**Radiological Characterisation – Know Your Objective**

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## Abstract

When developing a programme for mapping the radiological characteristics of a facility to be decommissioned, it is important to take into account the objectives of the programme. Will the results be used to plan for radiological control and selection of appropriate decontamination and dismantling techniques? Will the radiological inventory be used for dimensioning of future waste repositories? These are two examples of the applications for such studies, which could require that a radiological characterisation programme be adapted to provide the data appropriate to the intended use.

The level of detail and scope needed for a radiological characterisation will also vary depending on how the data will be used. An application to free-release a facility requires a comprehensive survey and well-documented analysis in order to ensure that no radioactive contamination above prescribed levels is present. A bounding calculation to determine the maximum anticipated volumes and activity of radioactive waste requires a different approach.

During the past few years, older decommissioning studies for the Swedish nuclear power plants have been updated (or are in the process of being updated). The decommissioning study's main purpose is to estimate the cost for decommissioning. The cost estimation is based on material and activity inventories, which in turn is based on previous and, in some cases, updated radiological characterisations of the facilities. The radiological inventory is an important part of the study as it affects the cost of decommissioning but also the uncertainties and accuracy of the cost estimation.

This paper discusses the challenges in specifying a radiological characterisation programme with multiple objectives, together with insights on how data delivered can be applied to yield results suitable for the intended purpose, without introducing excessive conservatism. The intent is to define issues that can be of use in various aspects of radiological characterisation: preparation of a specification, execution of a characterisation programme and application of the results, with the goal of optimizing the process and minimizing unnecessary work.

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# 1 Introduction

Radiological characterisation is a vital step in preparations for decommissioning and dismantling of nuclear sites and facilities. A successful radiological characterisation delivers data that is appropriate for the intended purpose without unnecessarily consuming time and resources. The objective of the characterisation should always be in focus.

# 2 Scope

Some challenges associated with the specification and application of radiological characterisation data are described.

There can be several different objectives when performing a radiological characterisation. It is important to clearly define the objectives when specifying a radiological characterisation in order to ensure an acceptable result that can be applied as intended. Different objectives can affect the execution of a radiological characterisation programme. The deliverables and data produced should be appropriate for the objective and end use. There should be an attempt to optimize the characterisation and some compromises may be necessary.

# 3 Different objectives of a radiological characterisation

A radiological characterisation can be prepared with the objective of addressing several different issues. These issues may include the prediction of waste activity inventories, the dimensioning of waste repositories and waste handling facilities, the preparation of decommissioning cost estimates, the calculation of dose budgets, the estimation of radiological releases and the application to free release a facility or a site that was used for nuclear operations.

## *3.1 Prediction of waste activity inventories*

It is important to have an indication of the waste activity inventory in order to plan the waste handling logistics, both during operation and for decommissioning, including waste packaging, the number and types of waste containers required. Specialized waste containers can have long lead times for manufacturing and delivery. In some cases a new waste packaging system may need to be developed, tested and certified. An example of such a project in Sweden is the packaging of reactor internals in BFA tanks.

Other waste management aspects that rely on information about waste activity inventories are decontamination, treatment onsite or offsite, interim storage and disposal in near surface repositories.

An example of a study where the waste activity inventories are of primary importance is an ongoing study concerning the decommissioning logistics and waste management for the Barsebäck 1 and 2 nuclear power plants in Sweden. These boiling water reactors were taken out of operation in 1999 and 2005, respectively. The study is based on previous waste activity inventories and decommissioning studies. The previous waste activity inventories were based on a combination of measurements and calculations.

## 3.2 Dimensioning of waste facilities

The waste activity inventory is also significant when dimensioning future waste disposal and treatment facilities. For example, the Swedish final repository for short-lived low- and intermediate level decommissioning waste (SFR) is planned to begin operation in 2020. It is important that the facility be designed based on reliable input data with respect to both waste volumes and waste activity inventory. These parameters are also vital in preparing the safety analyses for a facility.

In order to preclude the risk of building a facility with insufficient capacity, while avoiding the unnecessary extra expense of a facility with excessive capacity, it may be necessary to carry out several estimates of the waste activity inventory: conservative and best estimate. An assessment can then be performed based on this data to achieve the best possible result.

The waste activity inventory can also be useful in developing proposed waste acceptance criteria (WAC). The WAC ensures the long-term safety of the facility and the environment.

When determining waste activity inventories the benefits of measurements versus calculations should be considered, based on the information available and the relevant schedules that apply to operational life and any subsequent service operation period. It is also important to know whether decommissioning, and thus production of waste, will take place in the near or distant future. A longer period for radioactive decay can be beneficial but a delay can present risks for uncertainty in the applicable requirements, as such legislation tends to evolve and become more restrictive with time.

A relevant example is the planning for the extension of SFR, the final repository for short-lived low- and intermediate level decommissioning waste in Sweden. Inventories of waste activity and amounts are based on both radiological characterisation and theoretical calculations. Issues including transport and selection of waste containers are also affected by waste activity inventories. Because many long-lived nuclides are difficult to detect and quantify some of this waste may be sent to a separate Swedish repository for waste containing long-lived radionuclides, SFL (planned start of operation 2045), instead of SFR.

## 3.3 Decommissioning cost estimates

Radiological characterisation is a factor in performing cost estimates for decommissioning. When performing such an estimate several issues should be considered, including scope, uncertainty and objective.

A clearly defined scope is essential when performing a decommissioning cost estimate. It should be entirely clear what is included and what is excluded. Consider the timing of the dismantling and the status of the plant. A radiological characterisation performed during operation is most probably intended for a different purpose, and may not be fully applicable to the planning of the decommissioning.

There is inevitably uncertainty introduced when performing a decommissioning cost estimate, especially if the decommissioning will take place in 20 years time or more. The radiological characterisation forms a basis for the activity inventory, which can be an important factor that affects the costs. However it has been shown that personnel costs are often dominant. It should be considered whether the focus, that is the effort and corresponding funding, should be on aspects other than radiological characterisation, which may have a relatively minor impact on the total cost. It must be remembered that the primary objective of the decommissioning cost estimate, and thus the activity inventory, is to justify funding for the decommissioning.

A timely example of such a decommissioning cost estimate is the one currently being performed for the Ågesta former nuclear power plant, a heavy-water pressurized water reactor that has been out of operation since 1974. The unique nature of the Ågesta plant, which is constructed in a rock cavern, makes the limitation of the calculation challenging. The end state of the decommissioning is still under discussion. The objectives of previous radiological characterisations are unclear in some cases, and might not have been performed with the objective of decommissioning.

As a basis for the ongoing cost estimate for Ågesta, it was decided to rely on previous limited radiological characterisation data together with new theoretical calculations. This decision was based on the degrading status of the plant which poses a certain degree of risk to personnel, the limited accessibility and the fact that the gamma-emitting radionuclides, such as cobalt-60 have decayed to such an extent that any measurements would be time-consuming to perform and produce results with a high degree of uncertainty. The results of the calculations were judged to be adequate to provide data to the Swedish Nuclear Fuel and Waste Management Co (SKB) for the planning of the SFR extension.

A comprehensive radiological characterisation based on extensive sampling and direct measurement will be carried out as part of the preparatory work for dismantling of the Ågesta plant.

## 3.4 Estimating dose budgets

Dose budgets are also based on activity inventories, and they should generally be conservative. During the operations phase it must be considered that the plant status is dynamic and changes occur continually. For the dismantling phase, there are other factors to be considered. The timing of the actual dismantling is important. Nuclide vectors change over time as the shorter-lived radionuclides decay. For an older plant there are many unknowns, so the history of the facility should be researched in order to compensate for missing information. The dismantling strategy including the sequence of operations and the methods to be used should also be considered when establishing a dose budget. During waste handling operations, the characteristics of the waste matrix should be taken into account as a higher density provides a higher degree of self-shielding.

A recent project that can serve as an example is the handling of the reactor internals at the Forsmark nuclear power plant. The components were cut up in the reactor hall pools, transferred to shielded packages and then transported to an interim storage facility. Every phase of the operation was designed to minimize dose to the workers. The calculated dose budget was conservative, which affected the number and type of BFA tanks used.

## 3.5 Estimation of radiological releases

Radiological releases are usually estimated as a basis for licenses and compliance with regulatory requirements. These estimates are based on theoretical calculations and measurements from operating plants, during dismantling and from waste repositories.

In calculating radiological releases, and their subsequent effects on the population and environment, even the chemical form of the nuclides, iodine being an important example, is of interest.

Cases for normal operation and accident conditions are of interest. Both air and water are considered as release paths. Source terms are usually determined both for the conservative and the realistic, or “best-estimate”, cases.

The need for assessing the radiological consequences of the catastrophic events at the Fukushima reactors in Japan following the earthquake and subsequent tsunami that occurred in March 2011 provides a vivid example of the challenges involved. As in any such assessment the significant nuclides need to be identified and modelled. The many release paths through the geosphere and biosphere must be tracked.

A contrasting case that is normally more passive is that of a final waste repository, considering the long-term safety and modelling releases to the environment. The dose evaluations depend on the nuclide distribution and their behaviour in the environment.

## *3.6 Free release*

When free releasing a facility or a site, after operations have ceased, the regulatory authorities generally require that an application be submitted. For this purpose a comprehensive study is needed and some degree of measurement is essential. A full account of the operational history of a facility is extremely helpful in supporting such an application. The radiological characterisation needs to be well-documented to meet the regulatory requirements.

An application was submitted to the Swedish Radiation Safety Authority (SSM) in 2010 requesting the release from radiological controls of facilities outside the reactor building at the Ågesta former nuclear power plant, out of operation since 1974, as well as the surrounding land. Since Ågesta has been out of operation for many years, there are challenges associated with record keeping and operational history. An extensive study of the old documentation and records where performed. Additional radiological surveys were also performed in support of the application, which is still pending.

# 4 Specifications for radiological characterisation

Questions to be considered when writing a specification for a radiological characterisation include which radionuclides to account for, based on the objective of the characterisation and the nature of the facility. An appropriate degree of conservatism should be determined, so it is essential to ensure that multiple factors of conservatism aren't taken into account in other steps in the analysis. The result may be excessively conservative.

The user and the supplier need to be in agreement concerning how uncertainties are to be taken into account and applied to the results. If there are acceptance criteria that need to be met then they should be communicated to the supplier, as in, for example, for free release.

# 5 Execution of a radiological characterisation programme

The execution of a radiological characterisation programme, generally consisting of extensive sampling and measurements, should also consider the end use of the data produced.

Aspects that should be considered when developing such a programme include the relevant assumptions and limitations. A routine for handling radioactivity that is not related to operations should be developed. This radioactivity refers to natural radioactivity present in building materials, such as Radon and long-lived Radon daughter products. In Sweden Caesium-137 from the Chernobyl accident fallout is also detectable.

The programme should also include a plan for how unexpected results will be handled. An approach for compensating for missing data should be developed. Some measurements may be impossible due to lack of access or nuclides that are not detectable; the programme should describe how these can be modelled.

The programme should address those situations where it is advantageous to perform calculations instead of attempting measurements.

It is generally beneficial if some degree of benchmarking can be performed. During the dismantling of a plant an iterative approach may be preferable. In the early phases of decommissioning the investigations are on a general level, consisting of a review of systems that were of minor radiological interest during operation (not suspected of contamination or low to moderately contaminated systems). At the Barsebäck NPP a chemical decontamination project, DEKONT, provided the opportunity for radiological analysis of large areas of removed oxide layers, which can be considered representative of systems that were not decontaminated.

During later phases of dismantling benchmarking can be directed more towards specific issues and components as well as requirements governing dismantling methods.

In calculating specific activity levels (per square meter or gram), it is necessary to have a Quality Assurance (QA) programme that defines the properties of samples (size, areas, weights, photo etc) and sampling points (photo, location in equipment, properties of system/equipment sampled etc).

In evaluating the data a database tool that is easy to use is needed. Such a tool should include filtering capabilities for data extraction that facilitate and maximize the usefulness of the data. Visualisation capabilities can be beneficial, and cost efficient, for evaluation of large datasets.

# 6 Deliverables/data appropriate for the objective

The deliverables and data produced in the performance of a radiological characterization should be appropriate for the objective and end use. Several aspects should be considered when delivering the results.

The user of the data may need to update or adjust the assumptions and values in the study. It may not be practical for the user to be entirely dependent on the supplier of the data, especially since several years may elapse from the time the original characterisation was performed.

As it may not be certain when the data will be applied, the effects of radioactive decay should be taken into account in such a manner that source terms and nuclide vectors can be recalculated without unnecessary effort.

The presentation of the data can greatly affect its usefulness. The needs of the user should be taken into account as far as possible. For example, it may be practical to group the radiological data by plant system or by building. In other cases there may be advantages in compiling the data based on different operations, such as when the objective is to carry out a dose assessment.

Other uses that can be anticipated are radiological inventories based on waste types or material types.

Based on the quality of the input data and the extent of surveys performed the data obtained will have an associated uncertainty. It is important that this uncertainty be clearly presented in the data reports so that it is properly accounted for in any later data analysis. If the user is not vigilant there is a risk that multiple uncertainty factors are added with every application of the original radiological data. Such an approach may result in inappropriately conservative results.

The selection of database tools (software programs) is not an insignificant issue in carrying out and presenting the results of a radiological characterization. There is a balance to be achieved between the functions required in the program and the demands on the part of the user. A more complex tool will allow more advanced data analysis but may require significantly more training for the user. In selecting database programs the supplier should also take into account the future needs of the customer or end user of the data.

# 7 Optimisation

When performing a radiological characterisation there should be an attempt to optimise the work, and some compromises may be necessary. Factors that usually have to be considered include the time available to perform the radiological characterisation. There may be operational or weather considerations that limit the time available to collect data. For example, some radiological surveys can only be performed when the plant is shut down for outage. Furthermore, the end user of the data may be working with schedule constraints due to regulatory, safety or budget planning requirements.

In some facilities there may be areas or systems that have high dose rates and in the interest of minimizing personnel dose the decision is made to forgo certain measurements and to supply estimates based on secondary data. Other hazards such as limited space, the presence of dangerous chemicals or risk for structural collapse can also prevent the collection of direct measurement data.

The execution of a thorough radiological characterisation of an entire plant is a costly activity. Aside from purely technical considerations, the purchaser must consider the value added to the project when ordering the characterisation. If detailed results are not required by law and are not expected to significantly affect the future activities or the planning of safety measures then a radiological characterisation programme of more limited scope may be adequate. The question that should always be asked is how much precision is required in a radiological characterisation. Greater precision is more costly as more measurements must be taken and more analysis performed. The uncertainty contributed by factors other than radiological may have a much more significant effect on future activities, and this aspect should be considered when specifying the minimum precision of a radiological characterisation.
There may well occur cases where compromise is necessary, due to budget or schedule constraints, or when a radiological characterisation is to be performed to satisfy multiple objectives with different requirements.

# 8 Summary and conclusions

There can be several different objectives when performing a radiological characterisation and it is important to clearly specify these objectives.

Different objectives can affect the execution of a radiological characterisation programme
The deliverables and data produced should be appropriate for the objective and end use
There should be an attempt to optimize the characterisation and some compromises may be necessary.