Decontamination and Dismantling of Radioactive Concrete Structures

A Report of the NEA Co-operative Programme on Decommissioning (CPD)
DECONTAMINATION AND DISMANTLING
OF RADIOACTIVE CONCRETE STRUCTURES

A report of the NEA Co-operative Programme
on Decommissioning (CPD) project

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FOREWORD

The NEA Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking among member country organisations actively executing or planning the decommissioning of nuclear facilities. The objective of the CPD is to acquire information from operational experience in conducting specific decommissioning projects that is useful for future projects. Its working method is based on the exchange of knowledge currently drawn from approximately 60 participating reactor and fuel cycle decommissioning projects.

Although some of the information exchanged within the CPD is confidential in nature and is restricted to programme participants, experience of general interest gained under the programme’s auspices is released for general use (see the website at the following address: http://www.oecd-nea.org/jointproj/decom.html). Such information is brought to the attention of all NEA members through regular reports to the NEA Radioactive Waste Management committee (RWMC), as well as through published studies. The Working Party on Decommissioning and Dismantling (WPDD) of the RWMC would like to thank CPD for sharing the experiences form its important work.

This report presents the generic results obtained by a CPD Task Group on Decontamination and Dismantling (D&D) of Concrete Structures that undertook a comprehensive review of proven technologies and methods for decontaminating, demolishing and disposing of concrete structures.

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- Manuel Ondaro – ENRESA (Spain);
- Bart Ooms – Belgoprocess (Belgium);
- Stefan Wittenauer – WAK (Karlsruhe Reprocessing Plant, Germany);
- David Estvie - CEA (Vice Chair); and
- Bob Burton – (CPD Programme Co-ordinator)

The Task Group wishes to acknowledge the information supplied by the member organisations and the many individuals who organised and forwarded the material. In particular, the Task Group would like to acknowledge the many hours spent typing this report by Vera Verstraelen – SCK•CEN.
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1. Introduction

In response to growing interest in the decommissioning of nuclear facilities, the OECD Nuclear Energy Agency set up the Co-operative Programme on Decommissioning in 1985. Its basic scope is to facilitate the exchange of scientific and technical information between major decommissioning projects. Participation in the Programme has expanded significantly over the years to include organisations from 13 countries. Currently, about 60 projects participate in the Programme. The Programme is executed under an agreement between the participating organisations and companies. A progress report is issued every five years on the CPD and includes a brief description of each project. The most recent report is entitled *A Decade of Progress* [1].

The projects are divided into two groups: reactor projects (60%) and fuel facility projects (40%). A complete list of the different projects and their country of residence can be found in Annex 1. Many of the early projects in the Programme focused on experimental or prototype plants, however, a number of projects for the decommissioning of commercial facilities (power generation, fuel and reprocessing plants) have recently joined the Programme.

Limited feedback on concrete clean-up operations has been available until now due to the lengthy time frame of decommissioning projects and the fact that building demolition occurs in the very late stages of the project. Some of the early projects in the Programme are now complete or nearing completion, making available significant data and experience. This experience and lessons learnt can be applied to the further development of decommissioning and dismantling (D&D) clean-up processes. This report aims to supplement the previous NEA report dedicated to decontamination techniques [2] and to provide project engineers and/or project leaders involved in concrete infrastructure clean-up with:

- Guidelines for setting up appropriate and adequate strategies, taking into consideration the international framework and local regulations.
- An overview of modern project management tools.
- Experience gained from early trials of industrialisation of concrete decontamination techniques.
- State-of-the-art, proven decontamination techniques.
- Performance and productivity data for different techniques used on an industrial scale.
- Guidelines to address nuclear issues and safety concerns associated with the implementation of concrete clean-up techniques.
- State-of-the-art radiological characterisation tools, techniques, and methodologies available to optimise the radiological survey.
- Information on waste management and the minimisation of concrete material volumes.
1. Introduction

The contents of this report are the result of a compilation of data and the analysis of experience gained on projects within the CPD programme, which are listed in the following tables:

**Table 1: Completed reactor projects**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Objective</th>
<th>Power or throughput</th>
<th>Project time-scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triton</td>
<td>Pool type research reactor</td>
<td>1960-82</td>
<td>Brownfield</td>
<td>6 MWth</td>
<td>1983–2004</td>
</tr>
</tbody>
</table>

**Table 2: Reactor projects in progress**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Objective</th>
<th>Power or throughput</th>
<th>Project time-scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR-3 Mol, Belgium</td>
<td>PWR</td>
<td>1962-87</td>
<td>Greenfield or Brownfield</td>
<td>41MWt</td>
<td>1989–2014</td>
</tr>
<tr>
<td>EL4 Brennilis, France</td>
<td>Gas-cooled/heavy-water-moderated</td>
<td>1966–85</td>
<td>Storage</td>
<td>70 MWe</td>
<td>1989–2017</td>
</tr>
<tr>
<td>AVR, Germany</td>
<td>Pebble bed HTGR</td>
<td>1967–88</td>
<td>Greenfield or Brownfield</td>
<td>15 MWe</td>
<td>1994–2013</td>
</tr>
<tr>
<td>Vandelllos 1, Spain</td>
<td>GCR</td>
<td>1972–89</td>
<td>Safe store</td>
<td>500 MWe</td>
<td>1992–2000</td>
</tr>
<tr>
<td>KKR, Germany</td>
<td>WWER70 PWR</td>
<td>1966–1990</td>
<td>Greenfield or Brownfield</td>
<td>70 MWe</td>
<td>1990–2013</td>
</tr>
<tr>
<td>KGR Greifswald, Germany</td>
<td>WWER 440 PWR</td>
<td>1973–90</td>
<td>Greenfield or Brownfield</td>
<td>8x 440 MWe</td>
<td>1990–2013</td>
</tr>
<tr>
<td>WAGR, Sellafield, UK</td>
<td>Prototype AGR</td>
<td>1963–81</td>
<td>Brownfield</td>
<td>30MWe</td>
<td>1983–2028</td>
</tr>
</tbody>
</table>

**Table 3: Completed fuel facility projects**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Objective</th>
<th>Power or throughput</th>
<th>Project time-scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT-1 La Hague, France</td>
<td>Pilot reprocessing plant for FBR</td>
<td>1969-1979</td>
<td>Greenfield or Brownfield</td>
<td></td>
<td>1982-2001</td>
</tr>
</tbody>
</table>

**Table 4: Fuel facility projects in progress**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Objective</th>
<th>Power or throughput</th>
<th>Project time-scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eurochemic Reprocessing Plant Dessel, Belgium</td>
<td>Reprocessing of fuel</td>
<td>1966-74</td>
<td>Greenfield</td>
<td>1989-2012 (Main process building)</td>
<td></td>
</tr>
<tr>
<td>ATUE, France</td>
<td>Recovery of enriched uranium</td>
<td>1965-96</td>
<td>Greenfield or Brownfield</td>
<td>2000-2012</td>
<td></td>
</tr>
<tr>
<td>WAK, Germany</td>
<td>Prototype reprocessing plant</td>
<td>1971-90</td>
<td>Greenfield or Brownfield</td>
<td>1991-2023</td>
<td></td>
</tr>
</tbody>
</table>
2. General considerations

The following general discussion addresses issues common to all projects and also investigates issues unique to particular projects. Reactor projects are further broken down into power reactors and research reactors due to some succinct differences in the radiological considerations associated with each type. Each category has specificities regarding concrete D&D.

2.1 Historical perspective

Most or all of the facilities addressed in this report were constructed several decades ago under strict time constraints imposed by military sector needs or competitive commercial pressures for power generation. Little attention was given to facilitating eventual decontamination or to waste management issues. Contamination control was a secondary concern to productivity and contamination was frequently covered over rather than being cleaned up. Configuration control (record management) likewise was often not a priority. Records that were maintained were often lost over the years. Recreating lost records is hampered by the lack of operational staff (due to retirement) having direct knowledge of incidents that occurred during plant operation. Regulatory and quality controls were not applied according to the same rigorous standards that apply today. Therefore, the level of quality achieved was of a variable standard. Experiments and development ventures, were sometimes undertaken with little advance planning and are now presenting problems for decommissioners due to the lack of records. Most of these projects have to be managed flexibly, so that the Programme can respond readily to unexpected findings. Characterisation, decontamination and verification are of utmost importance.

2.2 Fuel cycle facilities and laboratories

The management and implementation of clean-up project(s) for fuel cycle facilities and laboratories should take into consideration the following specificities:

- Fuel cycle facilities and laboratories typically have only contamination problems. The residual neutron flux generated by spent fuel material which was manipulated in these facilities should be low enough not to generate the activation of infrastructures.
- Fuel production facilities have no liquid processes, meaning there are only superficially contaminated (a few millimetres of contamination).
- Conversely, fuel reprocessing facilities and laboratories have used liquid processes extensively. The risk of deep contamination in concrete is therefore of great concern.
- Use of chemicals, combined with radioactive contamination (e.g. liquid treatment with acid) increase the risk of deep contamination.
- Missing and/or scattered records and diagrams (e.g. accidents not recorded or reported, contamination which was covered up rather than removed, the installation of unknown pipes etc.) lead to difficulty in the cleaning of the facility.
- Several designs can be found for a given type of facility (e.g. enrichment by centrifuge or gas diffusion).
- Old leaks, spills and/or contamination may be not have been properly cleaned up.
2. General considerations

- In the case of laboratories, different activities may have been performed in the same room or cell, resulting in a highly varied contamination spectrum. The contamination spectrum therefore may be very large or contain only alpha emitters.
- The facilities with only alpha contamination require specific consideration due to alpha emissions which are typically contained by only a thin protective coating. There is therefore a risk of missing alpha contamination by direct measurement. All coating should be removed, unless it can be proven that the coating was applied on a clean, non-contaminated surface. For the final survey, a thorough surface finishing is required.

2.3 Research reactors

The management and implementation of clean-up project(s) for research reactors should take into consideration the following specifics:

- Activation and contamination must be considered.
- In pool type reactors (where water separates the core from the bioshield), concrete activation is concentrated around neutron beam channels.
- Several different designs exist which feature various power requirements, different types of fuel, high thermal flux (radioisotope production) and even fast neutron spectra. The diversity of applications and experiments (e.g. radioisotope production, fuel testing qualifications, materials testing and incident simulations) may lead to significant differences in contamination isotope vectors.
- A lack of records on operational history combined with the variety of experiments performed makes drawing up inventories difficult in the early stages of the project.
- To deal with high thermal fluxes, the density of concrete used for the bioshields in pool type reactors may have been increased by adding significant amounts of iron (as iron shot, iron wire, iron slag or even bar), resulting in much higher $^{60}$Co activity than in conventional concrete. This might constitute an additional challenge for cutting and decontamination operations.
- The contamination isotope spectrum is potentially wider than that of power plants, due to the variety of experiments and applications.
- The activation of structures within the reactor pool such as graphite thermal columns and Beryllium reflectors or matrix, leads to water contamination (e.g. $^{14}$C and $^1$H). These specific isotopes may therefore also be found in pool concrete. Beta and/or gamma emitters ($^{137}$Cs, $^{90}$Sr, $^{60}$Co) are the main isotopes present.

2.4 Power plants

Power plants are built for the specific purpose of electricity production. The activation of the bioshield in power plants is easier to predict than for research reactors as a result of better records of operating history, fixed configuration and constant neutron flux. The amount of activated concrete (bioshield) however, depends greatly on the reactor type and design (e.g. water, graphite).

Furthermore, a lack of records of non significant events from the point of view of safety (e.g. maintenance, small leakage on auxiliary circuits) may make the initial estimated inventory of contaminated concrete uncertain. Heterogeneous situations may exist in the same room resulting in different depths of liquid contamination. The range of radionuclides which can be found in power plants is limited in comparison to other types of facilities. The major radionuclides are beta and/or gamma emitters (e.g. $^{137}$Cs, $^{90}$Sr, $^{60}$Co, $^{57}$Ni, $^1$H).
3. Concrete decontamination and dismantling

3.1 Introduction

Taking into account all activities from initial characterisation to waste conditioning, dismantling and decontamination of the civil engineering works has a significant impact in terms of cost and planning on the overall decommissioning project. The concrete clean-up process is indeed very demanding in terms of management, manpower and technical equipment.

While the amount of contamination (i.e. the total activity) is predetermined, the selection and application of different dismantling and decontamination techniques can significantly influence the total amount of contaminated material that needs to be managed. For example, if a contaminated building is demolished, all debris is considered contaminated and requires special handling. However, by first using a surface-removal technique, the volume of contaminated material is limited to the removed surface material (this may be somewhat complicated by contamination in cracks and pipe penetrations.) The eventual demolition may then be performed conventionally. In this instance, a cost-benefit analysis should be prepared which takes into consideration all factors such as packaging, shipping and disposal.

The selected dismantling processes determine the nature of subsequent demolition and waste management activities. These activities need to be planned and undertaken taking into consideration all measurement requirements relating to characterisation and free release of material as well as the conditioning of accumulated debris. In almost every instance, the choice of the dismantling or decontamination technique is determined on a case-by-case basis by considering the advantages and disadvantages of each technique for the considered application. A combination of different techniques is usually necessary as there are no universally applicable techniques.

Important issues to be considered are the production of secondary waste, containment of contamination, safety issues, and the yield and reliability of the techniques. Often, the application of a specific technique is closely connected to the possible use of adequate tool guidance systems to ensure expected standards of accuracy and yield. Special consideration must always be given to not causing unacceptable damage, considering especially the stability of the building.

The following description of decontamination and dismantling techniques focuses on proven techniques which have been tested, qualified and/or applied on a representative scale and shown to be the best practices.

3.2 Decontamination techniques

When decontaminating building structures, mechanical surface-removal techniques are a primary consideration. Surface-removal techniques are used when future land-use scenarios include reuse, when it is impractical to demolish the structure (e.g. a laboratory within a building) or to minimise waste volume. The decontamination techniques described below may be considered for use in reducing the amount of contaminated material for disposal by removing surface contamination of varying depths.

Before any surface-cleaning or surface-removal activity takes place, surface preparation and safety precautions are necessary. Surfaces that are to be treated must be free of obstructions (e.g. piping and supports should be dismantled or segmented) and should be vacuumed in order to minimise release of airborne contamination during the application of the surface-removal technique. Furthermore, precautions need to be taken to prevent explosions when treating an area containing combustibles. When an area containing combustibles is being treated, all combustibles should be neutralised, stabilised or removed. Consideration should be given to industrial hazards associated with the use of these techniques and to the potential damage caused by these hazards.
Finally, contaminated debris (e.g. the removed portion of the surface) must be collected, treated and/or disposed of and any liquids used during the removal process (either as part of the process or as dust control), must be processed/recycled.

In cases where a contaminant has penetrated the material beyond the surface layer, further treatment may be required. Most of the surface-removal techniques leave an undesirable surface finish. If a smoothly finished surface is required (e.g. if the building is to be reused), a concrete cap or alternate surface-smoothing treatment must be applied.

### 3.2.1 Scarifying techniques

Scarifiers work by physically abrading coated or uncoated concrete surfaces. The scarification process removes multiple layers of contaminated surfaces until reaching a depth in which the surface is uncontaminated. A decade ago, concrete scarifying was considered as a radical approach to decontamination due to poor tool performance and an inability to provide a uniform surface profile upon removal of the contaminants. Today’s refined scarifiers are very reliable tools, with the ability to provide the desired profile for new coating systems in the event that the facility should be released for unconditional use.

**Needle scaling**

Needle scalers are usually pneumatically driven tools which use a reciprocating action to chip material and thus contamination from a surface. Needle sets are available in different diameters (typically 2, 3 or 4 mm) and various tip shapes in order to obtain the desired profile and performance.

![Figure 1: Example of a needle gun](image)

Most of the tools available on the market are equipped with specialised shrouding and vacuum attachments to collect dust and debris produced during needle scaling. Due to their high level of vibration and limited surface area coverage, needle scalers should be considered a complementary decontamination tool, used primarily to treat limited areas which are hard to access (e.g. corners, metallic inserts, pipe penetrations etc.). In order to prevent excessive wearing or damage, needle scalers are typically used on surfaces with numerous metal inserts (e.g. diamond tipped grinding machines) to remove a coating of 1 to 2 mm. Typical performance rates are about 0.1 m³/h, however production rates vary depending on the desired surface profile. Needle scalers are light tools, which should be considered only for the treatment of limited areas, rather than large area treatment.

**Scabbling**

Scabbling is a scarification process, used widely in civil engineering for concrete surface preparation. Scabbling tools typically incorporate several pneumatically operated piston heads which strike and chip a concrete surface. Commercially available tools mostly use tungsten carbide tipped striking heads. A variety of scabblers are available, ranging from one to three headed hand-held scabblers, to
remotely-operated scabblers. The most common version incorporates three to seven scabbling pistons, mounted on a wheeled chassis. Both electrically and pneumatically driven machines are available. According to manufacturers, cutting bit lifetime is approximately 100 hours; however tool wearing and throughput are highly dependent on concrete composition and quality, therefore making it hard to predict the bit life. In order to avoid the spread of contamination, scabller heads are equipped with adapted dust extraction systems.

**Figure 2: Example of single and multi headed hand held scabller**

Pneumatic hand-held and floor scabblers have been used extensively for concrete decontamination during the decommissioning of the Eurochemic facilities. Five to seven-headed scabblers were used for floor decontamination (at a work rate of 4 to 6 m²/h), while one and three-headed hand-held types were used for the decontamination of concrete walls and ceilings (at a work rate of 0.25 to 0.5 m²/h with a scabbling depth of about 3 mm).

**Figure 3: Seven-headed wall scabller**

**Figure 4: Rough surface finishing**

Multi-headed hand-held scabblers have also been used extensively at BR3, during the decontamination of the auxiliary building demineralisation cells. Production rates (machine working time) of up to 1 m²/h have been reported at a scabbling depth of 3 mm.

Before scabbling, combustible material must be stabilised, neutralised and/or removed. In practice, floor scabblers may not be operated any closer than 5 cm from a wall. Other hand-held scabbling tools are therefore required to remove the last 5 cm of concrete flooring next to a wall. Scabblers impact the surface of a contaminated area (rather than just grinding material), resulting in debris with large diameter particles which quickly settle. The risk of airborne contamination is therefore limited. When
using multi-headed hand-held scabblers, particular attention must be paid to vibration levels. The use of anti-vibration gloves is highly recommended.

Scabbled surfaces are generally flat, although coarsely finished, depending on the bit used. The resulting roughness may greatly reduce the accuracy of free release measurements and may even prevent the use of certain techniques (e.g. hand friskers used for alpha contamination measurement).

The scabbling technique is suitable for both large open and small areas.

**Shaving/milling**

Concrete shavers are suited for the large-area removal of thin floor, wall and ceiling layers. Shaving serves to remove coating and contamination that has strongly adhered to or penetrated concrete and other mineral surfaces. Most concrete shaving machines use rotating milling drums, on which the milling tools are arranged along several axes. This unit is referred to as a milling head and is enclosed by a metal housing which prevents the loss of removed material. The centrifugal force caused by the rotation of the drums causes the tools to move to their outer working positions, where the protruding tool tips and cutters hit the surface at a high speed. As a result, the material particles are detached from the composite and the surface is subsequently peeled off. Rollers in the milling heads that move along the untreated surface area provide for a constant working depth which can be adjusted with great precision, usually amounting to 3 mm. Regardless of the machine size, the maximum working depth of a concrete shaver is 5 mm.

A prerequisite for the large-area use of milling is a plane surface. Depending on the spatial conditions, partly automated guiding systems may be applied to reach high removal rates. Metals or iron reinforcements contained in the concrete cannot be cut by milling. If a mill does come in contact with iron, the result is a high wear of the tools. Smaller parts contained in the concrete such as anchors or similar components do not influence the process, provided they are flush with the surface. If the inserts are not flush with the surface, variable removal depths may result when the spacer rolls of the milling head move across the material. Due to the rotating bearing of the milling rings, damage of the machine caused by the contact of the tool with the reinforcing iron is almost eliminated.

Milling drums are either equipped with various tools or a specific milling drum is applied, depending on what material is being removed. Soft coatings and linings may be removed with relatively wide mills that are equipped with a cutter. Hard materials require toothed, star-shaped milling rings or milling stars which produce a very finely structured surface.

**Figure 5: Different milling cutters**

The tools can be rotated freely in the milling drums. Due to this mobility, no major reaction loads act on the machine, resulting in minimal contact pressure and feed force. Another advantage of the rotating bearing is that the area where the tools interact with the material is very small so not a lot of cross contamination takes place.

Standard devices are largely available for shaving floor surfaces. The main issues with applying milling heads on walls are their weight and the requirement of a suitable guiding device. Heavy duty carriers, forklifts or special kinds of scaffolding systems are required to apply such decontamination tools on wall and ceilings. Tailor made systems have been developed in several decommissioning projects, but only few of them have been successfully applied on an industrial scale. The four different automation concepts are as follows:
3. Concrete decontamination and dismantling

- The milling head(s) guiding and driving system is fixed on the surface which is to be treated;
- Milling heads are applied and moved along the surface with the aid of a fork lift, horizontal movements can be added with the use of a linear rail;
- Vertical movement is achieved when milling heads are fixed on a horizontal linear rail, using a scaffolding system and integrating a guiding rail, making ceiling decontamination possible; and
- Milling heads are applied using a compact heavy duty carrier

**STUDSVIK System**

**Figure 6: Double head milling machine interfaced on a fork lift**

**Figure 7: Milling cutters**

This shaver has been used on a fork-lift system as well as on a scaffolding system, consisting of modular racks of aluminium profiles fitted with linear actuators that are assembled to a unit.

**Belgoprocess system: single milling head interfaced on a fork lift**

**Figure 8: Single head milling machine supported on a fork lift**
3. Concrete decontamination and dismantling

As an alternative to conventional floor shavers, Belgoprocess has tested and successfully used a machine where the traditional milling head has been replaced with a diamond tipped rotary cutting head (see Figure 13) consists of successive diamond tipped disks, which are fixed on the axis (see Figure 14).
While the machine looks very similar to a conventional floor shaver, the working principle is actually closer to grinding than to milling. It will produce smooth surfaces which are easier to measure and ready for painting. It has proven itself capable of cutting through bolts and metal objects while, with a traditional scabbler, this could result in damage to the scabbling head. Actual cutting performance resulted in a 2 to 3 times higher mean working rate for floor decontamination (13 m²/h), compared to traditional floor shaver. In addition, there is much less physical strain on the operators due to the absence of machine vibration which is the case in manual use.

**Table 5: Performance of wall shaving systems**

<table>
<thead>
<tr>
<th>Process</th>
<th>Cutter type</th>
<th>Project</th>
<th>Production rate (machine working time)</th>
<th>Avail. Rate (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 headed milling machine on fork lift ( &amp; Figure )</td>
<td>Steel</td>
<td>CEA – ATUE</td>
<td>~ 10 m²/h (max. 10 mm depth)</td>
<td>30%</td>
<td>Overall yield strongly impaired by an uneven surface (blocks)</td>
</tr>
<tr>
<td>Single head milling machine on xy-frame</td>
<td>Diamond tipped rotating disks</td>
<td>BP – Eurochemic</td>
<td>15 – 25 m²/h (3 mm depth)</td>
<td>20%</td>
<td>Overall yield impaired by setup time (~ 1 day)</td>
</tr>
<tr>
<td>Milling machine on Brokk carrier (Figure &amp; Figure)</td>
<td>Diamond tipped rotating disks</td>
<td>CEA – EL4</td>
<td>8 m²/h (3 mm depth / pass)</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>PLB milling head (Figure)</td>
<td>WC teeth</td>
<td>CEA – EL4</td>
<td>1.2 m³/h (25 mm depth / pass)</td>
<td></td>
<td>Heavy tool Rough finishing</td>
</tr>
<tr>
<td>PLB milling head (Figure)</td>
<td>WC teeth</td>
<td>CEA - AT1</td>
<td>1.5 m³/h (25 mm depth / pass)</td>
<td></td>
<td>Heavy tool Rough finishing</td>
</tr>
</tbody>
</table>

**Table 6: Performance of floor shavers**

<table>
<thead>
<tr>
<th>Process</th>
<th>Cutter type</th>
<th>Project</th>
<th>Production rate (machine working time)</th>
<th>Avail. Rate (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor shaver - self-driven (34 cm wide milling head)</td>
<td>WC tipped</td>
<td>ATUE</td>
<td>5 – 6 m³/h (3 mm depth)</td>
<td>20%</td>
<td>Translation motion assisted by electrical motor</td>
</tr>
<tr>
<td>Floor shaver Multi-disc rotary head</td>
<td>Diamond tipped rotating discs</td>
<td>BP – Eurochemic</td>
<td>13 – 14 m³/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor Shaver Multi-disc rotary head</td>
<td>Diamond tipped rotating discs</td>
<td>CEA – Brennilis</td>
<td>~ 13 m³/h (3 mm depth)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Hand-held shavers**

A hand shaver uses a cupped disk with diamond segments bonded onto the face of the disk. It has a controllable dust extraction guard and produces very low vibration exposure to the operator. Decontamination rates from 4 to 6 m³/h machine working time are obtained compared to 1.5 m³/h
3. Concrete decontamination and dismantling

3.2.2 Abrasive blasting techniques

Abrasive blasting systems

Abrasive blasting systems are typically used in conventional industry to clean equipment or surfaces of removable or fixed contaminants (grease, rust, paint...) and/or to prepare surface for coating application. Depending on the objectives and the surface material (steel, concrete...), the process uses different abrasive mediums such as plastic, glass or steel beads, or grit, such as garnet, soda or aluminium oxide. Abrasives have been developed that allow the removal of a selective coating, such as varnish, without damaging underlying coatings (aeronautic industry). This process is most effective on flat surfaces and can also be used on “hard to reach” areas such as ceilings or behind equipment. Compared to scarifying techniques as previously described, these processes may produce significant amounts of secondary waste. The possibility of recycling the abrasive material should always be considered.

Early experience suggests that the use of pressurised water (with or without abrasive) to decontaminate concrete surfaces may result in contamination being embedded more deeply into the material surface (the so-called “hammering” effect) or even causing contamination of a hidden surface (for instance water spreading in the interface between 2 concrete layers). Wet abrasive systems also produce large volume of aerosols and sludge (water and abrasive mixture) that is difficult to confine and to treat. For these reasons, wet abrasive processes should not be used to treat radioactively contaminated concrete structures.

The dry abrasive blasting technique, commonly called sand blasting or abrasive jetting, has been used in non-nuclear industries since the late 1800s. Abrasives blasting processes make use of turbines, spinners (shot peening), compressed air or pressurised water to accelerate and accordingly throw the abrasive onto the surface to be treated. The process can be operated in open or closed configuration.

In open configuration, there is no confinement around the blasted surface and the removed surface material and abrasive is collected on the ground from time to time, sorted and placed in appropriate containers for further reuse, treatment and/or disposal. This working configuration requires adequate protection of the operators and additional manpower for collection and sorting of abrasives. In this configuration, abrasive is generally propelled through a narrow nozzle allowing treatment of hard-to-reach areas.

In closed configuration, the blasted surface is confined. Abrasives, dust and debris are directly collected at the source and transported to a separation unit, for instance by means of an air lift. The reusable abrasives are recycled thereby minimising the generation of secondary wastes. Cyclones provide a compact and efficient solution to separate contaminated dust from the reusable abrasive.

Dry abrasive blasting is applicable to most surface materials except those that might be shattered by the abrasive, such as glass or Plexiglas. Nonetheless, in the case of a nuclear application, it is recommended to remove oil, grease prior to surface treatment in order to minimise risks of cross contamination. Combustible contaminants should also be neutralised or removed prior to blasting since the impact of the abrasives can cause dust explosions. Static electricity may be generated during the blasting process and, therefore, the component being cleaned, or the installation itself, should be earthed. Industrial, remotely operated units are available for blasting of horizontal as well as vertical surfaces. Some devices include a built-in cyclone allowing the continuous separation of the dust and recycling of the grit.
3. Concrete decontamination and dismantling

**Abrasives media**

Depending on the application, a variety of materials can be used as abrasive media:

- minerals (e.g., magnetite, sand);
- steel pellets, aluminium oxide;
- glass beads/glass frit, silicon carbide, ceramics;
- plastic pellets;
- polyurethane foam with various grade embedded abrasive (referred as sponge); and
- natural organic products (e.g., rice hulls, ground nut shells).

Steel grit is very efficient to remove a thin layer (several mm) of concrete. Depth of attack can be adjusted with the grit velocity and treatment time. Abrasives can be delivered in various grade and shape. The specific use of round abrasives is referred as “shot peening”.

Although silica has been used as an abrasive, its use is not recommended as it can form a highly irritating dust which is moderately toxic and a significant cause of pulmonary disease. Prolonged inhalation of dusts containing free silica may result in the development of a disabling pulmonary fibrosis known as silicosis.

The volume of secondary waste generated is highly dependent on the lifetime of the abrasive (number of time it can be recycled). The harder the material, the longer it can be used. But risks of injuries and wearing of the equipment also increase with the hardness of the abrasive.

Dry abrasive blasting in open configuration generates a lot of dust which may even impair visibility in the working area. Adequate ventilation of the working area and monitoring of airborne contamination allow maintaining satisfying and safe working conditions.

**Sponge blasting**

Sponge blasting makes use of polyurethane sponge in which an abrasive particle is embedded. Sponges are available with different grades of abrasive ranging from plastic to steel particles. When impacting on a surface, the sponge has a scrubbing effect by expanding and contracting. In contrast to grit blasting, the sponges lose a lot of energy when impacting the surface and subsequently do not
require the operator to wear additional specific protection. Due to their volume, sponges are easily collected on the ground and the reusable ones are easily separated from dust and debris by sieving. However when blasting a concrete surface, the PU sponges quickly deteriorate and can be recycled only a few times. Their limited lifetime and low density result in the production of large volume of secondary waste (see Table 7).

**Specific applications**

Abrasive blasting is a versatile technique. Tailored installations can be built to cope with specific waste streams, such as, for instance, concrete shielding blocks or containers. The following paragraph describes the facility built at Belgoprocess for the treatment of concrete containers in the framework of a historical waste retrieval Programme.

**Figure 17: Abrasive blasting installation used for the decontamination of concrete containers**

This installation enables the decontamination of large concrete containers with an internal metal coating. In order to minimise the risk of additional cross contamination, the installation was developed to decontaminate the concrete material and steel liners at the same time.

The facility is installed in a ventilated hall and comprises three compartments in which the components are dried (if necessary) and blasted internally and externally. Resulting dust or contaminants are removed automatically by means of air and filters. After this operation, all surfaces of the container are checked to confirm the absence of contamination (operational check). In case some remaining contamination is detected, the operator can decide:

- In the case of large contaminated surfaces detected, the container is sent back to the blasting compartment for an additional cycle.
- In the case of spots or minor contaminated surfaces, the operator may clean these areas manually.
- Subsequently the container is fully re-checked by a health physics officer.
- As a variety of materials have to be decontaminated, two trolleys were developed to transport the containers and the components into the installation:
  - The first one is equipped with a turntable for non-cylindrical metal and/or concrete structures; and
  - The second is equipped with an adjustable rotating device that keeps cylindrical structures at an angle of 10°.
During blasting, radioactive material is removed from the surface. In order to protect the operators, the installation and the environment, a high ventilation air flow is created through all three compartments, extracting air from the ventilated hall via the first compartment. Contaminated particles are removed from the air flow by means of a pre-separator, two cyclones and a dust-collecting, self cleanable filter. The dust is automatically collected in specific drums and subsequently treated as radioactive waste.

**Figure 18: Principle of abrasive blasting installation at site BP2**

The key benefits of the installation are mainly to be found in the flexibility of the applications. After the cleaning process, metal parts are separated from the concrete. Both materials are further treated to ensure their use for other purposes (metal is melted and recycled; concrete is reused in the road construction industry).

Figure 19 shows another similar installation dedicated to the treatment of small concrete blocks.

**Figure 19: Dry abrasive blasting installation for small concrete blocks**

**Conclusions**

The advantages of using abrasive blasting for concrete structures clean-up can be summarised as follows:

- Abrasive blasting techniques have proven to be effective for a variety of applications: (selective) removal of coating (paints ...) on metal or concrete surface, degreasing and cleaning of tools or objects, metal or concrete surface finishing.
• Abrasive blasting systems are largely commercially available in a variety of configurations and sizes.
• A single machine can be used with different grades of abrasive thereby giving flexibility to perform different kinds of treatments and operations.
• Abrasive blasting techniques are neither sensitive to the roughness of the surface, nor to the presence of metallic inserts/plugs.
• In open configuration, nozzles of different geometry are available allowing to treat “hard to reach” surfaces, corners.
• Abrasive blasting machines are less strenuous to operate than scarifying techniques; and
• Very fine surface finishing can be achieved, which is of primary importance when surfaces have to be monitored for α contamination.

Nevertheless, particular attention must be paid to the following aspects:
• Abrasive blasting techniques produce significant amounts of secondary waste. Recycling of the abrasive should always be considered.
• Accumulation of contamination in the recycled abrasives might result in surface cross contaminations. The reuse of the abrasive therefore requires an efficient separation system.
• Abrasive blasting produces a very fine dust, which must be confined, extracted and collected. The use of a local ventilation unit equipped with self-cleaning filters is highly recommended. Monitoring of airborne contamination is compulsory.
• Open operation of blasting devices presupposes special personal protective equipment and clothing to protect against high-velocity abrasives.

Table 7: Performance of abrasive blasting systems

<table>
<thead>
<tr>
<th>Process</th>
<th>Media</th>
<th>Project</th>
<th>Objective (depth of attack)</th>
<th>Production rate (MWT)</th>
<th>Avail. Rate (%)</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| Sponge-Jet               | PU foam with alumina   | SCK-CEN – BR3  | Remove paint (< 1 mm)       | 5 m²/h                | 50% (excl. work preparation) | compressed air
|                          |                        |                |                             |                       |                | abrasives and debris are manually collected on the floor, sieved and sponges are recycled
|                          |                        |                |                             |                       |                | – 3 operators
|                          |                        |                |                             |                       |                | – waste balance: 15 kg/m² (dust + spent abrasives)                      |
| Shot blasting/peening    | Steel grit             | CEA – ATUE     | Remove a thin concrete layer (4-5 mm) | 2 m²/h               | 77% (excl. work preparation) | compressed air
|                          |                        |                |                             |                       |                | steel balls circulate
|                          |                        |                |                             |                       |                | grit lifetime ~ 1000 cycles
|                          |                        |                |                             |                       |                | waste balance ~ 40 L/m² (dust + spent abrasive)                         |

3.2.3 Hammering

Hot spots and possible penetration of contaminants along rebar or inserts like pipes, anchors etc. might, locally, require in-depth removal of concrete. Hand held pneumatic or electrical hammers can be used to extract inserts and/or remove in-depth contamination. More details are given in the chapter dedicated to demolition techniques in paragraph 3.3.2.
3.2.4 Other decontamination techniques

High pressure water jet

For renovation purposes in civil engineering cases the High Pressure Water Jet (HPWJ) technology has proved to be a very effective method to clean concrete surfaces and of removing corroded concrete layers. HPWJ can strip concrete layers up to several centimetres in a single working step. The main problem regarding radiological decontamination is of course the working medium. Water leads to deep cross contamination. Contaminated water might spread out at the interface between 2 concrete phases/layers and subsequently contaminate hidden surfaces previously clean (see feedback in Eurochemic case study in Annex 4). Complicated collection and recycling of the water can minimise the amount of secondary waste but is far away from an acceptable level. On the contrary HPWJ can successfully be applied to metal surfaces using very effective water catching devices and recycling installations.

High Pressure Water Jetting technology can also be used for cutting purposes when adding abrasives to the water jet. This is explained in chapter 3.3.3.

Thermal treatment

Thermal techniques are primarily applicable to removal of coatings but also for stripping and delamination of thin mineral or organic layers.

Thermal processes either work by applying or withdrawing heat from the surface to be treated. This induces changes in the material properties that take place at high or low temperatures or temperature gradients. The effects used are brittleness at low temperature and heat induced tensions. Tensions are created through different coefficients of thermal expansion of coating and substrate as well as local temperature differences on the material surface and in depth. Additionally soft mechanical mechanisms are used to destroy the bond forces of coatings but do not damage the substrate material. Media used for cooling are liquid nitrogen (-196°C) and solid carbon dioxide (-78°C). Heat is introduced by laser, microwaves or flames. Some techniques use combinations to maximise thermal stress.

CO₂ ice blasting

Cold Jet dry ice blasting uses compressed air to accelerate frozen carbon dioxide (CO₂) “dry ice” pellets at a temperature of -78°C to a velocity of about 300m/s. CO₂ ice blasting is typically used to remove deposit, such as grease, production residues, biofilm or paint (soft coatings), while preserving the substrate. In the nuclear industry, it has been frequently used to remove smearable contamination, for instance inside hot cells or glove boxes. CO₂ pellets have not an abrasive action on the surface. The active principle is based on mini-explosions caused by the high difference in temperature which lift the undesirable item off the underlying substrate. The ablation effect is also related to the expansion coefficients of the different materials (substrate and coating). High expansion differences amplify the ablation. Regarding the very limited abrasive force of the pellets the stripping of pure concrete therefore is rather ineffective. Enhancements for concrete abrasion additionally use a combination of laser and CO₂ ice blasting to increase local differences in temperature to cause spalling. The reachable abrasion depths in concrete are 5 mm. In contrast to all other blasting techniques CO₂ ice blasting does not produce any secondary waste as the dry ice immediately evaporates. At its current state of development this technology is not sufficiently abrasive to strip coating or fixed contamination on a concrete substrate. Moreover the technique induces a significant anoxia risk. Dry ice pellets can be made on-site or supplied.

Liquid nitrojet jetting

The R&D on application of liquid nitrogen at high pressure started in 1982 at the Idaho National Laboratory. This R&D Programme has led to the development of the high pressure liquid nitrogen jetting process, commercialised by the company Nitrocision in 2003.

Liquid nitrogen is blasted under pressure at high velocity on the surface to be decontaminated. When impacting the surface, material is removed from the surface through the combination of 3 different effects:

- the mechanical effects due to kinetic energy;
the thermal shock: when impacting the surface the liquid nitrogen (-140°C) vaporises and embrittles the material and eases its ablation; and
the blasting effect resulting from the high volume expansion (x 700).

The decontamination effect is comparable with the CO₂ ice blasting system. Depending on the type of nozzle used and the possible addition of abrasive, the following operations can be accomplished:

- removal of paint;
- removal of a thick layer of material (up to 30 mm in a single pass); and
- cutting (with abrasives).

The technology is rather complex and requires the implementation of the following components:

- a liquid nitrogen tank;
- a compressor;
- a heat exchanger; and
- a nitrogen hose and high pressure nozzle.

The connections between the different components have to be thermally insulated. The process involves pressurising a “warm” (-40°C) nitrogen stream up to 4 000 bars and later cooling it down. The nitrogen consumption ranges from 15 to 20 L/min. Under these conditions, the flow rate of nitrogen at the exhaust is about 600 m³/h.

The system has been tested recently in active conditions at one of AREVA facilities. The following advantages have been clearly shown:

- The system is versatile, allowing the selective removal of coatings and paint from surfaces as well as the removal of a variable thickness of concrete (3 to 30 mm in a single pass).
- No generation of secondary waste.
- Insensitive to surface state (roughness, metallic inserts ...).
- Efficient process for coating stripping (10 m²/h) and for concrete removal (2.5 m²/h for a 14 mm pass) [3].
- Automation.

However, it introduces a number of technical and safety issues:

- The prevention of contamination spreading requires adequate confinement and vacuuming at the source.
- The volume increase resulting from the nitrogen vaporisation (x700) significantly increase ventilation requirements.
- Liquid nitrogen tubing has to be thermally insulated.
- Anoxia risk.
- Safety issues might restrict its use to the most easily accessible area of the plant.

**Laser ablation**

The use of laser technology for decommissioning projects has been considered and studied for years for remote decontamination/clean-up operations and as a thermal cutting device [4]. Lasers can be used to heat local surface areas to temperatures of a few hundred degrees.

Extensive R&D projects have been led by CEA, KAERI or JAERI. Recent progress in the field has made available very compact and robust pulsed fibre laser technologies.
3. Concrete decontamination and dismantling

Recently the R&D Programme led by CEA has led to an active demonstration of the Aspilaser process at the ATUE facility [5]. The so-called Aspilaser system is made of 4 fibre lasers of 50 W each equipped with galvanometric heads allowing the laser to scan across a surface.

The principle of laser ablation (with low power) is based on the sudden heating up of the surface causing the superficial layer to expand and spall. The resulting local shockwave is sufficient to eject the paint/coating from the surface. This differs from previously tested high energy systems in that the contaminated layer is ejected from the surface rather than burnt. This technology resulted in a robust, compact and light tool offering the following advantages:

- Fibre lasers are insensitive to vibration.
- The units are compact and are not demanding in terms of cooling.
- Few adjustments are required (user friendly).
- Lightweight - the ablation head weighs ~ 30 kg.

Figures 20 and 21 show the decontamination/ablation head (laser generator not shown) of the tested prototype.

Figure 20: Ablation head

Figure 21: Aspilaser on carrier
3. Concrete decontamination and dismantling

The diameter of a single laser beam is 100 μm. The 4 lasers beams are butt-joined to minimise risk of contaminant re-deposition. This process has been specifically developed to remove paint and coatings on superficially contaminated surfaces. Previous studies performed at CEA laboratory have shown that, on a typical paint used in the nuclear industry, the ablation depth is of the order of magnitude of 10 μm per pass with a 50 W fibre laser.

The following preliminary conclusions can be drawn out of the active trial at the ATUE:

- The Aspilaser system is particularly suitable to remove paint or thin coating on large and flat surfaces;
- The compact and light weight ablation head eases process automation and allows using simple and low cost carriers;
- The production rate (MWT) is limited to 1.5 – 2 m²/h due to small beam diameter (low energy);
- Multiple laser beams can be combined to increase production rate;
- No significant re-deposition of contaminants has been measured on the treated area; and
- Only 600g of dust has been produced during the decontamination of about 6 m².

The main advantage of the Aspilaser process with respect to scarifying/abrasive blasting techniques is that it is able to "selectively" remove a coating (preserving the substrate), while generating little secondary waste (HEPA filters, vacuuming tubing).

**Ablation through heating**

Microwaves basically heat and therefore induce volume expansion of the water contained in the concrete pores. The heat cannot dissipate as fast as the expansion proceeds. The resulting tension induces spalling of the concrete. Another technique consists in heating electrically the near surface rebar, which induces dilatation of the steel. This causes spalling of the superficial concrete.

These techniques have been investigated in the recent past. They showed poor efficiency and were generally found to be incompatible with constraints and safety requirements of a decommissioning projects.

**3.2.5 Comparison of decontamination techniques**

The following table aims to summarise the previous discussion and to provide qualitative criteria to guide the selection of adequate decontamination techniques with respect to the clean-up operation objectives, relevant internal parameters (concrete quality, plant or room geometry) as well as external constraints (legal framework, requirements for free release measurement, operators safety).

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needle scaling (hand held)</td>
<td>- Flexible handling</td>
<td>- High vibration level</td>
</tr>
<tr>
<td></td>
<td>- Suitable for hard to reach areas</td>
<td>- Low yield (limited surface area coverage)</td>
</tr>
<tr>
<td></td>
<td>- Insensitive for metal inserts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Light weight tool</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- No secondary waste</td>
<td></td>
</tr>
<tr>
<td>Scabbling (hand held)</td>
<td>- Flexible handling</td>
<td>- High vibration level</td>
</tr>
<tr>
<td></td>
<td>- Suitable for hard to reach areas</td>
<td>- Rough finishing</td>
</tr>
<tr>
<td></td>
<td>- Light weight tool</td>
<td>- Low yield (limited surface area coverage)</td>
</tr>
<tr>
<td></td>
<td>- No secondary waste</td>
<td></td>
</tr>
<tr>
<td>Scabbling (assisted)</td>
<td>- Suitable for large surface areas</td>
<td>- Requires tailored interface with heavy duty</td>
</tr>
<tr>
<td></td>
<td>- Medium to high yield</td>
<td>carrier (vertical surfaces)</td>
</tr>
<tr>
<td></td>
<td>- No secondary waste</td>
<td>- High vibration level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Rough finishing</td>
</tr>
</tbody>
</table>
3. Concrete decontamination and dismantling

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaving / Grinding (hand held)</td>
<td>– Very good finishing&lt;br&gt;– High yield&lt;br&gt;– High performance&lt;br&gt;– Moderate weight&lt;br&gt;– Low vibration level&lt;br&gt;– Collection of dust and debris by default&lt;br&gt;– No secondary waste</td>
<td>– Fine dust&lt;br&gt;– Not suitable for rough surfaces&lt;br&gt;– Sensitive to metal inserts&lt;br&gt;– High consumable cost (disks)</td>
</tr>
<tr>
<td>Shaving / Milling (assisted)</td>
<td>– High yield&lt;br&gt;– High performance&lt;br&gt;– Collection of dust and debris by default&lt;br&gt;– Insensitive for metal inserts&lt;br&gt;– Moderate vibration level&lt;br&gt;– Low consumable cost</td>
<td>– Requires tailored interface with heavy duty carrier or engineered guiding system (vertical surfaces)&lt;br&gt;– Fine dust</td>
</tr>
<tr>
<td>Grit Blasting</td>
<td>– High to very high yield&lt;br&gt;– High performance&lt;br&gt;– Highly versatile technique&lt;br&gt;– Suitable for hard to reach surfaces (air powered configuration)&lt;br&gt;– Collection of dust and debris by default&lt;br&gt;– Insensitive for metal inserts&lt;br&gt;– Suitable for rough surfaces&lt;br&gt;– Low abrasive cost&lt;br&gt;– Continuous recycling of abrasives possible</td>
<td>– Secondary waste&lt;br&gt;– Risk of cross-contamination (abrasives recycling)&lt;br&gt;– High personal safety requirements&lt;br&gt;– High dust formation&lt;br&gt;– Deep abrasion produces rather rough surface finish</td>
</tr>
<tr>
<td>Sponge Blasting</td>
<td>– Low safety requirements&lt;br&gt;– Flexible handling&lt;br&gt;– Suitable for hard to reach areas&lt;br&gt;– Suitable for rough surfaces&lt;br&gt;– Insensitive for metal inserts&lt;br&gt;– High abrasive cost</td>
<td>– Secondary waste&lt;br&gt;– Continuous recycling of abrasive not possible (due to limited abrasive lifetime)&lt;br&gt;– High dust formation&lt;br&gt;– Blasting media has to be collected manually&lt;br&gt;– Low performance</td>
</tr>
<tr>
<td>CO₂ Ice Blasting</td>
<td>– Suitable to remove smearable contamination&lt;br&gt;– Preserve substrate&lt;br&gt;– No secondary waste</td>
<td>– Not aggressive enough to strip coating or fixed contamination&lt;br&gt;– High safety requirements&lt;br&gt;– Risk of anoxia&lt;br&gt;– Ventilation requirements</td>
</tr>
<tr>
<td>Laser Ablation</td>
<td>– Low safety requirements&lt;br&gt;– Low weight tool&lt;br&gt;– Automation through low cost carrier&lt;br&gt;– Suitable for large surfaces&lt;br&gt;– Suitable for rough surfaces&lt;br&gt;– Insensitive for metal inserts&lt;br&gt;– Selective removal of coating&lt;br&gt;– No secondary waste</td>
<td>– Low yield (very small surface area coverage)&lt;br&gt;– No feedback yet available on long term reliability and maintenance requirements</td>
</tr>
<tr>
<td>Liquid nitrogen jetting</td>
<td>– Versatile (coating stripping, removal of thick concrete layer, cutting)&lt;br&gt;– High yield&lt;br&gt;– Suitable for hard to reach areas&lt;br&gt;– Suitable for rough surfaces&lt;br&gt;– Insensitive for metal inserts&lt;br&gt;– No secondary waste</td>
<td>– High safety requirements (personal &amp; facility)&lt;br&gt;– Ventilation requirements&lt;br&gt;– High investment cost&lt;br&gt;– Complex technology&lt;br&gt;– Process components implantation</td>
</tr>
</tbody>
</table>

Table 8: Comparison of concrete decontamination techniques (cont’d)

3.3. Concrete dismantling and demolition techniques

Dismantling and demolition techniques are used whenever large quantities or deep layers of activated or contaminated concrete need to be removed. Depending on the plant layout, a large range of well proven, highly reliable and generally economical techniques, such as diamond wire sawing, is available. These techniques mostly require experienced operators, but a large choice of contractors
exists within the conventional construction industry. These techniques are very useful, even at an early stage of the decommissioning project, for creating openings and access to rooms, e.g. hot cells, or to enlarge existing openings allowing to slip equipment to the working place or to remove large components.

### 3.3.1 Concrete sawing

**Diamond wire sawing**

Diamond wire sawing enables the creation of wall openings and the detachment of large concrete structures. The sawcut surfaces are very smooth. In contrast to most other cutting techniques there are few limitations concerning the size and thickness of the components that have to be cut. The equipment required includes the basic machine with electrical or hydraulic actuation, the control cabinet, at least two deflection rollers and a wire storage capability in the case of larger cuts.

**Figure 22: Example of 15 kW sawing machine with pneumatic feeding system**

![Figure 22: Example of 15 kW sawing machine with pneumatic feeding system](image)

**Figure 23: Wire storage**

![Figure 23: Wire storage](image)
3. Concrete decontamination and dismantling

The cutter components require only a small amount of space and can also be installed some distance from the cutting location or even in another room by taking the wire through a small passage. Therefore the wire can be deflected several times with fixed deflection rollers.

Although diamond wire sawing technique is normally used with water cooling it is also possible to cut in dry conditions. Dust emissions can be reduced using a sealed collection system located at the outlet of the wire. Dry cutting of reinforced concrete has been successfully demonstrated and applied at:

- BR3 (Baryte concrete);
- Rheinsberg;
- KNK;
- CIEMAT PIMIC project;
- WAK.

In the example shown in Figure 24 and Figure 25, the cutting wire is cooled by local injection of cold compressed air (-10 to -15°C).

**Figure 24: Dust collection system**  
**Figure 25: Wire cooling system (cold air) + brush seals**

In a typical configuration shown in Figure 26, the assembly space needed is about 1.5 x 2.5 m. The weight of the equipment, depending on the situation, can vary between 150 and 600 kg.

**Figure 26: Assembly of a diamond wire saw in cramped confines**
3. Concrete decontamination and dismantling

In most applications using diamond wire saws the cutting wire is threaded through holes drilled in the structure to be cut. If the rear side of the structure is accessible, such as a wall, the wire can be fed through manually, threaded through the roller system and the ends joined. This can normally be accomplished through small holes with a diameter of a few centimetres. Good wire contact with media is important.

If the rear side of the structure is not accessible, cuts can also be accomplished by plunge cutting.

**Figure 27: Example of an arrangement of a plunge cut with wire saw**

Plunge cutting is typically applied to remove components embedded in a concrete structure (e.g. drain pipe). Plunge cutting requires bigger holes for immersion of pipes to clamp the additional deflection rollers. The diameter of the holes averages between 150 and 250 mm. To make plunge cuts in floors, blind holes are necessary. In this case, an extraction system to exhaust the dust out of the holes is required to prevent the roller system from clogging up. Plunge cutting is restricted to cut dimensions of about 250 cm in depth and 250 cm distance between the blind holes.

Diamond wires are typically about 11 mm in diameter. One meter of wire incorporates approximately 40 rings of galvanic or sinter-metal bound diamonds particles. Smaller steel springs between the diamond rings provide flexibility for the wire and assure that the slurry or the dust is transported away from the cut space. Depending on the cutting length, the width of the cut is about 15 to 20 mm. Each diamond ring is tapered at its ends to prevent the wire from jamming. If the cut component could collapse onto the cut, it is necessary to place steel packing plates or shims in the gap so the wire does not become jammed. In order to recover jammed wires, hydro-bags should be inserted into the gap and pumped up with hydraulic pumps to push the components apart.

The yield of a wire saw reaches values of up to 3 m²/h (wet conditions), depending on the quality of the concrete and the bulk of steel reinforcement. Concrete composition and reinforcement strongly influence wire wear and cutting rates. For cutting in dry conditions where higher wearing of the wire is expected, diamond ring numbers should be increased (~50 b/m), diamond grit size should be increased and brazed diamond beads are preferred. Dry cutting normally requires lower wire speed. Typical performances achieved in dry and wet conditions are summarised in the following table.

**Table 9: Performance of wire sawing in dry and wet conditions**

<table>
<thead>
<tr>
<th></th>
<th>Wet cutting</th>
<th>Dry cutting (BR3 demonstration 2005)</th>
<th>Dry cutting (WAK demonstration 2003)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete type</strong></td>
<td>any</td>
<td>Reinforced baryte concrete</td>
<td>Reinforced concrete</td>
</tr>
<tr>
<td><strong>Cooling system</strong></td>
<td>water</td>
<td>Cold compressed air</td>
<td>None</td>
</tr>
<tr>
<td><strong>Average cutting rate (m²/h)</strong></td>
<td>2.2</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Max. cutting rate (m³/h)</strong></td>
<td>3</td>
<td>1.7</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Wire lifetime (m³/m)</strong></td>
<td>~ 1.5</td>
<td>~ 1</td>
<td>~ 1</td>
</tr>
<tr>
<td><strong>Wire speed (m/s)</strong></td>
<td>21 - 25</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td><strong>Wire temperature</strong></td>
<td>-</td>
<td>66°C</td>
<td>55 – 60 °C</td>
</tr>
</tbody>
</table>
Set up time depends highly on:
- room configuration and accessibility;
- dry or wet conditions; and
- implementation of sludge/dust collection system

When sawing in dry conditions, the implementation of a dust collection system results in complete confinement of the space surrounding the in order to collect the dust. This has the advantage of improving safety as loose wire ends from broken wires are confined.

Segmented blocks can be pushed out with hydraulic presses or pulled out with ropes. Blocks should always be cut in tapered configuration way to avoid the binding of the blocks when pulling them out.

### Table 10: General comparison of dry and wet sawing

<table>
<thead>
<tr>
<th></th>
<th>Dry cutting</th>
<th>Wet cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performances</strong></td>
<td>– slightly lower working rate;</td>
<td>– slightly higher working rate</td>
</tr>
<tr>
<td></td>
<td>– reduced wire lifetime.</td>
<td>– extended wire lifetime.</td>
</tr>
<tr>
<td><strong>Secondary waste</strong></td>
<td>– induced by dust collection system (filters, confinement boxes).</td>
<td>– contaminated effluents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– induced by sludge collection and treatment system (filtration, drying)</td>
</tr>
<tr>
<td><strong>Set up</strong></td>
<td>– dust confinement and suction system to be implemented for each single cut</td>
<td>– screens preventing sludge clogging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– retention vessels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– settling tanks</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>– operation safety improved thanks to confinement of wire;</td>
<td>– rupture of the wire at high velocity poses safety hazard</td>
</tr>
<tr>
<td></td>
<td>– wire repair or jamming requires dismantling of dust confinement system</td>
<td></td>
</tr>
<tr>
<td><strong>Working site clean-up</strong></td>
<td>– bulk of dust is directly collected &amp; packed</td>
<td>– cross contamination of hidden surfaces</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– risk of liquid contamination/ migration through reinforcing bars, inserts...</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– clean-up of settled sludge might require mechanical treatment</td>
</tr>
</tbody>
</table>

**Circular sawing**

Circular sawing should be considered as the primary option when very precise cuts are required. Circular sawing enables flush cuts (e.g. along walls). Appropriate guiding devices are required to control the cutting forces and to avoid locking the blade. Rails have to be clamped to the structure by means of anchors. The preparation requires a lot of effort which reduces the popularity of this technique compared to others (e.g. a wire saw), especially if maintenance time is crucial. The maximum cutting depth is 1000 mm which is achieved by using big and therefore expensive saw blades with diameters of 2200 mm. When using this technique, a lot of space is needed to install the (mostly) hydraulic driven machines. Dry cutting is feasible for small to mid-size assignments, but when the production rate is the main concern water flushing is recommended, as for any diamond tipped concrete cutting tools. Circular sawing is closely related to wire sawing for cutting reinforced concrete and metals in general. A disadvantage might be the slower cutting progress in large depths. The durability of the blade is approximately 15 m² in reinforced concrete (with a diameter of 800 mm). Cutting performances range between 1.5 and 2.0 m³/h.

**3.3.2 Hammering**

When massive structures have to be removed, hydraulic hammering is a cost effective technique (low investment, high yield, simple implementation) but it requires particular attention to safety aspects.
(structural stability, release of vibration energy, falling rubble, high noise levels). The removal of the activated material in the biological shield is a typical application.

Hydraulic hammers are most effective when combined with excavators. Highly reliable, compact, electrically-powered and remote controlled excavators are commercially available in different sizes. Typical units used for demolition work in controlled areas can handle hammers with a weight of about 300 kg. Excavators can handle different complementary tools such as an excavation bucket, concrete and metal hydraulic shears, a core drilling device or circular (diamond) saw. Depending on the circumstances of the operation, the correlation between the excavator weight and the hammer should be in the range of 15:1 and 20:1. In areas where access for excavators is limited the use of manually operated powered hammers (Jack Hammers) may be considered but should be limited on the grounds of operator safety.

Hammering generates a high amount of dust both in the chiselling action and when pieces of concrete fall down and impact with other debris. Dust formation can be limited by using an extraction system near the chisel or by assembling a water drizzle atmosphere.

An extraction system, similar to the systems used for civil and underground engineering, can exhaust debris up to a size of about 80 mm. This technique has been used successfully (e.g. at KNK-Karlsruhe Germany), where non activated concrete has been dismantled.

**Figure 28: Extraction system applied at KNK**

*Performance*

The demolition rate (machine working time) highly depends on the type of hammer, the quality of the concrete, the amount of reinforcement and the operator skills. The compact 18.5 kW electrically powered unit presented in Figure 29 allows the achievement of demolition rates up to 2 m³/h on reinforced concrete, when operated by an experienced operator.
3. Concrete decontamination and dismantling

Figure 29: Example of a compact remotely operated rock breaker

Table 11: Performance of remotely operated rock breaker

<table>
<thead>
<tr>
<th>Machine</th>
<th>Hammer</th>
<th>Project</th>
<th>Operating conditions</th>
<th>Production rate (machine working time)</th>
<th>Available rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brokk 150</td>
<td>280 J Max. 2000 hits/min</td>
<td>CEA – AT1</td>
<td>In situ</td>
<td>Up to 3 m³/h</td>
<td></td>
</tr>
<tr>
<td>Brokk 180 (2t)</td>
<td></td>
<td>CEA – Melusine</td>
<td>In situ</td>
<td>up to 1.4 m³/h</td>
<td>60%</td>
</tr>
<tr>
<td>Brokk 250</td>
<td>TEX 250 H1 1000 J 800 hits/min</td>
<td>SCK•CEN BR3 Antimissile slabs Reinforced baryte concrete</td>
<td>Slabs in workshop</td>
<td>Up to 1.2 m³/h</td>
<td></td>
</tr>
<tr>
<td>Brokk 180 customised (2,4t)</td>
<td>Atlas Copco SB202 400 J Max. 1750 hits/min</td>
<td>SCK•CEN – BR3 Reinforced concrete</td>
<td>Block in workshop</td>
<td>Up to 2 m³/h</td>
<td></td>
</tr>
</tbody>
</table>

3.3.3 Concrete drilling and spalling

The drilling and spalling technique involves drilling 25-40 mm diameter holes, approximately 75 mm deep, into which a hydraulically operated spalling tool with an expandable tube is inserted. A tapered mandrel is then hydraulically forced into the hole to spread the ‘fingers’ and spall off the concrete. A second technology uses spreadable side pistons instead of mandrels. Reinforced structures can be treated as well. The rebar either stretches and then may be cut (if reachable) or it may even break. Applied forces reach up to 4 000 kN. Drilling and spalling is recommended for hard to reach areas, for the separation of medium scale blocks or as preparation for further treatment. Apart from the drilling process, spalling can be considered a quiet, safe and clean technique.
3. Concrete decontamination and dismantling

Expanding grouts have been successfully used at BR3 and at Sellafield to break up heavily reinforced mass concrete bases from 1 to 3 m³. The expanding grout was left to cure overnight and the cracked concrete bases were excavated using a small back actor machine.

Like the hydraulic spalling device, expanding grouts can be used to break up mass concrete. This process does not generate vibration and can thus be used in area deemed sensitive to vibration where hammering would not be permitted. The process requires a defined pattern of holes to be drilled in the concrete. Once all the holes are complete they are filled with the expanding grout which is left to cure. During curing the grout expands and causes the concrete to crack between the holes. The length and diameter of the holes, together with the drilling pattern is designed to suit the size of fragments required, the shape of the structure, the type of concrete and the quantity of steel reinforcement.

3.3.4 Explosives

The application of blasting techniques in controlled areas raises a number of safety considerations. The most important issues are the agitation and the implications of the blast waves and subsequent dispersal of dust.

Known applications of the blasting technique in a controlled area of this Task Group are restricted to the dismantling of the biological shield at KKN (NPP Niederaichbach, Germany). The details given in the following chapter are extracts from the associated final decommissioning report [6].

At KKN explosives have been used, not as a single technique but combined with the classic hydraulic hammer to dismantle the inner activated part of the biological shield with a depth of 60 cm. Explosives were used to loosen the concrete. The average activity of the concrete was only 10 Bq/g. All operations could be executed without inhalation protection. In combination with the low explosive charging level and a protective blanket covering, the formation of dust and the strength of the blast waves were reduced to a minimum. The highest barometric variation caused from the blasting was 8E+Pa. Due to this low magnitude, the ventilation system of the containment has not been compromised.
One of the main reasons that led to the choice of the blasting technique was the high level of reinforcement. Following the blasting, the exposed reinforcement may easily be removed by flame cutting. The fissured concrete near the blasting zone was further dismantled by hammering. The amount of debris produced directly from one blasting campaign was about 3 Mg. This debris could be placed directly into drums without further crushing or treatment. After the blasting, the H3 concentration in the containment temporarily rose from the normal level of 1-2 Bq/m³ to 10 Bq/m³.

**Figure 31: Drilling apparatus for blast holes adapted on excavator**

The biological shield was divided into target areas. Typical blasting parameters for each target area are:

- **Dimension of blasting area:** height: 200 cm, depth: 60 cm, length: 250 cm
- **Specific charging level:** approx. 1200g/m³
- **Charging level/blast hole:** 500g ammonium + 160 g penta-erythritol tetra nitrate
- **Order of ignition:** alternating (wave movement)
- **Distance of blast holes:** 2 shifted rows (30 and 60 cm from the inner surface), blast hole dist. lengthwise: 50 cm
- **Number of blast holes/blast:** 10 (5 in each row)
- **Covering of the blasting area:** 3 coats of rubber band, 4 coats of special mats against dust formation

One blasting campaign comprised two target areas as described above. All preparatory work for each target area was done simultaneously. The two sequences were then blasted quickly one after another.
3. Concrete decontamination and dismantling

The required time for one blasting campaign can be divided as follows:

<table>
<thead>
<tr>
<th></th>
<th>Drilling of the blast holes</th>
<th>2 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Armament of the blast holes, covering the blasting area and performance of the blasting</td>
<td>4 days</td>
</tr>
<tr>
<td>3</td>
<td>Disassembling and packaging of the reinforcement</td>
<td>4 days</td>
</tr>
<tr>
<td>4</td>
<td>Packaging and dismantling of the remaining concrete</td>
<td>4 days (3 days parallel to No. 3)</td>
</tr>
</tbody>
</table>

Conventional trial of mini-blasting have also been performed at BR3, on a 1:1 scale mock up of the bioshield, with the objective of removing the layer concrete before the first layer of rebar (~ 10 - 15 cm).

3.3.5. Other dismantling techniques

Chain saw

Minor cutting tasks can also be carried out by special chain saws. This technique works by a grinding process, similar to a wire saw. The diamond coated chain is mounted and guided on a bar-track mechanism which needs to be handled with a defined feed motion. Brickwork can be cut manually using a guide rail fixed on the wall. Due to the shortness of the chain and the friction between the guide bar and the chain, the device becomes hot very quickly and therefore is practical only when used with water cooling. The water is added through canals in the guide bar. Depending on the size of the guide bar and its cutting performance, the recommended amount of water is 1.5 to 8 l/min. Tests at the BR3 site showed that the water can be reduced up to ranges of a few millilitres per minute. The actuation is either done electrically or hydraulically.

Heat, but mainly the generated slurry, creates damage to the hinges between the single chain links as well as the guide bar. The chain elongates very fast and needs to be tightened (either automatically or manually) at very short time intervals in order to prevent chain break, especially in case of horizontal cuts. The abrasion is very high, such that the lifetime of one chain is limited to a surface area of about 2 m². In special cases the mechanical lifetime of the chain itself can be lower than that of the diamond coating. Also, the guide bar has to be changed approximately every third time the chain is changed.

Unlike a wire or circular saw, the chain saw can be used to quickly create openings in thin walls and ceilings without installing much equipment. It is also possible to plunge into the surface, so in some cases drillings can be omitted.

**Figure 32: Application of diamond chainsaw at WAK**
3. Concrete decontamination and dismantling

**Figure 33: Testing of a large diamond chainsaw under reduced cooling water flow (courtesy of Husqvarna, Belgium)**

Technical characteristics:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting speed</td>
<td>12 – 24 m/s</td>
</tr>
<tr>
<td>Feed motion</td>
<td>1 – 10 cm/min</td>
</tr>
<tr>
<td>Cutting depth</td>
<td>max 60 cm</td>
</tr>
<tr>
<td>Noise emission</td>
<td>88 – 102 dB(A)</td>
</tr>
<tr>
<td>Vibration</td>
<td>3 – 10.5 m/s²</td>
</tr>
<tr>
<td>Cost (wear parts)</td>
<td>180 $/m²</td>
</tr>
</tbody>
</table>

**High pressure water jet cutting**

Abrasive water jet technology (AWJ) uses a multifunctional tool that can be used for almost all kind of cutting, drilling and removal activities. The advantages are mainly attributed to the absence of mechanical interfering tools. Vibrations, thermal stress, seizures, abrasion of tools, material-conditions, cutting form and many other typical challenges either do not exist or create insignificant effects.

Although AWJ-cutting has been successfully applied to the underwater dismantling of reactor vessels and is considered an adequate tool for this application, the treatment of concrete is associated with some essential drawbacks which are difficult to compensate for. The most prominent issues are cross contamination through water and the high amount of secondary waste. High pressure water jet cutting might be considered in special cases or if efficient water and abrasive management is implemented.

There are two systems of abrasive water entrainment jets, also referred to as abrasive water injection jets (AWIJ) and abrasive water suspension jets (AWSJ). The differences in relation to the dismantling of concrete structures are mainly related to the waste aspects. If the abrasive medium is to be collected and reused, AWSJ is a better choice. AWSJ enables the reuse of the abrasives in wet
3. Concrete decontamination and dismantling

conditions, while for AWJJ they must be dried before reuse. Also, the suspension can be transported long distances to the cutting location through high pressure hoses. Collection and recycling of the water, together with the abrasive medium is possible, but requires large, complex equipment as well as the pressure pump-installation. Despite these concerns, the technique is available for suitable cyclones and filters.

The working principle of abrasive water jet systems is to pressurise the water by a high pressure pump (up to 400 Mpa) and accelerate it through a nozzle. The suspended material diameters in the water vary between 0.2 and 1.0 mm. The maximum cutting depth in reinforced concrete is about 1 000 mm. The consumption of abrasives, typically garnet, is 0.3 – 3 kg/min (up to 6 kg/min). Water throughput ranges between 10 and 20 l/min. Abrasives can be re-used approximately 10 times.

Example of cutting 400 mm heavy reinforced concrete with abrasive water injection jet:

| Pressure: | 300 MPa |
| Water throughput: | 17 l/min | 1.02 m³/h | 136 l/m² |
| Abrasive throughput: | 2.6 Kg/min | 156 kg/h | 21 kg/m² |
| Feed motion: | 50 mm/min | 3 m/h |
| Yield: | 0.125 m²/min | 7.5 m²/h |

3.3.6 Comparison of dismantling techniques

Table 12 summarises the previous discussion and to provide qualitative criteria to guide the selection of the adequate dismantling techniques with respect to the operational objectives and constraints.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond wire sawing</td>
<td>– Highly versatile technique</td>
<td>– Hazards related to rupture and locking of the wire</td>
</tr>
<tr>
<td></td>
<td>– No limit on structure size</td>
<td>– Generation of dust/slurry</td>
</tr>
<tr>
<td></td>
<td>– No vibration</td>
<td>– Risk of cross contamination of hidden surface (wet</td>
</tr>
<tr>
<td></td>
<td>– Precise cuts</td>
<td>conditions)</td>
</tr>
<tr>
<td></td>
<td>– Flush cutting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Can be operated in dry conditions</td>
<td></td>
</tr>
<tr>
<td>Circular sawing</td>
<td>– No vibration</td>
<td>– Limited cutting depth</td>
</tr>
<tr>
<td></td>
<td>– Precise cuts</td>
<td>– Hazards related to locking</td>
</tr>
<tr>
<td></td>
<td>– Flush cutting</td>
<td>– Generation of dust/slurry</td>
</tr>
<tr>
<td></td>
<td>– Can be operated in dry conditions (at</td>
<td>– Elaborate installation</td>
</tr>
<tr>
<td></td>
<td>reduced cutting rate)</td>
<td>– Risk of cross contamination of hidden surface (wet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>conditions)</td>
</tr>
<tr>
<td>Hammering</td>
<td>– High yield</td>
<td>– Heavy equipment</td>
</tr>
<tr>
<td></td>
<td>– Very reliable</td>
<td>– Generation of dust</td>
</tr>
<tr>
<td></td>
<td>– Insensitive to surface state</td>
<td>– High vibration level</td>
</tr>
<tr>
<td></td>
<td>– Insensitive to metal inserts</td>
<td>– Reinforcement requires additional cutting technique</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Needs additional treatment(s) to reach adequate surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td>finishing</td>
</tr>
<tr>
<td>Drilling and spalling</td>
<td>– No dust/slurry generation (besides</td>
<td>– Pre-treatment</td>
</tr>
<tr>
<td></td>
<td>drilling operations)</td>
<td>– Need for further handling (hammering)</td>
</tr>
<tr>
<td></td>
<td>– Applicable in hard to reach areas</td>
<td>– Reinforcement mostly requires additional cutting</td>
</tr>
<tr>
<td></td>
<td>– Ease further hammering operations</td>
<td>technique</td>
</tr>
<tr>
<td></td>
<td>– Simple to use</td>
<td>– Control of cracks spreading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Hazards related to damage to load-bearing structures</td>
</tr>
</tbody>
</table>
### Table 12: Comparison of concrete dismantling techniques (cont’d)

<table>
<thead>
<tr>
<th>Technique</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosives</td>
<td>– High performance</td>
<td>– Agitations and blast waves</td>
</tr>
<tr>
<td></td>
<td>– Uncovers reinforcement</td>
<td>– High generation of dust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Extensive preparation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Safety issues concerning unexploded loads</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Regulatory aspects</td>
</tr>
<tr>
<td>Chain saw</td>
<td>– Compact equipment</td>
<td>– Significant wearing of segments</td>
</tr>
<tr>
<td></td>
<td>– Allow plunge cut very close to a surface</td>
<td>– High consumable cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Water cooling compulsory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Low performance</td>
</tr>
<tr>
<td>High Pressure (Abrasive) water jet</td>
<td>– Low guiding and reset forces</td>
<td>– Demand of water</td>
</tr>
<tr>
<td></td>
<td>– Individual cutting forms</td>
<td>– Aerosols emissions</td>
</tr>
<tr>
<td></td>
<td>– No vibrations</td>
<td>– Very large amount of secondary waste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Requires water/sludge treatment installation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Risks of cross contamination</td>
</tr>
</tbody>
</table>

### 3.4 Safety considerations

#### 3.4.1 Ventilation and filtration

Concrete dismantling and clean-up operation generates a large amount of dust. Besides radiological risks associated with the inhalation of radioactive particles, “conventional” safety issues such as reduced visibility in the work area, dust explosion, and the inhalation of silica particulates should also be considered. Dust vacuuming at the source is never 100% efficient and cannot be implemented for every tool (e.g. jack-hammer, open abrasive blasting). Therefore, a local confinement of the work area with adequate independent ventilation is often obligatory for concrete clean-up operation.

Ventilation and filtration systems are designed and installed in nuclear facilities. The purpose of these systems is to prevent the spread of contaminated airborne particles, which pose a radiological risk of dose-uptake through human inhalation, by capturing and containing these particles in a system whereby they can be safely handled and disposed. These requirements are valid for both facility operations and final decommissioning. Additional requirements may be:

- To provide an airflow across a workface which prevents the accumulation of suspended particles over the entire work area.
- To control the removal of contaminated particles from the workface to specific equipment designed to handle the aerosols in an effective way.
- To collect waste materials from decommissioning that cannot easily be captured by the available handling systems for large waste items.

All these requirements should reduce the risk to the operators, the public and the environment from the radioactivity generated during decommissioning operations. In the specific case of concrete clean-up operations, specification of ventilation systems should also take into account conventional safety issues, such as reduced visibility or inhalation of silicate particulates.

The ventilation systems should be designed to provide an airflow from clean, non-radioactive areas to radiologically contaminated areas and to ensure that air is extracted through successive areas of progressively increasing radiological classification i.e., from areas with low radiation and contamination levels (green areas) to areas with high radiation and contamination levels (red areas). This principle is illustrated in Table 13.
### Table 13: Principles of ventilation and filtration

<table>
<thead>
<tr>
<th>From atmosphere</th>
<th>Direction of flow</th>
<th>To atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>“White”</td>
<td>Non-radiological area</td>
<td></td>
</tr>
<tr>
<td>“Green”</td>
<td>Low Radiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low Contamination</td>
<td></td>
</tr>
<tr>
<td>“Amber”</td>
<td>Medium Radiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium Contamination</td>
<td></td>
</tr>
<tr>
<td>“Red”</td>
<td>High Radiation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High Contamination</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filtration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increasing negative pressure relative to atmosphere (-Δp)</td>
<td></td>
</tr>
</tbody>
</table>

Normally, boundaries between areas of different classification are achieved by means of physical containment systems such as walls, lead bricks, steel partitioning or glove box walls. For concrete clean-up operation (mobile work), temporary confinement can be built out of modular solid tent systems or existing room boundaries can be used, with all unnecessary access or openings being tightly sealed off. These physical barriers limit the pathways for airflow to engineered monitoring systems and to smaller casual openings around doors, seals, etc. A controlled flow rate will generate a pressure drop over these physical boundaries. Consequently, the radiological areas will be at an increasingly negative pressure relative to the atmosphere, ensuring an inward airflow and preventing the back-diffusion of particles. Additional measures to avoid back-diffusion may be installed such as non-return valves or filters.

The extracted air should be filtered in order to capture the particulate material before the filtered air is released into the atmosphere (“once-through” system) or reused (recirculation system). Standards for designing ventilation systems may require minimum average flow rates. Additional requirements for air exchange rates in facilities may have to be met according to general health principles or with consideration being given to specific radiological requirements for areas with specific radiological classifications. As a result, areas with high radiation and/or contamination levels may require higher air exchange rates than areas with low radiation and/or contamination levels or non-radiological areas. For example, a primary containment area such as a glove box or a cave facility may have between one and 30 air exchanges per hour compared to a non-radioactive room with one to two air exchanges per hour.

In order to select or design the appropriate ventilation and filtration systems for a decommissioning project, the nature of the produced aerosols or particulate materials should be defined. In general, decommissioning activities comprise three main tasks:

- dismantling of equipment, circuits and materials;
- size reduction of dismantled equipment or materials; and
- decontamination in an appropriate workshop (concrete blocks) or in situ (building structures).

Most decommissioning projects are a combination of these three main activities, creating aerosols by agitating the existing contaminated particles or by generating new particles from solid materials during cutting and/or decontamination work. Different decontamination treatments generate different amounts of dust with different physical properties (size distribution). Aerosols may be sampled (e.g. using a particle fractionating sampler) to assess specific activity, particle size distribution and quantities. One should not necessarily expect a homogeneous distribution of contaminants. Depending on the treatment applied, dust collected in the ventilation and rubble...
collected on the floor may have significantly different activity levels and isotope distribution (e.g. the demolition of activated baryte concrete with hydraulic hammering at BR3). Large particles tend to settle quickly, while small particles are likely to remain suspended for a longer time period. Insufficient air flow may result in (contaminated) dust re-deposition on decontaminated surfaces and could require the additional cleaning of surfaces (through blowing or vacuuming) at the end of the project. Compact, mobile ventilation units equipped with self-cleaning filters are available, allowing continuous work. Flow capacity, lay out and the dust collection system (e.g. dustless emptying) can be tailored to meet the specific need of the project.

3.4.2 Radioprotection

The decommissioning activities have to deal with the specific radiological characteristics of the facilities. Depending on the level and type of contamination to be found on the surface, concrete decontamination operations are very likely to produce airborne contamination (except when water is sprayed, but this is not recommended since it could result in further migration of contaminants and cross-contamination of hidden/clean surfaces) and therefore the operators have to use an adequate combination of different kinds of protective clothing and equipment. In some cases specific breathing and cooling air systems should also be provided to enable the decommissioning tasks to be carried out in safe and acceptable working conditions.

In general, some of the basic protection means include:

- underwear with increased absorption capacity to protect the skin and increase comfort, socks, normal white overalls, cotton head protection, different kind of gloves, overshoes, boots;
- plasticised paper overall, when working in low contaminated areas and when there is no risk of contamination by liquids;
- integral plastic suit, covering the whole body and allowing the use of all other normal protective clothing, including filter mask, air-line and safety helmet, when working in highly contaminated areas;
- full-face mask, filter mask for use under integral plastic suits, air line with breathing and cooling air and emergency supply;
- ear protection, depending on the noise level; and
- safety helmet.

All protection systems that may be used should comply with the local applicable regulations.

Choice of the adequate protection relies on:

- Contamination isotope inventory: when alpha contaminants are present, a ventilated suit is preferable.
- Physical properties and amount of produced dust: the large amount of fine dust produced, for instance during dry abrasive blasting, may result in fast clogging of particle filters. In such conditions, an autoflow system or a ventilated suit is preferable.

When, for given work conditions, the choice between the different individual protection equipment is possible, the final decision results from a compromise between:

- operator comfort;
- cost of protective equipment;
- radiological risk.

Example: An operator might prefer to work in fully ventilated suit when performing strenuous work, such as hammering, though this is not obligatory (from a safety point of view) since no alpha contamination is present and rather low amount of dust is produced.
An overview of the use of some specific protection systems is given in the following sections.

**Head protection**

Simple head covers may be used such as caps or hoods, i.e. a contouring and stretchable head protection made of viscose, PVC, cotton or other non-woven material. In most cases, a hood will also include an elastic face closure to provide better fitting. The material may extend over the shoulders for increased coverage. This type of cap may be used to prevent any contamination of the head during undressing of the basic protective clothing.

**Eye, face and breathing protection**

When breathing protection is required full-face masks are preferable as they also provide additional eye and face protection if they are equipped with a blow-resistant polycarbonate window. These masks may also be equipped with frames for corrective glasses.

A specialised breathing apparatus should be used when the oxygen content in the air is below 17% by volume or when the concentration of toxic gases is higher than 1% by volume.

When using a filter mask, the operator should test the seal by covering the filtered air intake by hand and inhaling. A positive result is obtained when the mask effectively seals on the face and no air is allowed to enter. Safety tests must be repeated on a regular basis and filters should be exchanged before clogging.

The requirement to use equipment for breathing protection should be defined based on the level of airborne contamination determined by qualified radiation protection personnel. Inhalation of alpha particles should be avoided in all cases.

A combination of a (full-face) mask, air filter and additional breathing air supply should be used by operators who are exposed to dangerous radioactive substances (alpha particles) and when, due to the difficult working conditions, face mask seals may be compromised. A pressure control system (regulator) in an open loop configuration provides breathing air and creates a limited overpressure in the full-face mask. Compressed air may be taken from pressurised air bottles carried on the back of the operator or from an industrial air compressor with appropriate filters. If the breathing air source is from pressurised air bottles on the operator’s back, an audible signal should alert the operator that the supply is almost exhausted.

**Protective clothing**

Operators should be qualified by a medical doctor as physically fit for conducting work in suits. As well, the operator should be trained and qualified to work in a suit for each working circumstance. While working in a suit, an operator should have visual contact with another operator in the workplace or with an operator outside the workplace. The required equipment should be available to support an operator in emergency situations.

- Non-ventilated suits

Non-ventilated suits are generally made of plastic sheets (mostly PVC) without internal ventilation and consisting of a jacket, hood, and trousers. Adhesive straps may be used to improve the imperviousness. Dressing and undressing is very simple and the suits are not cumbersome as no internal ventilation systems are provided. They ensure good protection against contamination from dusts and are relatively cheap.

When the work is finished, undressing should be done with care to avoid the spread of contamination, the operator being supported by competent people wearing protective clothing as well, and adequate contamination control being implemented by the people responsible for radiological protection and industrial safety.

Before and after each intervention, operators working in non-ventilated suits should drink the required amount of water and/or specific drinks to compensate for the loss of water and minerals in the body due to perspiration.

- Ventilated suits
A ventilated suit is an impervious protection suit equipped with a breathing and/or cooling air supply ensuring an overpressure and internal ventilation within the suit, preventing the operators from being contaminated when working in areas with significant risk of radiological contamination and providing adequate cooling of the body.

In case of loss of imperviousness of the suit or loss of air supply, the operator should leave the workplace as fast as possible without taking any risk of further damage to the ventilated suit. An operator in a state of panic or an operator becoming ill should be evacuated from the workplace by his colleague(s) inside or outside the workplace. In case of an accident in which an operator is wounded, the operator should leave or should be removed from the workplace without undressing (only when life is threatened should a ventilated suit should be opened and/or removed).

The comfort criteria for a ventilated suit require that the internal ventilation flow rate should be sufficiently high to supply the necessary breathing air, to evacuate the produced CO₂, to minimise humidity and to protect the operator against elevated body temperatures. The ventilated suit might be equipped with a tap enabling the operator to control the airflow. The material should be supple, light and robust and not absorbent. The viewing field should be maximised and the viewing medium should be transparent with good optical characteristics. Voice transmission through the material should be acceptable. In the case of reusable suits, the surface should be smooth and easy to disinfect.

On the other hand, the internal ventilation airflow should not be excessively high in order to avoid high noise levels and extreme cooling effects. The suit should not be cumbersome or unduly heavy to limit physical movement. The supply air system should be designed, installed and maintained by qualified personnel. Viewing should not be distorted or limited by condensation at the inner side of the viewing screen.

*Protection of the upper limbs*

Gloves should be used in the case of risk of mechanical aggression or in case of radioactive contamination. Specific vibration absorbing gloves should be used when working with vibrating tools or equipment. Gloves can be made of cotton (white jersey cotton for use without or with top gloves in sensitive areas), rubber, synthetic material, PVC, polythene, non-woven material, polyurethane, leather, latex, or nitrile (coated nitrile rubber on textile backing instead of leather gloves providing improved general handling characteristics). For optimal protection different types of gloves can be worn simultaneously.

*Protection of feet*

Protection of feet is required if there is a risk of foot injury from falling objects or in case of risk of radioactive contamination. Overshoes may be worn over shoes or safety shoes. These are generally made of cotton, plastic, rubber, synthetic materials, PVC, non-woven material, polypropylene, or vinyl. Overboots are long overshoes and may protect shoes and the lower parts of trousers. They may be fixed with elastic or tightening straps. Sometimes they have an anti-slip sole.

### 3.4.3 Industrial hazards

Safety helmets are required in all areas where there is a risk of falling objects or materials.

*Fall protection*

Fall protection should be provided in work areas where operators are exposed to potential falls of more than two meters in height. Specific systems that may be used are belts, harnesses with flexible rope, security ropes (life-lines), safety nets, work ropes which provide safe means for ascent and descent and self-locking systems to prevent the user from falling should he/she lose control of his/her movements.

*Ear protection*

Concrete clean-up and dismantling operation often requires the implementation of equipment and machines which produce a high noise level. Examples of these machines are:
3. Concrete decontamination and dismantling

- Remotely operated rock breaker: 80 – 100 dB
- Abrasive blasting system (abrasive may be injected through a venturi): up to 110 dB. Special ear protection is required and a silencer should be implemented on the system.
- Vacuuming installation (some systems use venturi).

In areas where excessive noise may not be reduced by other means, ear protection should be worn in case of daily exposure to noise levels above the limits indicated in the applicable regulations [e.g. 90 dB(A)].

Specific protection devices may include earplugs, ear caps, individual ear protection or silencers. To improve communication between operators on the field, the use of tailored ear protection including frequency filters (allowing to filter out a given frequency range) may be considered.

Risk of heat stress

When decommissioning nuclear facilities, one of the most prominent hazards is the potential for internal contamination through the inhalation of radioactive particles. Combinations of different protective clothing and equipment may be used to protect operators. Prevention of heat stress for operators working in protective clothing is normally accomplished with breathing and cooling air from an external source. The time working under these abnormal conditions should be limited. Special systems (i.e. individual air systems mounted on a filter mask, that deliver breathing air connected to a full-face mask and cooling air to the body) may be used in order to reduce the risks of heat stress.

Exposure to hand-arm vibration

The decommissioning of nuclear installations involves a category of activities (construction, demolition and breaking up of concrete) where relevant workers are exposed to hand-arm vibrations. Health effects induced by hand-arm vibrations are indicated by the following symptoms: “white finger” syndrome or numbness of the fingers, reduced muscular strength, pain and stiffness of muscles, physical deformations of bones and joints and some general complaints.

The “white finger” syndrome is indicated as the most common consequence of long term exposure to high frequency hand-arm vibrations. More details can be found in Annex 2.

When evaluating vibration loads, the daily exposure of an operator working with vibratory equipment is indicated by means of an energy-equivalent frequency-weighted acceleration $a(t)$, expressed in $m/sec^2$. The energy transmitted by the energy equivalent frequency weighted acceleration $a(t)$ is equivalent to the energy produced by the whole of the vibrations created by a tool and transferred to the operator in a time interval $t$, corrected through adapted weighting factors to allow for the variation in human response across the frequency range.

A literature review shows that in different countries, alternative standards or target values have been proposed to limit vibration loads on operators. In addition, in the ISO 5349 standard, guidelines are given for making measurements and further evaluations with respect to exposures of hand-arm vibrations as well as information which may be used to predict the probability of the occurrence of “white finger” as a function of the energy equivalent frequency weighted acceleration and the exposure time expressed in a number of years.

In order to gain perspective on the importance of the exposure of hand-arm vibrations, a global representative evaluation method may be used, requiring workers to list the activities and the tasks that include exposure to vibrations, as well as induced vibration levels and the exposure time. This means that:

- Relevant personal data should be collected for workers who are exposed to vibrations on a regular base, as well as the data relating to the used decommissioning tools.
- Tools which may be considered as sources of vibration should be identified.
- A reference should be defined for the corrected vector sum of the frequency weighted acceleration for each of these tools, resulting from data sheets of the supplied material or from tables with reference values.

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3. Concrete decontamination and dismantling

- The duration of the work activities should be defined for each task, each operator and each tool.

To quantify the vibration load an operator is exposed to, the ISO 5349 standard [7] recommends to calculate the gour hour-energy-equivalent frequency-weighted acceleration a(4). Detailed formula for the calculation of a(4) and some examples of values obtained in the frame of the Eurochemic project are provided in Annex 2.

Calculated values of a(4) help classify workers into different risk categories and evaluate possible improvements to work conditions. An example is given in Annex 2. In the meantime, in the directive 2002/44/EG from the European Commission [8], the legal limit for exposure to hand-arm vibrations has been fixed at 5 m/sec² for the 8 hour-energy-equivalent frequency-weighted acceleration. To improve working conditions and to keep the vibration load on the operators below the proposed health limit, four types of additional measures may be considered in order to protect operators against the impact of excessive vibration loads:

- Technical measures: Remote control of tools, reduction of vibrations at the source, selecting tools and machinery with low vibration levels at the time of purchase, active vibration reduction, passive isolation and attenuation by means of spring systems connected between the machine and its handles (pneumatic hammers) and the use of anti-vibration handles.

- Personal protection measures: Considering the use of anti-vibration gloves, having the advantage of a vibration absorbing layer that may reduce the effect of hand-arm vibrations.

- Organisational measures: Application of adapted working methods, regular and adequate maintenance of used tools and machinery and reducing exposure time in those cases where other methods and/or techniques give insufficient results (i.e. job rotation).

- Medical supervision: Workers exposed to vibration may be medically screened on a yearly basis.

3.5 Performance of concrete dismantling and decontamination techniques

A summary evaluation of the current performance of the main techniques currently in use for concrete dismantling and decontamination of concrete is shown on the following tabulation.
### Table 14. Performance of concrete dismantling and decontamination techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Set up</th>
<th>Working material</th>
<th>Use of water</th>
<th>Typical depth/ performance</th>
<th>Secondary waste</th>
<th>Production rate (MWT)*</th>
<th>Costs (excl. manpower)</th>
<th>Health and Safety aspects</th>
<th>Typical application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needle scaling</td>
<td>Hand-held</td>
<td>Coatings/ concrete</td>
<td>none</td>
<td>1 - 2 mm/pass</td>
<td>None</td>
<td>0.1 m³/h</td>
<td>low</td>
<td>High vibration level</td>
<td>– Remove paint – Hard to reach surfaces (corners, outlines of metal inserts) – Surface finishing</td>
</tr>
<tr>
<td>Scabbling</td>
<td>Hand-held</td>
<td>Coatings/ concrete</td>
<td>none</td>
<td>Up to 3 mm/pass</td>
<td>None</td>
<td>0.25 – 0.5 m³/h</td>
<td>low</td>
<td>High vibration level, debris projection</td>
<td>– Remove thin concrete layer – Hard to reach surfaces (corners, outlines of metal inserts) – Rough surfaces</td>
</tr>
<tr>
<td>Floor scabbling</td>
<td>Floor scabber, Wall</td>
<td>Coatings/ concrete</td>
<td>None</td>
<td>5 mm</td>
<td>None</td>
<td>up to 6 m³/h (floor scabber)</td>
<td>low</td>
<td>High vibration level, debris projection</td>
<td>– Remove a thin concrete layer – Large surface area – Rough surfaces</td>
</tr>
<tr>
<td>Shaving</td>
<td>Hand-held (grinding)</td>
<td>Coatings/ concrete</td>
<td>None</td>
<td>1 – 2 mm</td>
<td>None</td>
<td>Up to 6 m³/h (horizontal surface)</td>
<td>average</td>
<td>Dust emission</td>
<td>– Remove coating – Remove a thin layer of concrete – Surface finishing</td>
</tr>
<tr>
<td>Shaving</td>
<td>Floor shaver, Wall</td>
<td>Coatings/ concrete</td>
<td>None</td>
<td>5 - 30 mm (highly dependent on tool)</td>
<td>None</td>
<td>Up to 14 m³/h (floor shaver)</td>
<td>low</td>
<td>Dust emissions, debris projection</td>
<td>– Remove a concrete layer – Large surface area – Flat surfaces</td>
</tr>
<tr>
<td>Grit blasting</td>
<td>Hand-held, air</td>
<td>Coatings/ concrete</td>
<td>None</td>
<td>Variable several mm (adjustable with treatment speed)</td>
<td>None</td>
<td>100–200 g/m² (depending on machine and objectives)</td>
<td>low</td>
<td>Dust emissions, debris &amp; abrasive projection</td>
<td>– Remove coating – Remove a layer of concrete – Presence of metal inserts – Slightly rough surfaces – Surface finishing</td>
</tr>
<tr>
<td>Sponge blasting</td>
<td>Carrier</td>
<td>Coatings/ concrete</td>
<td>None</td>
<td>Paint/Coating</td>
<td>None</td>
<td>5 m³/h</td>
<td>high</td>
<td>Important dust emissions, abrasive projection</td>
<td>– Selective removal of coating – Remove a thin concrete layer – Hard to reach surfaces – Presence of metal inserts</td>
</tr>
<tr>
<td>Laser ablation</td>
<td>Carrier</td>
<td>Coating</td>
<td>none</td>
<td>10 µm/pass (on typical paint)</td>
<td>None</td>
<td>1.5 - 2 m³/h (can be increased by adding extra laser beams)</td>
<td>Aerosols</td>
<td>– Selective removal of coating – Large and flat surfaces – Presence of metal inserts</td>
<td></td>
</tr>
<tr>
<td>Liquid nitrogen jetting</td>
<td>Hand-held or Carrier</td>
<td>Coatings/ concrete</td>
<td>none</td>
<td>Up to 30 mm/pass</td>
<td>None</td>
<td>10 m³/h (coating stripping) 2.5 m³/h (for a 25 mm pass)</td>
<td>High</td>
<td>Anoxia, cold, aerosols</td>
<td>– Coating removal – Removal of a thick layer of concrete – Rough surface – Presence of metal inserts – Large surface area</td>
</tr>
<tr>
<td>Hammering</td>
<td>Hand held</td>
<td>Concrete</td>
<td>none</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>– Remove large concrete objects – Presence of metal inserts – Large surface area</td>
</tr>
<tr>
<td></td>
<td>Excavator</td>
<td>Concrete</td>
<td>none</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>– Scouring of metal objects – Presence of metal inserts – Large surface area</td>
</tr>
</tbody>
</table>
Table 14. Performance of concrete dismantling and decontamination techniques (cont’d)

<table>
<thead>
<tr>
<th>Technique</th>
<th>Set up</th>
<th>Working material</th>
<th>Use of water</th>
<th>Typical depth/performance</th>
<th>Secondary waste</th>
<th>Production rate (MWT)*</th>
<th>Costs (excl. manpower)</th>
<th>Health and Safety aspects</th>
<th>Typical application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond wire sawing (wet)</td>
<td>Water cooling</td>
<td>Reinforced Concrete/metal</td>
<td>30 – 40 l/m²</td>
<td>unlimited</td>
<td>Water / sludge</td>
<td>1 – 3 m³/h</td>
<td>Average</td>
<td>Rupture and locking of the wire</td>
<td>– Massive structures/assembly - Openings</td>
</tr>
<tr>
<td>Dry</td>
<td>none</td>
<td>limited</td>
<td>Water / sludge</td>
<td>0.5 – 1.7</td>
<td></td>
<td></td>
<td>Average</td>
<td>Rupture and locking of the wire</td>
<td>– Massive structures/assembly - Openings</td>
</tr>
<tr>
<td>Circular sawing</td>
<td>Wet/Dry</td>
<td>Reinforced Concrete/metal</td>
<td>Max. 1 000 mm</td>
<td>Water / sludge or dust</td>
<td>1 - 2 m³/h (wet conditions)</td>
<td>Average</td>
<td>Looking of the blade</td>
<td>– Requirement for accurate cuts - Massive structures - Create notch (for diamond wire sawing)</td>
<td></td>
</tr>
</tbody>
</table>
4. PROJECT MANAGEMENT ISSUES

4.1 Regulatory aspects

International discussions on the declassification of materials for reuse and recycling take place mainly within the framework of the following organisations or environments:

- The IAEA defines the levels of clearance for each radionuclide, material and type of practice in IAEA Safety Guide RS-G-1.7. [10]. These criteria are expected to be incorporated into the new IAEA Basic Safety Standards which are currently under development.

- The EC (European Commission) has its own recommendations for its member countries. EC published specific recommendations for the clearance of waste materials through:
  - The Recommendation RP 122 part I (2000) [11]. This document sets generic levels of clearance applicable to any type of materials, considering all possible situations of exposure. These criteria are expected to be incorporated into the new EC Basic Safety Standards which are currently under development.
  - The Recommendation RP 113 (2000) [12]. This document establishes the levels of clearance applicable to the conventional management of rubble arising from the demolition of the buildings of major nuclear facilities in the dismantling process. It is applicable to the surfaces, walls, rooms, areas and structures of these buildings. It also includes the rubble that might be generated in partial demolitions. It contemplates and establishes the levels of clearance for the three scenarios in the case of concretes: 1) Clearance for reuse or the demolition of buildings (the levels are established in terms of Bq/cm² for each of the radionuclides), 2) Clearance for demolition only (the levels are established in terms of Bq/cm² for each of the radionuclides) and 3) Clearance of rubble (the levels are established in terms of Bq/g for each of the radionuclides).

Once recommendations have been established, national regulatory authorities are responsible for establishing requirements for declassification of the site, which requirements are applied to the operators in dismantling projects. These may include limitations or specific conditions applying to individual projects, e.g. concerning the management of materials resulting from dismantling. Decommissioning practices must be authorised, reported and audited on a case-by-case basis by the regulatory authority, under the relevant national legal framework. Following declassification the decommissioning site is no longer controlled by the regulator, and there is generally no restriction on the activities that may be performed on the site.

The NEA document [13] includes the different activities within the regulatory framework of the different countries in relation to the removal (release) of materials and sites from regulatory control. The countries in question are: Belgium, Canada, Finland, France, Germany, Hungary, Italy, Japan, Slovak Republic, Spain, Sweden, Switzerland, the United Kingdom and the USA. In France where there are no clearance levels for materials, the declassification process for a site (including buildings) is authorised by the Nuclear Safety Authority (NSA) based on a case by case approach. All the materials removed in a contaminated or irradiated area is managed as nuclear waste.

In summary, most of the countries (except France and the United States) have a regulatory framework and associated criteria for clearance established in their national legislation for the management as conventional materials of those materials that have been subject to regulated practices. There is currently no international consensus on clearance levels. A recent report of the OECD/NEA [14] gives an overview of the different regulatory frameworks.
4. Project management issues

As a consequence of these different regulatory frameworks, available evacuation routes for material and waste (ILLW, VLLW, conditional or unconditional clearance, facility delicensing), which are among the most significant cost drivers for a decommissioning project, differ from country to country. Subsequently, the strategy for the clean-up of concrete infrastructures, which represents the highest volume of material in a nuclear facility, is strongly influenced by the regulator. Where no Very Low Level repositories are available, disposal of large volumes of radioactive concrete rubble in a repository at high cost might be an incentive for the decommissioner to develop /implement a broader range of decontamination techniques to cope with the miscellaneous radiological situations, while minimising the volume of radioactive rubble produced.

The EU recommendations establish as a starting point that the clearance of materials implies their subsequent management without consideration being given to any restriction from the radiological point of view (unconditional release). When the destination of the waste materials is previously bound and defined, the recommendations of the EU underline the fact that it is possible to study case by case under specific conditions (conditional release).

4.2 Decontamination and dismantling scenario

It is important during the preparation or design of a dismantling project that early consideration is given to the final management of the concrete buildings and structures of the facility. This aspect is in turn directly related to the choice of the overall dismantling strategy, as described in [15] and [16]. Considering the management routes (strategies) for concrete buildings and structures, the following may be singled out as being the most important:

- conventional (initially non-impacted areas);
- clearance (reuse and/or demolition, unconditional or conditional); and
- radioactive waste (VLLW and ILLW).

Regardless of whether they are of one type or another, or a combination, the route initially considered, or those selected during performance, will imply works, activities and resources that will need to be taken into account during the initial phases of planning.

In view of the large quantities of materials generated, in terms of volume and weight, which to a large extent will contain low values of residual contamination, clearance and subsequent management for use as a conventional material should be considered as the preferred management route, as long as this route is feasible (authorised by the national regulatory bodies and with clearance limits established). Otherwise, a large quantity of waste will be generated requiring treatment as a radioactive waste.

Depending on the strategies selected, consideration should be given to the following factors:

- the development, licensing and implementation of the materials and surface clearance methodology;
- national policy;
- the availability of applicable documentation and procedures;
- isotopic characterisations, key radionuclides, difficult to measure isotopes, the presence or otherwise of alpha emitters;
- the existence or otherwise of activation and/or contamination, total inventory, the levels of activation/decontamination encountered, the existence or otherwise of contamination at depth;
- the decontamination techniques to be used, the cutting methods to be used for major structures, the separation of embedded metallic parts, radiological or otherwise, the type of machinery to be used for crushing;
- the radiological control of materials;
- the conditioning of the wastes generated (including secondary wastes);
4. Project management issues

- the radiological control of the personnel involved;
- the contracting of specialist companies;
- the availability of storage installations, the existence of management organisations for the recycling of the materials, the existence or otherwise of clearance levels;
- environmental aspects, social and economic impact;
- associated costs; and
- the work schedule.

As is reflected in the above, many aspects need to be taken into account. An analysis of these aspects allows the most adequate decision to be taken, or makes it possible to determine those candidates that might be selected depending on the specific characteristics of each project (volume of materials to be managed, dismantling strategy selected, regulatory aspects and others).

If reuse is contemplated, the following may be considered as potential applications for the released material in the nuclear field:

- aggregate material for the manufacturing of concrete mortar;
- refill or encapsulation material for waste disposal containers;
- manufacturing concrete for shielding;
- manufacturing of concrete containers for waste storage or disposal; and
- use in the construction of new installations (specific cases).
- in the case of reuse for conventional purposes, the applications might be as follows:
  - fill material for the construction of roads;
  - additive for concrete manufacturing;
  - paving and basements with rubble;
  - refill of voids existing in installations or mines;
  - landscape restoration in mining projects; and
  - manufacturing of containers.

In these cases it will also be necessary to comply with laws in other areas, such as those relating to the environment and others.

4.3 Inventory and characterisation

Considering the previously established objectives it is necessary to perform an extensive campaign for the characterisation of concrete structures. Once studied and assessed, the results will allow the most appropriate decisions to be taken. Among other considerations, this characterisation campaign may allow for the following:

- determination of the areas and depth of radioactive and/or chemical contamination in concrete;
- the scope and volume of the materials to be managed by the routes established, depending on the initial values and the work and resources to be dedicated in attempts to apply other routes; i.e., is it worthwhile decontaminating a large volume of material to arrive at clearance levels;
- the scope and volume of material to be decontaminated or remediated, if this route is chosen for management prior to clearance;
4. Project management issues

- the scope and volume of radioactive material to be handled for final management as radioactive waste;
- insight into the isotopes present and the possibility of assessing the source term,
- evaluation of the key vector nuclides and acquisition of scaling factors for difficult to measure radionuclides compared to those easy to measure (gamma isotopes);
- establishing the conditions required for adequate radiological protection in order to be able to carry out the works safely and using adequate confinement resources to prevent the dispersal of waste material; and
- possibility of determining whether there have been migrations of contaminants towards neighbouring land, this being especially important in the case of groundwater and below the sub-soil.

The objective of the characterisation campaign is to propose the bases and criteria to be taken into account when planning sampling (or in situ measurement) for the radiological characterisation of the concrete structures in question. In this respect it is necessary to define the source term based on the technical characteristics and operating lifetime of the installations involved. This source term will allow insight to be gained in the type of analysis to be applied on the samples, and in those radionuclides not requiring analysis.

Likewise, the possible origin of the materials will be defined, along with their generic location within the installations, and the number of measurements to be performed will be estimated. Furthermore the comprehension of migration or activation phenomena will allow optimisation of the sampling plan. Once these have been analysed, the different origins of the different materials will be defined. This characterisation shall be performed in accordance with a previously established plan regarding sampling, and the acquisition of results using different methodologies in sampling, as well as measurement of the radionuclides (gamma, beta and/or alpha emitters) by means of direct or indirect techniques.

To ensure that appropriate data are obtained, well trained staff who understand both the data gathering process and the overall objectives of the characterisation programme is necessary.

In large facilities, concrete infrastructure might represent several tens of thousands of square meters of surface to be investigated. A systematic approach, even when using statistic sampling, might result in a tremendous cost. A good characterisation campaign should provide sufficient data to allow using logical assumptions, justified extrapolation and/or theoretical calculation to complete the inventory with a high confidence level where samples and measurement are missing. The characterisation programme uses complementary tools and information sources:

- historical operational records;
- visual and structural analysis (materials, singularities like cracks...);
- theoretical calculations;
- radiological measurements; and
- experience gained from early dismantling work and clean-up operations.

4.4 Management of activated concrete

The volume of activated concrete present in a power plant, research reactor or accelerator is highly dependent on plant design and geometry, composition of the concrete and plant history. In some cases, it might represent the largest volume of radioactive material to be dealt with.

At BR3, the raw volume (standing) of activated concrete (baryte concrete ~ 3.5 t/m³) to be considered as radioactive waste amounts to 100 m³ (after segregation of material which meet average mass specific clearance criteria) while the best estimate for contaminated concrete only amounts to 70 m³.

At Melusine, about 70 t of contaminated concrete has been produced versus 120 t of activated materials.
These huge volumes have mostly low specific activities. This should be an incentive to consider alternative evacuation routes, such as recycling, decay storage or conditional clearance.

The total activity contained in the activated concrete of the biological shield of a neutron source (e.g. research or power generating reactor, discharged fuel elements) is significantly lower than the total activity in the metallic construction materials (e.g. reactor pressure vessel and internal fittings). Also the specific activities are low, compared with those found in construction materials or operation waste (e.g. waste from water treatment). The main problems that arise from activated concrete are associated with the huge volumes (and mass) of the material.

### 4.4.1 Origin of the concrete activity

The activity in concrete is generated – except for the pre-existing natural activity of K-40 – by activation due to the neutron irradiation resulting from its function as a shielding material. The nuclides are formed mainly from elements which are contained in the concrete as traces and do not influence its characteristics as a building material. In general, these elements vary between concrete origins and cannot be accurately predicted in historic structures. Furthermore, components of the reinforcement material (steel) and additives (e.g. barium, hematite, Fe-granulate) can be activated. Coatings on the concrete should be identified for components which can be activated. These coatings, and surface contamination on untreated concrete surfaces can be removed and dealt with separately.

Although activation will normally be the dominating process, the portion of (volume) contamination due to undesired ingress of activity must also be considered.

### 4.4.2 Materials and activation

In this chapter, the concrete components will be investigated with respect to their activation potential.

Table 14 provides typical examples of European concrete compositions.

![Table 14: Concrete compositions](https://example.com/table14.png)
The heavy metal content may be subject to strong fluctuations. Further information is contained in document [17].

The document [18] lists trace element contents:

Table 15: Band width of trace element contents of standard German cements

<table>
<thead>
<tr>
<th>Tracer element</th>
<th>Content in g/t (ppm)</th>
<th>Tracer element</th>
<th>Content in g/t (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony (Sb)</td>
<td>&lt; 1 – 35</td>
<td>Nickel (Ni)</td>
<td>5.5 – 80</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>1 – 55</td>
<td>Mercury (Hg)</td>
<td>&lt; 0.02 – 0.35</td>
</tr>
<tr>
<td>Beryllium (Be)</td>
<td>&lt; 0.2 – 2.5</td>
<td>Selenium (Se)</td>
<td>&lt; 1 – 2.5</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>2 – 200</td>
<td>Tellurium (Te)</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>&lt; 0.1 – 8</td>
<td>Thallium (Tl)</td>
<td>&lt; 0.5 – 2</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>12 – 105</td>
<td>Vanadium (V)</td>
<td>15 – 200</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td>1 – 30</td>
<td>Zinc (Zn)</td>
<td>20 – 450</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>5 – 280</td>
<td>Tin (Sn)</td>
<td>&lt; 1 – 22</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>90 – 4 200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 15 does not contain the elements Europium nor Holmium, important candidates for activation. Also, the tables do not take into account the fact that Lithium can be added to the concrete to prevent an alkali-silica reaction (Reaction leads to forming of alkali-silicate gel, which is hygroscopic and has the effect of net fracture forming, separating and flaking-off). It is important to remember that the chemically bound water should not be forgotten in the neutron-physical calculations.

Activation product data resulting from the elements given in Table 14 and Table 15, as well as lithium, europium and holmium, is compiled in Table 16. The possible formation of tritium from boron is not taken into account, as this transformation needs fast neutron flux densities. The nuclear data are from [19] and [20], the release values for building rubble are taken from [21], and the inhalation dose coefficients for workers are taken from [22].

The nuclides with lowest release criteria are the determining factors for disposal routes. For a residual material to be released for a disposal path the following must be valid [21]:

\[
\sum_{i=1}^{N} \frac{a_i}{F_i} \leq 1
\]

\(i = \text{Radio nuclide}, \ N = \text{Total number of radio nuclides} \ i, \ a_i = \text{Activity of the radio nuclide} \ i, \ F_i = \text{Release value of the radio nuclide} \ i.\)
Where free release is not practised or allowed by regulation, a similar formula is applied (with different weighting factor) to distinguish low level and very low level waste.

In Table 14, a bar in the release value column means that no value is given in [21]. In this case, it has been specified that a release value must be calculated or a substituted value must be used for small quantities. This substituted value is given in brackets behind the bar.

The last column indicates if the nuclide, generated in the concrete from neutron irradiation, is a significant safety consideration for the demolition work. The activity of the reinforcement material is not taken into account. It is assumed that the demolition starts at the earliest 10 years after shutdown of the plant.

A nuclide is important for safety reasons if it has a low release value, a high inhalation dose coefficient, or a half life significantly more than two years. The activity concentration may be assumed to be equal for all nuclides. Exception: Eu-155 is not taken into account, as this means as a precondition that Eu-154 has already been formed. Eu-155 if present will exist in orders of magnitude lower concentrations than Eu-152 and 154.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>From reaction</th>
<th>Thermal activation cross section in barn</th>
<th>Half life</th>
<th>Release value of rubble (in Bq/g)</th>
<th>γ measurement possible?</th>
<th>Significance for decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>3H</td>
<td>6Li(n,a)3H</td>
<td>953</td>
<td>12.33 a</td>
<td>6E+1</td>
<td>No</td>
<td>Little</td>
</tr>
<tr>
<td>14C</td>
<td>14N(p,α)14C</td>
<td>1.81</td>
<td>5730 a</td>
<td>1E+1</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>39Ar</td>
<td>39K(n,p)39Ar</td>
<td>0.1</td>
<td>269 a</td>
<td>-</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>61Ca</td>
<td>40Ca(n,γ)41Ca</td>
<td>0.4</td>
<td>1.03E+05 a</td>
<td>(1E+5)</td>
<td>No</td>
<td>Little</td>
</tr>
<tr>
<td>54Mn</td>
<td>54Fe(n,p)54Mn</td>
<td>312 d</td>
<td>3E-1</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>59Fe</td>
<td>54Fe(n,γ)55Fe</td>
<td>2.26</td>
<td>2.73 a</td>
<td>2E+2</td>
<td>No</td>
<td>Little</td>
</tr>
<tr>
<td>59Ni</td>
<td>58Ni(n,γ)59Ni</td>
<td>4.6</td>
<td>7.6E+04 a</td>
<td>8E+2</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>63Ni</td>
<td>62Ni(n,γ)63Ni</td>
<td>14.2</td>
<td>100.1 a</td>
<td>3E+2</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>60Co</td>
<td>59Co(n,γ)60Co</td>
<td>18.7</td>
<td>5.27 a</td>
<td>9E-2</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>60Zn</td>
<td>64Zn(n,γ)65Zn</td>
<td>0.76</td>
<td>244 d</td>
<td>4E-1</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>137Ba</td>
<td>132Ba(n,γ)133Ba</td>
<td>?</td>
<td>10.5 a</td>
<td>- (1E+2)</td>
<td>Yes</td>
<td>Very</td>
</tr>
<tr>
<td>137Cs</td>
<td>133Cs(n,γ)134Cs</td>
<td>29</td>
<td>2.1 a</td>
<td>1E-1</td>
<td>Yes</td>
<td>Very</td>
</tr>
<tr>
<td>156Eu</td>
<td>151Eu(n,γ)152Eu</td>
<td>9.2E+03</td>
<td>13.5 a</td>
<td>2E-1</td>
<td>Yes</td>
<td>Very</td>
</tr>
<tr>
<td>156Eu</td>
<td>153Eu(n,γ)154Eu</td>
<td>312</td>
<td>8.6 a</td>
<td>2E-1</td>
<td>Yes</td>
<td>Very</td>
</tr>
<tr>
<td>156Eu</td>
<td>154Eu(n,γ)155Eu</td>
<td>85</td>
<td>4.76 a</td>
<td>8</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>168Ho</td>
<td>165Ho(n,g)166Ho</td>
<td>64.7</td>
<td>1.200 a</td>
<td>- (1E+1)</td>
<td>Yes</td>
<td>Very</td>
</tr>
</tbody>
</table>

### 4.4.3 Characterisation methodology

The following points are key components of an activated concrete characterisation study:

- Determination of areas irradiated with neutron radiation: mainly reactor vicinity, but also vicinity of fuel cooling installation.
- Analysis of building plans regarding non-homogeneous concrete (different types of concrete) and concrete structures (e.g. cable or pipeline penetrations or other potential locations for activity deposition).
- Analysis of operational effects influencing the apparent activity of the concrete (ingress of contaminated water or contaminated air): If there are indications that the activated concrete is also internally contaminated the demolition of the concrete structure must be planned and performed differently as described below. If the activated concrete is contaminated, the relationship between the neutron flux density and activity is distorted.
• Determination of project and construction data of the concrete structure, origin of the concrete and its additives.

• Undertaking a search for historic retained samples (e.g. test samples for concrete strength).

• Investigation of the chemical composition of recovered samples. Core samples, which reach radially and axially to the neutron source (reactor) up to the areas of rather high neutron flux density, are particularly important. The densities of all elements, contained in the concrete will be needed for calculations (analysis of the material from non-activated areas may be used without additional radiation protection effect).

• The radionuclides, important for the demolition, are to be specified on the basis of the chemical composition;

• Quantitative analysis of the activity composition of core samples of suitable low activity (that can be easily measured and handled), regarding the above determined important radio nuclides in a certified laboratory, for the purpose of determining a nuclide vector (or – if necessary – several nuclide vectors) for the mineral contents (including possibly contained metallic additives) and for the reinforcement steel. Therefore, the activities of the \( \gamma \) as well as the \( \beta \)-emitters must be determined.

• The use of scaling factors to determine Hard-to-measure radionuclide activities must take into account possible discrepancies in trace elements/impurities relative concentrations in the bulk material. Different concentrations distribution will result in isotope specific in-depth activity distribution profiles.

### 4.4.4 Activation calculations

The following are key components for activation calculations:

• Determination of the chronological and local sequence of the capacity density distribution in the neutron source, e.g. in the reactor. Deduction of suitable representative neutron source density distributions (also for axial expansion) for the neutron flux density and activation calculations.

• Creation of a geometry model, which takes into account geometrically unclear areas. It should be noted that the source structure is reflected also in the activation in areas close to the source. Therefore, it is helpful for the interpretation of measured values of these areas, if e.g. the reactor core is not composed of ring zones, but according to the real geometry with a realistic neutron source density distribution in the edge fuel elements.

• Calculation of the spatial neutron flux density and activity distribution by taking into account the standstill times.

• Adjusting the calculated activity distribution to the measured activity distribution.

### 4.4.5 Bringing together the results

It is possible to plan the demolition with these results. In certain cases removal of surface contaminations in order to minimise the disposal quantities and simplify disposal routes should be considered. The following points should be included in the demolition planning process:

• division of the demolition area into zones of the same demolition methodology and disposal goals, (e.g. unrestricted release, conditional release, planned-for decay storage period, intermediate storage);

• estimation of the respective masses and activities;

• specification of the demolition procedure;

• specification of the transportation routes;

• evaluation of the employed personnel’s radiation exposure, specification of protective measures, use of additional measuring equipment;
4. Project management issues

- specification of the release measurement types and radiological control measures (sampling procedures, sample analysis, comparison with predictions); and
- agreement with the supervisory authority regarding the required documentation.

4.5 Procurement issues

Contracting, a key aspect of D&D Programmes can successfully be used when certain conditions are met. The following contracting methods are described in detail in Annex 5:

- Fixed-price contracts:
  - Firm fixed-price
  - Fixed-price with fixed per-unit pricing
  - Fixed-price with economic price adjustment
  - Fixed-price with incentive and firm target price
  - Fixed-price with prospective price re-determination
  - Fixed-price using a fixed unit rate

- Cost-reimbursement contracts:
  - Cost and cost-sharing contracts
  - Cost-plus-inventive-fee
  - Cost-plus-award-fee

Experience has shown that fixed price contracts are appropriate when projects are well defined, uncertainties can be allocated between parties, and sufficient price information and/or multiple competing bidders are available to help determine fair and reasonable price for the work. While fixed price contracts are not suitable for every D&D project, this type of contract generally provides the greatest incentive for the contractor to perform efficiently and to control the cost. The cost risk of overruns due to poor performance is generally borne by the contractor, which helps protect the owner’s interest.

Demolition and clean-up work are normally of sufficient magnitude that a call for tender is generally required by national competition legislation. An open competition process also helps the owner determine a fair price for the work.

When the scope of the work has not been clearly defined, the use of fixed-price contracts will not prevent significant cost overruns and schedule delays. The following elements should be considered when defining/describing the scope of work and the type of contract:

- an accurate characterisation, activity analysis (minimum thickness to be removed);
- an accurate structural analysis (paint, quality of concrete, surface roughness);
- information on the rooms (size, ventilation, entrance, climatic conditions…);
- waste information (management included or by owner, ILLW or VLLW…);
- technology available;
- safety constraints;
- final dust removal and control of radiological cleanliness after work (different than final survey for release);
- removal of equipment; and
- special requests, limitations from authorities or local governments.
4. Project management issues

In the particular case of concrete infrastructure decontamination, regardless of how good the initial characterisation survey may be, it cannot be fully exhaustive and significant uncertainty remains locally, mainly on the contaminant penetration depth (subsequently on the residual activity after treatment in area where no sampling has been performed). When using fixed price contract, the scope of work and the responsibilities of both the plant owner and the contractor have to be very clearly defined. The criteria selected to evaluate if the objectives have been reached also have to be very well defined. Therefore it is highly advisable to express objectives in quantitative terms such as concrete thickness or volume to be removed.

The type of contract negotiated between the owner/licensee and the contractor is a powerful mechanism to control costs and to maintain a project within budget and schedule. The driving force of competition among contractors will lead them to commit to perform the work and to absorb a certain amount of risk in return for a potentially attractive return (fee). The more risk they absorb, the higher the potential fee to the contractor, and conversely, the potential for greater losses if they cannot perform the work scope within the agreed upon contract price and face major financial losses. The owner balances the benefits of putting a contractor at risk, versus sharing the risk to ensure the project is completed successfully. When the facility site conditions are not well known, the owner generally accepts some of the risk, and accordingly it is advisable to structure the contract to protect the relevant interests of both the owner and the contractor.
5. RADIOLOGICAL SURVEY

The previous chapter discusses characterisation requirements from a project planning perspective. This chapter is dedicated to the means and methods of performing the radiological surveys including feedback and results from specific projects.

Radiological surveys of buildings can be performed at three different stages:

- before clean-up to assess the depth of migration or activation, the radiological spectrum, and the radioactivity level of waste;
- during clean-up to check and possibly revise initial data; and
- after clean-up to confirm that the structures meet release criteria.

Characterisation methods and techniques of the surveys may be different in order to optimise the cost and the duration while still obtaining the necessary accuracy of measurement results.

The following chapters describe the main methods for:

- the initial assessment survey; and
- the final radiological survey after cleaning up, so as to release materials and facilities.

5.1 Characterisation and inventory methods

As discussed in §4.3 and 4.5, the level of contamination and neutron activation in concrete can be assessed using different complementary methods:

- historical operations documentation and structural analysis;
- theoretical calculations;
- radiological measurements;
- review and evaluation of the data obtained; and
- feedback from other projects.

These methods are detailed in the following chapters. General information extracted from [19] is summarised. This report focuses generally on reactors but much of the information such as historical analysis and radiological measurements is relevant to all nuclear facilities. Information is complemented with the feedback from specific projects.

5.1.1 Historical operations documentation and structural analyses

Method

Material for analysis may come from historical documentation reviews, personnel recollections of process and activities information including contamination spills or other unusual events, and previous surveys and measurements. Important in this context are records of occupational exposures incurred during inspections, surveys, maintenance and repair or replacement of major contaminated components. Information on process upsets or unusual events that might have spread contamination to unsuspected areas is particularly important.
5. Radiological survey

The knowledge of the structural design of the facility facilitates the identification of:

- the main features of the structures (density, thickness);
- singularities which could carry contamination deep in the walls (cracks, joints...); and
- modifications that may hide contamination.

In the case of deferred dismantling, structural analysis must be carried out in addition to radiological characterisation.

Particularly important are as-built drawings detailing modifications to structures and equipment in restricted areas where radioactive materials are processed or stored and of locations of possible inaccessible contamination, such as buried pipes.

The following example illustrates the importance of historical and structural analyses.

Mélusine: drawings analysis showed that a gutter was filled by concrete. The gutter function was conventional but it was located in a room with a liquid contamination (primary circuit pumps and exchanger).

In this case it was necessary to remove the “new” concrete so as to characterise and, if necessary, to clean-up the former concrete.

Table 17 below shows how these studies were applied in several projects studied by the task group. Globally, each project carried out historical analysis. It is interesting to notice that most of the projects assigned a surface classification however the classification definition varies between the projects. Classification can be based on either historical analyse (CEA’s projects, BR3 project for example) or initial radiological inventory (e.g. the PIMIC project).

Most regulations now require that information on unusual events be documented so that it is accessible at the time of decommissioning.

Another source for historical information is the result of previous surveys and measurements. For example, analytical results from fuel pools can indicate the kinds of contaminant present (and, as significantly, those absent). Similarly, measurements of radioactive contaminants collected in an ion exchanger can give good indication of the amounts of less abundant contaminants and allow an estimate of the relationship between common and rare radionuclides present. Routine radiation surveys and surveys conducted to support special work are both useful. The information that they provide may be sufficient or, at the very least, may be used to optimise the characterisation plan.

Historical and structural analyses should be considered obligatory and should be performed at an early stage of decommissioning planning, even before the cessation of plant operation, while many zones are inaccessible for measurements. This analysis is useful for the first decommissioning studies (feasibility analysis, planning and cost evaluation).

Reviewing the historical information of a facility provides valuable knowledge of possible radiological conditions present. In addition, by identifying the list of possible contaminants from a review of facility history, one can optimise the characterisation effort and avoid spending time, money and unnecessary exposure of workers trying to measure something known not to be present, as in the case for alpha emitters in a reactor that has suffered little or no fuel damage.

Conclusions should be drawn cautiously. Historical records (e.g. as-built drawings and survey information) are scarce or inadequate at some old facilities, as the culture of the time did not require such records. Particular attention should be paid to the possibility that unrecorded unusual events may have occurred. Lack of this type of information will result in greater characterisation efforts being required. If this is the case, extensive radiological characterisation for decommissioning purposes should begin soon after the facility is shut down. To some extent, the availability of experienced staff may compensate for the lack of records.

Although historical information is a valuable asset in preparing a characterisation programme, it should be viewed with some scepticism and an intuitive sense of doubt. At least some of the characterisation effort should aim at testing the validity and completeness of the historical data.
### Table 17: Methodologies used for historical analyses

<table>
<thead>
<tr>
<th>Project (Country)</th>
<th>Identifying process and activities</th>
<th>Operation reports analysis</th>
<th>Operator logbooks, procedures/notes, radiological controls results</th>
<th>Drawings analysis (new and old)</th>
<th>Operators interview</th>
<th>Surfaces classification</th>
<th>General comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mélusine (France)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes Few records</td>
<td>Yes</td>
<td>Yes</td>
<td>4 categories (0 to 3) depending on origin of radioactivity (liquid or dry contamination, activation)</td>
<td>Required by the French regulation. The interviews of experienced staff (even retired staff) provided a lot of information, in particular on the usual practices in the different rooms. Information gathered per room or zone in a technical report In some cases, database.</td>
</tr>
<tr>
<td>ATUE (France)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brennilis (France)</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eurochemic (Belgium)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>BR3 (Belgium)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>4 categories (0 to 3) depending on origin of radioactivity (liquid or dry contamination, activation) and on depth contamination measured or assessed</td>
</tr>
<tr>
<td>PIMIC (Spain)</td>
<td>Yes</td>
<td>Not available</td>
<td>Not available</td>
<td>Yes</td>
<td>Not available</td>
<td>Yes</td>
<td>Categories depending on Initial Radiological Survey</td>
</tr>
<tr>
<td>Vandelllos (Spain)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Categories changed during dismantling according to radiological risk</td>
</tr>
<tr>
<td>KKR (Germany)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>WAK (Germany)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>2 categories: – Surfaces of free accessible areas – Surfaces of exclusion areas</td>
</tr>
</tbody>
</table>

Decontamination and dismantling of radioactive concrete structures - © OECD/NEA 2011
5. Radiological survey

5.1.2 Theoretical calculations

For reactors that have undergone normal operation, the principal component of the radioactive inventory is the activation of the materials of construction. The extent and levels of activation in a facility can be estimated on the basis of theoretical calculations based on geometry, material composition and operating history.

Contamination in facilities results from radioactive releases:

- For reactors: from the fuel together with the activated products of corrosion and erosion which occurred during normal operation or unplanned events.
- For other plants: from the various radionuclides manipulated (examinations or fuel manufacture for instance).

These releases may include radioactive materials handled, treated or stored within a facility, such as fuel, fission products and actinides, activation products and their daughter decay products.

In contrast to activation, it is difficult to estimate theoretically the amount and distribution of contamination remaining throughout the plant. Indeed, the main difficulty is the large number of different variables such as: the physical features of concrete (quality, homogeneity, painting...), the duration of contaminant contact with concrete, and physical phenomena according to the nature of the contamination (dry or liquid, chemical composition...). Moreover, concrete is often very heterogeneous. As a result, at this time, there is no available theoretical calculation method for contamination extent and level assessment.

Therefore, the only reliable theoretical calculation method is the activation calculation, which is based on two main steps:

- First step: calculation of the spatial and energy distribution of the neutron flux, which requires details of the reactor geometry, the materials and fuel features.
- Second step: calculation of the spatial extent of activation from the neutron flux distribution, which requires the irradiation history and the material composition including trace element concentrations.

Calculations are performed by using specific computer codes, such as MCNP (Monte Carlo N-Particle), TRIPOLI, CINDER’90...

The result is a three dimensional modelling of the extent and level of the activation in materials.

**Figure 34: Activation profile around Melusine neutron beam channels**
Measurements and sampling have to be performed in specified regions to provide an experimental basis for the characterisation and to permit the computational methods used and the historical information on plant operation to be evaluated.

**Advantages**

- This method makes it possible to get a global 3D cartography of the activation without having access at the activated area. The calculations can be performed very soon in the decommissioning planning, even before the final shut down. Hence it is useful for the first decommissioning studies (feasibility analysis, planning and cost evaluation).
- The activation calculations provide valuable knowledge of possible radionuclides present. In addition, it makes it possible to limit investigations and avoids spending time, money and unnecessary exposure of workers trying to measure something determined not to be present.
- Useful for worker dosimetry and waste radioactivity level assessment.
- This method can calculate metals activation inside concretes.

**Drawbacks**

- Results are subject to large variation dependant on the reliability and accuracy of the database. The lack of historical information can lead to very conservative assumptions resulting in an important overestimation of the activation. On the contrary, the omission of material impurities can lead to an important underestimation of the activation. This will result in greater characterisation efforts being required to test the validity of the calculation. If this is the case, extensive radiological characterisation for decommissioning purposes should begin soon after the reactor shut down.
- This study has always to be validated with real results (neutron flux measurement during the operation, sampling) to verify the modelling data. Results allow confirmation or readjustment of the assumptions used for modelling. An iterative process can improve reliability.

**Experience gained from the projects represented in this study:**

Among the specific studied projects, those that carried out activation calculation are: Mélusine, Siloé, Brennilis, PIMIC, Vandellos, BR3 and KKR.

The results are very different depending on the project. In the case of PIMIC, samples demonstrated a lower level than estimated by calculation. The main reason is the use of very conservative assumptions due to the lack of historical data, and uncertainties due to the low level of activation and non continuous distribution of chemical element in concrete. On the contrary, in the case of Mélusine, samples and calculation roughly matched. Reactor cycles, neutron flux, fuel used and experiments implementation have been found in documentation.

**5.1.3 In situ characterisation techniques**

Pre-dismantling characterisation requires the use of some complementary in situ measurement techniques. The choice of techniques to be utilised needs to take into account certain parameters, for example:

- the nature of the radioactivity (activation, contamination) and the type, nature and intensity of the radiation emitted;
- the physical and geometrical conditions; and
- the accuracy required of the results (e.g. qualitative and/or quantitative information).

Three kinds of in situ measurement may be used in relation to characterisation:

- dose rate measurements;
- radioactive contamination measurements; and
5. Radiological survey

- measurement of relative individual radionuclide activities by spectrometry.

In each case, particular attention must be paid to ensure that the methods of measurement take into account the geometry, the surface conditions and the nature and extent of the radioactive contaminants. Clear operating procedures must be prepared which take into account the physical limitations of the measurement equipment and techniques.

The table in Annex 6 present, per project, the different techniques used to perform the characterisation surveys.

The main details concerning irradiation and contamination measurements are given in the following three subsections.

(a) Dose rate measurements

Measurements of radiation fields can provide an acceptable estimate of the activity if the relationship between activity content and radiation field is well established. These measurements should be made at fixed, convenient distances from contamination. The accuracy of this method depends on factors such as surface geometry, relative isotope mixture, distribution of activity on the surface, background radiation and actual measurement procedure (distance from the measured surface, measurement points, instrumentation used, detector orientation etc.).

Advantages

- As a first approach, very early in the decommissioning plan, dose rate measurement can give good information on the main hot spots location.
- Easy to implement.
- Useful for dosimetry assessment for decontamination and/or demolition operations.
- Associated with surface measurements, make it possible to identify external irradiation sources, which could disturb contamination measurements (scanning). For the Brennulis project, dose rate measurements were performed at the same time as radioactive contamination measurements.

Drawbacks

- Not appropriate for detection of alpha or low energy beta emitters
- Insufficient accuracy to meet usual release requirements. Therefore, if dose rate measurement is the only technique used for initial characterisation, there is an important risk of overlooking contamination and hence not meeting release criteria after decontamination.
- Gross radiation readings alone will not indicate the nature and quantity of each of the major isotopes unless a detailed analysis is performed in order to derive isotopic concentrations comparable with total radiation readings.

(b) Loose contamination measurements

Among the different techniques for concrete surface contamination measurement, loose contamination has to be distinguished by the other techniques.

Loose contamination is measured by taking a small piece of material such as a filter paper and rubbing it over a specified area of the component surface (usually, 100–300 cm²). This action transfers an assumed fraction of the activity to the paper, which can be measured by counting equipment. Additionally, mechanical, chemical or electrochemical techniques can be used for contamination removal and measurement.

Advantages

- Technique usually used to define the operating conditions.
- When performed before and after dismantling operations, it is a good indicator to check the radiological cleanliness of the operations.
• Associated with analysis, can give information on radiological spectrum.

**Drawbacks**

• Loose contamination is not necessarily representative of the concrete contamination in depth. Indeed, loose contamination can be caused by dismantling operations or incident and not be related to the origin of the contamination inside the concrete.

(c) **Surface counting**

The other method for concrete surface contamination measurement is scanning a surface. In this case a measuring instrument is held close to the surface, but is moved systematically along the surface at a speed that is sufficiently low to allow detection of changes in the radiation field (dynamic measurement). The limiting speed is a function of the detector sensitivity, the type and intensity of the radiation and the instrument resolving time. Speeds of more than 3-5 cm/s are not recommended. Large area probes may allow a faster scan rate or yield an improved sensitivity at a comparable rate. The operator receives both visual and audible output from the instrument.

Another method (static measurement) consists of making several successive static measurements over the surface. In this case results are more accurate, and the accuracy is a function of the measurement time.

The main advantages and drawbacks of this method are summarised in [23].

**Advantages**

• Easy to implement.

• Detection limits are relatively low: generally 0.4 Bq.cm² (beta/gamma emitters), 0.04 Bq.cm² (alpha) with a counting time of only a few seconds.

• Useful to detect hot spots and to define a sampling plan.

**Drawbacks**

• Contact or very near contact measurements are necessary, raising problems in the case of relatively inaccessible surfaces such as high walls or ceilings. Scaffolding can sometimes be time-consuming and costly to set up.

• Sensitive to radioactive background; in variable background, needs many background measurements
5. Radiological survey

- For alpha emitters, surfaces need to be flat, smooth, dusted off and dry. Moreover, care needs to be taken not to overlook contamination behind paints, for example if surfaces have been repainted.
- A special problem in detecting contamination is posed by pipes and ducts. Often these are difficult to access and characterise. Drains and gutters that are either buried or are encased in concrete must often be excavated to satisfy survey requirements. Therefore, characterisation efforts require significant additional effort and cost.
- Another problem area arises directly from the ease of use of these probes. The operators are not necessarily highly qualified, and the results are not always of high quality due to: confusion between corrected and uncorrected results (which is crucial when measuring low activity levels), improper calibration, inadequate counting time, etc.

(d) Spectrometry measurements

The most detailed analysis for radionuclides can be obtained by using spectrometry.

Among spectrometry techniques, gamma spectrometry is the most commonly used for concrete in situ measurement. By using appropriate algorithms, it is possible to transform the measured spectrum to a radionuclide specific contamination (Bq/cm² or Bq/g).

The most widely used types of detectors are GeHP and NaI. More recently, CdZnTe, LaBr³ and LaCl³ were also evaluated by CEA.

The main advantages and drawbacks of this method are summarised in [23].

Advantages

- Sensitivity: for the measurement conditions and interpretation hypotheses described above the detection limits for ¹³⁷Cs and ⁶⁰Co are below 0.1 Bq·g⁻¹ with counting times of a few minutes: 3 minutes in the case of Ge detectors with 40% relative efficiency, and about 10 minutes for NaI(Tl) (3'' × 3'') or LaBr³ (2'' × 2'') detectors.
- Discrimination between natural and artificial activity, which is useful in the case of naturally radioactive materials.
- Suitability for inspecting large surfaces at acceptable measurement rates.
- Activity quantification in Bq·g⁻¹ by postulating hypotheses concerning the spatial distribution of contamination.
- Measurement at distance (ceilings for example).

Drawbacks

- Interpretation is more difficult than for simple direct readouts, and must be based on hypotheses concerning the spatial distribution of the activity. Requires skilled staff.
- The equipment is fragile and expensive.
- Until now, the detector with the highest efficiency (Ge) had to be cooled with liquid nitrogen. Instruments are now available which do not require liquid nitrogen cooling system, but it is costly. For instance, ENRESA carried out successfully a system using ultra low microphonic electrical cooling.
- Sensitive to background radiation.
- The use of a collimator (generally heavy) is a major constraint, especially for inspecting high walls. When accessibility is poor the collimator can be eliminated, but the spectrum will be interpreted as if the collimator were present: i.e. the total signal is assumed to come only from the field corresponding to the collimator detection area. The actual measurement results are thus largely overestimated. If an unacceptable level of activity is detected, the collimator may be installed to determine whether the activity is attributable to the directly observed surface area.
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5.1.4 Destructive assay

Despite the important progress achieved recently in the field of in situ measurements, physical sampling and destructive assay remains necessary at the very early stages of the decommissioning programme for these reasons:

- to list all radionuclides of significant importance for the decommissioning project;
- to establish scaling factors for hard-to-measure radionuclides (cf. §5.1.6.);
- to establish radioactive waste inventories and define adequate waste evacuation routes;
- to perform environmental impact assessment studies;
- later in the project, to discriminate isotopes migrating in the concrete and define contamination tracer(s);
- to evaluate contamination depth, when non destructive methods (see §5.1.3.) cannot be implemented or do not provide sufficient accuracy for the purpose of selecting the right decontamination technique;
- to determine chemical composition of activated structures, including trace elements with high activation cross section; and
- to assess activation calculation (distribution profiles).

Emphasis should be placed not only on measuring the most abundant radionuclides shortly after shutdown, but also on determining the presence of long lived radionuclides, which, depending on their concentration, might have a strong impact on final waste categorisation.

For cycle fuel facilities, destructive assay is generally unavoidable, due to limited performance of alpha in situ measurement.

**Advantages**

- Very high sensitivity.
- Quantification of “hard to measure” radionuclides like Pu and U isotopes, $^3$H, $^{14}$C, $^{60}$Ni, $^{89}$Sr, $^{55}$Fe.
- Allows the measurement of concrete activation or contamination in spite of a high background radiation level.
- Associated with core drilling, it provides optimal information regarding the depth of activation or contamination.

**Drawbacks**

- Time consuming method (from the sampling operation to the analysis results).
- Uncertainties due to the sampling techniques, mainly in the depth corresponding to the sample. For example, in some cases, sampling of 5mm layers is performed to assess contamination depth profile: if a scarifying technique is used, uncertainties due to this technique can be important and directly impact the depth to be removed.
- To be effective, such analysis generally requires the use of sophisticated equipment such as germanium detectors and multichannel analysers, alpha spectroscopy equipment or liquid scintillation systems.
- Requires highly skilled staff and a qualified laboratory.
- The overall accuracy of this technique, when applied under characterisation conditions, can be limited by the small size of the samples being analysed. Small sample sizes, unless supplemented by multiple samples, may not necessarily give a true indication of the radionuclide content of the entire material.
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- For a statistically significant correlation, a relatively large number of measurements and analyses of hard-to-detect radionuclides have to be made. The use of the correlation method of measurement can significantly reduce the number of samples that would otherwise have to be taken and analysed, thereby reducing the cost of the characterisation effort.

Details on the methodologies and techniques used to perform destructive assays in the different project of the Programme can be found in the table in Annex 7.

**Sampling and analytical programme methodology**

An important goal of the sampling programme is to obtain statistically significant information at a minimum cost. The programme will provide an updated database containing information on the range of compositions (spectrum), level and location of concrete contamination or activation.

The sampling and analysis plan defines the parameters of the data necessary to achieve the characterisation objectives. The plan should define the following:

- the types, numbers, sizes, locations and analyses of samples required;
- the instrumentation requirements;
- the radiation protection aspects or controls of the activity;
- the data reduction, validation and reporting requirements;
- the quality assurance (QA) requirements;
- the methodology to be employed when taking the samples and performing the analyses; and
- the requirements for disposal of waste generated during sampling.

A sampling programme may be divided into unbiased and biased sampling schemes.

Unbiased sampling schemes should be performed for areas expected to have little or no surface contamination present or where the general area could be expected to be homogeneous in the degree and characteristics of the contamination. The facility to be characterised should be divided into discrete sampling areas and survey units for measurements.

Biased sampling concentrates on finding or defining contamination or activation that is known to exist or is thought likely to occur. The biased sampling programme actively examines sample locations in areas where contamination or activation is likely (based on historic analysis, see §5.1.1.).

Typical survey areas are:

- floors: areas of potential spills, areas of heavy traffic (components requiring regular intervention like filters);
- walls: settling of dust, sprays or steam leaks, particularities like draining gutter, sump;
- other horizontal surfaces (railings, ledges, etc.) where dust has preferentially settled;
- Ceilings: duct leaks, contaminated air circulation;
- Bioshield.

As seen in §5.1.1., a limitation of historic analysis for old facilities is the limited, or absence of, recording of events. In this case, a biased Programme could result in some contamination being missed.

As shown on Table 17, feedback from the projects represented in this study suggests that biased surveys are mainly used during initial characterisation. Biased surveys are systematically based on historic and in situ measurements (or activation calculations).
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5.1.5 Review and evaluation of the data obtained

During the characterisation process, licensees should assess and analyse the data as early as possible to develop a sufficient characterisation of the facility and to determine whether or not the data requirements are being met. It is expected that characterisation plans may change during the conduct of the characterisation as a result of these ongoing assessments. Reviews should continue during sampling and analyses to allow for early detection of errors or anomalies so that corrections or alterations can be made without affecting the whole programme – facility characterisation is an iterative process.

It is often difficult to carry out a complete characterisation at the beginning of a project. Indeed, rooms are sometimes narrow, often full of equipment or waste. Moreover, radioactive background levels can be too high relative to the detection limits required for release measurements.

In some cases, full characterisation of the entire facility is not necessary. Instead, a pragmatic approach for decommissioning projects may be followed. Rather than extensively characterising the entire project, enough data is collected to enable dismantling work to begin. Detailed procedures are developed as the work progresses, and additional information is collected as necessary. This process avoids efforts that may be rendered useless by newly discovered problems, but requires flexibility in scheduling and completing activities.

A large quantity of data associated with a large number of documents (end-state report, characterisation report, procedure, photos) may be generated during characterisation activities. Data obtained from characterisation process may be recorded by marking the measured value at the appropriate location on a map or survey form. Data may subsequently be recorded in a computer database. Data identifying the instrument, its calibration, the operating conditions (background radiation level and detector integration time), orientation and the date of measurement are generally included, along with signature blocks for persons carrying out and approving the measurement.

It is recommended that a report be prepared which summarises the characterisation process and the data collected. The information contained in the report will be used to guide the decommissioning planning.

Creation of a specific database is recommended. For example, such a database has been developed and is still used by BR3 project [24]. The database gathers data per room, regarding historical and physical inventory, ambient dose rate, measurement, sampling location, surface category, and contamination or activation depth. It allows editing characterisation reports useful to choose decontamination strategy and tools. Furthermore, the database can be used to produce a clearance request for a room or a group of rooms.

5.1.6 Optimisation of radiological survey

Statistical techniques

In order to reduce characterisation costs, one can use statistical techniques that allow inferences to be made about an entire area or an individual component from the results of a limited number of samples [19]. In all cases, it is most efficient to restrict data gathering to the minimum necessary. For example, one can choose a less powerful statistical test or even single measurements for some initial characterisation when this information is adequate for the purpose. However, in many facilities, the statistical approach is often limited by access problems due to high dose rates or space access constraints.

The characterisation objective itself defines the type of measurement or sampling needed and, in turn, the analyses desired and the sensitivity required. The level of confidence required in the results defines the number of samples or measurements required and their desired locations.

Correlation method for measurement of hard-to-detect radionuclides

Within the wide spectrum of radionuclides representing the radioactive inventory of a nuclear facility, there are several radionuclides whose common characteristic is that they emit low energy radiation which is difficult or impossible to measure in the presence of other, more energetic emitters. A method that enables a realistic estimate of a particular low energy radionuclide in a mixture of various radioactive substances is the correlation or scaling factor approach. It should be noted that
the scale factors are both facility and position dependent and due caution must be exercised in their application.

To use this method it is necessary to determine the relative fractions of the radionuclides in a mixture by sampling and analysis in the laboratory. With these relationships established, it is possible for example to use direct measurements of the strong $\gamma$ emitters in the mixture to infer the inventories of the hard-to-detect radionuclides. These scaling factors need to be recalculated to account for decay times if delay times between the laboratory analysis and the direct measurements are significant.

Radionuclide pairings for possible use in correlations can be categorised in three classes: activated corrosion/erosion products (with typically $^{60}$Co, $^{152}$Eu and $^\alpha$H), fission products (with typically $^{137}$Cs) and actinides (with typically $^{241}$Am and $^{239}$Pu isotopes).

For defining concrete contamination depth, the knowledge of radionuclide diffusivity capacity is important to choose relevant tracers for scaling factors use. R&D on radionuclide diffusivity capacity in concrete, together with feedback from the projects represented in this study, leads to the following general conclusions:

- $^\alpha$H has a very particular diffusivity behaviour and cannot be used as tracer of the other radionuclides;
- Apart from $^\alpha$H, $^{137}$Cs is the radionuclide that has the best diffusivity in concrete among the other most common radionuclides (including alpha emitters). Therefore when it is present in the radiological spectrum, it is expected to be a good tracer to determine contamination depth. This was observed in many projects; and
- Diffusivity capacity can be very different regarding the chemical form of the source of contamination. For example, in the case of acid solutions, migration is made much more prevalent.

5.1.7 Ongoing R&D and future needs

Sampling or non destructive examination of both contaminated and activated surfaces or bulk material uses established technology in most applications although new techniques are nevertheless emerging for specific applications. Following is a summary of such techniques.

Non-destructive assay of the contamination depth in concrete structures

In the decommissioning field there is an ongoing desire to utilise non destructive methods, providing immediate results, to determine the contamination depths in concrete. Unfortunately, experience suggests that no correlation between surface contamination (fixed or non fixed) and in depth contamination can be made from direct radiation level measurements. Therefore, more advanced non destructive assay techniques are under development.

Two such techniques are of particular interest. The first one was developed by SCK•CEN in BR3. It combines gamma spectrometry with existing modelling software according to absorption laws [25]. It has been tested with $^{133}$Ba (activation) and $^{137}$Cs, which are multi-energy X-ray/gamma-ray emitting radionuclides. Differences in absorption for photons of different energy emitted by a single radionuclide are used in an iterative modelling process to assess in depth distribution (activities of two energy lines should be equal). This method is providing very promising results (for $^{137}$Cs uncertainty at depth is lower than 70%) but needs extensive validation in order to extend the scope of application to various concrete compositions.

The second method is being developed by the CEA Techniques and Methods Laboratory at Marcoule, in collaboration with the Kurchatov Institute of Moscow, and with the support of the R&D Department of EDF [26]. In this case, some specific software developments allow the spectrum analysis to be performed online and are capable of determining the contamination depth comprising 80% of the total observed area activity. The method is currently being developed and qualified for $^{137}$Cs and $^{60}$Co.

It is important to underline that these non destructive assay methods will not be able to completely replace traditional destructive methods. A risk-cost-benefit optimised combination of both methods should enable reduction of the characterisation costs.
Geostatistics

The goal of statistical tools in the characterisation process is to set up a sampling strategy that guarantees at least the detection of a given percentage of hot spots, for instance 95%. Classical statistics allow the computation of confidence intervals and the determination of the number of samples that should be collected to reach this goal.

However, these techniques assume that the contamination is randomly distributed within the premises. This may be the case after the decontamination process, but commonly is not the case before or during the initial contamination characterisation step. Actually, the initial activity usually presents a spatial continuity within the premises, with preferential contamination of specific areas or the existence of activity gradients. Taking into account this spatial continuity it is essential to avoid bias while setting up the sampling plan.

In such a case, geostatistics extend the statistical framework by providing methods that integrate the spatial structure of the contamination. Once the spatial structure is characterised, most probable estimates of the surface activity at unsampled locations can be derived using “kriging”-like techniques. Variants of these techniques can be used to estimate the uncertainty associated with the spatial prediction, or to calculate the probability of exceeding a given decontamination threshold. Geostatistics is already widely applied for contaminated soils characterisation.

The ability of geostatistics to provide alternative sampling strategies to the systematic control has been evaluated on several premises located in former nuclear installations of the CEA in France [39]. Work undertaken by CEA demonstrates that geostatistics provide interesting and useful results such as uncertainty and probability maps with non-exhaustive data sets. The risk of exceeding a given threshold can be calculated so as to guide new investigations in the area. Moreover, it demonstrates the advantages of regular sampling strategies rather than random, coupled with short distance investigation such as sampling crosses. The next step in this research will be the integration of destructive samples in relation to the in-situ measurements in order to assess the contamination depth for the decontamination step. Contaminated volumes and their location in the premises will possibly be calculated using conditional simulation based on the contamination spatial structure. The final aim of the ongoing research work will be to integrate these geostatistical methodologies with software to aid sampling optimisation of contaminated premises and soils during decommissioning and dismantling of nuclear installations. Ultimately, the main objective remains the minimisation of waste production and the control of the decontamination costs.

Software for low-resolution detectors

Some detectors (scintillators) using more recent technology have been evaluated by CEA (LaBr3, LaCl3) and have been found advantageous for low-level measurements and VLLW characterisation despite their intrinsic radioactivity. Better known and inexpensive NaI detectors are suitable for low signal levels by virtue of their high sensitivity but are capable of only very limited resolution. These types of detectors are presented in Figures 35 and 36.

Figure 37: CdZnTe detector  
Figure 38: LaBr3 detector
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Low-resolution detectors all share the same problem when processing low signal levels or seriously perturbed measurements in that it is difficult to determine the peak area reliably and reproducibly. In this context a software solution, (“SIGALE”), is now being qualified in collaboration with CEA/DETECS after two years of development work. SIGALE is designed for automatic processing of “degraded” spectra, i.e. spectra that are seriously perturbed (strong Compton front) or obtained from low-resolution detectors. Under certain conditions, manual processing is a significant factor in the quantification uncertainty for isotopes in the spectrum. SIGALE is designed to mitigate this problem through software that is easy to use in the field. An automatic peak detection algorithm and automated surface processing routines are implemented in the Programme. This software is particularly useful for dealing with spectra obtained using CdZnTe probes, which characteristically generate spectra with skewed peaks despite their satisfactory resolution.

5.1.8 Use of decommissioning projects feedback and data

Experience suggests that some results/reports are quite similar from one project to another. Therefore they can be transposed to a new project, but one must carefully compare sensitive assumptions and parameters which can cause results to vary significantly. Some examples are given below.

Transposition of activation calculation

Activation of the pool concrete at Mélusine was first evaluated from the existing Triton’s activation calculation. Indeed, both pool conception and operation history of the two reactors were very similar.

A simplified study was performed, consisting of:

- identifying the differences between the two reactors;
- translating these differences in order to adjust the neutron flux; and
- performing activation calculation with the new neutron flux.

Then calculation results were compared to samples.

The conclusion was that the pool concrete was activated from the ground to 3 m high, and for the whole depth. The part of the floor below the reactor was also activated to 25 cm in depth. Calculation and sampling fit quite well, with a global overestimation of calculation from 20% to 50%, corresponding to only a few centimetres of concrete. Subsequently, a second calculation was performed, but this time a detailed one, specific to Mélusine, and taking into account the rebar.

For concrete, the results are quite similar to the previous study, though activity levels in rebar are higher than in concrete (tritium excluded). Hence, the part of the pool that is activated is more extensive than previously assessed. The walls are activated to a height of 3.8 m and the floor below the reactor to a depth of 65 cm.

In conclusion the first study provided sufficient detail of the extent of concrete activation to determine the basic strategy (necessity to remove the whole lower part of the pool, and a part of the floor). Nevertheless, the second calculation was essential to determine precisely the boundaries for removal, taking into account the rebar activation.

Contamination Depth Migration - Experience from Projects represented in the Study

Apart from activation, the only phenomenon that can lead to concrete contamination at depth is the contact between concrete and liquid contamination. Liquid contamination migration in concrete is not readily predictable by modelling, although depth contamination may be assessed as a result of experience and feedback from similar projects. To make predictions based on previous experience one must consider:

- the radiological spectrum. The diffusivity of different radionuclides in concrete are variable;
- the chemical form of liquid contamination, e.g. acidic liquids highly favour contamination migration in concrete;
- the contact time between concrete and liquid contamination: time-limited contamination (for instance a leak immediately followed by concrete decontamination) or stagnant liquid (in a pit for instance); and
the concrete coating quality (cracks, water tightness...).

Generally, it is observed that the depth of contamination for time-limited liquid contamination is limited to the first millimetres (one or two centimetres). On the other hand the depth of contamination in case of stagnant liquid contamination can reach several centimetres or even dozen of centimetres in the case of corrosive liquids.

As a first approach, feedback and the facility history should allow one to make a preliminary assessment of depth of contamination in concrete. Nevertheless radiological measurements are essential to check the reproducibility of external feedback on a given facility. Preliminary assessments, using feedback from similar projects can be used to optimise the physical sampling plan.

5.1.9 Conclusions

Experienced gained on projects participating in the CPD suggests that, generally, the initial radiological assessment is divided into two steps. First, a systematic (exhaustive) assessment of the surface activity is performed using in situ measurements methods such as surface counting and/or in situ gamma spectrometry. Location of in situ measurement is mostly determined according to the historical and building structure analyses (singularities...). In most cases, it leads to measure preferentially the total floor area and the walls up 2 or 3 m high (easily accessible surfaces and thus subjected to greater risks of contamination). Secondly, in order to assess the contamination depth, concrete samples taken at several locations within the premises are collected and analysed.

Initial characterisation therefore aims at answering several issues:

- identifying surface hot spots, e.g. areas that present a surface activity greater than a target level;
- quantifying the average residual contamination level or the residual amount of radionuclide present in the premises; and
- Providing a reliable estimate of activity levels and contamination or activation distribution in three dimensions.

The set up of an appropriate sampling strategy is of crucial importance for the project cost.

5.2 Final radiological survey

Techniques used for final survey are generally the same as for initial radiological inventory (see §5.1.3. and §5.1.4.)

The OECD report “Radioactivity Measurements at Regulatory Release Levels” (OECD 2006 – NEA N°6186) describes in details the available and adequate methods for measuring radioactivity on materials to be released from regulatory control.

5.2.1 Different techniques used by CPD Projects

Table 18 summarises methodologies and techniques used (or planned to be used) by selected projects within the CPD programme.
### Table 18: Final surveys for specific projects

<table>
<thead>
<tr>
<th>Project (Country)</th>
<th>Release criteria</th>
<th>Measurement plan</th>
<th>Non destructive measurement</th>
<th>Destructive assay</th>
<th>Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mélanine (France)</td>
<td>(1 \text{ Bq/l for the total activity (except H-3 and C-14), derived in:}) (0.4 \text{ Bq/cm² for surface counting}), (0.4 \text{ Bq/l for gamma spectrometry}), (100 \text{ Bq/l for H-3 (only for activated concrete)})</td>
<td>No</td>
<td>For surface counting (on category 0 and 1 surfaces) Standard ISO TR 8550</td>
<td>No</td>
<td>(beta) Static for categories 0 and 1 Dynamic for categories 2 and 3 Yes For categories 2 and 3</td>
</tr>
<tr>
<td>ATUE (France)</td>
<td>(0.4 \text{ to } 0.8 \text{ Bq/cm² for surface counting}), (0.4 \text{ to } 0.6 \text{ Bq/l in total Uranium})</td>
<td>No</td>
<td>For surface counting (category 0 only) Standard ISO TR 8550</td>
<td>No</td>
<td>(alpha) Static, for categories 0, 1 and 2 Yes For category 3 100% of the surface</td>
</tr>
<tr>
<td>Brennitis (France)</td>
<td>(0.4 \text{ Bq/l for the total activity, derived in:}) (0.4 \text{ Bq/cm² for surface counting}), (0.1 \text{ Bq/l in 137Cs and 0.1 Bq/l in 60Co for gamma spectrometry}), (800 \text{ Bq for a localised contamination})</td>
<td>No</td>
<td>For surface counting (on category 0 and 1 surfaces) Standard ISO TR 8550</td>
<td>No</td>
<td>Yes (beta) Static for categories 0 and 1 Dynamic for categories 2 and 3 Yes For categories 2 and 3 100% of the surface</td>
</tr>
<tr>
<td>Eurochemic (Belgium) (main process building)</td>
<td>surface contamination in alpha (\leq 0.04 \text{ Bq/cm²}), surface contamination in beta-gamma (\leq 0.4 \text{ Bq/cm²}), Total specific beta-gamma activity (\leq 1 \text{ Bq/l, mean value over an arbitrary mass of 1 000 kg with an individual maximum of 10 Bq/l})</td>
<td>No</td>
<td>For milled concrete sampling (concrete from cells) according to DIN51701, EN932-1 and NBN B11-002 For in situ sampling (other rooms), based on a formula: amount of samples (\text{n} = 0.2 \times \sqrt{\text{surface m²}})</td>
<td>Yes</td>
<td>Yes (alpha and beta) 100% of the surface</td>
</tr>
<tr>
<td>BR3 (Belgium)</td>
<td>surface contamination: (\leq 0.04 \text{ Bq/cm²}), Total (\leq 0.4 \text{ Bq/cm²}) ISOCS: Cs-137 &lt; 1 Bq/cm² (RP-113, demolition after clearance)</td>
<td>Yes</td>
<td>Biased statistic sampling plan</td>
<td>No</td>
<td>Yes (beta) For categories 1, 2 and 3 25 to 100%</td>
</tr>
</tbody>
</table>
### Table 18: Final surveys for specific projects (cont’d)

<table>
<thead>
<tr>
<th>Project (Country)</th>
<th>Release criteria</th>
<th>Measurement plan</th>
<th>Non destructive measurement</th>
<th>Destructive assay</th>
<th>Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIMIC (Spain)</td>
<td>Depending – case by case Isotopic-Previous measurements-Scenario Following MARSSIM Methodology</td>
<td>Yes (MARSSIM)</td>
<td>Yes (MARSSIM)</td>
<td>&lt; 0.5 μSv/h In Area</td>
<td>Yes</td>
</tr>
<tr>
<td>Vandellos (Spain)</td>
<td>Depending – case by case Isotopic-Previous measurements-Scenario Following MARSSIM Methodology</td>
<td>Yes (MARSSIM)</td>
<td>Yes (MARSSIM)</td>
<td>&lt; 0.5 μSv/h In Area</td>
<td>Yes</td>
</tr>
<tr>
<td>KKR (Germany)</td>
<td>In preparation</td>
<td>Yes Both, but mainly in situ measurement</td>
<td>Yes (Post-investigation)</td>
<td>Yes (beta)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Decontamination and dismantling of radioactive concrete structures - OECD/NEA 2011
5.2.2 Optimisation of final radiological survey

The different decommissioning projects feedbacks illustrate that different methods may be used to limit the number of measurements. Some examples of application are given below.

MARSSIM method

The final surveys being undertaken on the Vandellos and PIMIC projects are based on the "MARSSIM" method. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [27] provides information on planning, conducting, evaluating, and documenting building surface and surface soil Final Status radiological Surveys (FSS) for demonstrating compliance with dose or risk-based regulations or standards, while at the same time encouraging an effective use of resources. The MARSSIM is a multi-agency consensus document that was developed collaboratively by four Federal United States agencies having authority and control over radioactive materials.

The Nuclear Regulatory Commission's criterion for unrestricted release can be summarised as follows: "The concentrations (typically in soil or in building surfaces) that result in 250 μSv yearly uptake by an average member of the critical population are referred to as Derived Concentration Guideline Levels (DCGLs)". Different criteria are applied in other major nuclear countries, on the basis that these criteria need to be established taking account of national and local circumstances.

Figure 39, extracted from the paper [28], is a simplified version of the Figure in the MARSSIM roadmap section entitled: The Data Life Cycle applied to the FSS (MARSSIM Figure 1, page: Roadmap-3). This Figure describes the MARSSIM framework. It includes:

- Planning, conducting, assessing, and deciding phases;
- A graded-approach to survey requirements in terms of area classification;
- The treatment of uniform contamination and small areas of elevated activity (hot-spots) separately and then integrating the two categories in the plan, though conducting the assessments separately;
- Utilisation of the Data Quality Objectives (DQO) process [29] to plan the FSS and then using the Data Quality Assessment (DQA) process to validate plan; and
- Allowing the process to be iterative at every step.

![Figure 39: MARSSIM process flow diagram](image)

A more detailed description of the different phases is given in Annex 3.
5. Radiological survey

Statistical tools

Generally, regulatory bodies allow applying statistical methods to determine the number of measurements to be carried out for final survey. For example, the French regulatory body [30] advocated the standard ISO TR 8550 [31]. It was applied for Mélusine and Brennilis projects final surveys. The norm ISO TR 8550 [31] defines the sample (n) to check in a discrete population of units (N) to guarantee that, if all the controls are in accordance, the probability so that the number of units in distance is superior to (x), is of (y).

N, n, x and y are linked according to the formula:

\[ n = \left( N - \frac{x}{y}\right)(1 - y^{x-1}) \]

The use of the norm supposes the uniqueness of the origin of the remaining possible activity for every lot to be checked. This norm was applied for Mélusine’s final survey on certain surface categories (only surface counting) with the following assumptions:

- n: is the number of measurement to carry out for one category of surface;
- N: is the total number it would be necessary to carry out for the whole surface measurement;
- x: is the maximal number of distances tolerated among the N measurement (x was taken equal to 1% N); and
- y: is the probability of the tolerated error. It was taken equal to 10^{-6}.

The application of the standard ISO TR 8550 shows that for the control of a surface superior to 500 m², the number of measure to be realised aims towards 450, such as presented on Figure 40.

**Figure 40: Number of control measurements as a function of the surface area**

It should be noted that the number of measurements has little dependence on the surface of the control device, as illustrated in table 19.

**Table 19: Number of measurement points as a function of the control device surface area**

<table>
<thead>
<tr>
<th>Surface of control of the device (cm²)</th>
<th>50</th>
<th>170</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of measurements required for an infinite surface</td>
<td>457</td>
<td>453</td>
<td>430</td>
</tr>
</tbody>
</table>

As mentioned in [32] a CEA task group is working on other statistical analysis methods adapted to release surveys, such as the "Wilks" formula and the resampling method "Bootstrap".
5. Radiological survey

Regarding “Wilks” formula, the results of a study [33] show that the Wilks formula produces comparable and additional results in the formula of the standard ISO TR 8550 [31], in particular for proportions of non-compliances superior to 10⁻⁶.

**Statistical sampling of crushed concrete**

Eurochemic is a good illustration of the various types of measures that can be combined on crushed concrete during the final radiological survey to demonstrate that the requirements of the criteria are met.

**Introduction: Final survey of two storage buildings (pilot project)**

Belgoprocess started its decommissioning activities with the dismantling and decontamination of two small storage buildings for end products from reprocessing. After decontamination, two independent measurements of all building surfaces were carried out in order to confirm that release criteria were reached (0.04 Bq/cm² for alpha and of 0.4 Bq/cm² for beta-gamma emitters). A third random control measurement was performed by an officially approved radiation protection control organisation. All three measurements gave the same results. Core samples were taken on the previously most contaminated spots. The specific activities of these samples proved to be well below 1 Bq/g. The final steps in the pilot decommissioning project were the demolition of the two buildings, the removal of the demolition waste to an industrial dumping ground for inert waste and restoration of green field conditions.

The results of the multiple 100% surface measurements in the two buildings and the additional controls on selective core samples (gamma spectrometry and total alpha and beta measurements) showed that the requirements of the first two criteria were met, as was the third criterion, in the case of the core samples taken. Finally, concrete core samples were taken at the previously most contaminated spots to demonstrate the lack of any remaining alpha contamination, as characterised by sufficiently low specific activities.

**Final survey of the main process building**

The final demolition of the main process building requires a specific clearance methodology. It has been evaluated that application of the methodology applied for the pilot project is complicated for several reasons, the most important being:

- The type and spread of contamination: at the end of the reprocessing activities, all cells were cleaned using the high-pressure water jet technique, which caused in-depth penetration of contamination;
- The total surface is large, which will require extensive manpower if all surfaces have to be monitored twice in view of unconditional release; and
- Taking core samples at the previously most contaminated places would result in a large number of samples being taken and requiring to be analysed, and it would be very difficult or impossible to prove that these samples are representative for the remaining structures of the building.

Although the application of the methodology used for the two small buildings in the pilot project is not rejected as such, an alternative has been thoroughly studied. It considers at least one complete measurement of all concrete structures and the removal of all detected residual radioactivity.

This monitoring sequence is followed by an in situ statistic sampling procedure for the corridors and the complete fifth and sixth floor at locations based on historical information. Indeed it was proven that in the past there was very little or no contamination present. The sampling procedure was based on the formula: amount of samples \( n = 0.2 \times \text{sqrt}(A) \), with \( A \) the surface to be measured in m². When no residual contamination is measured, this concrete rubble (including rebar) is unconditionally free released.

The same principles could not be applied for the cells. In order to free release concrete from the cells, a “concrete crushing, milling and sampling facility” was developed in order to crush, mill, sample and monitor concrete dust similar to the procedure that is adopted for the melting of metal material. Discussions were organised with the independent radiation protection control organisation in order to
install crushing and milling equipment so that the resulting concrete material could be free released and reused in the conventional industry.

As a first step, rebar is separated from the concrete by means of an electrically powered jaw crusher. The jaw crusher also breaks the concrete into pieces that may not exceed 40 x 20 x 20 cm which are loaded into metal containers. The containers are subsequently moved to a bunker where they are emptied by means of a tilting device. The bunker is equipped with a vibration mechanism that ensures a gradual flow of the debris to the crusher. After crushing, remaining pieces of rebar are removed by a magnetic device. A remote controlled hammering device can be activated in case of obstructions inside the container.

Representative sampling of the crushed concrete is based on prevailing standards (DIN51701 [34], EN932-1 [35] and NBN B11-002 [36]) from the mineral processing industry. A specific sampling unit was developed comprising a crusher to bring the granulate dimensions to the requested level for measurement, and a sample divider to split the total sample into a reduced sample and a reference sample. Approximately 2% per processed batch of 12 Mg or 120 partial samples of 2 kg, is sent to the laboratory for further analysis.

Automated measurement of slightly contaminated debris

During the concrete decontamination activities (prior to demolition) in the main Eurochem process building large amounts of concrete debris are produced. The small concrete pieces mainly appear during the demolition of some walls or floors and during the removal of the pipe penetrations.
between cells. In total, about 1 258 Mg slightly contaminated debris are expected during the total decommissioning project.

**Figure 45: Removal of pipe penetrations in the main Eurochemic process building**

These concrete parts, suspected to be contaminated with alpha and/or beta emitters, are very difficult to measure with conventional hand held monitors. With the aim to reduce costs a new measuring process with NaI-detectors has been tested. Further automation is foreseen with a:

- drum handling system (with dosing unit);
- concrete crusher (diameter of the concrete parts up to max. 5 mm) with sieve;
- magnetic metal separator;
- measuring unit “Concretespec” (6 NaI detectors) with separation unit “Concretecargo”;
- sampling unit (identical to concrete crushing and sampling installation above described);
- ventilation and cleaning system; and
- conveyor belt for internal transportation of the material.

The start-up of the complete automated installation is expected in 2010.

**Figure 46: Installation for automated measurement of debris**
5.2.3 Conclusions

The different studies and techniques carried out by specific projects to establish the initial inventory and for final surveys are summarised in Annex 8.

Radiological characterisation is an essential early step in the development of a decommissioning plan for a nuclear reactor and should be well planned; otherwise significant extra costs and doses, and project delays may be incurred.

The objectives of the characterisation need to be clearly defined in order to ensure an adequate characterisation without performing unnecessary work.

Characterisation is an essential step to classify wastes according to type so that transport and disposal criteria can be met. Waste classification will then allow preliminary estimates of the costs of waste management.

The characterisation process is iterative in nature and should be reassessed as more data become available.

Characterisation should be performed on a cost-benefit basis, taking into account the need to reduce doses following the ALARA principle. This process can take advantage of knowledge of items such as documented history of the reactor and material composition.

Characterisation should not rely on the use of a single assessment method but requires the joint use of theoretical calculations, in situ measurements, sampling and analyses. Only by using a range of approaches can validation and consistency of results be ensured.

Contrary to characterisation phase, the objective of the final survey is not to estimate exactly the radioactivity level but to check that the radioactivity is lower than the release criterion. Therefore, statistical tools are relevant and even advocated by regulatory authorities.

Methods, techniques and equipment for performing both characterisation and final survey are available. Normal radiological survey techniques can be used to take measurements during the characterisation process. However, special sampling and analytical techniques (e.g. radiochemical analysis) may be required in some circumstances. Such techniques are expensive, time consuming and require very specialised skills and equipment.

It is important in all cases that all relevant radiological measurement is in a well documented form consistent with quality assurance requirements. This need requires operators to store and maintain historical information and to document new information obtained during characterisation.
6. CONCRETE MATERIAL MANAGEMENT

6.1 Introduction

A large proportion of the building materials (concrete, bricks) arising from the decommissioning of nuclear facilities are inactive, which means that they are available for unconditional release. Inactive solid materials can be disposed of in accordance with applicable regulations and using conventional methods. If appropriate segregation and decontamination processes are available, the volume of radioactive materials requiring treatment (and disposal) can be reduced significantly.

The objectives of waste management on a decommissioning project are to limit the generation and spread of radioactive contamination and to reduce the volume of wastes for storage and disposal, thereby limiting any consequential environmental impact, as well as the total costs associated with contaminated material management. The main elements of a waste management strategy can be grouped into four areas: source reduction, prevention of contamination spread, recycle and reuse, and waste management optimisation.

Four fundamental principles should be considered when planning and implementing a waste management programme. These fundamental principles can be summarised as follows:

- keep the generation of radioactive waste to the minimum possible or practicable;
- minimise the spread of radioactivity leading to the creation of radioactive waste as much as possible by containing it to the greatest extent possible;
- optimise possibilities for recycling and reuse of valuable components from existing and potential waste streams; and
- minimise the amount of radioactive waste that has been created by applying adequate treatment technology.

Practical implementation of these fundamental principles can be achieved using administrative or organisational arrangements and technical approaches. It must be re-emphasised that the first step of any waste management strategy is to keep the generation of radioactive wastes to a minimum. Application of adequate waste management technologies should be considered as a final step, when the creation of radioactive wastes is unavoidable.

Proper characterisation and segregation of materials arising during decommissioning operations are very important factors in any waste management strategy. Characterisation helps develop a complete understanding of the physical, chemical and radiological characteristics of these materials in order to enable them to be segregated and to be sent for selected processing and/or disposal. Segregation favours the maximisation of unconditional release, allows consideration of conditional release, reuse or recycling of materials, and permits reduction in the volume of radioactive wastes that do not meet clearance, recycling or reuse criteria.

6.2 Free released material

The general concept of clearance from regulatory control implies a complete removal of control to the extent that cleared material is treated as if it were not radioactive. Unconditional clearance of materials requires that all possible public exposure pathways be examined and taken into account in the derivation of the clearance levels irrespective of its eventual use or destination. As an example, in Belgium valuable components such as concrete containers (without metal lining) may be cleared for unrestricted reuse in the conventional industry. Cleared wastes can be disposed of to landfills that are
6. Concrete material management

not subject to radiological restrictions (e.g., municipal waste dumps). Some materials, such as concrete, may be used as a filling material for roads. The underground structures of nuclear facilities might be buried rather than dismantled.

6.3 Reuse of radioactive rubble

Alternatively, criteria less restrictive than those required for unconditional clearance might be applied to a limited amount of material provided that either this is reused in the nuclear industry or its final destination is known and the resulting public exposure complies with the general limit defined by the regulator. This type of situation is called conditional or restricted clearance.

Various studies have shown that the separated (non active) gravel particles can be reused as aggregate for concrete and that the mechanical properties of this concrete shows no deviations from normal concrete. The objectives of these research projects were to determine the optimal recycling conditions.

Potential applications for reusing the material in the nuclear industry include:

- preparation of the filler, backfill or encapsulation material for waste drums and containers in near-surface storage sites;
- fabrication of concrete for certain radiological protection shields;
- fabrication of waste storage containers; and
- the construction of new facilities under certain conditions.

Other studies showed that significant quantities of slightly contaminated concrete could be reused entirely for active immobilisation of solid, low radioactive waste. Some examples are given below.

Reuse of dust from shaving activities (Belgoprocess)

In 1998, a study was performed to evaluate the possible reuse of active dust from concrete decontamination activities. Due to the presence of paint in a large amount of produced dust, the study was ended in a preliminary stage. Paint proved to have a negative influence on the obtained results (mainly the compression strength).

Separation

Assays have shown that contamination primarily penetrates into cement through the fine aggregate component (cement, sand filler) which is relatively porous, while the coarse aggregates are practically unaffected because of their mineral composition and high density. The fine aggregates represent about 30 wt% of the concrete mass. Separation of the porous and dense components of concrete will therefore result in substantial volume reduction of radioactive waste. This is beneficial for economical and environmental reasons. Depending on the concrete composition, volume reduction of 60% to 70% can be reached of material that has to be treated and stored as radioactive waste. It is feasible to separate concrete into contaminated and clean parts by means of a process based on heating, milling and sieving over 1mm [37].

Reuse of activated, heavy concrete (Belgoprocess)

At the SCK•CEN, 510 tons slightly activated heavy concrete will be produced from the biological shield of the BR3 reactor. In cooperation with the SCK•CEN research centre, Belgoprocess investigated the restricted reuse of this concrete in a matrix for active immobilisation of solid, low radioactive waste. The study showed that a large fraction of the heavy concrete can be reused as sand to produce an active mortar for immobilisation of solid, low radioactive waste [38].

6.4 Disposal

Solid wastes arising from decommissioning operations consist principally of contaminated and activated structural materials including concrete, reinforcement and structural steels. The principal objectives of the treatment and conditioning of solid wastes are:
to minimise the waste volumes in order to minimise the mobility of the contained radioactive materials and the radiation doses associated with waste handling and processing;

- to segregate the waste into groups according to the types of radioactive contaminants present in order to facilitate emplacement in the appropriate disposal facility;

- to process and package the wastes in containers suitable for transport from the site to be disposed of in the appropriate disposal facility; and

- to accomplish these actions in an economical manner.

Solid low and intermediate level wastes are generally segregated into combustible, compactable and non-compactable wastes. In Belgium (Belgoprocess) solid low and intermediate level rubble is compacted as the first step. Numerous high force compactors are commercially available for compressing compactable wastes within steel drums. Subsequently compacted disks (e.g. from waste in 200 litre drums) are immobilised with cement in 400 litre drums.

The methods for storage and disposal of radioactive wastes are governed by the applicable national (and international) regulations, by the availability of appropriate storage and disposal facilities, and by the need to achieve an optimum cost-benefit ratio for accomplishing the disposal. The type and specific activity of the radioactive material present in the waste are the two most important factors in selecting the storage and disposal method. Other important factors are the size of the package and the difficulty in handling the package during disposal.

The principal methods for disposal are near surface disposal, emplacement in rock cavities or repositories in deep geological formations. Near surface disposal is generally employed for low and intermediate level radioactive wastes. Rock cavities may potentially be used for all kinds of solid low and intermediate level waste. Disposal in deep geological formations is envisaged for high level wastes with significant quantities of long lived radionuclides.

In Belgium category A wastes (category of which the radionuclides present specific activities low enough and half-lives short enough to be compatible with surface disposal) are immobilised into 400 litre drums. Subsequently, four 400 litre drums are immobilised in a concrete container, a so-called ‘monolith’. Finally, each monolith is transferred to a ‘module’ that has a capacity of a few 100 monoliths.

**Figure 49: Example of surface disposal project**

Stacking of the monoliths (1) in the modules (2), the multi-layer cover (3) and the inspection gallery (4)
7. GENERAL CONCLUSIONS

- There is a growing trend towards prompt decommissioning rather allowing a period of several years of safestore/decay prior to final dismantling. Modern technology, improved work processes and emphasis on safety have negated the advantages of long term decay. Advances in dismantling techniques (including remote dismantling, recycling/re-use, increasing waste storage costs, and improved planning processes have made this approach cost effective. Prompt decommissioning also tends to be the preferred option of communities near to the installation being decommissioned.

- In many nuclear facilities, concrete makes up the bulk of the material to be dealt with resulting from dismantling. There will be a significant increase in concrete volume to be handled in the near future as a result of prompt decommissioning strategies.

- Emphasis on decontamination, release and recycling of material should continue in order to minimise the volume of nuclear waste.

- To facilitate the decommissioning process the decommissioning planning cycle should take place during the entire life cycle of the facility including concept, design, construction, operation, and decommissioning. More collaboration between designers, construction, and operators will be beneficial for future decommissioning projects.

**Plant operation**

- Better feedback of experience from decommissioning to plant operators will help avoid bad practices such as covering up contamination rather than its immediate clean-up.

- Care is needed with the systematic use of water jet technology (HPWJ) to clean-up spills on bare concrete or where protective coating/paint is damaged - this can increase contamination ingress in the material.

- Improvements are needed to approaches for records management and archiving (i.e. level of detail). Unrecorded events of seemingly minor importance on the plant operation (leaks in auxiliary circuit or purification loops) can result later in significant clean-up costs.

- A proportion of the staff from plant operation should be retained for decommissioning.

**Planning**

- There is a trend toward sequential licensing rather than a global licence for a project. This avoids the need to revise the entire licence when changes are required.

- Further progress is needed towards the development of common international licensing strategies to the extent possible.

- The selected decommissioning strategy:
  - is highly dependent on the local regulatory framework (municipal laws, available evacuation routes, geography, public opinion); and
  - represents a fine balance between costs, waste optimisation, and schedule and safety aspects. For example, nuclear demolition of a (part of a) building could be preferred to conventional demolition after clean-up for schedule and/or economical reasons provided a repository exists to take the very large volume of radioactive waste produced and the disposal cost is not prohibitive.
Characterisation

- Radiological characterisation is an essential early step in the development of a decommissioning plan and should be well planned; otherwise, significant extra costs and doses, and project delays, may be incurred. A proper and thorough characterisation at the beginning of the project facilitates planning and avoids repeating, for a given area of the plant, the decontamination/survey process, which could result in significant additional delay and costs. The objectives of characterisation need to be clearly defined in order to avoid the performance of unnecessary work (classification of room surfaces according to the risk of contamination and in-depth migration of contaminants).

- Characterisation is an essential step towards classifying wastes according to available categories so that transport and disposal criteria can be met. The existence of a waste inventory facilitates preliminary estimates of the costs of waste management.

- The characterisation process is iterative in nature and should be reassessed as more data become available.

- Characterisation should be performed on a cost–benefit basis, taking into account the need to reduce doses following the ALARA principle. Use of statistical or geostatistical tools should allow the optimisation of the measurement plan while guaranteeing the reliability of the results with a given level of uncertainty.

- Characterisation should not rely on the use of a single assessment method but requires the parallel use of historical records, operations input, material composition, theoretical calculations, in situ measurements, sampling and analyses. Only by using a range of approaches can validation and consistency of results be ensured.

- Continued R&D is required to improve instrumentation, equipment and techniques. Innovative γ spectrum analysis methods may provide useful diagnosis of the in-depth distribution of contamination without requiring destructive assays that are costly and time consuming.

Decontamination and dismantling

- Decommissioning work undertaken during the past decade has provided broad feedback on concrete decontamination and dismantling techniques.

- When considering the use of scarifying techniques, a major issue is process automation. Scarifying tools are mostly extremely heavy which tends to limit the size of the tools and subsequently its intrinsic performance. Automation will be made difficult by: the self weight of the tool, surface state, presence of exposed beam/obstacles, room dimensions. For the particular case of reactors, rooms to be decontaminated have very variable dimensions and geometry. Therefore different (automated) handling devices might have to be considered in order to implement a given decontamination technique in different parts of the facility. There is a need for flexible, robust and simple systems.

- As a consequence of numerous fruitless trials of automation of scarifying techniques, manual treatment techniques are often preferred since these have been proven to be the most efficient in terms of global operation yield. It should be noted that manual scarification is particularly strenuous for operators and therefore requires working with several shifts and regular breaks.

- In recent years, alternatives to strenuous/low yield mechanical techniques (hammering, scarifying) have been thoroughly investigated (microwave, rebar heating, explosives), though few have proven to be compatible with the constraints of a dismantling project (nuclear and industrial safety, minimisation of waste volume, economics). However, recent active trials with (low energy) laser and nitrojet processes have demonstrated that both techniques are now mature enough to be implemented in the frame of a decommissioning project.

- Well known techniques, such as diamond sawing and drilling techniques, can still be improved to match the specific needs of a dismantling operation. For instance, common
efforts of diamond tools manufacturers and the decommissioning industry have led, in
several projects, to the successful demonstrations of dry sawing of reinforced concrete.

- Abrasive blasting techniques, and more particularly grit blasting, have proven to be very
  versatile techniques for both in-situ decontamination and for dismantled components (e.g.
  shielding blocks, containers...). Concrete layers of several millimetres in thickness can be
  removed at high production rates provided that an adequate abrasive is chosen and that the
  latter is continuously recycled. Possible cross-contamination of surfaces is an issue to
  consider when planning the operation.

- Because of the porosity of the concrete, wet techniques which can induce cross
  contamination should be avoided.

- In the specific case of reactors, the preferred clean-up strategy may be highly dependent on
  the volume of activated concrete.

- Specific (operator) safety issues related to concrete D&D include - dust control/ventilation of
  the work area, airborne contamination, vibration, noise, projection (debris, abrasive ...) and
  falls.

To deal with various radiological situations (contamination vector and penetration depth), different
concrete quality and shapes, size constraints, different techniques will have to be used. Moreover,
different handling devices might be required to implement a given technique in different rooms.

Procurement issues

For concrete clean-up or dismantling operations, definition of clear and measurable objectives (by
both the licensee and the contractor) is obligatory, e.g. thickness of concrete to be removed on a given
surface area and dimensions of items to be removed. Experience suggests that contracts based on a
final radiological target are not appropriate, since no room or surface can be exhaustively
characterised (for economical and planning reasons) and subsequently there remains inevitably a
degree of uncertainty as regards the spread of contamination and its in-depth distribution.

Within a single facility, one has to consider various types of concrete depending on function (load
bearing, biological shielding etc.), which functions impact the mechanical properties of the concrete
and have a significant influence on the observed performances of a given decontamination technique
as regards tool wear and on the overall yield of the operation. When detailed composition of the
concrete is not available, one should consider defining the substrate by physical parameters (hardness,
type, size and concentration of aggregates) to avoid conflict with the contractor regarding execution
delay, additional cost for equipment (higher wearing).

Verification

Contrary to the characterisation phase, the objective of the final survey is not to estimate exactly the
radioactivity level but to check that the radioactivity is lower than the release criterion. Therefore,
statistical tools are relevant and even advocated by regulatory body.

Methods, techniques and equipment for performing both characterisation and final survey are
available. Normal radiological survey techniques can be used to take measurements during the
characterisation process, though special sampling and analytical techniques (e.g. radiochemical
analysis) may still be required in some circumstances. Such techniques are expensive, time
consuming and require very specialised skills and equipment.

It is important in all cases that all relevant radiological measurements are in a well documented form
consistent with quality assurance requirements. This results in operators having to store and
maintain historical information and to document new information obtained during characterisation.
The use of computing databases is recommended to deal with the huge amount of information
generated during the clean-up process.

Waste

The main elements of a waste management strategy can be grouped into four areas: source reduction,
prevention of contamination spreading, material management, radioactive waste volume
minimisation through decontamination/declassification and implementation of adequate evacuation
routes.
In the particular case of building clean-up, the volume of primary waste packages should be commensurate with the very large volume of material which has to be dealt with, to avoid bottlenecks and/or to optimise the capacity of the on-site interim storage facility.

For materials which cannot be unconditionally cleared, alternative management routes (with respect to disposal of the radioactive waste) include recycling as radioactive conditioning mortar, recycling within the nuclear industry (shielding blocks ...) and conditional clearance.
8. REFERENCES

[1] A status/progress report is issued every five years on the CPD Programme and includes a brief description of the projects. The most recent report is entitled 'A Decade of Progress'.

[2] NEA "Decontamination techniques used in decommissioning activities"


[4] (Nuclear Decommissioning '98: p95 for concrete decontamination at JAERI, 2 kW YAG underwater test p135)


[7] ISO 5349 standard


[9] Not used


[17] Klassifikation von Abschirmbetonen nach Elementanteilen; (Classification of shielding concrete according to element proportions)


8. References

[22] “Dosiskoeffizienten bei äußerer und innerer Strahlenexposition; Beilage 160 a und b zum Bundesanzeiger vom 28. August 2001”; (Dose coefficients for outer and inner radiation exposure; Supplement 160a and b of the Federal Notification of 28th August 2001)


[27] MARSSIM (NUREG-1575)


[30] ASN – “Méthodologies d’assainissement complet acceptables” – Note SD3-DEM-02 Indice 0 – April 2006


[34] Deutsches Institut Für Normung – Testing of solid fuels – Sampling and sample preparation – DIN 51701 – 01/12/2007,


[37] European Commission EUR 16917, final report of the development of a process for separating radioactive constituents of concrete, including active pilot-scale testing, Kema Netherlands, 1996

[38] Belgoprocess 2006-04333, “Haalbaarheidsstudie voor hergebruik van licht geactiveerd bariet, afkomstig van het biologisch schil van de BR3-reactor, onder de vorm van een actieve immobilisatiematrix voor het conditioneren van vast, laag radioactief afval”.

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Annex 1

Projects within the CPD programme
## Annex 1: Projects within the CPD programme

<table>
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<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Decommissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gentilly 1, Canada</td>
<td>Heavy-water moderated/ boiling light-water-cooled prototype</td>
<td>1972-78</td>
<td>Variant of Stage 1</td>
</tr>
<tr>
<td>2. NPD, Canada</td>
<td>PHWR CANDU prototype</td>
<td>1962-87</td>
<td>Variant of Stage 1</td>
</tr>
<tr>
<td>3. Rapsodie, Cadarache, France</td>
<td>Experimental sodium-cooled fast-breeder reactor</td>
<td>1967-82</td>
<td>Stage 3</td>
</tr>
<tr>
<td>5. KKN Niederaichbach, Germany</td>
<td>Gas-cooled/ heavy-water moderated</td>
<td>1972-74</td>
<td>Stage 3</td>
</tr>
<tr>
<td>6. HDR, Karlstein, Germany</td>
<td>BWR, nuclear superheat</td>
<td>1969-71</td>
<td>Stage 3</td>
</tr>
<tr>
<td>7. JPDR Tokai, Japan</td>
<td>BWR</td>
<td>1963-76</td>
<td>Stage 3</td>
</tr>
<tr>
<td>8. Shippingport, USA</td>
<td>PWR (2 cores)</td>
<td>1957-1982</td>
<td>Stage 3</td>
</tr>
</tbody>
</table>
Reactor Projects in Progress (Dec. 2010)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Decommissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BR-3, Mol Belgium</td>
<td>PWR</td>
<td>1962-87</td>
<td>Stage 3 (Partial)</td>
</tr>
<tr>
<td>2. Whiteshell Research Lab Site Decommissioning</td>
<td>Organic Cooled, Heavy Water Moderated</td>
<td>1965-1985</td>
<td>Stage 3</td>
</tr>
<tr>
<td>3. EL4, Brennilis France</td>
<td>Gas-cooled/heavy-water-moderated</td>
<td>1966-85</td>
<td>Stage 2</td>
</tr>
<tr>
<td>4. Bugey 1 France</td>
<td>Gas graphite reactor</td>
<td>1972-94</td>
<td>Stage 3</td>
</tr>
<tr>
<td>5. Melusine France</td>
<td>Pond research reactor</td>
<td>1988-93</td>
<td>Stage 3</td>
</tr>
<tr>
<td>7. MZFR, Karlsruhe Germany</td>
<td>Heavy-water-cooled and moderated</td>
<td>1965-84</td>
<td>Stage 3</td>
</tr>
<tr>
<td>8. Greifswald Decommissioning Project, Germany</td>
<td>VVER</td>
<td>1973-90</td>
<td>Stage 3</td>
</tr>
<tr>
<td>9. AVR Germany</td>
<td>Pebble bed HTGR</td>
<td>1967-88</td>
<td>Stage 3</td>
</tr>
<tr>
<td>10. KNK, Karlsruhe Germany</td>
<td>Fast breeder reactor</td>
<td>1971-91</td>
<td>Stage 3</td>
</tr>
<tr>
<td>11. Garigliano Italy</td>
<td>BWR (Dual cycle)</td>
<td>1964-78</td>
<td>Stage 3 planned by 2020</td>
</tr>
<tr>
<td>12. Latina Italy</td>
<td>GCR (Magnox)</td>
<td>1963-86</td>
<td>Stage 3 planned by 2020</td>
</tr>
<tr>
<td>13. Fugen Japan</td>
<td>Light water cooled Heavy water moderated</td>
<td>1979-2003</td>
<td>Stage 3</td>
</tr>
<tr>
<td>14. Tokai 1 NPP Japan</td>
<td>GCR</td>
<td>1966-98</td>
<td>Stage 3</td>
</tr>
<tr>
<td>15. KRR-1 &amp; 2 Korea</td>
<td>Pool type research reactors (Triga 1 &amp; 2)</td>
<td>1962-95 1972-95</td>
<td>Stage 3</td>
</tr>
<tr>
<td>17. Bohunice V1 Slovak Republic</td>
<td>PWR: Unit 1 1976-2008 Unit 2 1978-2008</td>
<td>Stage 3</td>
<td></td>
</tr>
<tr>
<td>18. Vandellos 1 Spain</td>
<td>GCR</td>
<td>1972-89</td>
<td>Stage 2</td>
</tr>
<tr>
<td>19. JEN-1, PIMIC Spain</td>
<td>MTR Reactor</td>
<td>1958 - 1984</td>
<td>Stage 3</td>
</tr>
<tr>
<td>22. Taiwan Research Reactor Chinese Taipei Light water cooled Heavy water moderated</td>
<td>1973-88</td>
<td>Partial dismantling</td>
<td></td>
</tr>
<tr>
<td>23. WAGR, Sellafield, UK AGR</td>
<td>1962-81</td>
<td>Stage 3</td>
<td></td>
</tr>
<tr>
<td>24. Prototype Fast Reactor PFR, Dounreay, UK Sodium cooled fast breeder reactor</td>
<td>1974-94</td>
<td>Stage 1</td>
<td></td>
</tr>
</tbody>
</table>
### Completed Fuel Facility Projects (January 2010)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Decommissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tunney’s Pasture Facility, Ottawa, Canada</td>
<td>Isotope handling facility</td>
<td>1952-83</td>
<td>Stage 3</td>
</tr>
<tr>
<td>2. BNFL Co-precipitation Plant, Sellafield, UK</td>
<td>Production of mixed plutonium and UO₂ fuel</td>
<td>1969-76</td>
<td>Stage 3</td>
</tr>
<tr>
<td>3. AT-1, La Hague France</td>
<td>Pilot reprocessing plant for FBR</td>
<td>1969-1979</td>
<td>Stage 3 without demolition</td>
</tr>
<tr>
<td>4. AB SVAFO ACL Project Sweden</td>
<td>PU &amp; enriched fuel research</td>
<td>1963-97</td>
<td>Stage 3</td>
</tr>
<tr>
<td>5. West Valley, USA</td>
<td>Reprocessing LWR Fuel</td>
<td>1966-1972</td>
<td>Stage 2</td>
</tr>
</tbody>
</table>

### Fuel Facility Projects in Progress (January 2010)

<table>
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<tr>
<th>Facility</th>
<th>Type</th>
<th>Operation</th>
<th>Decommissioning</th>
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</thead>
<tbody>
<tr>
<td>1. Eurochemic Reprocessing Plant, Dessel, Belgium</td>
<td>Reprocessing of fuel</td>
<td>1966-74</td>
<td>Stage 3</td>
</tr>
<tr>
<td>2. Building 204, Bays Project Chalk River, Canada</td>
<td>Fuel storage pond</td>
<td>1947-1996</td>
<td>Stage 2</td>
</tr>
<tr>
<td>3. Radio Chemistry Laboratory, Fontenay-aux-Roses, France</td>
<td>Reprocessing R &amp; D</td>
<td>1961-95</td>
<td>Stage 3</td>
</tr>
<tr>
<td>4. ATUE France</td>
<td>Recovery of enriched uranium</td>
<td>1965-96</td>
<td>Stage 3</td>
</tr>
<tr>
<td>5. Elan IIB France</td>
<td>Manufacture of ¹³⁷Cs &amp; ⁹⁰Sr sources</td>
<td>1970-73</td>
<td>Stage 3 without demolition</td>
</tr>
<tr>
<td>6. APM, Marcoule France</td>
<td>Pilot reprocessing plant</td>
<td>1965-1997</td>
<td>Stage 3</td>
</tr>
<tr>
<td>7. UP1, Marcoule France</td>
<td>Industrial reprocessing plant</td>
<td>1958-97</td>
<td>Stage 2</td>
</tr>
<tr>
<td>9. WAK Germany</td>
<td>Prototype reprocessing plant</td>
<td>1971-90</td>
<td>Stage 3</td>
</tr>
<tr>
<td>10. SOGIN – PilotU-Th Reprocessing Plant</td>
<td>Reprocessing and re-fabrication of fuel</td>
<td>1975-1978</td>
<td>Stage 3</td>
</tr>
<tr>
<td>11. JRTF, Tokai Japan</td>
<td>Reprocessing test facility</td>
<td>1968-70</td>
<td>Stage 3</td>
</tr>
<tr>
<td>13. Uranium Conversion Facility Korea</td>
<td>Conversion of yellowcake to UO₂/UF₄</td>
<td>1982-92</td>
<td>Stage 3</td>
</tr>
<tr>
<td>14. BNFL, B204 Primary Separation Plant, Sellafield, UK</td>
<td>Reprocessing facility</td>
<td>1952-73</td>
<td>Stage 2</td>
</tr>
</tbody>
</table>
Annex 2

Calculation of vibration
White finger syndrome

“Vibration induced white finger syndrome” is a consequence of the reduction of the diameter of the small blood vessels in hands and fingers and damage to the peripheral nerves. These blood vessels also take care of heat regulation of the skin surface which is an essential function with respect to the sense of touch.

In an early stage, the symptoms of “white finger” syndrome are tingling and a loss of feeling and control in the affected fingers, which is often also provoked by the cold, creating some confusion about the exact cause. Examples of complaints that arise are being unable to wash one’s car, facing problems when working in the garden or when dressing or undressing and manipulating buttons. Workers suffering from “white finger” syndrome often find that it limits their ability to perform the functions of their job.

The results of recent studies give strong indications that early stages of “white finger” syndrome can be reversed. With continued exposure, however, a progressive disorder has to be considered. It is found, that the likelihood of recovery from the occurrence of “white finger” syndrome is influenced in a negative way by longer exposure times at higher vibration loads and by an advanced age, these symptoms may become irreversible.

Vibration load calculations

Based on the recommendations of the ISO 5349 standard the value of the 4 hour-energy-equivalent frequency-weighted acceleration should be determined for each operator, as a standard for his vibration load, by calculating:

- The effective exposure time for each tool, based on a user’s evaluation, and expressed as a percentage of the working time.
- The 4 hour-energy-equivalent frequency-weighted acceleration for each task as the exposure to vibrations during these activities, using the formula: \( a(4) = a(t) \times \sqrt[3]{t^2 / b / d / 4} \), in which:
  - \( a(4) \) = the 4 hour-energy-equivalent frequency-weighted acceleration;
  - \( a(t) \) = the frequency weighted effective acceleration of the tool;
  - \( t \) = the total exposure time for the specific tool on an annual basis;
  - \( b \) = the effective exposure time as a percentage of the intervention time;
  - \( d \) = the total available working days in a year.
- The global energy-equivalent frequency-weighted acceleration as the total exposure for each operator in a year, being the quadratic mean value of the individual 4 hour-energy-equivalent frequency-weighted accelerations for each task.

Depending on the obtained individual values for \( a(4) \), in specific projects the workers have been categorised into classes, similar to the proposal made by the Dutch Ministry of Social Services and Employment, the Directorate-General of Labour:

- Class 0: \( a(4) \leq 1.5 \, \text{m/sec}^2 \) (no indications of complaints or measures recorded, i.e. no exceeding of health limits).
- Class A: \( 1.5 \, \text{m/sec}^2 < a(4) \leq 3.0 \, \text{m/sec}^2 \) (after prolonged exposure, light forms of “white finger” syndrome can occur. A reduction of exposure would be desirable. When changing the production process, or when new equipment is envisaged, reducing vibration exposure can be taken as one of the boundary conditions).
- Class B: \( a(4) > 3.0 \, \text{m/sec}^2 \) (working conditions have to be improved. For long exposure it is very likely that health effects can be expected for a number of workers).
Annex 3

MARSSIM
The information below complements chapter 5.2.2.

**MARSSIM data life cycle**

In all four phases of the data life cycle, communication between the licensee and the regulator is essential. The four phases can be summarised as follows:

1. **Planning Phase** (design the survey).
2. **Implementation Phase** (perform the survey).
3. **Assessment Phase** (evaluate the measurements).
4. **Decision Making Phase** (what to do if the survey unit fails to meet the release criterion).

**Planning Phase**

The planning phase utilises the information obtained during the Historical Site Assessment (HSA) to classify the various regions of the property or site, determine what measurements will be performed, how many measurements will be performed, and where the measurements will be performed. Determining the minimum detectable concentrations (MDCs) of the instrumentation is an important part of this process. Main steps can be summarised as follows:

- Determine the Derived Concentration Guidance Level (DCGL) for Individual Nuclides (outside scope of MARSSIM).
- Determine the Gross DCGL for Multiple Nuclides when performing Gross alpha or beta measurements.
- Determine the maximum permitted average concentration in a hot spot.
- Classify the site according to contamination potential (Class 1, Class 2 or Class 3 – cf § Classification of areas and designation of survey units).
- Establish survey unit.
- Determine whether Sign Test (one-sample statistical test) or Wilcoxon Rank Sum Test will be used to assess the data.
- Determine if the Unity Rule will be used in the Statistical Tests (for Sites with Multiple Radionuclides).
- Select Type of Detection Equipment.
- Determine Measurement Protocols.
- Determine the measurement and Scan MDCs.
- Determine the Scan and Measurement Investigation Levels.
- Determine Acceptability of Type I and Type II errors.
- Determine appropriate number of measurements or samples.
- Class 1 – Number of Measurements might need to be increased.
- Establish reference grid and determine measurement/sample locations.

**Implementation Phase**

In the implementation phase, the data required by the plan is collected through a radiological survey. There are two parts to the survey: a scan and static measurements at fixed locations. The scan is performed to identify small areas of elevated activity (hot spots). The static measurements are performed to determine the average levels of contamination. Main steps can be summarised as follows:

- Scan Surfaces for contamination.
- Perform Static Measurements on Surfaces and/or collect surfaces/soil samples.
**Assessment Phase**

In this phase the data collected is evaluated. Non-parametrical statistical analyses are performed on the static measurements to determine whether or not the average levels of contamination meet the release criterion. In MARSSIM, the two major statistical analysis tools are the Sign Test and Wilcoxon Rank Sum Test (WRS). An elevated measurement comparison is performed on the hot spots identified in the scans as well as all the measurements performed at fixed locations to determine if isolated areas of contamination cause the release criterion to be exceeded. Main steps can be summarised as follows:

- Data verification & data validation.
- Preliminary data review.
- Data are plotted/graphed.
- If necessary, the sign test is performed.
- If necessary, the Wilcoxon rank test is performed.
- Perform an elevated measurement comparison.
- Determine total dose from all sources is below release criterion.

**Decision Making Phase**

In essence, this involves a determination of what to do if the residual level of contamination exceeds the release criterion or if the data is of insufficient quality or quantity to meet the goals specified in the Data Qualitative Objectives (DQO) process. A decision must be made as to how to proceed if the survey unit was misclassified, failed the elevated measurement comparison, failed the statistical assessment, or the total dose from all radiation source exceeded the release criterion.

**Data Quality Objectives (DQO) process**

The seven step DQO process is an integral component of the planning phase of the data life cycle. Its primary purpose is to ensure that all the important issues are addressed. These seven steps can be boiled down to the following:

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>State the problem: Identify the planning team, decision makers, deadlines, resources and a concise description of the problem</td>
</tr>
<tr>
<td>2.</td>
<td>Identify the decision: For a final status survey this would be “Is the level of residual contamination in a given survey unit below the release criteria”. Then, the alternative actions are identified e.g. further remediation, re-evaluation of the DCGLs, restrictions on release, etc.</td>
</tr>
<tr>
<td>3.</td>
<td>Identify inputs to the decision. Identify the specific questions to be answered, e.g., “What physical characteristics of the site need to be evaluated”, “What chemical characteristics of the contamination need to be determined”. The chosen means to answer these questions are identified. The information needed to establish the DGCLs is identified. What methods will be used to provide the necessary data is determined.</td>
</tr>
<tr>
<td>4.</td>
<td>Define the study boundaries Areas of the site to be evaluated are defined and the time frame in which the survey will be performed is defined.</td>
</tr>
<tr>
<td>5.</td>
<td>Develop a decision rule: The statistical method for describing the residual activity is identified e.g. the mean, median for the survey unit. The action levels are identified. These investigation levels are measurements that if exceeded require some decision to be made as to the need for a more detailed investigation. There are investigation levels for the average survey unit measurements as well as the elevated measurements comparison (hot spots).</td>
</tr>
<tr>
<td>6.</td>
<td>Specify limits on decisions errors: Estimate the likely variation in the measurements for the survey unit, identify the null hypothesis and define the consequences of Type I and Type II errors in terms of health, political and resources issues. Specify acceptable values for Type I and II error rates (alpha &amp; beta).</td>
</tr>
<tr>
<td>7.</td>
<td>Optimise the design of the survey for obtaining the data. Evaluate data collection design alternatives, develop the mathematical expressions that will be necessary to implement the alternatives and select the optimal options.</td>
</tr>
</tbody>
</table>
Classification of areas and designation of survey units

Area Classification: Areas are first classified as impacted or non-impacted according to the results of the historical site assessment.

| 1. Non-Impacted Areas: | These areas have no reasonable potential for residual contamination |
| 2. Impacted Areas: | Areas with some potential for residual contamination are classified as impacted areas. Impacted areas are further divided into one of three different classifications: |
| Class 1 Areas: | Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history). |
| Class 2 Areas: | Areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the DCGL. |
| Class 3 Areas: | Any impacted areas that are not expected to contain any residual activity or are expected to contain levels of residual radioactivity at a small fraction of the DCGL based on site operating history and previous radiation surveys. |

MARSSIM contents

Chapter 1: Generic material that outlines the scope and limitations of MARSSIM.
Chapter 2: This chapter provides a general overview of a variety of topics: the basic types of radiological surveys, the classification of the areas within a site into 3 classes, the type of measurements required for the different classes, the data quality objectives DQO process, the data life cycle, and alternative methodologies.
Chapter 3: Discusses the Historical Site Assessment (HSA) process.
Chapter 4: Discusses preliminary issues pertinent to the planning of a survey: the concentration limits (criteria), surrogate measurements, multiple radionuclides, classification of the areas, selection of background reference areas, survey units, site preparation, gridding, selection of instrumentation and measurement/sampling techniques.
Chapter 5: Provides additional information pertinent to the planning of a survey. Discusses the nature of the different types of radiological surveys, provides checklists for each. The most important part deals with the final status survey. It gives the step by step methods for determining the required numbers of measurements and the measurement locations.
Chapter 6: Discusses measurement methods, data quality indicators, instrumentation and MDCs. Appendix H provides additional information about the survey equipment. The most important parts of this chapter describe the calculation of the instrument minimum detectable concentrations MDCs for stationary measurement and scanning.
Chapter 7: Describes sampling and analytical techniques. Appendix H provides additional information about laboratory instrumentation.
Chapter 8: Describes the methods used to evaluate the collected data. It indicates the statistical tests that are used to determine whether the release criteria have been met. Appendix I provides additional information and statistical tables.
Chapter 9: Discusses quality assurance and quality control
Appendix A: Provides an example of a Final Status Survey report employing MARSSIM.
Appendix B: Provides a simplified procedure for those facilities where only sealed sources were handled, the material was short lived, or only very small quantities were employed.
Appendix C: Lists and briefly describes pertinent regulations and requirements.
Appendix D: Provides additional information regarding the data quality objectives process and the design of the survey plans.
Appendix E: Describes the evaluation of the data.
Appendix F: Describes the relationship between CERCLA, RCRA and MARSSIM.
Appendix G: Identifies a number of items of information for the Historical Site Assessment process.
Appendix H: Describes in some detail the field and laboratory instruments that will be employed in the radiological surveys and sample analyses.
Appendix I: Provides statistical tables of use in the data evaluation process
Appendix J: Provides a derivation of the equations pertaining to scanning for alpha contamination
Appendix K: Outlines and equates various quality assurance documents.
Appendix L: Gives the addresses and phone numbers for the regional EPA, DOE, NRC, DOD, offices.
Annex 4: Feedback experience (Case studies)
Annex 4: Feedback experience (Case studies)

Fuel reprocessing facilities & laboratories (Eurochemic reprocessing plant)

Introduction

Construction of Eurochemic was started 50 years ago as an international cooperation project between 13 European member states. It was a unique project in many respects. Eurochemic was the only company conducting both research and industrial production in the field of reprocessing. Reprocessing enables still usable fissile material from spent nuclear fuel to be recovered. Eurochemic was built and started by pioneers from all over Europe. Internationally, Eurochemic guaranteed a definitive leap into the future in nuclear chemical research.

The plant consisted of a rectangular heavy concrete facility about 80 m long, 27 m wide and 30 m high. The plant had seven floors with 106 cell structures containing a total of approximately 1,500 tons of metal components in the form of equipment and approximately 12,500 m² of structural concrete with 55,000 m² of contaminated concrete surfaces.

The main process building is a large rectangular structure (Figure 1). The core of the building consists of a large cell block of 40 main cells, containing the chemical process equipment. Some cells have contamination levels up to 125 Bq/cm² (beta) and 200 Bq/cm² (alpha). Some hot spots give a gamma dose rate of several mSv/h. There is no activation.

Figure 1: Process building of the former Eurochemic reprocessing plant

Timeline

The Eurochemic reprocessing facility at Dessel in Belgium, was constructed from 1960 to 1966. A consortium of 13 OECD countries operated this demonstration plant from 1966 to 1974, and reprocessed 180 tons of natural and low-enriched and 30 tons of high-enriched uranium fuels.

After shutdown, the plant was decontaminated from 1975 to 1979 to keep it in safe standby conditions at reasonable cost.

In preparation for the final, large-scale approach to the dismantling project, Belgoprocess started a pilot project from 1987 to 1990 to completely decontaminate and demolish two smaller storage
facilities (6A/6B), which during the reprocessing phase had been used for filtration and storage of process fluids and applied solvents. The objectives of this pilot project were:

- To demonstrate feasibility of dismantling nuclear facilities.
- To gain practical information regarding dismantling methods and techniques.
- To test and/or develop dismantling equipment.
- To train personnel in these new techniques and applications.
- To evaluate the costs/benefits related to dismantling activities.
- To confirm or reassess the results of the applied studies for dismantling the existing Eurochemic infrastructure.

Both buildings were emptied and decontaminated to background levels. They were demolished and the remaining concrete debris was disposed of as industrial waste. Green field conditions were restored. The pilot project was successfully completed in October 1989.

The timeline is given in the Figure 2.

**Figure 2: Eurochemic Timeline**

1957 Foundation of Eurochemic.
1966 Start-up of the installations.
1974 End of the reprocessing activities.
1984 Foundation of Belgacem.
1987 Start of the decommissioning studies.
2008 Completion of the first phase, start of the demolition.
1960 Start of the construction.
1968 Exploitation of the reprocessing facility.
1975 Take-over of Eurochemic by the Belgian government.
1986 Transfer of the Belgacem shares to NIRAS.
1989 Start of the decommissioning of Eurochemic.

**Applied strategy**

The demolition of Eurochemic will be performed in three phases. The plant has been subdivided since 2004 into an eastern, a western and a central part. Decommissioning started in 1990 and it is anticipated that all three sections will be demolished by 2012. The eastern part, containing 35% of the total concrete inventory, was demolished in 2009. The commencement of demolition of the central part is planned for 2010, and is scheduled over a six month period. This section is the most extensive and contains 39% of the total concrete inventory. Afterwards the demolition of the western and smallest part, or 26% of the total concrete inventory follows.
The decontamination and dismantling of the forty cells, or 106 cell structures, always follows basically the same procedure. First, the ‘hot-spots’ (places with high radioactivity) in each cell are removed to reduce the exposure and contamination risks to the operators. During a second phase, all metal components are dismantled using plasma torches and the parts removed to waste handling facilities for decontamination/recycling or treated as radioactive waste. During a third phase, all concrete surfaces of the empty room are decontaminated with the aid of shavers and scabblers. When intensive radioactive surveys indicate that radioactive fields due to contamination (no activation present) have been reduced to below release levels the cell can be released for conventional demolition.

**Difficulties met**

In general, the main difficulties encountered up to 2010 were:

- The final demolition of the main process building required a specific clearance methodology. The application of the methodology applied for the pilot project was not directly applicable for several reasons, the most important ones being:
  - The type and spread of contamination: at the end of the reprocessing activities, all cells were cleaned using the high-pressure water jet technique, which caused in-depth penetration of contamination into the concrete.
  - The total surface is large, which requires extensive manpower to monitor all surfaces twice in view of unconditional release.
  - Taking representative core samples at the previously most contaminated places was not possible due to the size of the building.

- High dose rates due to remaining liquids from former reprocessing activities reduce access time to some cells. Radiation sources have to be removed before large scale operations can take place.

- More material/equipment to be removed than considered in the inventory of several cells creating delays for planned decommissioning activities;

- Pipe penetrations between cells have to be removed in order to obtain the low radiation background levels required for making release measurements, a type of work that was scheduled to be done just before or during building demolition.
Results

Production flows

Until the end of 2007, a total of 4,588 tons of waste material was produced by the dismantling activities at Eurochemic. 557 tons of this material were labelled as non-contaminated materials, 1,530 tons were marked as radioactive waste, and 2,356 tons (out of 2,501 tons) were decontaminated. The final conclusion is that at the end of the 1990-2007 period, 63% of all generated waste was recycled. The portion that was processed and conditioned as radioactive waste was stored awaiting later permanent disposal.

At the end of 2008, these results will be even more favourable because large quantities of concrete structures (9,552 tons) will be integrally recycled. In the end, 88% of all waste generated by the dismantling of Eurochemic will be recycled. Based on experience and the applied techniques, more than 90% will have been recycled.

Man hours

The initial estimate for complete dismantlement of Eurochemic called for 403 man years. The current estimate is 600 man years. This substantial difference can be explained by the fact that extensive decontamination was chosen, fundamental deviations were found from the initial inventory, and additional, labour-intensive pre-release measurements were taken.

Average individual dose

From 1990-2009 average doses of less than 2 mSv/year per person. These good results were obtained due to rinsing programme that was performed before the start of decommissioning activities.
Finances

The most important message with respect to finances is that the overall cost of the dismantling virtually remained unchanged throughout the years (175 million Euros). In terms of itemisation, the item “dismantling expenses” almost doubled due to extensive decontamination of material before release. In contrast, radioactive waste processing, temporary storage and continuing storage to this day are barely one third of the original estimate. The explanation lies in the labour-intensive release (= man hours), which resulted in a much smaller quantity of conditioned waste to be stored...

Pictures

Sources and references


**Research reactors: MELUSINE (BNF 19)**

**Introduction**

Melusine, commissioned in 1958, was the CEA/Grenoble’s first research reactor, and was also one of the first pool-type reactors built in France. The users’ needs led the reactor’s power to be gradually increased from 1 up to 8 MW.

BNF 19 includes: the reactor hall, with an area of 680 m² (34m long, 20m wide, 19 m high) and different external rooms.

The facility has no below ground-level compartments, apart from the two pits where there are 2 tanks (number 6 on Figure below).

![Diagram of MELUSINE (BNF 19)](image)

**Dismantling project – main dates**

- 1988 to 1993: Works to prepare for the final shutdown,
- 12/1993: BNF shut down,
- 12/2002: Clean-up Authorisation,
- 01/2004: Decree authorising for decommissioning operation of the BNF 19 prior to its dismantling and decommissioning
- 03/2009: end of decommissioning operations and survey.
**State of the facility (12/2009)**

*Physical inventory*

- The cooling pool was emptied and cleaned up,
- The forward pool compartment, which had been activated, has been cut up and removed (VLL waste),
- All the equipments, pipes, inserts have been removed,
- Buildings have been cleaned up
- Final radiological survey has been carried out.

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**Facility’s radiological state**

- The whole facility is a non-controlled zone in terms of radiation protection.
- The declassification of this building structure has been approval by NSA.
- The delicensing of the based nuclear facility is in progress.

**Strategy chosen**

**Final objective**

The final objective was to enable the re-use of the buildings without any radiological restraints, for any or all types of research or industrial activity. All the facility’s rooms had to meet the requirements for a conventional (non nuclear) waste zone and for a non-controlled zone in terms of radiation protection. Two end state options are being considered: industrial (non nuclear re-use) or conventional demolition to free up the area for re-use.

**Project organisation**

The dismantling of BNS 19 Melusine is part of the PASSAGE project, which should lead to the complete downgrading (non-nuclear) of the Grenoble Centre by 2012.
The project’s industrial structure

Passage - industrial organisation

Definition and implementation

Project schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
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<tr>
<td>Preliminary studies</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparatory activities</td>
<td></td>
<td></td>
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<td></td>
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<td>Equipments dismantling</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pool cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final status surveys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End of these operations</td>
<td></td>
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</tr>
</tbody>
</table>

The plan for BNF 19 - MELUSINE’s dismantling included the following phases:

- phase 1: end of pool clean-up after emptying;
- phase 2: electromechanical dismantling and clean-up to under 100Bq/g;
- phase 3: final clean-up, enabling the facility’s decommissioning.

The final phase mainly corresponds to the clean-up methodology’s implementation. This methodology is based on a definition for four surface categories within the nuclear waste zones (Information File provided to the Nuclear Safety Authority under the terms of the note DGSNR-SD3-DEM-02 [27]).

Once the equipment, cables and pipe networks have been removed, different types of work will need to be carried out on the structure elements. Different types of tools may be used.
Techniques used during the works are described in chapter 3

<table>
<thead>
<tr>
<th>Category</th>
<th>Type of contamination</th>
<th>Types of operations</th>
<th>Tools and techniques used for concrete cleaning</th>
<th>Final checks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No risk of contamination</td>
<td>No clean-up planned. Final aspiration</td>
<td>N/A</td>
<td>Surface checks by probe</td>
</tr>
<tr>
<td>1</td>
<td>Only dry contamination</td>
<td>Removal of painting and a thin layer of concrete (about 1 mm). Final aspiration</td>
<td>Shaving</td>
<td>– surface checks for 100% of the floors, – surface checks of the other surfaces by probe</td>
</tr>
<tr>
<td>2</td>
<td>Superficial liquid contamination</td>
<td>Removal of the superficial layer over the entire surface: concrete peeling to the target thickness (2.5 cm on floors and 1 cm on walls and ceilings), brushing or sand-blasting of those metallic elements which must be left in place. Final aspiration</td>
<td>Sand-blower, nibbler, chipping, pneumatic hammer, planer, sander …</td>
<td>Concrete: check in the mass by gamma spectrometry gamma in situ on 100% of the surfaces + surface checks to verify the absence of heterogeneity, metal: surface checks for 100%.</td>
</tr>
<tr>
<td>3</td>
<td>Activation or in depth liquid contamination</td>
<td>After consultation, case by case definition in order to meet the decision criteria set for the facility’s decommissioning. Final aspiration</td>
<td>Nibbler, chipping, core drill, cable cutting (cable saw and stone saw), pneumatic hammer, Brokk equipped with hydraulic jack hammer …</td>
<td>Check in the mass by gamma spectrometry in situ on 100% of the surfaces, surface checks to verify the absence of heterogeneity, sampling.</td>
</tr>
</tbody>
</table>

Difficulties met

The surfaces of the nuclear waste zones that could not be treated and/or checked had to be removed (dismantled, cut up …) as nuclear waste.

Analyses of core samples carried out on the forward pool compartment revealed a residual activation of the concrete through the entire thickness of the wall. An additional clean-up work phase became necessary to deal with this section of the pool in order to obtain the facility’s decommissioning objective. The solution decided on was to demolish the forward compartment of the pool for its complete height. This demolition was carried out by cutting up the forward compartment into blocks, which were then stored in boxes to await their removal.

Detailed characterisation led to some unknown and unexpected radiological conditions within the facility. Moreover, the regulator required a re-definition of the clean-up methodology midway through the project in order to conform to the new final clean-up regulation effected in 2006. This resulted in an increased scope of work for the project and entailed the retrieval of either all the contaminated and/or activated structures, or the removal of residual radioactivity present in the civil engineering structures.

Specifically the works involved:

- deconstruction of the plug storage cells;
- deconstruction of the pool block;
- work including surface treatment and removal of inserts and elements which were not an integral part of the structure.

Clean-up report

As shown in the table above, the final surveys were dependent on surface category. Criteria were:

- 0.4 Bq.cm² for surface checks;
- 0.4 Bq/g for gamma spectrometry in situ or on sampling;
- 100 Bq/g for H3 on sampling (only for activated surfaces).
For the surface measurement, the categories 2 and 3 were measured at 100%. The table gives the quantity of surfaces which were measured (surface measurement or gamma spectrometry measurements):

Waste results

The distribution of solid waste is:

<table>
<thead>
<tr>
<th>Category</th>
<th>Monitoring surface in m² (nbr of points of measure) for surface measurement of first level</th>
<th>A. max (Bq/cm²)</th>
<th>Monitoring surface in m² (nbr of points of measure) for gamma spectrometry measurements of first level</th>
<th>A. max (Bq/g)</th>
<th>Monitoring surface total (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cat 1 (except floor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cat 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cat 3</td>
<td>m² Number of samples</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>65.14 (1087) 43.86 (731) 5.76 (96) &lt; 0.4 Bq/cm² 1580.8 (343) 94 64 0.36 1798.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
VLLW (Very Low Level Waste): Waste in contaminated area with activity less than around 100 Bq/g
LLW (Low Level Waste): Waste in contaminated area with activity more than around 100 Bq/g

Final state

The final clean-up works were as described in the BNF 19 – MELUSINE dismantling file completed by the final clean-up methodology. Delicensing documentation in preparation.

Sources and references

Decree n° 2004-26 dated 8th January 2004, authorising the CEA (Commissariat à l’Énergie Atomique) to modify the basic nuclear facility n° 19, known as the Melusine reactor, located on the territory of the Grenoble (Isère) commune, to prepare for its dismantling and decommissioning.

Décret n° 2004-26 du 8 janvier 2004 autorisant le Commissariat à l’énergie atomique à modifier l’installation nucléaire de base n° 19 dénommée réacteur Mélusine sur le territoire de la commune de Grenoble (Isère) en vue de son démantèlement et de son déclassement.

DA SILVA P. (ASSYSTEM France), Bilans et compte-rendu de démantèlement de l’INB 19 - Mélusine au titre du décret de démantèlement, LEIG/SY/6000/08/3176 Ind. B du 23/12/2008
Power plants (Vandellos-1 NPP)

Background

Vandellos-1 NPP, located in the province of Tarragona (Spain), was first coupled to the electricity grid on March 6th 1972. This facility owned by the Spanish-French company named (HIFRENSA), was the only Spanish plant to use natural uranium and graphite-gas technology.

Decommissioning Plan

The NPP was retired from service as a result of the fire that occurred in the second turbine-alternator set on October 19th 1989. Although this incident had no radiological consequences and damaged only conventional areas of the facility, the Ministry of Industry and Energy suspended the plant’s operating licence, thus putting an end to its activities after 17 years of operation and the generation of 55,65 GWh.

The project designed by ENRESA and approved by the Ministry of Industry and Energy implies decommissioning to level 2, in accordance with the terminology coined by the IAEA.

<table>
<thead>
<tr>
<th>Level</th>
<th>Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1991 to 1997</td>
</tr>
<tr>
<td>2</td>
<td>February 1998 and June 2003</td>
</tr>
<tr>
<td>Latency period:</td>
<td>On completion of Level 2, the unreleased parts of the site remain under the responsibility and surveillance of ENRESA. This situation will continue for 25 years, during which time the radiological activity of the internal structures of the reactor will decay to approximately 5% of the initial level.</td>
</tr>
<tr>
<td>3</td>
<td>On completion of the latency period, around the year 2028, work will begin on the last level of decommissioning which will include the removal of the reactor box and its internals and the complete release of the site.</td>
</tr>
</tbody>
</table>

Decommissioning Process
Preparatory activities
ENRESA’s activities began in March 1998 and included the start-up of a programme of preparatory activities necessary for decommissioning of radioactive zones.

Decommissioning
ENRESA began to work simultaneously on the two pillars supporting the Decommissioning Plan: 1) the Conventional Components Decommissioning Plan (CCDP) which had been in force since 1998, and the Active Parts Decommissioning Plan (APDP).

Conventional Components Decommissioning Plan (CCDP)
This set of activities includes disassembly, demolition and restoration of the land in relation to all the buildings, systems and components not having any radiological implications. Generally, these were tasks that, while did not require Radiation Protection demands typical of APDP, did need to be carried out with major safety measures applied.

Active Parts Decommissioning Plan (APDP)
The decommissioning of the active parts commenced in March 1999 and the APDP was applied as from that time. This work is an industrial process and began with a characterisation campaign. This was followed by the disassembly of all the equipment and systems in the building. The next step after dismantling of the interior is to focus on the structure building itself. All the surfaces are re-measured to locate contamination hot spots and depth. This is followed by decontamination of the affected areas and a new characterisation campaign to demonstrate the absence of radioactivity. The building will then be declassified and demolished. Finally, the land will be restored and released. Main buildings dismantled were as follows:

- Reactor building,
- Irradiated fuel building,
- Spent fuel pool building
- Graphite silos & Conditioning workshop
- Effluents building
- Other Installations
Materials management

One of the essential points of the project has been the exhaustive control of all the materials from the site with a view to segregating those that had radiological implications from those others that were clean and might be reused. It is estimated that between March 1998 and June 2003 some 15900 tons of non contaminated materials were generated, mainly metallic materials, which were recycled, and minor amounts of conventional wastes that were sent to authorised centres.

To these should be added 1961 tons of rubble from the active zones, which were reused for land restoration following declassification, along with almost 77000 tons of concrete from the demolition of the plant buildings.

As regards the volume of radioactive wastes, the 2000 tons initially foreseen finally ended up at 1763 tons. This reduction in waste volume has been possible thanks to the segregation and decontamination techniques used and to the policy of recycling implemented by ENRESA during the decommissioning.

Since April 1999 work conducted under the ADPD has generated 11736 tons of materials, of which 1763 were low and intermediate radioactive wastes. The remaining 9973 tons are materials (8012 t) and facings (1961 t) included in the materials and structures Declassification Plan which has allowed them to be managed as conventional materials and dispatched to recycling plants for other industrial uses or reuse in restoration of the site. During the decommissioning, the tasks included in the CCDP have generated 7894 tons of materials, mainly scrap and ferrous materials which have been removed from the site under control. To this figure for materials from conventional areas are to be added almost 77000 tons of concrete rubble from the demolition of buildings, which have been used throughout decommissioning for the restoration of land on the site.

The disassembly of the building
Material destination

Initial situation

- Conventional concrete rubble
- Low and intermediate radioactive wastes

Conventional scrap

15,906 t

78,960 t

1,763 t

Toxic and hazardous Products

Minor quantities

Recycling

Controlled tip

Final situation

El Cabril Disposal Facility

15,906 t

© OECD/NEA 2011
Recycling

Diagram of recycling at Vandellós 1

The policy for the recycling of materials implemented by ENRESA in the decommissioning of the Vandellós 1 NPP has allowed new uses to be found for approximately 95% of the materials generated during the works. The different materials recycling routes used were as follows:

- Conventional materials
  - Internal recycling
  - External recycling
- Contaminated materials
  - Internal optimisation
  - External optimisation
Organisational flowchart for decommissioning

Decommissioning schedule
Difficulties met

At the beginning of the work related to concrete structures we needed to re-calculate the isotope vector and the source term in order to know whether or not these structures had the same scaling factors as the main materials arising from the first phase of the dismantling tasks, such as metallic, cables, plastics or others.

This meant, it was necessary to prepare a new plan of sampling, new radiological measurements, new alpha spectrometric data and others things... Therefore; the cost and time were increased.

Other problems in old concrete structures were also found such as contamination deeply imbedded in small or big cracks in the floors or structures under ground level. We also found a lot of problems in the Silos 1, 2, 3; mainly in Silo 1 and 2 due to the poor quality of the concrete (specifications of 70s) comparing with Silo 3. Silo 3 was erected including an inner plastic thick layer in order to protect or prevent infiltrations.

Regarding with the methodology, the Regulatory Authorities "recommended" that we measure almost 100% of the surfaces of the different concrete structures. Vandellós-1 was the first Project in Spain in which the Surface Methodology was applied. This meant development of new methodologies, documentation, procedures, reports, audits and other.

There are some problems with the diamond wire technique due to the large quantity of water (secondary waste) that this technique needed.

In addition and due the dust generation it was necessary to keep in mind the consumptions of HEPA filters, the maintenance of the portable ventilation units, minimise the noise or the secondary radwaste generated.

Sources and references

Final works report – Level 2 dismantling and closure of the VANDELLÓS 1 NFP, 051-IF-CV-2435, ENRESA.
Annex 5: Major features and types of contracts used for clean-up projects

Major features and types of contracts used for clean-up projects
<table>
<thead>
<tr>
<th>Type of contracts</th>
<th>Major features of contract type</th>
<th>Circumstances when contract type is generally used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed-price contracts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Firm fixed-price</strong></td>
<td>− Price is set at contract award by competitive prices or negotiation.&lt;br&gt;− Price is not adjusted based on contractor’s costs during performance.&lt;br&gt;− Low flexibility for owner because changes must be negotiated.&lt;br&gt;− Low cost risk for owner as long as scope does not change; high cost risk for vendor.&lt;br&gt;− Low performance risk for owner as long as scope does not change; high performance risk for vendor.</td>
<td>− Work scope is well defined and no major changes are expected.&lt;br&gt;− Uncertainties are quantifiable.&lt;br&gt;− Best for purchase of commercial products</td>
</tr>
<tr>
<td><strong>Fixed-price with fixed per-unit pricing</strong></td>
<td>− Price quoted on a per-unit basis in this variant of firm-fixed-price.&lt;br&gt;− Allows owner some flexibility by stating work in units, usually with minimum and maximum amounts guaranteed during a set contract period.&lt;br&gt;− Low cost risk for owner but must pay for minimum quantity; high cost risk for vendor.&lt;br&gt;− Low performance risk for owner; high performance risk for vendor.</td>
<td>− Work scope can be adjusted within stated limits to fit owner priorities and funding availability.&lt;br&gt;− Minimum units of work are known (e.g. x barrels of waste are in storage ready to be processed).&lt;br&gt;− If vendor cannot use facilities for other clients, contact may provide for idle facility payments.</td>
</tr>
<tr>
<td><strong>Fixed-price with economic price adjustment</strong></td>
<td>− Price adjusted up or down using agreed-upon criteria such as a labour or material cost index.&lt;br&gt;− Low flexibility for owner without renegotiating work scope and cost.&lt;br&gt;− Low cost risk for owner; high cost risk for vendor except for cost components covered in the adjustment provision.&lt;br&gt;− Low performance risk for owner; high performance risk for vendor.</td>
<td>− Work scope is well defined and no major changes are expected or likely.&lt;br&gt;− There is a serious doubt about market condition, e.g. large potential fluctuations in the costs of key components such as materials or labour.&lt;br&gt;− Component costs covered in the price adjustment provision are not under the vendor’s control but changes cannot be estimated with a high degree of accuracy.&lt;br&gt;− Contract covers and extended performance period, e.g. several years.</td>
</tr>
<tr>
<td><strong>Fixed-price with incentive and firm target price</strong></td>
<td>− Pricing arrangement negotiated places an appropriate share of risk on vendor.&lt;br&gt;− Low flexibility for owner because price and targets must be negotiated if work scope changes.&lt;br&gt;− More cost risk for owner than under firm-fixed-price; vendor assumes some cost risk because fee is tied to cost control.&lt;br&gt;− More performance risk for owner than under firm-fixed-price because owner shares in cost overruns; less performance risk for vendor.</td>
<td>− Work scope is well defined.&lt;br&gt;− Objective in addition to cost control are deemed important, e.g. workplace safety, waste minimisation, etc...&lt;br&gt;− Relates incentive fee (profit) to cost control and may include incentives for performance on critical aspects of work.&lt;br&gt;− Cost control incentives required when performance incentives are used to preclude reward for performance if cost outweighs its value.&lt;br&gt;− Contractor must have an acceptable accounting system prices because owner shares in cost overruns; less performance risk for vendor.</td>
</tr>
</tbody>
</table>
### Annex 5: Major features and types of contracts used for clean-up projects

<table>
<thead>
<tr>
<th>Contracts Type</th>
<th>Features</th>
<th>Examples</th>
</tr>
</thead>
</table>
| **Fixed-price with prospective price re-determination** | - Price for initial performance period is fixed when contract is negotiated.  
- Price is subsequently adjusted at stated periods during the life of the contract in anticipation of future conditions affecting the cost of performance.  
- Other features are the same as firm-fixed-price except the owner bears more cost risk because the final cost is not set at contract award. | - A fair firm-fixed price can be negotiated for an initial period but not for the entire contract period.  
- A relatively brief period of performance will provide the pricing information needed to set price for the remainder of the contract.  
- Suitable for a contract with a lengthy performance period (e.g. 10 to 20 years). |
| **Fixed-price using a fixed unit rate** | - Price for a unit of work is known but total price of work is not known.  
- More flexible for owner than fixed-price with per-unit pricing, but vendor has no incentive to minimise the amount of work done.  
- Higher cost risk for owner than other forms of fixed-price contracts; lower cost risk for vendor.  
- Low performance risk for owner; higher performance risk for vendor. | - Work scope in terms of the number of units to be done is not known with certainty.  
- Not enough information is known to set minimum and maximum levels of work scope. |
| **Cost-reimbursement contracts**       | - Cost contract includes no fee (profit) portion, but the vendor is reimbursed for all allowable costs incurred.  
- A cost-sharing contract includes no fee (profit) portion, but vendor is reimbursed for only negotiated portion of costs incurred.  
- Increases owner flexibility.  
- Increases cost risk for owner; lessens vendor’s cost risk.  
- Increases performance risk for owner; minimal performance risk for vendor. | - Work scope cannot be precisely defined.  
- Cost contracts are usually used for research and development work done by non-profit organisations such as universities.  
- Cost-sharing contracts can be used any time, but the vendor expects other compensating benefits from participation (e.g. follow-on contracts, patentable process, …).  
- Contractor must have an acceptable accounting system. |
| **Cost and cost-sharing contracts**    | - Target cost and incentive fees are negotiated for a specific scope of work; incentive is adjusted based on relationship between total target cost and total actual cost.  
- Low flexibility for owner because changes to work scope require renegotiation of target cost and incentive fees.  
- High cost risk for owner; some cost risk for vendor because vendor shares in cost overruns.  
- High performance risk for owner; low performance risk for vendor.  
- Cost control incentive required but additional incentives can be added. | - Work scope can be reasonably well-defined, but significant uncertainties remain.  
- Performance features subject to incentives can be objectively measured.  
- Used for development and testing programs and to motivate vendor to manage projects more effectively.  
- When incentive fee includes a “negative” portion, vendor may not recover all costs incurred.  
- Fee pool for fixed and performance incentive is negotiated; performance incentives are assigned a negotiated value from the relevant fee pool.  
- Contractor must have an acceptable accounting system. |
| **Cost-plus-incentive-fee**            | - All allowable costs are reimbursed.  
- Maximum flexibility for owner to respond to funding and or priority changes during performance period.  
- High cost risk for owner; low for vendor.  
- High performance risk for owner; low for vendor.  
- Award fee is subjectively determined by owner and is intended to motivate the vendor for excellent performance. | - Work scope cannot be precisely defined and or is subject to significant, frequent changes.  
- Changes to work scope may require renegotiation if they will impact the vendor’s ability to meet criteria for earning award fee.  
- Conditions beyond the control of the vendor are expected to have a major impact on the vendor’s ability to perform.  
- Performance cannot be objectively measured and or non cost considerations are of high priority (e.g. safety in nuclear operations).  
- Contractor must have an acceptable accounting system. |
Annex 6

Characterisation methodologies and techniques used in D&D projects
<table>
<thead>
<tr>
<th>Project (Country)</th>
<th>Main nuclides expected in concrete</th>
<th>Measurement plan</th>
<th>Dose rate counting</th>
<th>Loose contamination measurement</th>
<th>Surface counting α emitters</th>
<th>Surface counting β emitters</th>
<th>In situ γ spectrometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Méhusine (France)</td>
<td>Contaminated structures: $^{137}$Cs, $^{60}$Co, $^{90}$Sr, + $^{14}$C (only in 1 room). Activated structures: $^3$H, $^{152}$Eu, $^{55}$Fe, $^{60}$Co, $^{134}$Ba.</td>
<td>Yes</td>
<td>No</td>
<td>Only if surface counting was positive.</td>
<td>Unitary surface of measurement: 170 or 600 cm$^2$. Detection limit &lt; 0.4 Bq/cm$^2$. Unitary duration of measurement: a few seconds per measure. Location: on suspected zones, generally 100% on floor and walls until 2 m high.</td>
<td>No</td>
<td>Only for singularities (narrow holes, cracks, embedded piping). Detectors: GeHP, LaBr3. Use of specific modellisation. Detection limit depending on the modellisation. Unitary duration of measurement: a few minutes to a few hours.</td>
</tr>
<tr>
<td>ATUE (France)</td>
<td>Contaminated structures: $^{238}$U, $^{235}$U, $^{234}$U, $^{137}$Cs, $^{241}$Am. No activation.</td>
<td>No</td>
<td>Surfaces were cut in squares 3 m x 3 m. 9 surface counting measures per square if high variability, complementary measures for which location is determined by geostatistic. 1 gamma spectrometry per square.</td>
<td>No</td>
<td>to detect radioactivity variation. Unitary surface of measurement: 170 or 200 cm$^2$. Detection limit = 0.1 Bq/cm$^2$ (eq $^{238}$U). Unitary duration of measurement: 15 s. Location: On floors and walls until 3 m high + a few measures on ceilings. Surfaces were cut in squares 3 m x 3 m. 9 measures per square regularly distributed so as to obtain a statistic profile.</td>
<td>No</td>
<td>Detector: GeHP. Modellisation: square 2 m x 2 m and 1 cm thickness. Unitary duration of measurement: 30 min. Location: 1 measurement per square 3 m x 3 m.</td>
</tr>
<tr>
<td>Project (Country)</td>
<td>Main nuclides expected in concrete</td>
<td>Measurement plan</td>
<td>Dose rate counting</td>
<td>Loose contamination measurement</td>
<td>Surface counting β emitters</td>
<td>Surface counting α emitters</td>
<td>In situ γ spectrometry</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------------------------</td>
<td>------------------</td>
<td>-------------------</td>
<td>-------------------------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Brennils (France)</td>
<td>Contaminated structures: 137Cs, 60Co. No activation in buildings cleaned up.</td>
<td>Yes (mainly based on dose rate counting)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Eurochemic (Belgium)</td>
<td>Contaminated structures: 60Co, 137Cs, 241Am. No activation</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No (too high background).</td>
<td></td>
</tr>
<tr>
<td>BR3 (Belgium)</td>
<td>Contaminated structures: 137Cs, 60Co. Activated structures: 133Ba, 85Sr, 152Eu, 154Eu, 60Co.</td>
<td>Yes (mainly based on dose rate counting).</td>
<td>No</td>
<td>Yes, to localise hot spot.</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Measurement plan
- **Based on history**
- **Statistical**

### Dose rate counting
- No

### Loose contamination measurement
- Yes

### Surface counting β emitters
- Yes

### Surface counting α emitters
- Yes

### In situ γ spectrometry
- Yes

---

**Main nuclides expected in concrete**
- **Contaminated structures:** 137Cs, 60Co.
- **Activated structures:** 133Ba, 85Sr, 152Eu, 154Eu, 60Co.

---

**Measurement plan**
- Yes
- No

**Dose rate counting**
- Yes (mainly based on dose rate counting)
- No

**Loose contamination measurement**
- Yes
- Yes

**Surface counting β emitters**
- Yes
- Yes

**Surface counting α emitters**
- Yes
- No (too high background)

**In situ γ spectrometry**
- Yes
- Yes

**Main nuclides expected in concrete**
- **Contaminated structures:** 137Cs, 60Co.
- **Activated structures:** 133Ba, 85Sr, 152Eu, 154Eu, 60Co.

---

**Measurement plan**
- Yes
- No

**Dose rate counting**
- Yes (mainly based on dose rate counting)
- No

**Loose contamination measurement**
- Yes
- Yes

**Surface counting β emitters**
- Yes
- Yes

**Surface counting α emitters**
- Yes
- No (too high background)

**In situ γ spectrometry**
- Yes
- Yes

---

**Main nuclides expected in concrete**
- **Contaminated structures:** 137Cs, 60Co.
- **Activated structures:** 133Ba, 85Sr, 152Eu, 154Eu, 60Co.
<table>
<thead>
<tr>
<th>Project (Country)</th>
<th>Main nuclides expected in concrete</th>
<th>Measurement plan</th>
<th>Dose rate counting</th>
<th>Loose contamination measurement</th>
<th>Surface counting β emitters</th>
<th>Surface counting α emitters</th>
<th>In situ γ spectrometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIMIC (Spain)</td>
<td>Contaminated structures: Research reactor: $^{137}$Cs, $^{60}$Co, $^{134}$Cs, $^{135}$Cs, $^{137}$Cs, $^{60}$Co, $^{152}$Eu, $^{154}$Eu, $^{155}$Eu, $^{90}$Sr. Pilot reprocessing facility: $^{137}$Cs, $^{90}$Sr, U and Pu isotopes, $^{241}$Am. Activated structures: $^{60}$Co, $^{55}$Fe, $^{59}$Ni, $^{152}$Eu, $^{154}$Eu, $^{90}$Sr.</td>
<td>Yes (mainly based on dose rate counting).</td>
<td>No</td>
<td>Yes, to localise hot spot and for paved or large covering areas, before sampling. In high expected beta-gamma contamination zones.</td>
<td></td>
<td></td>
<td>Yes. Dynamic (in average 5 cm/s) and static measurement (2 mm at 5 mm from the surface).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Yes. Detection limit: at least 10% below the derived operational clearance level.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Initial characterisation: 0.4 Bq/cm².</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Location: much of the time 100% on floor and walls until 2 m high.</td>
</tr>
<tr>
<td>Vandellos (Spain)</td>
<td>Contaminated structures: $^{137}$Cs, $^{134}$Cs, $^{60}$Co, $^{137}$Cs, $^{135}$Cs, $^{137}$Cs, $^{60}$Co, $^{152}$Eu, $^{154}$Eu, $^{90}$Sr, $^{65}$Zn. Activated structures: $^{60}$Co, $^{55}$Fe, $^{59}$Ni, $^{152}$Eu, $^{154}$Eu, $^{90}$Sr.</td>
<td>Yes, mainly based on dose rate counting.</td>
<td>No</td>
<td>Yes, to localise hot spot and for paved or large covering areas, before sampling. In high expected beta-gamma contamination zones.</td>
<td></td>
<td></td>
<td>Yes. Dynamic (in average 5 cm/s) and static measurement (2 mm at 5 mm from the surface).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Initial characterisation: 0.4 Bq/cm².</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Location: much of the time 100% on floor and walls until 2 m high.</td>
</tr>
<tr>
<td>KKR (Germany)</td>
<td>Contaminated structures: $^{60}$Co, $^{137}$Cs. Activated structures: $^{152}$Eu, $^{154}$Eu, $^{241}$Am.</td>
<td>Yes</td>
<td>Being considered.</td>
<td>Yes, to localise hot spot. Criteria:  three times higher than background.</td>
<td></td>
<td></td>
<td>Yes. Dynamic measurement on each grid and static measurement on the maximum point.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Without reliable information about the distribution of contamination 100% of the surface will be measured.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Yes. Detection limit depending on the modelisation but at least 10% below the derived operational level. Unitary duration of measurement.</td>
</tr>
</tbody>
</table>
### Decontamination and dismantling of radioactive concrete structures

<table>
<thead>
<tr>
<th>Project (Country)</th>
<th>Measurement plan</th>
<th>Measurement type</th>
<th>Methodology</th>
<th>Technique</th>
<th>Surface counting α emitters</th>
<th>Surface counting β emitters</th>
<th>Loose contamination measurement</th>
<th>Dose rate counting</th>
<th>Dose rate measurement</th>
<th>In situ γ spectrometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAK (Germany)</td>
<td>Based on history</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes.</td>
</tr>
</tbody>
</table>

- Yes. Building joints. Measuring surface approx. 10 m².
- Measuring time approx. 30 min.

- Surface counting α emitters:
  - Measuring surface: 200 cm².
  - Nuclide vector known by sampling and/or history.
  - Threshold value 50% of free release value according to the German radiation protection regulators.
  - Activity measuring of the whole surface.

- Surface counting β emitters:
  - Measuring surface approx. 10 m².
  - Nuclide vector known by sampling and/or history.
  - Threshold value 50% of free release value according to the German radiation protection regulators.

- Main nuclides expected in concrete:
  - Contaminated structures:
    - 131C (39, 137Cs, 134Cs, 239Pu, 238Pu, 241Pu, 239Pu, 240Pu, 241Pu, 242Pu, 243Pu, 90Sr).
    - No activation.

- Loose contamination measurement:
  - No, surfaces normally vacuum cleaned.

- Dose rate counting:
  - No.

- Dose rate measurement:
  - No.

- In situ γ spectrometry:
  - Yes.

- Measurement plan:
  - Based on history
  - No activation.
Annex 7

Destructive assay methodologies and techniques used in D&D projects
<table>
<thead>
<tr>
<th>Project (Country)</th>
<th>Based on historic and/or in situ measurement</th>
<th>Statistic</th>
<th>Core drilling</th>
<th>Scarifying</th>
<th>Gamma spectrometry</th>
<th>Hard to measure nuclides</th>
<th>Gamma scanning (on core drilling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mélusine (France)</td>
<td>On hot spots in rooms with liquid contamination</td>
<td>No</td>
<td>– In contaminated cracks, deep contaminated zones (&gt; 10 cm) and activated concrete (mainly for category 3)</td>
<td>– By layer of 5 mm in order to define depth and profile contamination (category 2 and 3)</td>
<td>– for all samples</td>
<td>– for a few samples (³⁵⁵H, ¹⁴C, ⁹⁰Sr, ⁶⁰Ni, ⁵⁵Fe, alpha spectrometry), in order to define radiological spectrum for scaling factors and residual impact assessment</td>
<td>– In order to define the sampling location on the core drilling (activated concrete). Give the profile of activation but not the specific activity.</td>
</tr>
<tr>
<td>ATUE (France)</td>
<td>Yes</td>
<td>Geostatistic (experimental), to define depth and profile contamination</td>
<td>No</td>
<td>Yes</td>
<td>– Systematic</td>
<td>– Alpha spectrometry</td>
<td>On 5 samples by workshop</td>
</tr>
<tr>
<td>Breuilis (France)</td>
<td>On hot spots, to define:</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>(³⁵⁵H, ¹⁴C, ⁹⁰Sr, ⁶⁰Ni, ⁵⁵Fe)</td>
<td>Yes</td>
</tr>
<tr>
<td>Eurochemic (Belgium)</td>
<td>No destructive assay for initial inventory</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>(³⁵⁵H, ¹⁴C, ⁹⁰Sr, ⁶⁰Ni, ⁵⁵Fe)</td>
<td>Yes</td>
</tr>
</tbody>
</table>
### Annex 7: Destructive assay methodologies and techniques used in D&D projects

#### Decontamination and dismantling of radioactive concrete structures

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<table>
<thead>
<tr>
<th>Sampling technique</th>
<th>Sampling plan</th>
<th>Core drilling</th>
<th>Radiation detection</th>
<th>Hand to measure nuclides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scarifying</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Core drilling</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Statistic</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

### Gamma spectrometry

<table>
<thead>
<tr>
<th>Sample analyses</th>
<th>Gamma scannings (on core drilling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scarifying</td>
<td>For a few samples ($^{90}$Sr, $^{63}$Ni, $^{55}$Fe)</td>
</tr>
<tr>
<td>Core drilling</td>
<td>For all samples ($^{60}$Co and $^{137}$Cs)</td>
</tr>
<tr>
<td>Statistic</td>
<td>No</td>
</tr>
</tbody>
</table>

### Project (Country)

<table>
<thead>
<tr>
<th>BR3 (Belgium)</th>
<th>P/MC (Spain)</th>
<th>Vandellos (Spain)</th>
<th>KGR (Germany)</th>
<th>WAK (Germany)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR3 (Belgium)</td>
<td>P/MC (Spain)</td>
<td>Vandellos (Spain)</td>
<td>KGR (Germany)</td>
<td>WAK (Germany)</td>
</tr>
</tbody>
</table>

---

**Decontamination and dismantling of radioactive concrete structures**

- **Gamma scanning (on core drilling):**
  - For a few samples ($^{90}$Sr, $^{63}$Ni, $^{55}$Fe) to define the sampling location on the core drilling (activated concrete). Give the profile of activation but not the specific activity.

- **Core drilling:**
  - In contaminated cracks, deep contaminated zones (>10 cm) and activated concrete (mainly for category 3).

- **Radiation detection:**
  - Gamma spectrometry for all samples ($^{60}$Co and $^{137}$Cs).

---

**Sampling plan**

- **Based on historic and/or in situ measurement:**
  - BR3 (Belgium): 3 samples per room (delineation, average level of surface contamination (max. average and min) for each homogenous risk.
  - P/MC (Spain): At least 15 samples for each homogeneous risk.
  - Vandellos (Spain): No standard for pre-investigation in situ measurement used.
  - KGR (Germany): No standard for pre-investigation in situ measurement used. Average area (target: 10 m²).

- **Hand to measure nuclides:**
  - For all samples ($^{60}$Co and $^{137}$Cs) for a few samples ($^{90}$Sr, $^{63}$Ni, $^{55}$Fe) in order to define the sampling location on the core drilling (activated concrete). Give the profile of activation but not the specific activity.
Annex 8

Return of experience related to radiological characterisation surveys
### Initial radiological inventory

<table>
<thead>
<tr>
<th>PROJECTS</th>
<th>CEA</th>
<th>BELGOPROCESS</th>
<th>ENRESA</th>
<th>SCK-CEN</th>
<th>EWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial radiological inventory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical documentation and structure analysis</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Identifying process (pumpage, storage, filtration... and type of contamination: liquid, gas...)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Not available</td>
<td>X</td>
</tr>
<tr>
<td>Operation reports</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Not available</td>
<td>X</td>
</tr>
<tr>
<td>Operator logbooks, procedures/note, radiological controls results</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Not available</td>
<td>X</td>
</tr>
<tr>
<td>Drawings (new and old)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Not available</td>
<td>X</td>
</tr>
<tr>
<td>Operators interview</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Surfaces classification</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical calculation (activation)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

#### In situ measurements

<table>
<thead>
<tr>
<th>PROJECTS</th>
<th>CEA</th>
<th>BELGOPROCESS</th>
<th>ENRESA</th>
<th>SCK-CEN</th>
<th>EWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

#### Sampling and analysis

<table>
<thead>
<tr>
<th>PROJECTS</th>
<th>CEA</th>
<th>BELGOPROCESS</th>
<th>ENRESA</th>
<th>SCK-CEN</th>
<th>EWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core drilling sampling</td>
<td>X(4)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Scarifying sampling (scabbing, shaving,...)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Other sampling technique</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling plan based on feedback (suspected zones, “hot” spots...)</td>
<td>X(3)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Statistics tools for sampling plan</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geostatistics tools for sampling plan</td>
<td>X(1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma spectrometry (on samples)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hard measure nuclides (C-14, H-3, Fe-55, Ni-63...) analysis</td>
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<td>Gamma scanning (core drilling)</td>
<td>X(10)</td>
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#### Review and evaluation of the data obtained

<table>
<thead>
<tr>
<th>PROJECTS</th>
<th>CEA</th>
<th>BELGOPROCESS</th>
<th>ENRESA</th>
<th>SCK-CEN</th>
<th>EWN</th>
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<tbody>
<tr>
<td>Database (compilation of all results)</td>
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<tr>
<td>Statistics tools</td>
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<tr>
<td>Geostatistics tools</td>
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<td>X(1)</td>
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<tr>
<td>Modelling (equation based on results)</td>
<td>X(6)</td>
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<tr>
<td>Reuse of other decommissioning project feedback</td>
<td>X(9)</td>
<td>X(2)</td>
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*OECD/NEA 2011*
### Final radiological survey

<table>
<thead>
<tr>
<th>TECHNIQUE</th>
<th>CEA</th>
<th>BELGOPROCESS</th>
<th>ENRESA</th>
<th>SCK-CEN</th>
<th>EWN</th>
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<tbody>
<tr>
<td><strong>In situ measurements</strong></td>
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<td>Dose rate measurement</td>
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<td>Loose contamination measurement</td>
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<tr>
<td>Surface counting (beta emitters)</td>
<td>X(8)</td>
<td>X(3)</td>
<td>X(2)</td>
<td>X(1)(3)</td>
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<tr>
<td>Surface counting (alpha emitters)</td>
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<td>X(1)(3)</td>
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<td>Gamma spectrometry measurement</td>
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<td><strong>Sampling and analysis</strong></td>
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<td>Core drilling sampling</td>
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<td>X(1)</td>
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<td>Scarifying sampling (scabbling, shaving...)</td>
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<td>X(3)</td>
<td>X(3)</td>
<td>X(1)</td>
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<tr>
<td>Sampling plan based on feedback (suspected zones, &quot;hot&quot; spots...)</td>
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<td>X(1)(1)</td>
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<td>Statistics tools for sampling plan</td>
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<td>X(1)</td>
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</table>

Melusine

1. Only if surface counting was positive.
2. Only for singularities.
3. On hot spots, to define contamination depth.
4. In activated concrete and contaminated cracks.
5. Only for testing this method of extrapolation, but not enough samples.
6. Tested for superficial liquid contamination. Without success. Impossible to find a standard migration equation for all category 2 surfaces.
7. 1 sample per 10 m² and a minima 1 sample per surface (roof, wall...) – Only on activated and in-depth contaminated surfaces – Gamma spectrometry (+ Tritium on activated surfaces).
8. Statistical or 100% depending on the initial surface’s category – Norm NF ISO TR 8550.
9. For a first activation assessment (Triton’s feedback) and to define the maximum contamination depth in the category 2 surfaces (Brennilis Feedback).
10. In order to define the sampling location on the core drilling (activated concrete). Give the profile of activation but not the specific activity.
Annex 8: Return of experience related to radiological characterisation surveys

DECONTAMINATION AND DISMANTLING OF RADIOACTIVE CONCRETE STRUCTURES

(1) in test.
(2) To define the maximum contamination depth in the category 2 surfaces (bibliography on alpha contamination migration).
(3) Final survey not yet performed.

Brennus

(1) Only if surface counting was positive
(2) Statistic or 100% depending on the initial surfaces’s category – Norm NF ISO TR 8550.
(3) Gamma camera in room 901.

BR3

(1) ISOCS, NaI
(2) Hammering
(3) Gamma scanning before laboratory analysis
(4) ISOCS
(5) Thin wall cylindrical Geiger Müller for high energy β emitters (Co60, Cs137).
(6) For operational conditions

RELGOPROCESS

(1) Final survey for the main process building corridors: 1 independent measurement on 100% of surfaces + sampling.
(2) Final survey for main process building cells; 1 independent measurement on 100% of surfaces + a third random control measurement + core samples (sampling frequency meets the prevailing standards).
(3) Final survey for the storage building: 2 independent measurements on 100% of surfaces + a third random control measurement + core samples on the previously most contaminated spots (gamma spectrometry + total alpha + beta analysis).
(4) Too high background.

PIMIC & VANDERLOOS

(1) MAKSIM method.

KKR

(1) planed.
(2) Not yet defined.