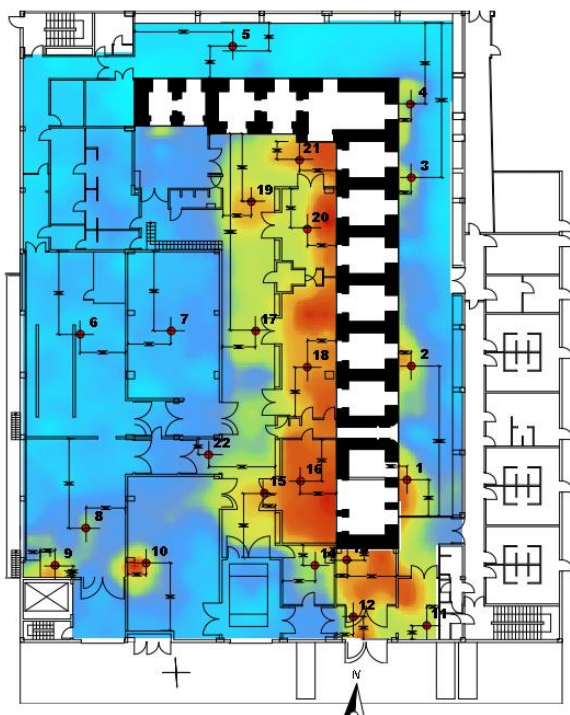

Figure 8 : basement samples layout

Figure 9 : ground floor samples layout

More samples are located on the ground floor because the initial mapping shows that pollution is less homogeneous than in the basement. The number of samples is limited by the allocated budget. The in-depth characterization uncertainties could be reduced with more samples.

Samples are taken directly from the concrete after removal of the surface coating when there is one. The aim is to plot contamination profiles in the civil engineering of the installation. The surface of a sample point is about 1m² (Figure 10). Samples are taken by grinding through a bush hammering, 5 mm per sample to a depth of 5cm (10 samples made for each of the sampling points).

Figure 10 : sample surface

All samples (260) are analyzed by gamma spectrometry in laboratory. According to the gamma spectrometry results, 50 samples are selected to be analyzed through alpha spectrometry and liquid scintillation in order to identify alpha and pure beta radionuclides.

As expected, profiles are homogeneous and relatively similar at the basement and more specific and particular on the ground floor. Profiles examples are presented below (Figure 11 and Figure 12).
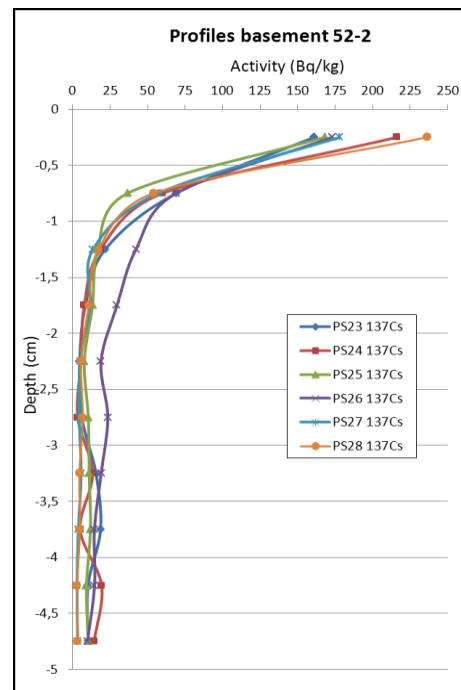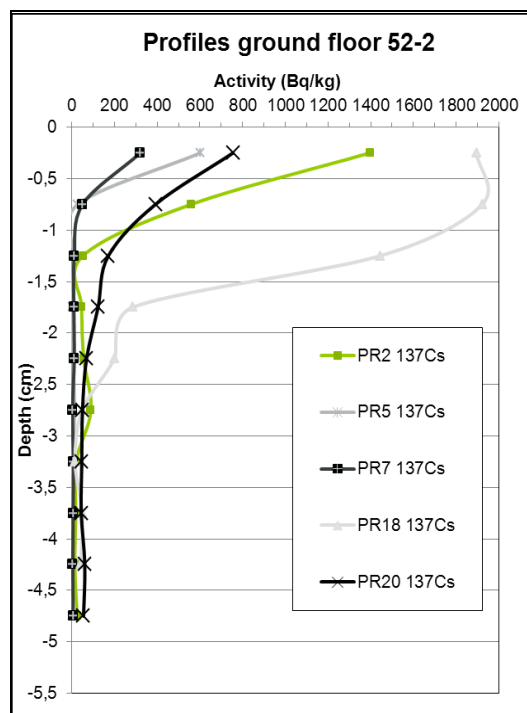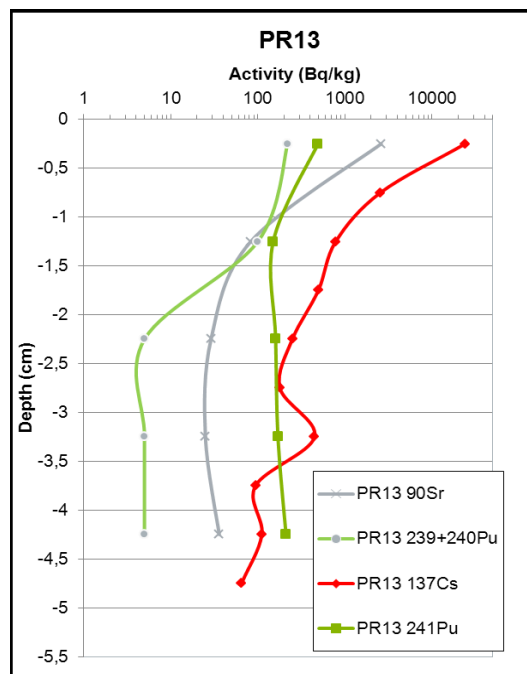

Figure 11 : basement ^{137}Cs profiles

Figure 12 : ground floor ^{137}Cs profile

Relevant samples are selected for radiochemical analysis (Figure 13). The consideration of all radionuclides and not only ^{137}Cs is essential for a sound characterization.

Figure 13 : α and βγ profile of drilling n°13

All the analysis results are considered to define a mean spectrum.

Spectra presented below are average standard calculated from the results of samples analysis. Significant uncertainties are present because the total area has not been sampled and also because calculations are based on few samples taken. In addition, when the detection limit of the devices and testing protocols are significantly different from zero, especially for ^{241}Pu and ^{90}Sr radionuclides, it is not possible to conclude that there is a complete absence of pollution.

Standard spectra are calculated by averaging the activities of the first pass (0 to 0.5 cm) for each sample (Table 1 and Table 2).

Table 1 : ground floor standard spectrum

Radionuclide	Ratio %
Cs-137	84,3
Sr-90	8,9
Pu-238	1,7
Pu-239	1,3
Pu-240	1,3
Am-241	2,6
Pu-241	0,000055*
TOTAL	100

Table 2 : basement standard spectrum

Radionuclide	Ratio %
Cs-137	79,2
Sr-90	7,3
Pu-238	2,2
Pu-239	5
Pu-240	5
Am-241	1,3
Pu-241	0,00022*
TOTAL	100

*^{241}Pu considered with its alpha component

^{137}Cs is preponderant. The calculation was also performed for other depths (0.5 to 1cm and 1 to 1.5 cm). Given the uncertainties on the analysis results and assumptions, the average standard spectra obtained are not significantly different.

Spectra of basement and ground floor are quite similar. Given these results, it might be possible to make a single medium spectrum for both floors.

Conclusion of the general characterization (mapping and samples) of the facility is summarized below:

- o More than one third of the investigated surfaces present significant activities

- o In the basement, the predominant radionuclide is ^{137}Cs. It represents more than 79% of the source term. Other radionuclides are ^{241}Am, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Pu. Pollution is fairly homogeneous with spots of larger contamination. The area under the front zone has a moderate pollution below 1Bq/g. Pollution is mainly contained in the first two centimeters. The area under the rear zone n°5 appears to have a greater contamination but no sample was taken to confirm.

- o In the ground floor, the contamination profiles are more various than in the basement, as well as the encountered activity levels. Contamination areas are smaller and come from different events. ^{137}Cs represents more than 84% of the total source term. Other radionuclides present are like in the basement, ^{241}Am, ^{90}Sr, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Pu. The maximum activity encounter is about 30 Bq/g in the room 009 (Figure 13). In the rear zone, the total activities measured are of the order of a few Bq/g, and in the front zone, they are less than 1Bq/g. The average depth of contamination is about three centimeters.

SINGULARITY INVESTIGATION

Singularities as cracks and expansion joints are preferential paths for the contamination. Contamination depth is generally more important in singularities. A dedicated sampling campaign gives important information concerning the penetration of the contamination.

In the facility, eight singularities are investigated, they are selected from a civil engineering study. The amount is optimized to take into account the necessary time to achieve radiochemical analysis.

The following pictures (Figure 14 and Figure 15) present two examples of singularities.

Figure 14 : example 1 of singularity

Figure 15 : example 2 of singularity

Core samples are taken and analyzed by gamma spectrometry and few of them are selected for radiochemical analysis.
As expected few singularities are deeply contaminated. For one of them, (
Figure **16**), the pollution goes through the slab (15 cm) to the ground under the slab.
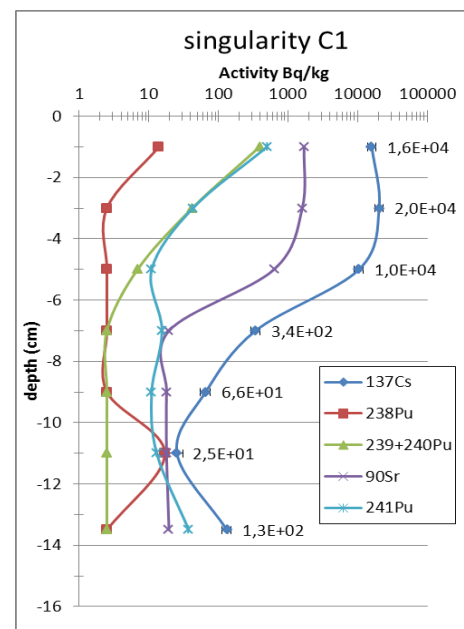

Figure 16 : example of a singularity profile

A global treatment should be defined for singularities.

SOILS CHARACTERIZATION

Soils pollution under the slab could have two origins:
- o the facility with a migration of the pollution under the slab
- o historical pollution which comes from former facilities or incidents before the construction of the building

Facility ground pollution

The migration under the slab is considered with the singularities campaign. Soil sample in the ground under the C1 singularity (at the depth of 15-35 cm) shows a contamination of 20Bq/g in ^{137}Cs. More investigation is needed to delimitate the extent of the contamination.

Historical ground pollution

The first campaign was operated in 2000-2001, to confirm the absence of contamination in soils under the facility. 5 drillings are carried out. Drillings layout is conducted according to the position of the former plutonium facility.
The Figure 17 shows the old Plutonium facility buildings (in red) and the present facility (in green). Drillings are carried out in areas where the historical report shows soil pollution during the plutonium facility running.
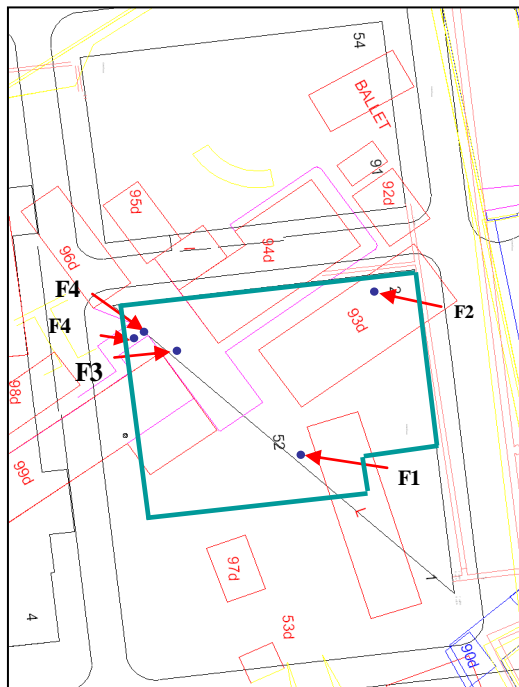

Figure 17 : former buildings and drillings layout

Drillings depth is 4 m which allows reaching the natural ground. Analyses show no added artificial radioactivity greater than the detection limit (10 Bq/kg in ^{137}Cs and 20 Bq/kg in ^{241}Am).

The second campaign was operated in 2011. In 2010, a drilling program was carried out in the soils of another facility in the same building, which is the neighbour of the present facility . These investigations led to data processing and radiological cartographies that show soil pollution along the wall adjoining the facility (Figure 18)
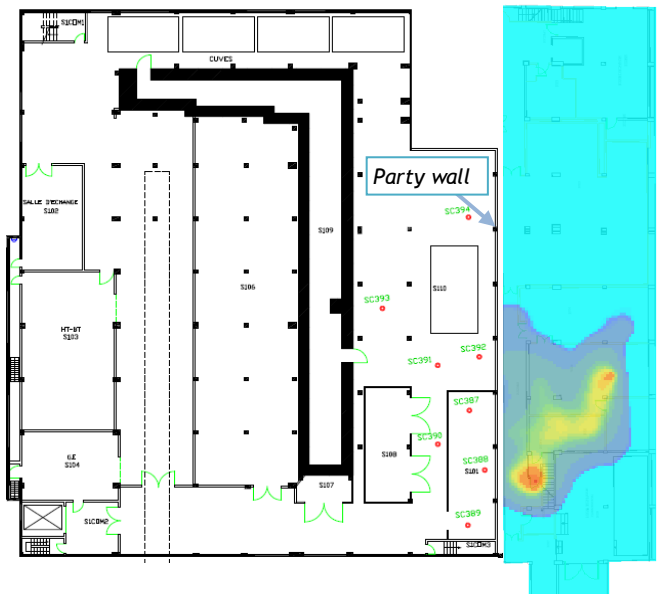

Figure 18 : facility B soil pollution and drillings layout

This soil pollution under facility B originated also the former plutonium facility. In 2011, it was decided to conduct drillings on the other side of the party wall with the aim to delimit the extent of pollution under the facility and to assess activity levels.

8 drillings of 2 m depth are carried out with a 25 cm sampling step. The Figure 18 shows the drillings layout. 64 samples are analyzed by gamma spectrometry in laboratory. Profiles of the 4 drillings with significant activity are presented Figure 19.
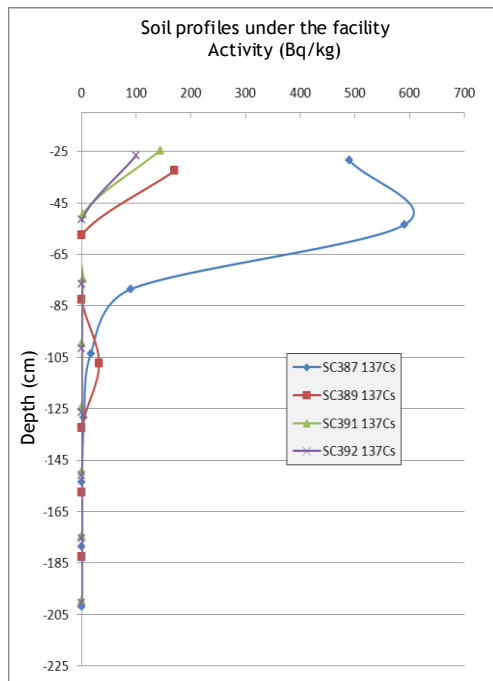
Figure 19 : drillings profiles

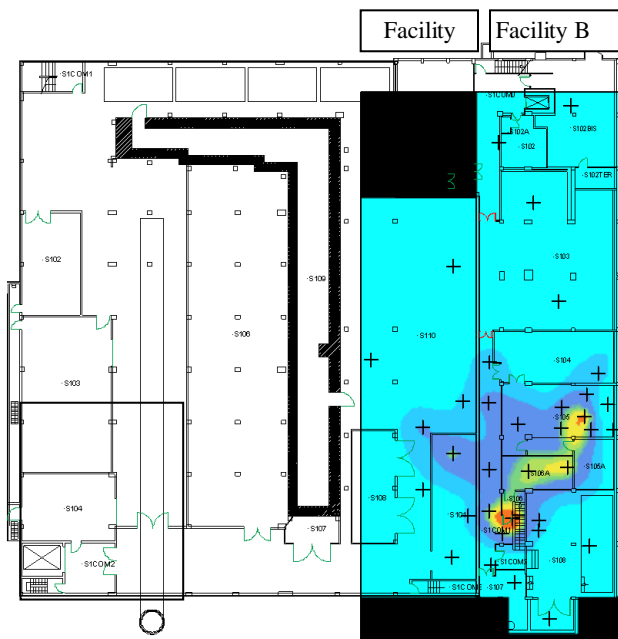Mapping of the facility B kriging has been updated, including the 8 new drillings (Figure 20).

Figure 20 : Updated kriging of the soil pollution

As expected, the contamination area spreads over a small portion under the facility. The extent on the facility side is about 80 m². Radiological activities measured are less important than in the facility B and the contamination is contained in the first meter.

CONCLUSIONS

The original approach and methodology developed at CEA for soils characterization is now transferred to nuclear facilities. The aim is to provide a suitable framework to address a tremendously increasing demand about the characterization of contaminated concrete structures and facilities.

The essential step is the perfect command of the initial radiological state in order to propose a sound and viable dismantling strategy. Indeed it happens that the characterization calls completely into question the initial strategy scheduled for decommissioning.

The graph below (Figure 21) represents the main idea of the paper, that is to say the interest in putting financial means at the beginning of the project. Knowing as much information as possible regarding the facility and the contamination, allows decreasing significantly the global cost of the project.
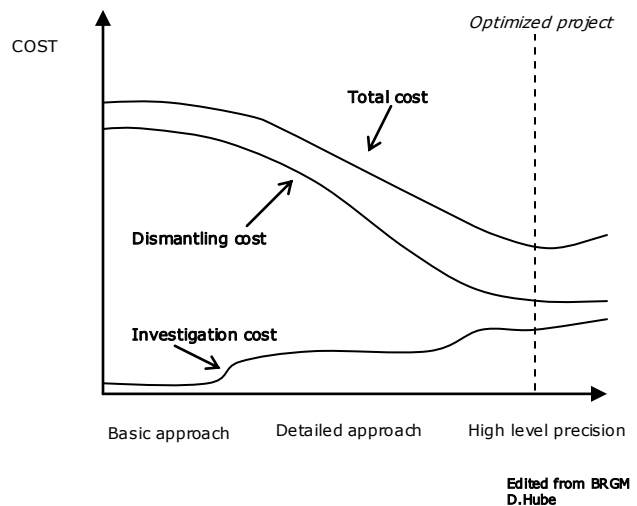

Figure 21 : project optimization graph

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2. Y. DESNOYERS, D. DUBOT, "Geostatistical methodology for waste optimization of contaminated premises," ICEM international symposium, Reims, France, September 2011.