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H2020 INSIDER PROJECT: PROGRESS ON SAMPLING STRATEGY AND IMPLEMENTATION ON THREE USE CASES

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Abstract

Within the H2020 INSIDER project, the main objective of work package 3 (WP3) is to draft a sampling guide for initial nuclear site characterization in constraint environments, before decommissioning, based on a statistical approach. Corresponding work has been divided into four parts. The first task consisted in providing an overview of available sampling design methods described in standards and guides followed by a brief presentation of the statistical methods that can be used to demonstrate meeting the objectives in the context of initial nuclear site characterization in constraint environments. The second task aims at developing a strategy for sampling in the field of initial nuclear site characterization in view of decommissioning, with the most important goal to guide the end user to appropriate statistical methods (including, but not limited to those identified during the first task) to use for sampling design and data analysis. Third and ongoing task consists in applying the developed data analysis and sampling design strategy to three real use cases: a tank containing radioactive effluents and sludge, a reactor bio-shield and contaminated soils beneath a building. Finally, the fourth task will summarize at the end of the project all the findings in a comprehensive sampling strategy guide.

1. Introduction

The EURATOM work program project INSIDER was launched in June 2017 (18 partners from 10 European countries). It aims at improving the management of contaminated materials arising from decommissioning and dismantling (D&D) operations by proposing an integrated methodology of characterization. The methodology is based on advanced statistical processing and modelling, coupled with adapted and innovative analytical and measurement methods, in line with sustainability and economic objectives.

The overall objective of INSIDER is to develop and validate a new and improved integrated characterization methodology and strategy during the D&D process, based on three main use cases:

1. A nuclear R&D facility: radioactive liquid and sludge in tank at JRC Ispra (Italy),
2. A nuclear power plant: activated bio-shield concrete of the BR3 reactor (Belgium),
3. A post accidental site remediation: contaminated soils beneath a CEA building (France).

INSIDER's activities are divided into 7 Work Packages, each targeting a specific objective (Figure 1).

Figure 1 INSIDER work package distribution.

The main objective of Work Package 3 (WP3), is to draft a sampling guide for initial nuclear site characterization in constraint environments before decommissioning, based on a statistical approach. This is done by selecting state-of-the-art techniques concerning sampling design optimization, using prior information and multiple iterations, testing the approach through different case studies and reviewing the feedback from overall uncertainty calculations. The process followed to meet the main WP3 objective consists of four steps:

1. Status: provide an overview of the available sampling design methods and state-of-the-art statistical techniques.
2. Development: develop a strategy/methodology that makes use of state-of-the-art techniques, and present it in a user-friendly software application.
3. Implementation: apply the methodology to the different test cases considered in order to test its adequacy.
4. Guidance: summarize all the findings in a comprehensive sampling strategy guide.

This paper aims to present and share the mid-term outputs of WP3 on sampling strategy and the ongoing implementation in the three selected use cases.

2. State-of-the-art on sampling strategy

Many guides and references in the specific field of decommissioning focus on the back end of decommissioning (e.g. release of regulatory control) whereas the INSIDER project is more looking at the front end (pre-decommissioning characterization), with the aim of applying a waste-led approach. Moreover, many of the generic sampling design techniques and state-of-the-art statistical techniques used in preliminary analyses and data processing are often considered as stand-alone methods.

The first task of WP3 then lists the various objectives of initial site characterization, defining the expected benefits and providing an overview of the relevant existing standards and guidelines in the field of initial site characterization before decommissioning [1]. Furthermore, specific chapters on preliminary statistical analyses and data processing describe available and currently applied methods. About data processing, a distinction is developed between approaches considering spatial structure or not. In the context of initial site characterization in constraint environments, the very limited amount of available data is particularly challenging. That is why a chapter is entirely dedicated to this specific issue.

This document reports on the currently used methodologies and its main objective is to provide input for the next step of the WP3 process, that is: strategy development. Nevertheless, the generic sampling design techniques and state-of-the-art statistical techniques used in preliminary analyses and data processing are often considered as stand-alone methods. In many cases, an integrated and overall pre-decommissioning characterization approach, which notably consists in evaluating historical data, making on-site measurement campaigns, sampling and analysing, developing scaling factors and applying numerical codes, is missing.

3. Sampling strategy development

This second task aims at developing a strategy for sampling in the field of initial nuclear site characterization in view of decommissioning, with the most important goal to guide the end user to appropriate statistical methods (including, but not limited to those identified during the first task) to use for data analysis and sampling design [2]. To aid the end user in applying this strategy, a user-friendly application for guiding the end user through the contents of the strategy and the initial characterization process is available on-line at https://insider-h2020.sckcen.be/.

3.1 Overall strategy

While the data analysis and sampling design methods that can be applied depend strongly on the situation and specific goals of initial nuclear site characterization, the overall strategy often takes the form of the generic workflow illustrated in Figure 2.

The starting point considered here is the request for initial nuclear site characterization to a radiological characterization team. Such a request can come from different kinds of actors (safety authority, decommissioning project, radiological protection, waste disposal…), and can come with different amounts of detail. Following this request, a clear list of all objectives and identification of the constraints is absolutely required, and might ask for some iterations with the applicant to agree on the goals and priorities. The highest-priority objective should be tackled first in most cases, and the other secondary objectives can possibly be derived from data collected for the main objective, or required additional and specific characterization effort.

All prior information that is available and relevant for the investigated case should be gathered as a first step. If some data would already be available, a first analysis to check if the objective is achieved is probably very useful, even if the results come with lots of uncertainty. In D&D, such prior information is nearly always available. Work is carried on historical installations and/or sites that have been shut down, or are going to be. Therefore, there is always a history of the exploitation phase, with available data, so this initial data-gathering step is of vital importance.

The data analysis following the data collection consists, in general, of the following steps: pre-processing, exploratory data analysis, the actual data analysis, and potentially a postprocessing step. If the objective is not achieved, a sampling design should be proposed using the most appropriate method(s) given all prior information and the data analysis result. Following the design, the corresponding characterization campaign should be performed. Additional characterization can reveal unexpected issues, and often revisiting the gathering of prior information is then useful. After the additional characterization, the updated dataset is again analysed, and the iterative procedure is continued until the objective is finally reached. The entire process can then be repeated to tackle the remaining objectives. Once all objectives have been achieved, the initial characterization study should be reported in a transparent way, making clear what has been measured, which results were obtained from the data analysis, and how large the corresponding uncertainty is. The different steps are more extensively discussed one by one below.

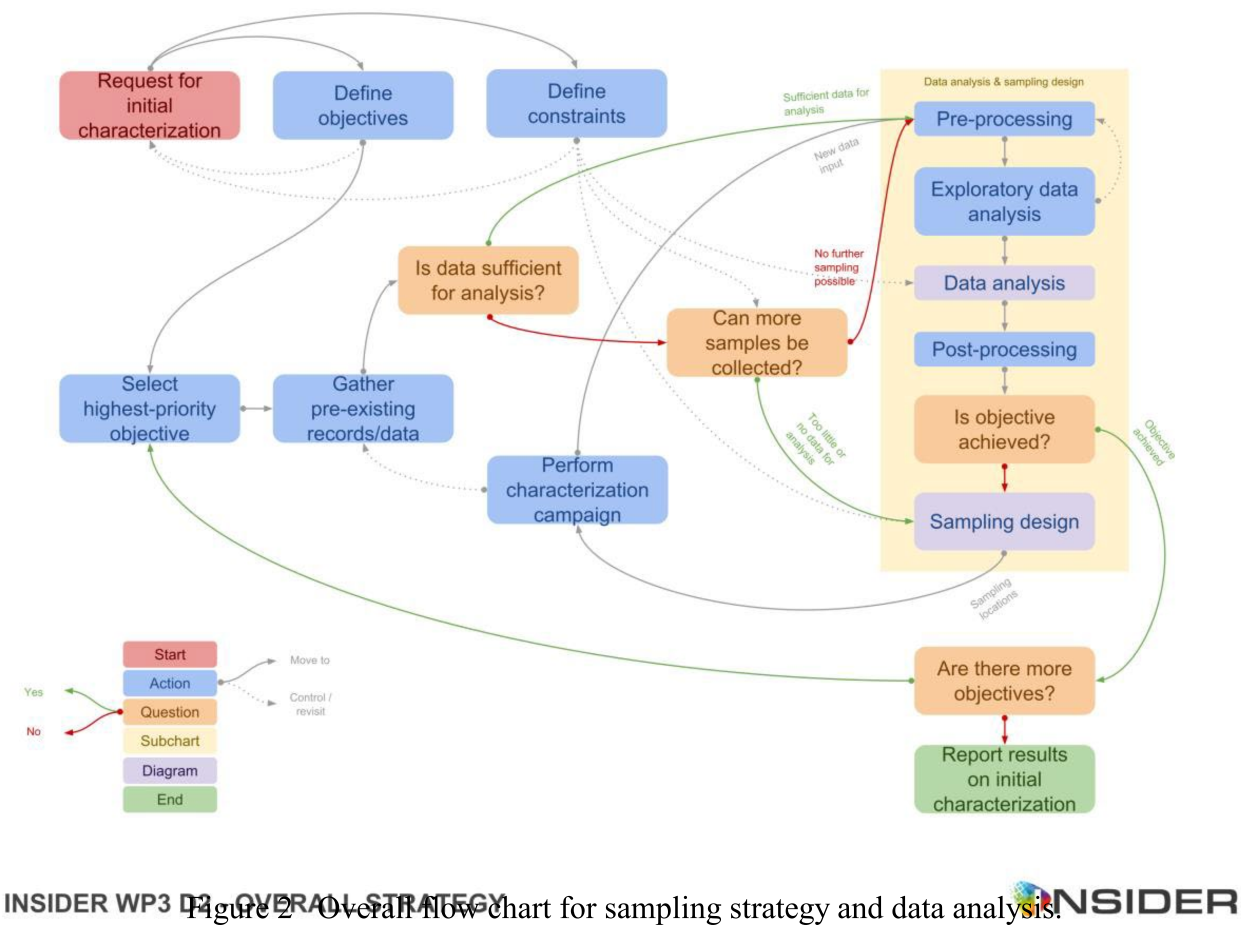

Figure 2 Overall flow chart for sampling strategy and data analysis.

3.2 Data analysis

For organizing the different data analysis techniques, the Venn diagram presented in Figure 3 is developed. The different categories are based on the four aspects of the data, studied in the exploratory data analysis step:

- the requirement for multivariate methods to valuate correlations between variables,
- the presence of spatial structure (non-randomness of activity spatial distribution),
- the presence of spatial trends (to be prior modelled possibly),
- and the requirement for robust methods (case of small datasets).

The methods that are able to handle two, three or all aspects, are listed in the corresponding intersections in Figure 3. It is also possible none of these aspects apply, in which case the method are presented outside of the diagram. The work deliverable [2] briefly explains the different data analysis techniques one by one. In case it would not be clear which method to use, or if multiple methods are mentioned in the relevant section of the diagram, it is recommended to go through these brief introductions first. If it would still be unclear what method to use, further reading is recommended, or the consultation of a more experienced person.

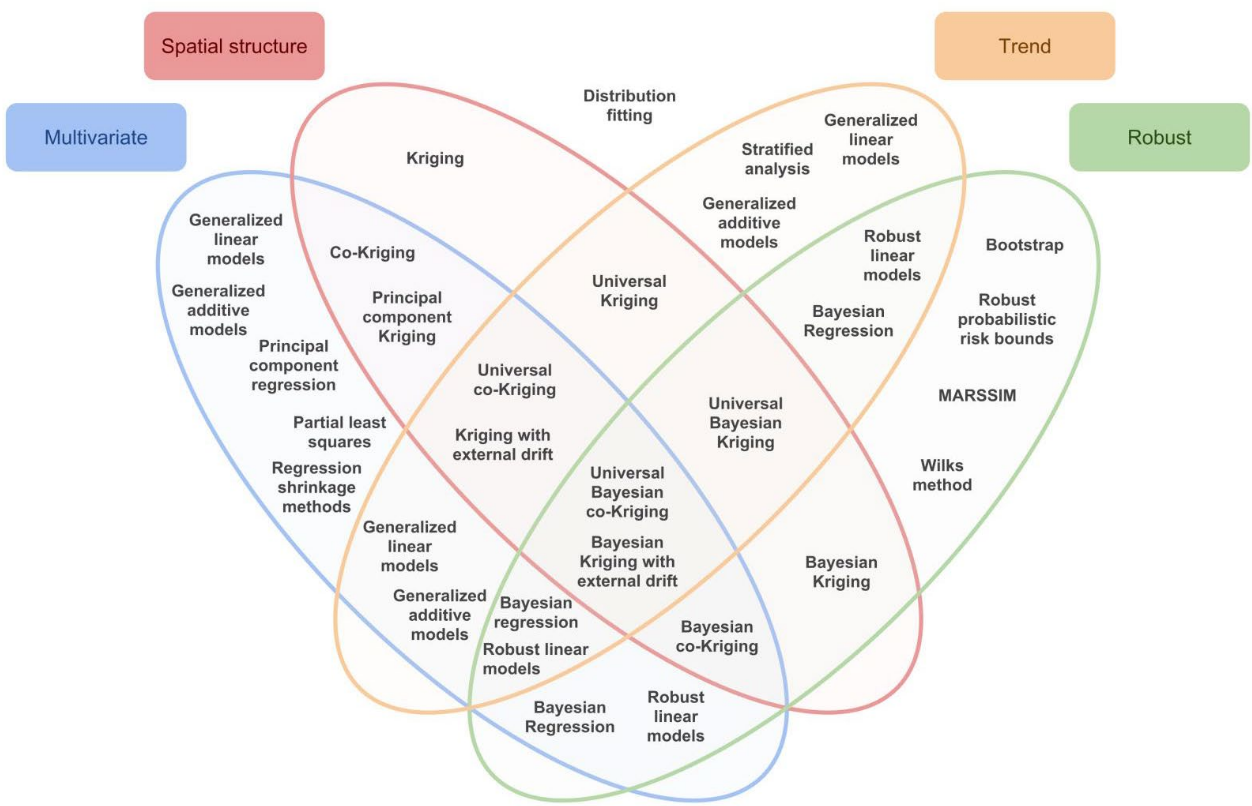

Figure 3 Data analysis Venn diagram.

3.3 Sampling design

If the objective cannot be achieved with the available data, more information is required, and a proper sampling design should be made before collecting new data. There exists a variety of different ways to approach this, and the main drivers here are the available data, the type of problem at hand (revealed by the exploratory data analysis), the outcome of the data analysis, and the reason why the objective cannot be achieved. Note that the list of approaches discussed here is non-limitative. A similar Venn diagram presents the discussed sampling approaches whether if it is based on a probabilistic on judgmental way on the one hand and according to an equal or unequal probability of selection.

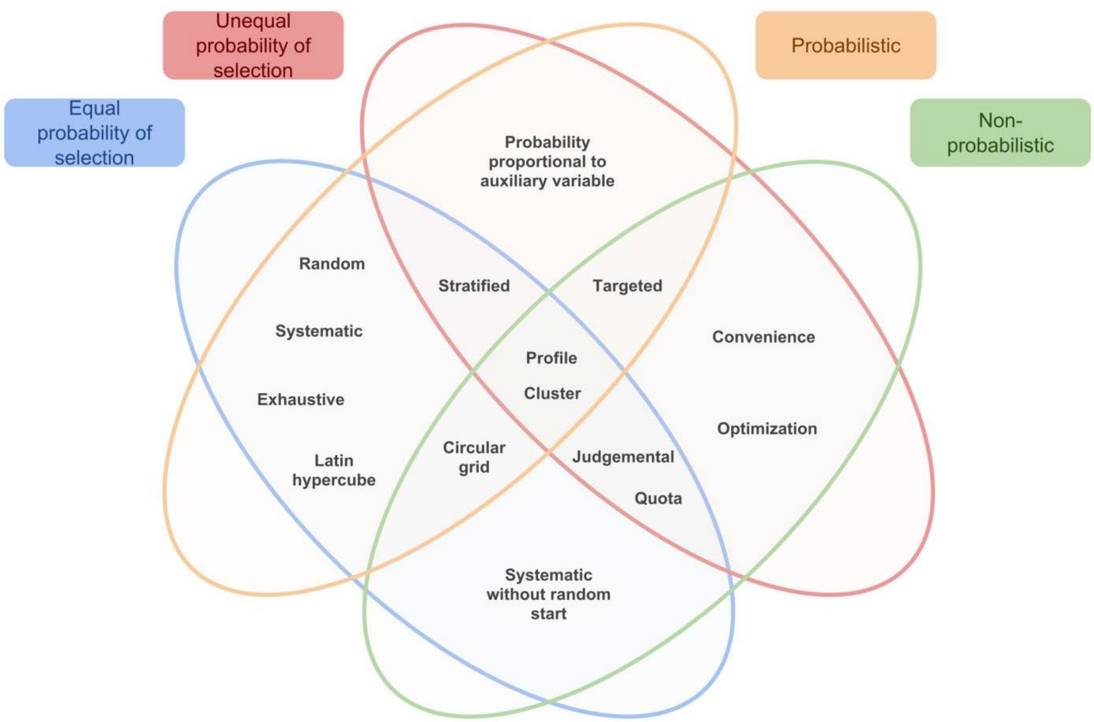

Figure 4 Sampling design Venn diagram.

It should be noted here however, that in practice, sampling design consists most often of a combination of these approaches, as objectives and/or sampling targets are often multiple in real life.

4. Development on three use cases

The third task is targeted at applying the strategy developed on three selected use cases:

- Use case 1: Decommissioning of a back/end fuel cycle and/or research facility [3];
- Use case 2: Decommissioning of a nuclear reactor [4];
- Use case 3: Post accidental land remediation [5].

4.1 Radioactive liquid and sludge in tank at JRC Ispra (Italy)

The facility selected for the case study UC1 is the liquid waste storage facility at the JRC site of Ispra (Italy), referred to as "tank farm" (Figure 5). This is a building commissioned in 2010, designed to collect all remaining liquid waste present on site, mostly stored in tanks in the old liquid effluent treatment station (STRRL), to be routed for cementation or other solidification and conditioning treatment. Most of the liquid waste or sludge is contained in two double walled tanks, 12 mm total wall thickness (stainless steel), called VA001 and VA002. A small lead-shielded tank for intermediate level waste was added to the storage facility a couple of years later. The latter is explicitly excluded from the sampling plan to be established for this exercise, but may contribute to the overall dose rate in the building.

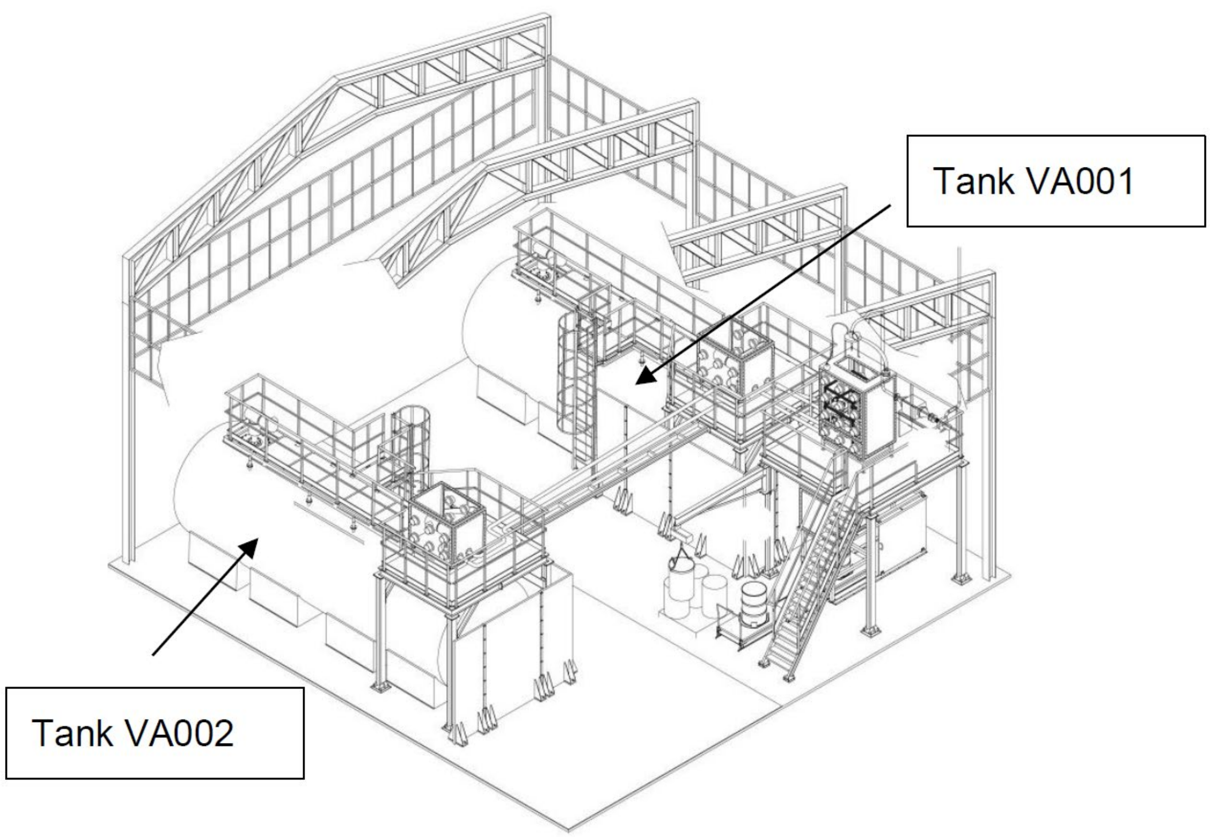

Figure 5 Schematic of tank farm building at JRC Ispra (Italy).

The main objective here is to fulfil the necessary requirements for conditioning and removing the waste according to the relevant waste acceptance and possibly disposal criteria. It is noted that relevant waste acceptance criteria for this waste have not yet been determined by the relevant Authority, and applicable clearance or acceptance limits are therefore not known. The intended treatment or conditioning strategy is still in the process of being defined; while cementation has been investigated as a possibility, this has yet to be confirmed.

Given this background, the primary objective for this campaign is to characterize the waste as exactly as possible, both in relation to its physico-chemical properties as well as to its radiological content.

Activities required in order to reach the main objective could be summarised as follows:

- Determine physical and chemical properties of the waste, and
- Determine radiological properties of the waste: dose rate in the working area, degree of homogeneity/spatial distribution, nuclide inventory and quantification, and waste classification.

The validity and usefulness of scaling factors must be determined, using as a starting point the pre-existing data as an input. While preliminary scaling factors for specific process streams at Ispra have been determined in the past, these have not been provided so as not to prejudice the analysis of the pre-existing data.

The two low level waste tanks at Ispra are characterized by activity concentrations of gamma emitting nuclides of a few Bq/g (tank VA001) up to about 135 Bq/g (tank VA002). Non-destructive gamma spectrometry from the tank surface may be used to determine if elevation profiles in the tank can be identified prior to mixing.

Biased sampling may be used to confirm inhomogeneity within the tanks, if suggested by non-destructive testing. If not, non-biased sampling only can be used to confirm the trends observed in the pre-existing data, and to supplement it where additional information is needed.

4.2 Activated bio-shield concrete of the BR3 reactor (Belgium)

BR3 is a relatively small 10 MWe (about 41 MWth) Pressurised Water Reactor (PWR) of the SCK•CEN (Belgian Nuclear Research Centre). The pilot PWR for the later Belgian nuclear commercial Power Plants BR3, was brought into operation in October 1962 and was definitively shutdown in 1987 after 25 years of operation and eleven campaigns. The reactor core, the reactor pressure vessel (RPV) and primary circuit were located in the reactor building (RB). The whole primary circuit (RPV, Steam Generator (SG), pumps & primary loop, etc.) has been dismantled, as well as the ventilation and the anti-missile slabs. The bottom part of the reactor building consists of reinforced ordinary concrete. The remainder of the reactor building consists of reinforced heavy concrete.

The concrete of the reactor pool close to the reactor pressure vessel is activated. Since the reactor pressure vessel was surrounded by a neutron shield tank, the surrounding concrete is not activated, except locally near the hot and cold legs. Historical measurements confirm this. Figure 6 gives a 3D model of the part of the BR3 bio-shield taken into consideration for the radiological characterisation programme. The main goal of the radiological characterisation programme is to economically optimise the bio-shield dismantling strategy using a waste-led approach.

The main goal of the radiological characterisation programme for the BR3 bio-shield is to economically optimise the bio-shield dismantling strategy using a waste-led approach. In order to reach this main goal, the main objective is divided into three sub objectives:

1. Create a 3D activity concentration distribution map
2. Quantify and localise the different end-stage volumes
3. Economically optimise volumes in view of a waste-led approach

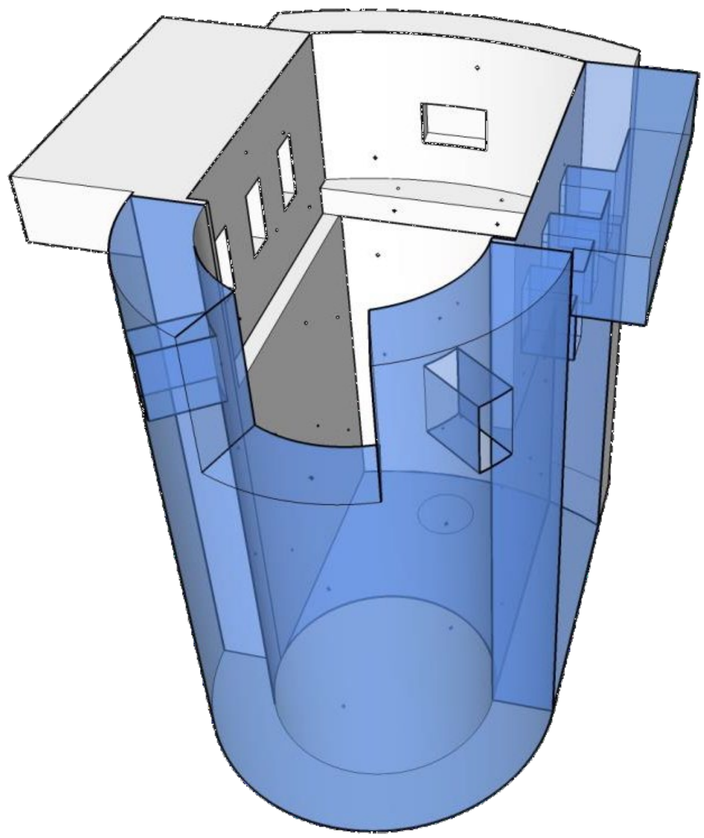

Figure 6 3D model of BR3 bio-shield for radiological characterisation programme (in blue).

After removing the liner, the SCK•CEN performed an in-situ total gamma surface mapping (June 2018), consisting of about 300 individual measurements using a Como 300G plastic scintillator of 300 cm² surface. This roughly amounts to about one measurement per square meter. SCK•CEN used regular grid sampling to achieve full coverage, as the idea is to use these data as secondary information for the activity concentrations within the concrete.

The destructive sampling design mainly consisted of systematic sampling (probabilistic approach) supplemented with judgemental selected sampling locations (specific structures such as the "poubelle" and the refuelling channel and close to the location with the maximal activation level). In addition, the expected trend extreme locations were selected as well, and symmetry of the activation is used to maximize the results with a minimum number of samples. Resulting sampling plan foresee to take 30 samples.

4.3 Contaminated soils beneath a CEA building (France)

For some confidentiality reasons the strict minimum of the site context information has been made available within the INSIDER project. However, this situation is sometimes representative of real circumstances for old facilities for instance, for which historical knowledge results are very limited. What can be mentioned is this nuclear facility was devoted to radiochemistry on trans-uranium elements. It was under operation until 1992 on a CEA site in France. The contaminated soil area is located beneath this building, just below a former tank room (Figure 7).

It has been reported that different incidents occurred during nuclear facility operation. Contamination of soils beneath the tank room with few TBq of various alpha et beta emitters is expected due to leaks of very high radioactive effluent in the tank room and several potential contamination pathways to reach the soils such as ingress, cracks or expansion joints of the concrete slab.

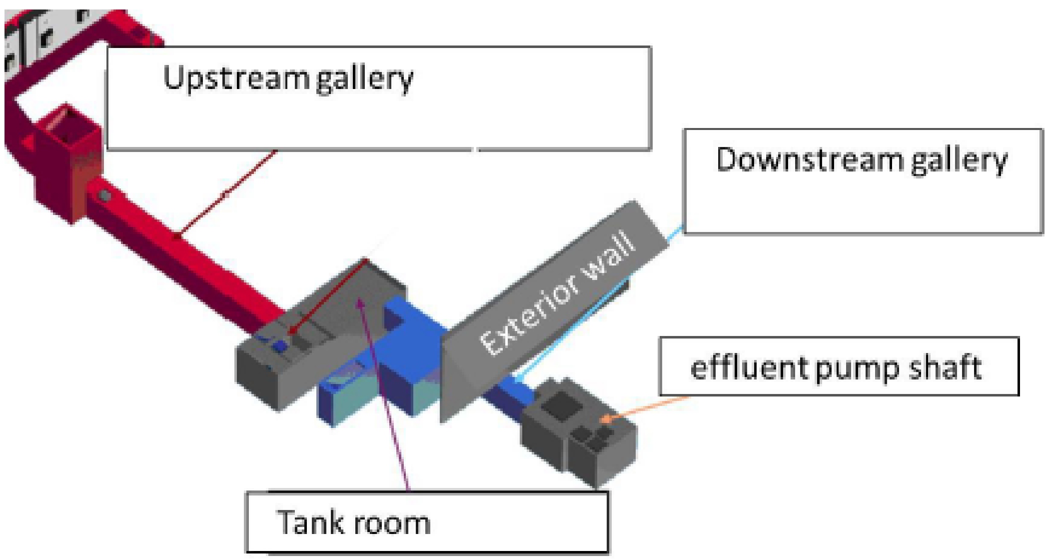

Figure 7 Use case 3 location beneath a tank room of a former nuclear facility.

In order to improve the radiological assessment of soils below this tank room, different sampling campaigns have been conducted. They consist in 7 horizontal drill holes between 2012 and 2015. The 7 drill holes are distributed in two horizontal layers at 0,5 and 1,5 m below bottom of the tank room slab. The drilling machine was located at the bottom of a circular pit outside of the building to access this area and go horizontally. This approach is not very common for soil sampling as generally vertical drill holes from the top surface is preferred. However, due to the presence of the building and the impossibility to introduce the drilling machine in the tank room, this aside and long-range horizontal drilling location has been preferred.

Within the INSIDER project, the existing dataset is considered as the final one for this use case 3. There is no sampling design definition as for the other use cases, but the statistical analysis promises to bring interesting and relevant conclusions for the whole project due to the number (220) of available samples. This will be performed by conducting sensitivity analysis (extracting different sub-datasets) and possibly valuate the correlation with 5-cm gamma-scanning values along the cores.

5. Conclusion and future works

At the halfway stage of the INSIDER project, outputs are in line with the expected planning. Sampling strategy and data analysis are currently deployed to three use case according to existing literature and developed integrated strategy. The fourth and last task of WP3 will analyse the return of experience from implementation on these test cases in order to compile and summarise all findings in a comprehensive sampling strategy guide on radiological characterization in constraint environment. This document is expected by beginning of 2021.

At the INSIDER level, uncertainty coming from the sampling strategy and data analysis step will be quantified and integrated to a global uncertainty budget (in relation with other work packages, mainly WP4 and WP5).

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6. References

All public document from the H2020 INSIDER project and concerning WP3 are available at http://insider-h2020.eu/results/#sampling_strategy

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