

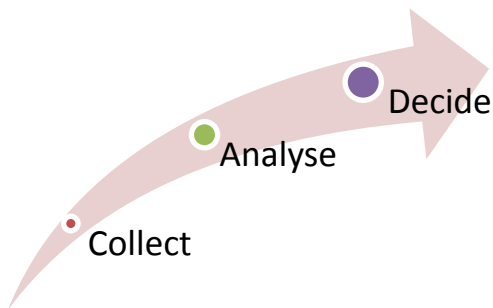
# Integration of characterisation and categorisation in waste management to increase efficiency in clearance

Arne Larsson and Per Lidar, Studsvik, Sweden (arne.larsson@studsvik.se, per.lidar@studsvik.se)

Yvon Desnoyers, Geovariances, France (desnoyers@geovariances.com)

## Introduction

Decommissioning of a nuclear facility is very costly. Waste management, disposal costs and costs for clearance of materials, buildings and site areas contributes largely to the total cost. Two activities closely related to waste management and clearance of materials, buildings and land areas are radiological characterisation and categorisation.



Radiological characterisation plays an important role in a decommissioning project. It is a platform for planning, identification of the extent and nature of contamination, assessing potential risk impacts, cost estimation, implementation of decommissioning framework, radiation protection, management of material arising from decommissioning as well as for release of buildings and sites.

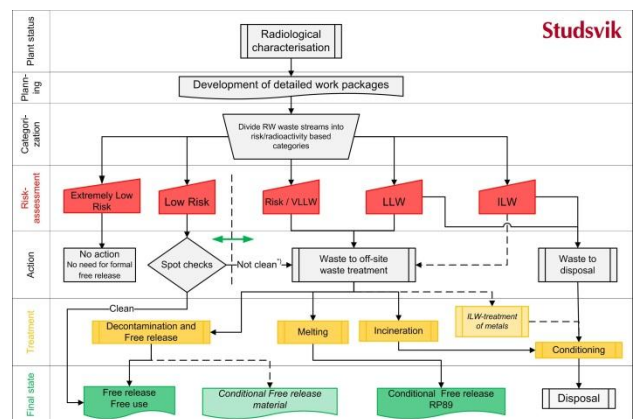
Key issues in radiological characterisation are identification of objectives, development of a measurement and sampling strategy (probabilistic, judgmental or a combination thereof), knowledge management, traceability, recording and processing of obtained information.

## Waste management strategy

Categorisation of systems, materials and buildings is needed both initially as an input to a characterisation campaign as well as afterwards (re-categorisation, as required, based on findings). A well founded and well working methodology for categorisation is a basis for implementation of a graded approach concept for efficient clearance in decommissioning [1].

Decommissioning of nuclear facilities generate large volumes of materials with no or very low levels of contamination. The handling of this low risk material is costly and time consuming. By a further integration of characterisation and categorisation in waste management, in combination with certified or validated

processes for a safe and efficient clearance, significant savings in time and money are within reach.



## Importance of initial characterisation

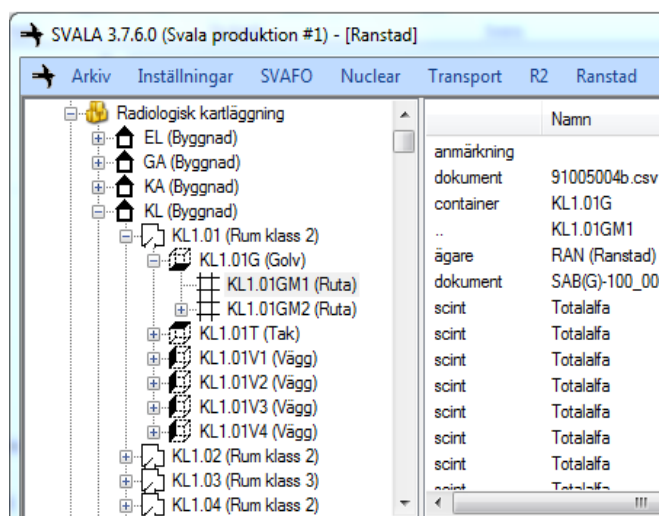
D&D projects are largely impacted by the contaminated state of the facility. Initial characterisation stage is then a crucial issue for project management: radiological hazards, cost estimation, planning and waste



management. "Segregation and characterization of contaminated materials are the key elements of waste minimization" [2].

Deterministic numerical models are generally used to describe the contamination distribution in simple cases. They deal with activation, migration, dispersion, etc. But most of the time, they fail to represent accurately the reality due to its complexity.

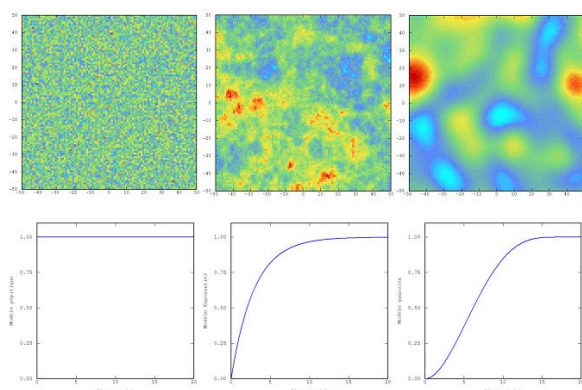
Model parameters and hypotheses become easily too numerous to be managed properly. As a consequence, a more appropriate evaluation methodology has to be implemented for the initial radiological characterisation for building structures (and for lands), using a probabilistic approach and putting the emphasis on measurements and samples.



## Geostatistics and spatial continuity

The geostatistical framework is an efficient way to meet the radiological characterisation requirements providing a sound decision-making approach for the decommissioning and dismantling of nuclear premises.

The relevance of the geostatistical methodology relies on the presence of a spatial continuity for radiological contamination. The phenomenon variability is analysed through the variogram which estimates the variance contribution between data points [3]. Generally, for a structured phenomenon, the spatial variability increases with distance and tends to stabilize (“sill”) at a distance named “range” (last two examples on the next figure).



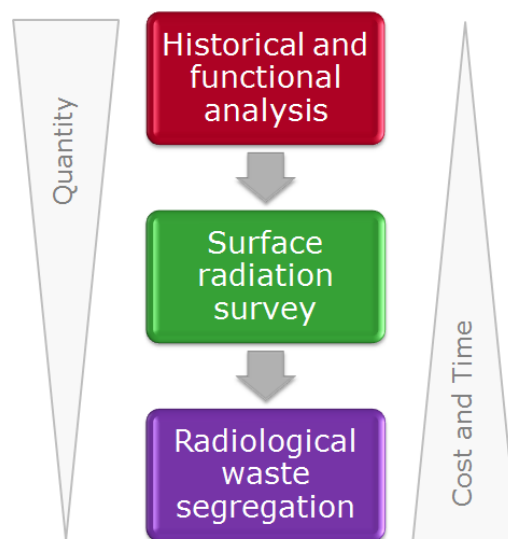
Data separated by a distance larger than the range are no longer spatially correlated. In the case of a spatial random phenomenon, the variability keeps the same value whatever the distance between points; white noise is analysed as a pure nugget effect on the variogram (first example on the figure). The three examples above have the same statistical characteristics, but clearly not the same spatial structure.

Thus geostatistics provides reliable methods for activity estimation, uncertainty quantification and risk analysis, leading to a sound classification of radiological waste (for surfaces and volumes, as change-of-support problem is correctly addressed) [4].

## Initial characterisation

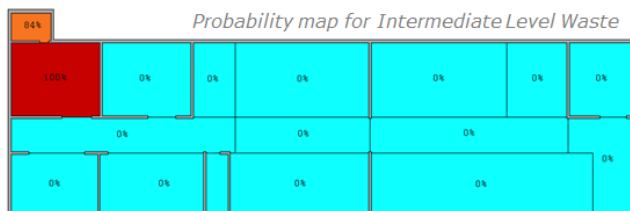
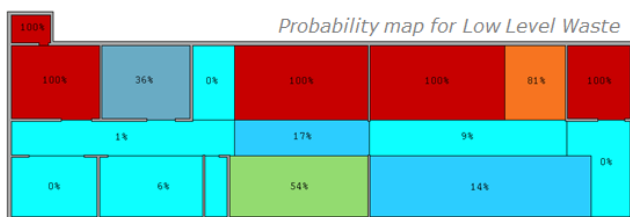
Using geostatistics as data analysis, the radiological characterisation of contaminated premises can be divided into three steps:

- First, the most exhaustive facility analysis provides historical and qualitative information.
- Then, a systematic (exhaustive or not) surface survey of the contamination is implemented on a regular grid.
- Finally, in order to assess activity levels and contamination depths, destructive samples are collected at several locations within the premises (based on the surface survey results) and analysed.



Combined with historical information and radiation maps, such data improve and reinforce the preliminary waste zoning [5].

Cost-benefit analyses may be presented by comparing the risk threshold and the corresponding waste surfaces/volumes. For different radiological thresholds, surface classification can be performed according to the tolerated risk (probability of exceeding) and the remediation support (punctual or block).

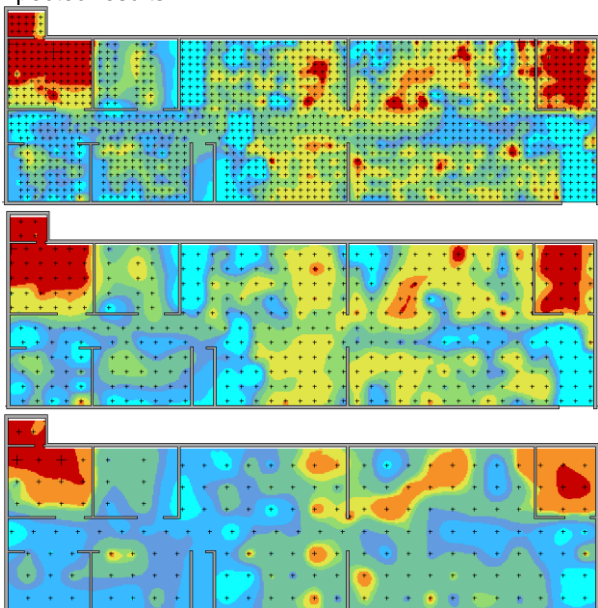


## Sampling optimisation

For the initial radiological characterisation the geostatistical framework is not only a data processing technique but also an efficient way to optimise the sampling strategy.

First, the initial mesh for the radiation map is determined thanks to the historical and functional analysis and to the experience feedback on geostatistical analysis of similar contaminations: indeed spatial structure ranges (maximum autocorrelation distance) show similarities on the various case studies. To be more precise, radiological contamination ranges<sup>ii</sup> for concrete structures classically vary from 1 meter to 5 meters. In other words, on the one hand a 5m mesh is useless for geostatistical processing as the spatial structure is not going to be identified; on the other hand a 10cm mesh implies redundancy between collected values as well as time and money wasting.

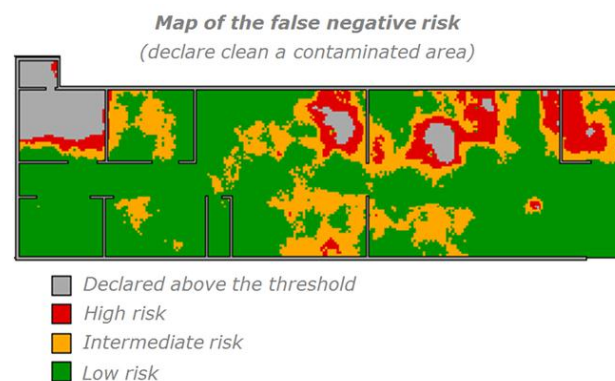
Next three figures illustrates the impact of the sampling mesh (dose rate for radiation mapping) on the estimated map (kriging interpolation): 0.66m, 1.3m and 2.0m. Hot spots are better recognised with the densest design but global trends are correctly estimated with the largest mesh. The correct map (and the corresponding sampling mesh) still depends on the evaluation objective and the expected results.



As for external soils, spatial structure ranges typically varies between 10 and 30 meters for contaminations around or under nuclear facilities. It may increase up to dozen of kilometres for major incidents on regional scale, such as Fukushima event. In that case of post-incident monitoring, geostatistics correctly addresses the anisotropy issue using directional variograms and suitable neighbourhood for interpolation.

Then, as the added value of geostatistics lies in the uncertainty quantification of the prediction (kriging), it is a powerful tool to identify areas where the confidence interval is too large. Similarly the probability of exceeding a fixed threshold may require additional measurements. The possibility for quick and easy update of the geostatistical results is proven to be of significant value for the development of an iterative and optimised sampling plan.

The false negative risk, namely estimating as clean a contaminated area, is also an interesting indicator for risk analysis. On the next figure, grey areas are declared to be above the radiological threshold, red areas have the highest risk to be misclassified while this risk decreases in orange areas and is very low in green ones.



For the third investigation phase, destructive samples are basically located according to the radiation and contamination map results. This is the judgmental part of the methodology. Additional sampling points might then be located using the same approach than for the surface radiation mapping (reduction of uncertainty, intermediate probability validation...). The vertical variability of the phenomenon is significantly higher than in the horizontal plane. Sampling resolution in the vertical direction has to be denser as a consequence (typically a few centimetres or less for building structures and a few dozens of centimetres for soils).

## Integrating characterisation and categorisation

On the one hand, the geostatistical framework is an efficient way to satisfy the initial radiological characterisation requirements providing a sound decision-making approach for the decommissioning and dismantling of nuclear premises. The relevance of the geostatistical methodology relies on the presence of a spatial continuity for radiological contamination. The phenomenon variability is analysed through the variogram which estimates the variance contribution between data points.



Geostatistics provides reliable methods for activity estimation, uncertainty quantifications and risk analysis in the categorisation process of radioactive waste, using the three steps as described above.

In addition, geostatistics provide a methodology to optimize the characterization effort according to an evaluation objective. First, the initial mesh is determined based on the expected spatial structure and the gained experience on comparable contaminations. Then geostatistics proves to be a powerful technique to identify areas where to perform additional measurements in order to reduce uncertainties (confidence interval, probability of exceeding a fixed threshold, risk of false negative....). The quick update of the geostatistical results demonstrates to be relevant for an iterative and optimised sampling strategy.

It should be highlighted that demonstration of compliance with the clearance/site release levels within the final survey will benefit on classic statistical approaches. Selection of an appropriate method based on the actual objectives should be performed for each step. There is no tool or approach that give an optimised result and efficiency in all steps. For the waste management process geostatistical methods should be evaluated.

Statistics and geostatistics are complementary rather than opposite as they are not used at the same characterisation stage [6].

## Conclusion

- Geostatistical methods can in an efficient way support the characterisation and categorisation of radioactive waste most likely subject to clearance.
- Integrated and well working characterisation and categorisation methods can be of considerable assistance in the efforts to shorten decommissioning projects.

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## Short facts about Studsvik

Studsvik offers a range of advanced technical services to the international nuclear power industry and other operations involving ionising radiation. Studsvik performs services in areas as waste treatment, decommissioning, engineering & services, and operating efficiency.

Studsvik has more than 60 years' experience of nuclear technology and radiological services.

Studsvik has 1,100 employees in seven countries and the company's shares are listed on the NASDAQ OMX Stockholm.

## Short facts about Geovariances

- Geostatistics world leader
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  - o Oil & gas
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  - o Air quality
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<sup>i</sup> "sill" or variance

<sup>ii</sup> i.e., spatial structures