Co-operative Programme for Exchange of Scientific and Technical
Information Concerning Nuclear Installations Decommissioning Projects

Decontamination Techniques Used in Decommissioning Activities

A Report by the
NEA Task Group on Decontamination

NUCLEAR ENERGY AGENCY
ORGANISATION FOR THE ECONOMIC CO-OPERATION AND DEVELOPMENT

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INTRODUCTION

Decontamination is a major decommissioning activity that may be used to accomplish several goals, such as reducing occupational exposures, limiting potential releases and uptakes of radioactive materials, permitting the reuse of components, and facilitating waste management. The decision to decontaminate should be weighed against the total dose and cost. This document presents both proven and emerging techniques which may be used to accomplish the goals stated above. The planner must familiarise himself or herself with these techniques to integrate decontamination with other decommissioning activities.

At its thirteenth meeting on October 20-23, 1992, in Rome, the Technical Advisory Group of the NEA Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installations Decommissioning Projects established a Task Group on Decontamination in order to prepare a state-of-the-art report on decontamination in connection with decommissioning. The work focused on decontamination for dose reduction as well as for waste decategorisation or for conditional or unconditional release of materials. The decontamination of both metallic and concrete surfaces was considered.

During its early meetings, the group developed a questionnaire, which was sent to decommissioning project managers. The information requested in this questionnaire covered the technical and economical aspects of the selected decontamination techniques. Project managers were asked to complete a separate questionnaire for each specific application of a given process, including actual data on the efficiency of the process as well as data on operating and investment costs.

This overview of decontamination techniques is intended to describe some of the critical elements involved in choosing techniques to address practical decontamination problems.

This overview of decontamination techniques is based on the results of the previously-mentioned questionnaire, which was received, reviewed and summarised for this report by the Task Group. The information presented here is not exhaustive, but does represent the state-of-the-art, for the techniques mentioned, as of June 1998. This overview is intended to describe some of the critical elements involved in choosing techniques to address practical decontamination problems.

Chapter 1

DEFINITION AND GENERAL CONSIDERATIONS

Decontamination is defined as the removal of contamination from surfaces of facilities or equipment by washing, heating, chemical or electrochemical action, mechanical cleaning, or other techniques. In decommissioning programmes, the objectives of decontamination are:

- to reduce radiation exposure;
- to salvage equipment and materials;
- to reduce the volume of equipment and materials requiring storage and disposal in licensed disposal facilities;
- to restore the site and facility, or parts thereof, to an unconditional-use condition;
- to remove loose radioactive contaminants and fix the remaining contamination in place in preparation for protective storage or permanent disposal work activities; and
- to reduce the magnitude of the residual radioactive source in a protective storage mode for public health and safety reasons, to reduce the protective storage period or to minimise long-term monitoring and surveillance requirements.

Some form of decontamination is required in any decommissioning programme, regardless of the form of the end product. As a minimum, the floor, walls, and external structural surfaces within work areas should be cleaned of loose contamination, and a simple water rinsing of contaminated systems may be performed. The question will arise, however, whether to decontaminate piping systems, tanks and components.

A strong case may be made in favour of leaving adherent contamination within piping as well as components in a dispersed form on the internal metal surfaces rather than concentrating the radioactivity through decontamination. In most cases, decontamination is not sufficiently effective to allow unconditional release of the item without further treatment after dismantling. Therefore, savings both in occupational exposure and cost could be achieved by simply removing the contaminated system and its components and only performing certain packaging activities (*e.g.,* welding end caps on pipe sections, using adequate equipment to cut and crimp smaller piping to reduce chances of airborne activity). However, additional cost for the disposal of materials must be weighed in this scenario.

A decontamination programme may also require a facility capable of treating secondary waste from decontamination (*e.g.,* processing chemical solutions, aerosols, debris, etc.) The concentrated waste, representing a more significant radiation source, must be solidified and shipped for disposal in licensed disposal facilities unless properly treated in the waste reduction/recycling/ reclamation processing alternative. The optimal waste reduction configuration must be defined after an economic assessment of treatment *versus* transportation/disposal costs has been completed. Each of these additional activities may increase:

- occupational exposure rates;
- the potential for a release;
- the uptake of radioactive material.

These could conceivably result in even higher doses than those received from removing, packaging and shipping the contaminated system without extensive decontamination. Resolution of this question depends on specific facts, such as the exposure rate of the gamma-emitting contamination, the contamination level , and the effectiveness of the containing component and piping (wall thickness) in reducing radiation fields in the work area.

Chapter 2

OBJECTIVES AND SELECTION CRITERIA

2.1 Objectives of decontamination technologies for decommissioning

There are three main reasons for considering the use of decontamination techniques.

The first reason is the importance of removing contamination from components or systems to reduce dose levels in the installations. Access to the installations could then be made easier so that it becomes possible to use hands-on techniques for dismantling rather than the more expensive use of robotics or manipulators.

A second reason is to minimise the potential for spreading contamination during decommissioning activities, especially when dealing with systems containing highly radioactive particles and actinides.

The third reason is that it may be possible to reduce the contamination of components or structures to such levels that they may be disposed of at a lower, and therefore more economical, waste treatment and disposal category or, indeed, be unconditionally released for recycling or reuse in the conventional industry or disposed of as waste exempt from regulatory concern.

Several decontamination techniques have been developed to support maintenance work in nuclear installations. With relative success, the same techniques have also been adopted when decommissioning nuclear installations and components (Table 1). Objectives differ between these applications, however.

In maintenance work, the highest degree of decontamination is sought, avoiding any damage to the component so that it may be adequately reused. In contrast, the main aim of decontamination for decommissioning is the removal of as much activity as possible, not only to decategorise waste, but to reach clearance levels so that the material from the system may be reused without radiological restrictions. In many cases, it will be necessary to remove all oxides liable to trap contaminants, as well as a thin layer of structural material in order to achieve this aim. The radionuclides indeed tend to concentrate in the intergranular regions, together with other impurities accumulated during the growth of the metal grains. Therefore, much more aggressive decontamination methods are required than those used during the service life of a plant. In this view, technical methods presenting high decontamination factors at high contamination levels do not always allow achievement of the very low levels required to release the material (*e.g.*, inner surfaces of piping), without restrictions, provided that measurement of these very low levels is feasible.

During decontamination for maintenance, components and systems may not be damaged and the use of very aggressive decontamination methods is not appropriate. In decontamination for decommissioning, however, it is mainly the use of somewhat destructive techniques that present the possibilities of meeting the objectives to release the material at clearance levels.

Table 1. DECONTAMINATION FOR DECOMMISSIONING

° Decontamination before Dismantling • Reduction of Occupational Exposure	Pipe Line System Decontamination	Chemical Method Mechanical Method
	Pool, Tank	Hydro Jet Method Blast Method Strippable Coating Method, etc.
° Decontamination after Dismantling • Recycle of Contaminated Metal • Reduction of Radioactive Waste	Pipes, Components	Electropolishing Method Chemical Immersion Method Blast Method Ultrasonic Wave Method Gel Method
° Decontamination of Building • Unconditional Release of Building • Reduction of Radioactive Concrete Waste	Concrete Surface	Mechanical Method * Scabbler * Shaver * Drill & Spawling * Steel Grit Blast Thermal Stress Method * Microwave Irradiation * Flame Scarfing

Another aspect in which techniques for thorough decontamination of materials differ from maintenance or laboratory scale decontamination is the need for industrialisation. The large amount of contaminated materials produced during decommissioning procedures and available for decontamination, generally do not favour methods or techniques that are labour intensive or difficult to handle, or that present difficulties when automation is envisaged. The latter is also true in the case of full-system decontamination for maintenance.

Other factors presenting differing influences on the choice of techniques are, for example, secondary-waste production and the possibilities to recycle products from decontamination processes. For both decontamination for maintenance and decontamination for decommissioning, these may be among the parameters for decision-making.

The absolute requirement to obtain effectively residual contamination levels that prove to be below clearance limits is also a factor of primary influence when making the choices of decontamination techniques to be used. Even if techniques for the decontamination of complex geometries (*e.g.*, pipe bends, small diameter piping) exist, the non-accessibility of areas may prevent direct radiological measurements being used to show that the clearance levels are met.

Presently, the interest of the nuclear industry is moving from decontamination techniques for maintenance to decontamination for decommissioning. Limited data are available from decommissioning on the efficiency of usable techniques to meet the low unconditional-release criteria. In most cases, using available techniques, the clearance levels are only met in an asymptotic way. Not all methods and techniques available present the possibility of decontaminating to below the required clearance levels. So, in some cases, decontamination is carried out in different stages, the last step specifically aiming to obtain the required objectives.

Based on these considerations, when selecting a specific technique for system and/or component decontamination, mainly the following requirements must be considered:

- **Safety** – The application of the method should not result in increased radiation hazards due to external contamination of workers or even inhalation of radioactive dust and aerosols formed during its implementation; it should not add other hazards *(e.g.,* chemical, electric, etc.).
- **Efficiency** – The method should be capable of removing radioactivity from a surface to the level which would enable hands-on work instead of robotics, or which would permit recycle/reuse of material or, at least, a lower waste treatment and disposal category.
- **Cost-effectiveness** – Where possible, equipment should be decontaminated and repaired for reuse; however, the method should not give rise to costs which would exceed the costs for waste treatment and disposal of the material, whether including replacement of the equipment or not.
- **Waste minimisation** – The method should not give rise to large quantities of secondary waste, the treatment and disposal of which would result in excessive requirements for workpower and costs, thereby causing additional exposures.
- **Feasibility of industrialisation** – Due to the large quantities of contaminated materials involved, methods or techniques should not be labour-intensive, difficult to handle, or difficult to automate.

2.2 Selection of decontamination technologies for decommissioning

Very early in the process of selecting decontamination technologies for decommissioning, it is important that a cost/benefit analysis be performed to see if it is actually worth decontaminating the component or facility, or to determine whether a mild decontamination at low cost is more advantageous than an aggressive decontamination at a higher cost. This analysis is usually accompanied by extensive experimental work on selected samples from the facility in view of characterisation before the final choice of a decontamination technique is made.

To achieve a good decontamination factor (DF), a decontamination process must be designed for site-specific application taking into account a wide variety of parameters, some of which are listed below:

- type of plant and plant process: reactor type, reprocessing plant, etc.;
- operating history of the plant;
- type of material: steel, zircaloy, concrete, etc.;
- type of surface: rough, porous, coated, etc.;
- type of contaminant: oxide, crud, sludge, loose, etc.;
- composition of the contaminant (*i.e.*, activation products, fission products, actinides, etc.), and the specific radionuclides involved;
- ease of access to areas/plant to be decontaminated, external or internal surfaces to be cleaned;
- regulatory requirements and decontamination factor required;
- destination of the components being decontaminated: disposal, reuse, etc.;
- time required for application;
- proven efficiency of the process for the type of contamination in the facility;
- type of component: pipe, tank, etc.

Other factors which are important in selecting the method, but which do not affect the decontamination factor are:

- availability, cost and complexity of the decontamination equipment and consumables;
- need and capability of treatment and conditioning of the secondary waste generated;
- potential exposure to hazardous materials and/or chemicals used in the decontamination process;
- occupational and public doses resulting from decontamination (justification of the practice);
- other safety, environmental and social issues;
- availability of trained staff;
- extent to which the plant needs to be decontaminated to achieve acceptable conditions for decommissioning;
- salvage value of materials which would otherwise be disposed of;
- extent to which the facility must be modified to do the decontamination: isolate systems, enclosed and ventilated spaces, etc.

In addition, the choice of a process or of a combination of several processes will finally depend on several other factors such as:

- the specific nature of the application, the complexity of the system;
- the feasibility of industrialisation;
- the cost/benefit analysis taking into account all aspects of the decontamination operation, *i.e.*, until disposal of remaining radioactive waste.

The decision whether to proceed with decontamination and the final process selected will depend on the best overall balance of the above factors in order to minimise the overall impact of the decommissioning activities on workers, the public and the environment at acceptable costs.

Chapter 3

SURVEY OF APPLIED DECONTAMINATION TECHNIQUES

As indicated previously, the NEA Task Group on Decontamination was created in order to review the existing decontamination techniques and their application in the framework of the dismantling of nuclear installations. One of its objectives was also to prepare a state-of-the-art report on decontamination in connection with decommissioning, and of describing critical elements of choosing techniques for a practical decontamination problem. The work has been focused on decontamination for dose reduction as well as for waste decategorisation. The decontamination of both metallic and concrete surfaces has been considered.

To achieve its goal, the Task Group developed a questionnaire which was sent to decommissioning project managers and customers of decontamination techniques who have applied decontamination processes in a radioactive environment. As indicated in Annex 2, the information requested in this questionnaire covered both the technical and economical aspects of the selected decontamination techniques. Project managers and customers were asked to complete a separate questionnaire for each specific application of a given process, including actual data on the efficiency of the process and data on operating and investments costs.

A list of processes has been identified as being of interest for decontamination (Table 2). For decontamination of metals, the processes are divided into chemical, electrochemical and physical processes. Moreover, a distinction has been made between the processes used in closed systems (*e.g.,* full-system decontamination of the primary circuit of a reactor or the partial decontamination of closed loops), and the processes used in open tanks (*e.g.,* decontamination of dismantled pieces). For the decontamination of concrete, surface-decontamination processes and demolition processes have been selected.

An extensive and detailed overview of the acquired data on decontamination techniques for decommissioning, resulting from the survey carried out, is given in Annex 3. It presents a comprehensive list of real-case examples for various decontamination techniques and processes applied in decommissioning.

Based on the information gathered, some specific characteristics of selected decontamination techniques for segmented components and for building surfaces are discussed in the following sections. In addition, some critical elements of choosing techniques for a practical decontamination problem are mentioned.

It should be pointed out that the information presented is not exhaustive. In addition, practical experience in decontamination has shown that a universal decontamination process does not exist. As such, future users should familiarise themselves with the characteristics of proposed techniques, in order to make adequate choices based on specific requirements and thorough case studies.

Table 2. **Overview of decontamination processes for decommissioning**

METAL DECONTAMINATION	**Closed systems**	**Open systems**
Chemical processes		
• Oxidation processes		
– ODP/SODP	×	
– Cerium/Sulphuric acid		×
– Cerium/Nitric acid		×
• Oxidation-reduction processes		
– APCE/NPOX	×	×
– TURCO	×	×
– CORD	×	×
– CANDEREM, CANDECON		×
– CONAP		×
– AP/NP + LOMI for PWR	×	
– EMMA	×	
• LOMI for BWR	×	
• Phosphoric-acid-based processes		×
• Foams	×	
• Various reagents		
– HNO_3		×
– HNO_3 + HF	×	×
– HNO_3/NaF	×	×
– HCl	×	×
– DECOHA		×
Electrochemical processes		
• Phosphoric acid		×
• Nitric acid		×
• Nitric acid - Electrodeplating		×
• Sodium sulphate - ELDECON Proc.		×
• Oxalic acid		×
• Citric acid		×
• Sulphuric acid		×
• Other electrolytes		×

METAL DECONTAMINATION	**Closed systems**	**Open systems**
Physical processes		
• Ultrasonic cleaning		×
• High pressure water		×
• CO_2 ice blasting		×
• Ice water		×
• Freon substitutes		×
• Abrasives wet	×	×
• Abrasives dry		×
• Grinding/Planing		×
Combined mechanical/Chemical processes		
• Pastes + HP cleaning		×
• Foams/Gels/HP cleaning		×
• Vacuum cleaning (Dry/Wet)		×

CONCRETE DECONTAMINATION	**Surface decont.**	**Concr. demol.**
• Kelly process	×	
• Scabbling	×	
• Sand blasting	×	
• Wet abrasives	×	
• Milling	×	
• Explosives		×
• Microwaves	×	
• Drill/Spalling		×
• Drill/Lime expansion		×
• Jackhammer		×

× : decontamination technique applied for open or closed systems.

Chapter 4

CHARACTERISTICS OF SELECTED DECONTAMINATION TECHNIQUES FOR SEGMENTED COMPONENTS

4.1 General considerations

Simplified overviews of some decontamination techniques in view of their efficiency regarding some selection criteria may be found in the literature. Practical experience indicates that these overviews have to be considered with great care. Small changes in details of application of the selected techniques may have significant impacts on the qualification of influencing parameters. Though the objective of this section is not to provide a detailed overview of all advantages and disadvantages of available techniques, some specific considerations on selected categories of decontamination techniques are described. More detailed information about general applied processes and procedures may be found in Annex 3.

Chemical decontamination uses concentrated or dilute chemical reagents in contact with the contaminated item, to dissolve the contamination layer covering the base metal and eventually a part of the base metal. In most cases, required decontamination levels may be obtained by continuing the process as long as necessary, taking care to ensure that tank walls or piping are not penetrated by corrosion.

In mild chemical decontamination processes, dissolution of the contamination layer is envisaged, but the process should be non-destructive to the base metal and is generally used for operating facilities. Aggressive chemical decontamination techniques involving dissolution of the base metal should only be considered in decommissioning programmes where reuse of the item will never occur. Chemical flushing is recommended for remote decontamination of intact piping systems.

Chemical decontamination has also proven to be effective in reducing the radioactivity of large surface areas such as drip trays as an alternative to partial or complete removal. They are also suitable for use on complex geometries as well as for a uniform treatment of inner and outer pipe surfaces. These techniques, however, require efficient recycling of reactive chemicals. Insufficient recycling of decontamination products results in very large amounts of secondary waste which are difficult to treat and increase costs.

Electrochemical decontamination may be considered in principle to be a chemical decontamination assisted by an electrical field. It may be considered the opposite of electroplating as metal layers are removed from a surface rather than added as a coating.

Electrochemical decontamination has been applied by immersion of the contaminated item in an electrolyte bath or by passing a pad over the surface to be decontaminated. The electric current causes the anodic dissolution and removal of metal and oxide layers from the component. The electrolyte is continuously regenerated by recirculation.

These processes may only be applied to conducting surfaces. They are highly effective and give a high decontamination factor. Their use is limited:

- when immersion is used, by the size of the bath, and
- when a pad is used, by the geometry of the surfaces and the available clearance around the part being treated.

This makes the method almost inapplicable for industrial decontamination of complex geometries (*e.g.,* pipes, valves, pumps, etc.). The volume of effluents may be limited. However, handling the parts to be immersed or the pad may lead to additional exposure to workers.

Decontamination by melting presents the particular advantage of homogenising a number of radionuclides in the ingots and concentrating other radionuclides in the slag and filter dust resulting from the melting process, thus decontaminating the primary material.

Melting may provide an essential step when releasing components with complex geometries, simplifying monitoring procedures for radioactive metal characterisation. In addition to the decontamination effects of melting, the problem with inaccessible surfaces is eliminated, and the remaining radioactivity content is homogenised over the total mass of the ingot.

Therefore, melting may be a last step in the decontamination and release of components with complex geometries after they have been decontaminated, for example, by chemical methods which remove radionuclides, such as cobalt-60. It should be noted that cobalt-60 originating from activation of the base metal will remain in the ingot after melting.

Mechanical and manual decontamination are physical techniques. More recently, mechanical decontamination has included washing, swabbing, foaming agents, and latex-peelable coatings. Mechanical techniques may also include wet or dry abrasive blasting, grinding of surfaces and removal of concrete by spalling or scarifying. These techniques are most applicable to the decontamination of structural surfaces. Some of them are also applicable to non-metallic surfaces, such as plastics.

Abrasive blasting systems, both wet and dry, have been used with success. They provide mechanical methods, derived from the conventional industry, that give very high decontamination factors. The longer the operations are continued, the more destructive they are. However, wet abrasive systems produce a mixture of dust and water droplets that might be difficult to treat. Care must be taken not to introduce the contamination into the material surface (hammering effect) in order for the ability to meet clearance levels not to be jeopardised. These techniques are not appropriate for complicated surfaces where uniform access may not be guaranteed.

In recent years, many **innovative decontamination techniques** have been proposed in the framework of radioactive waste management research and development programmes. For the most part, these emerging technologies are hybrid technologies comprising one or more of the following methods: chemical, electrochemical, biological, mechanical, laser or sonic methodologies. These innovative techniques are described in the literature.

4.2 Chemical decontamination

4.2.1 General considerations

Chemical decontamination is usually carried out by circulating the selected reagents in the system. However, segmented parts may be decontaminated by immersing them in a tank containing the reagent, which is then mostly agitated. Application of specific chemical decontamination depends on many factors, *e.g.,* shape and dimensions of the item to be decontaminated, kind and nature of the chemical reagents, type of material and contamination, availability of proper process equipment, etc.

Many chemical reagents and techniques have been developed for the routine decontamination of systems during operation and decommissioning of nuclear facilities. Chemical decontamination processes are basically divided into two groups. Mild chemicals include non-corrosive reagents such as detergents, complexing agents, dilute acids or alkalis. Aggressive chemicals include concentrated strong acids or alkalis and other corrosive reagents. The dividing line between these two groups of processes is usually at about 1 to 10-per-cent concentration of the active reagent.

Mild chemical decontamination techniques have generally been used for items where the objective is to remove contamination without attacking the base material. Their advantages are low corrosion rates and low chemical concentrations which facilitate the treatment of the spent decontamination solutions (secondary waste). Although some low-concentration decontamination techniques have low decontamination factors and require long contact times, they may be made more effective by combining with processes using non-corrosive oxidising or reducing agents, and complexing and chelating agents, and applying them in several stages. In many cases, the effectiveness may also be improved by increasing the treatment temperature usually in the range of 20 to 90°C. The selection of redox and chelating agents will depend on the composition of the surface corrosion products to be removed. Descriptions of different low-concentration decontamination techniques may be found in many publications.

Aggressive chemical and electrochemical decontamination techniques may involve one or more stages using different chemical solutions. Intermediate rinses are recommended in order to avoid potential problems with recontamination. The advantages of the process include short-time application and high decontamination factors (usually 10:1 to 100:1 decrease in activity levels). Its limitations include high chemical concentrations and potential problems for effluent-treatment systems.

A multistep process (*i.e.,* the application of a strongly oxidising solution followed by a complexing acid solution) is a common technique for removal of the contaminated oxide layer from metal surfaces, such as stainless steel. The first (alkaline) stage is intended to oxidise the chromium oxides to yield soluble chromate ions. The second (acid) stage is primary a dissolution reaction for the complexing of dissolved metals.

Alkaline permanganate solutions are the most common reagents used at the first stage. At the second stage a variety of reagents such as ammonium citrate, ammonium citrate followed by EDTA, oxalic acid, a mixture of citric and oxalic acid, sulphuric acid, etc., have been used successfully for various applications for the decontamination of stainless steel, carbon steel, inconel, zircaloy cladding, etc. Sulphuric, phosphoric, hydrochloric, hydrofluoric acids and other reagents have been successfully used separately as individual aggressive decontaminants, generally at concentrations from 2 to 15 per cent. The required decontamination level may necessitate repeating the process a number of times. Care must be taken if the dissolution process might result in unacceptable surface corrosion, *e.g.,* where direct reuse of an item is required. Chemical techniques are generally suitable for use on complex geometries as well as for uniform treatment of inner and outer surfaces of equipment, particularly where good contact between the chemical and the surface is provided, (*e.g.,* tank immersion).

Factors considered for in-line chemical decontamination are also valid for the immersion process. However, because the tanks are usually open at the top, a proper ventilation system must be installed, and special care must be taken to avoid contact between the operators and the highly corrosive reagents. It should be noted that chemical reagents at excessively high temperatures may result in undesirable effects, such as toxic or explosive gases, *e.g.,* hydrogen.

Chemical decontamination requires efficient recycling of reactive chemicals, as insufficient recycling of decontamination products may increase the amount of secondary waste which may be difficult to treat. It may generate mixed waste, and it may result in corrosion and safety problems when misapplied. In addition, it requires both different reagents for different surfaces, and drainage control. For large jobs, it generally requires constructing a chemical storage and collecting equipment as well as addressing criticality concerns, where applicable. Chemical decontamination is usually not effective on porous surfaces.

In general, knowledge of chemical cleaning methodology is a prerequisite for assessing decontamination technology as most of the procedures and chemicals used to decontaminate nuclear materials and equipment were also used for cleaning equipment and materials in the chemical processing industry. Both chemical cleaning and decontamination require the same areas of knowledge and experience: chemistry of fouling, corrosion technology, and waste-generation/removal techniques. Furthermore, the same engineering knowledge is required to devise suitable procedures for mixing, pumping, as well as heating solvents and other chemical-cleaning constituents. Compliance with basic health and safety practices regarding chemical agents is required, in addition to the radiological safety aspects. As a minimum, workers should go through a training programme and be equipped with glasses, full-body protective coveralls, impermeable gloves and foot covers. Additional safety equipment depends on the toxicity of contaminants.

4.2.2 Chemical reagents

For decommissioning programmes, there is a wide range of chemical reagents to choose from, since corrosion of the base metal is of little concern. Certain chemical reagents exhibit a time dependency in the mixing, heating, recirculation and draining cycle, which affects both the chemical solution stability and the solubility of contained contamination. Each process under consideration should be evaluated for the effect of a loss-of-flow accident and associated cooling of the solvent. Factors considered would include toxic or explosive-gas generation, excessive plate-out and excessive corrosion. The selected process must include appropriate emergency procedures, *e.g.*, emergency draining, gas detection, and emergency ventilation.

When the concentration of the contaminants in the solution increases during the decontamination process, the item being cleaned may become recontaminated. This problem may be minimised by cleaning the least contaminated items first and by cleaning or replacing (recycling if possible) the solution, if the concentration of contaminants exceeds certain levels.

Some multistep processes are commonly used for removing highly adhesive contamination layers. In many cases, chemical decontamination may be used as one step in a multistep process (*e.g.,* before electropolishing), items covered with thick oxide layers are submitted to chemical decontamination in order to reduce the oxide coatings.

4.2.3 Spent decontamination solutions

The selection of the chemical reagent obviously determines the chemical characteristics of the secondary waste arising from the process. Continuously renewing the solution increases the decontamination effectiveness, but the quantity of spent solution to treat and to dispose of also increases dramatically. In more recent years, the regeneration of chemicals has become a fundamental part in all chemical decontamination processes. Several conventional chemical processes may be used for regenerating the spent solutions, eventually in combination with, for example, ion exchange, evaporation/distillation, and electrodialysis.

The problem of limiting the secondary waste arising from the decontamination process may result in the selection of other similar processes like electropolishing or ultrasound using chemicals, rather than solely chemical decontamination. As stated previously, only a detailed cost/benefit analysis may provide the actual criteria for selecting the best option for a specific decontamination task.

4.2.4 Guidelines for selecting appropriate chemical decontamination techniques

When selecting a suitable chemical decontamination process, in addition to the general considerations given in Section 2.2 and in view of the variety of chemical decontamination processes available, several criteria must be considered in a detailed analysis based on site-specific conditions. Most of the criteria are related to the specific features of a nuclear installation, such as:

- location of the contamination (*e.g.*, inner *versus* outer surfaces of closed systems);
- physical integrity status of the systems;
- materials (*e.g.*, steel, concrete);
- history of operation (to determine contamination-strata profile);
- nature of the contamination (*e.g.*, oxide, crud, particulate, sludge);
- effectiveness of previously used chemical decontamination processes;
- distribution of contamination (*e.g.*, surface, cracks, homogeneous distribution in bulk material);
- exposure to humans and the environment;
- safety, environmental, and social issues;
- exposure-level-reduction requirements (*e.g.*, recycling *versus* disposal);
- quantity and type of secondary waste from decontamination and conditioning;
- ultimate fate of decontaminated materials;
- time;
- costs.

Taking into account the general considerations presented in these sections on chemical decontamination, an overview of the main advantages and disadvantages of this technique is provided for the selection of the most appropriate technique.

Advantages

- Chemical decontamination is relatively simple and similar to classical cleaning in the conventional industry for which a lot of experience exists. It may also be relatively inexpensive where additional equipment is not required.
- Chemical decontamination is a known practice in many nuclear plants and facilities.
- With proper selection of chemicals, almost all radionuclides may be removed from contaminated surfaces. Problems of recontamination may be reduced by continuously rinsing the surface with water.
- With strong mineral acids, a decontamination factor of more than 100:1 decrease in activity levels may be achieved, and in many cases, the item may be decontaminated up to releasable levels.
- Chemical decontamination may also remove radioactivity from internal and hidden surfaces. However, in this case, its effectiveness may be low, and measurement at release levels will be a problem.
- Chemical decontamination involves relatively minor problems of airborne contamination, similar to those of the closed-system approach.

Disadvantages

- The main disadvantage of chemical decontamination is the generation of secondary liquid waste, resulting in relatively high volumes compared to other processes, such as electropolishing. The treatment and conditioning of this secondary waste requires appropriate processes to be considered when selecting the decontamination option. Moreover, in some cases (*e.g.*, internal and hidden surfaces), the effectiveness of the decontamination may be relatively low.

- Usually the solution must be heated up to 70 to 90°C in order to improve the kinetics of the decontamination process.
- A further disadvantage in obtaining high decontamination factors is that corrosive and toxic reagents may need to be handled.
- Chemical decontamination is mostly not effective on porous surfaces.

4.3 Electrochemical decontamination

4.3.1 General considerations

Electrochemical decontamination may be considered in principle to be a chemical decontamination assisted by an electrical field. Electropolishing is a process widely used in non-nuclear industrial applications to produce a smooth polished surface on metals and alloys. It may be considered the opposite of electroplating as metal layers are removed from a surface rather than added as a coating.

Electrochemical decontamination uses direct electric current, which results in the anodic dissolution and removal of metal and oxide layers from the component. The dissolution may be conducted by immersing items to be decontaminated in an electrolyte bath as anode or fitted with anodes. This method is useful for decontaminating items with easily-accessible surfaces. Current may also be delivered to a submerged component by moving a pad over the surface to be decontaminated, as an efficient method for regular surfaces. The electrolyte is continuously regenerated by recirculation.

For in-tank electropolishing, at least two (stainless steel) tanks are required. One tank contains the electrolyte, electrodes and parts to be decontaminated. The other tank holds the water used for rinsing the parts after decontamination. Power supply amperages of up to 2,700 A are common. To control vapours released from the electrolyte during the electropolishing process, an extraction hood is located alongside the electropolishing tank. Provisions for heating and agitating the electrolyte as well as rinsing the tank are also required.

Electrochemical decontamination processes may only be applied for removing radionuclide contamination from conducting surfaces, such as iron-based alloys (including stainless steel), copper, aluminium, lead and molybdenum. They are highly effective and give a high decontamination factor. Important operating parameters for electrochemical decontamination are electrolyte concentration, operating temperature, electrode potential and current density.

The effectiveness of the decontamination may be limited by the presence of adhering materials on the surface of the items to be decontaminated. Materials such as oil, grease, oxides (rust) and paint or other coatings should be removed before decontamination. The use of electrochemical decontamination is limited:

- when immersion is used, by the size of the bath, and
- when a pad is used, by the geometry of the surfaces and the available free space around the part being treated.

This makes the method almost inapplicable for industrial decontamination of complex geometries (*e.g.*, small-diameter pipes).

4.3.2 Chemical reagents

Phosphoric acid is normally used as electrolyte in electropolishing because of its stability, safety and applicability to a variety of alloy systems. Moreover, the non-drying nature of phosphoric acid helps minimise airborne contamination, and the good complexing characteristics of phosphoric acid for metal ions is a significant factor in minimising recontamination from the electrolyte.

Other electrolytes, as nitric acid and sodium sulphate have been investigated and proposed as alternatives to phosphoric and sulphuric acid. The need for new electrolytes was initially motivated by the incompatibility of phosphoric and sulphuric acids with the existing treatment facilities and the possibility of producing secondary liquid waste which is more easy to process or regenerate. Today, problems associated with the treatment of secondary liquid waste have only partly been resolved.

4.3.3 Secondary-waste generation

Electrochemical decontamination by electropolishing causes a steady increase of dissolved iron in the phosphoric acid. If the iron content exceeds 100 g/dm^3, a precipitation of iron phosphate occurs and stops the efficiency of the decontamination process. Therefore, the acid has to be exchanged or regenerated periodically. In doing so, the volume of effluents is limited; however, handling the parts to be immersed or the pad, may lead to additional exposure to workers.

4.3.4 Guidelines for selecting appropriate electrochemical decontamination techniques

When selecting a suitable electrochemical decontamination process, criteria must be considered in a detailed analysis based on site-specific conditions. These are similar to the criteria mentioned in Sections 2.2 and 4.2.4, but taking into account that electrochemical decontamination processes require conducting surfaces.

From the general considerations presented in the foregoing sections on electrochemical decontamination, some main advantages and disadvantages of this technique may be indicated to allow selection of the most appropriate technique.

Advantages

- Electropolishing is commercially available. Major equipment is relatively inexpensive and process and processing procedures fairly simple. It is capable of decontaminating to background levels for decommissioning purposes, removing practically all radionuclides covering the surface, including plutonium, uranium, radium, cobalt, strontium, caesium and americium, giving typically decontamination factors of more than 100:1 decrease in activity levels.
- Electropolishing may decontaminate flat areas, corners, recessed geometries, tanks, etc., where measurement up to release levels do not cause any problem. It produces a smooth polished surface with a low inherent ability to be recontaminated. The thickness of metal removed during decontamination is generally less than 25 µm.
- When compared to the volume of liquids required for chemical decontamination, electrolyte volumes for electrode contamination are relatively low.

Disadvantages

- For the most widely used process (*i.e.,* in-tank), the item to be decontaminated must be removed from the plant and immersed in the tank with electrolyte. For the *in-situ* process, access or entry for the device into the item to be decontaminated is required. Therefore, the use of electrochemical decontamination is limited by the size of the bath, when immersion is used, and by the geometry of the surfaces and the available free space around the part being treated, when a pad is used. This makes the method less applicable for industrial decontamination of complex geometries(*e.g.,* small diameter pipes).
- The treatment of the electrolyte for disposal (if not recyclable) requires neutralisation and processing in a treatment system for liquid radioactive waste.

- Electropolishing does not remove (or removes with difficulty) fuel fines, sludge or any insulating material from the surfaces.
- Hidden parts as the inside of tubes are treated poorly.
- Handling of components may lead to additional exposure to workers.

4.4 Mechanical decontamination

4.4.1 General considerations

Mechanical decontamination methods may be classified as either surface cleaning (*e.g.,* sweeping, wiping, scrubbing) or surface removal (*e.g.,* grit blasting, scarifying, drilling and spalling). Mechanical decontamination may be used either as an alternative to chemical decontamination, or simultaneously with chemical decontamination or in sequence with chemical decontamination.

In general, mechanical decontamination methods may be used on any surface and achieve a very good result. When these methods are used in combination with chemical methods, an even better result may be achieved. Moreover, when dealing with porous surfaces, mechanical methods may be the only choice.

There are two basic disadvantages with the mechanical methods. First, the methods require the surface of the workpiece to be accessible (*i.e.,* the workpiece should generally be free of crevices and corners that the process equipment cannot easily or effectively access). Second, if no necessary precautions are taken, many methods may produce airborne dust. If contamination is a concern, this requires that a containment is provided to maintain worker health and safety and to prevent the spread of contamination.

As with chemical decontamination, the selection of the most effective technique depends on many variables, such as the contaminants involved, surface material and cost. The selected treatment may have to be applied several times to meet the established decontamination objective. Because each of these techniques may be modified to site-specific conditions, the actual effectiveness and implementability of a technique should be explored in site-specific feasibility studies.

Surface-cleaning techniques are used when contamination is limited to near-surface material. Some techniques may remove thin layers of the surface to remove the contamination. However, these techniques differ from surface-removal techniques in that the removal of the contaminant from the surface is the goal rather than the removal of the surface itself. Certain surface-cleaning techniques generate contaminated liquids that need to be collected and treated. Many surface-cleaning techniques may be used for both equipment and building decontamination, and some surface-cleaning techniques may be used as a secondary treatment following surface removal.

Because these techniques are versatile, it may be advantageous to locate a centralised decontamination facility on site in which one or more of these techniques are used. Such a facility could then be used to decontaminate components that were dismantled in large pieces or segmented.

4.4.2 Abrasive-blasting decontamination systems

Wet and dry abrasive-blasting systems, derived from the conventional industry, may provide very high decontamination factors. The longer the operations are continued, the more destructive they are. Care must be taken not to introduce the contamination into the material surface (hammering effect) in order for the ability to meet clearance levels not to be jeopardised. Wet abrasive systems also produce a mixture of dust and water droplets that might be difficult to treat.

A wet abrasive-blasting system is a closed-loop, liquid abrasive decontamination technique. The system uses a combination of water, abrasive media and compressed air, and is normally applied in a self-contained, leaktight, stainless steel enclosure. There is no danger of airborne contamination, since a self-contained air ventilation system with absolute filter maintains a negative pressure inside the cabinet. Radioactive waste is mechanically separated from the cleaning media (*e.g.,* by cyclone/ centrifuge separation, sieving, etc.). Water may be filtered and recycled, and no soluble or hazardous chemicals are required.

Wet abrasive cleaning is being used in many nuclear facilities to remove smearable and fixed contamination from metal surfaces, such as structural steel, scaffoldings, components, hand tools and machine parts. The equipment may be used on close-tolerance parts, such as turbine blades or valves, where the removal of metal is not desired, or it may be adjusted to remove heavy-duty corrosion and paint by varying the amount of air pressure and abrasive media.

The dry abrasive-blasting technique, commonly called sandblasting or abrasive jetting, has been used in non-nuclear industries since the late 1800s. This technique, which uses abrasive materials suspended in a medium that is projected onto the surface being treated, results in a uniform removal of surface contamination. Compressed-air or blasting turbines are normally used to carry the abrasive. Removed surface material and abrasive are collected and placed in appropriate containers for treatment and/or disposal. Recirculation of abrasives allows the minimisation of secondary waste.

Dry abrasive-blasting is applicable to most surface materials except those that might be shattered by the abrasive, such as glass, transite or plexiglass. Application on aluminium or magnesium should also be avoided due to the risk of dust explosions. It is most effective on flat surfaces and because the abrasive is sprayed, it is also applicable on hard-to-reach areas. Nonetheless, materials such as oil and grease, or obstructions close to or bolted to components must be removed before application, and precautions should be taken to stabilise, neutralise or remove combustible contaminants, because some abrasives may cause some materials to detonate or generate dust explosions.

Static electricity may be generated during the blasting process; therefore, the component being cleaned, or the installation itself, should be grounded. Industrial remotely-operated units are available.

4.4.3 Abrasive media used

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

- minerals (*e.g.,* magnetite or sand);
- steel pellets, aluminium oxide;
- glass beads/glass frit, silicon carbide, ceramics;
- plastic pellets;
- natural products (*e.g.,* rice hulls or ground nut shells);
- carbon dioxide (dry ice, for “cold” oxides, painted surfaces, etc.).

Silica has also been used as an abrasive; however, its use is not recommended since it is moderately toxic as a highly irritating dust and is the chief cause of pulmonary disease. Prolonged inhalation of dusts containing free silica may result in the development of a disabling pulmonary fibrosis known as silicosis.

4.4.4 Secondary waste generation

As indicated previously, abrasives may be applied under either wet or dry conditions. Under dry conditions, dust-control measures are needed to control dusts and/or airborne contamination. This problem may be reduced by using filtered vacuum systems in the work area.

When water is used to apply the abrasive, large volumes of waste are produced including the waste water, the abrasive and the removed debris. Proper treatment and disposal of this waste is necessary. Recirculation of abrasives and recycling of the wastewater (treated or not before reuse) allows a significant reduction of the amount of secondary waste.

Table 3 gives some results on work rates and secondary-waste production during decontamination work carried out with both a dry and a wet abrasive-blasting system at the scale of a pilot project. Water consumption includes washing water to clean components and installation after each decontamination cycle.

Table 3. **Some results of dry and wet abrasive blasting decontamination of metals**

	Dry abrasive blasting	**Wet abrasive blasting**
Efficiency	Very high	Lower
Grit consumption	55 g/kg metal	109 g/kg metal
Secondary-waste production		
– Intervention clothing	5.3%	8.2
– Grit waste	5.5%	10.9%
– Water consumption	–	6.9 1/kg metal
Decontamination rate		
– Plates	57.4 kg/h	48.0 kg/h
	2.8 m^2/h	2.3 m^2/h
– Profiles	127.7 kg/h	106.8 kg/h
	1.8 m^2/h	1.3 m^2/h
Grit cost	0.5 ECU/kg	2.25 ECU/kg

4.4.5 Guidelines for selecting appropriate abrasive-blasting decontamination techniques

When selecting a suitable abrasive decontamination process, again criteria must be considered in a detailed analysis based on site-specific conditions. These criteria are very similar to the criteria mentioned in Sections 2.2 and 4.2.4, taking into account the specific characteristics of the abrasive-blasting decontamination process.

Some main advantages and disadvantages of dry and wet abrasive blasting are provided for the selection of the most appropriate technique.

Advantages

- Generally, abrasive-blasting techniques have proved effective. In many cases, the equipment is well developed and commercially available. Industrial equipment is also available for remote operation.
- Several methods remove tightly adherent material, including corrosion layers. Special tools for cleaning the inside of tanks and pipes are also available.
- The abrasive-blasting technique gives result in a relatively short time.

Disadvantages

- Abrasive-blasting techniques generally produce a large amount of waste, if recirculation and/or recycling of abrasives and/or water is not available. In some cases, it is difficult to control the amount of base metal removed. In dry abrasive systems, dust-control measures are needed to control dust and/or airborne contamination. Wet abrasive systems also produce a mixture of dust and water droplets that might be difficult to treat.

- Care must be taken not to introduce the contamination into the material surface (hammering effect) in order for the ability to meet clearance levels not to be jeopardised.

4.5 Decontamination by melting

4.5.1 General considerations

During decommissioning of nuclear plants, large quantities of slightly contaminated metallic scrap are generated. This scrap may also result from maintenance and from the replacement of equipment. Much of this waste consists of bulky equipment (*e.g.*, heat exchangers, moisture separators, steam generators, etc.) that, if disposed of in appropriate repositories, would consume considerable volumes of the available space. Moreover, in many cases, this equipment contains valuable material that may be recycled, including pressure-vessel steel, stainless steel and inconel. By melting slightly contaminated scrap, it is possible to recover much of these valuable metals while simultaneously conserving valuable space at final disposal facilities. The pieces of equipment considered frequently also have complex geometries, making it extremely difficult, time-consuming and expensive to determine the exact location and level of radioactivity on the internal surfaces. After melting, however, the radioactivity may be precisely determined from samples of each ingot. Moreover, an ingot may be released for restricted or unrestricted reuse, or stored for decay to appropriate limits.

Melting completely destroys components and, as a decontamination technique, is effective only for contaminants that are volatile or that concentrate in the slag (*e.g.*, plutonium) rather than in the molten metal. The decontamination efficiency varies widely depending on the radioisotope present. The radionuclides remaining in the molten material are distributed homogeneously and effectively immobilised, thus reducing the possibility of the spread of contamination. In some cases, when ingots are found to be so active that they must be sent to a final repository, melting will have achieved maximum volume reduction and thus preserved valuable repository capacity. As an alternative, some ingots with activity levels above unconditional-release limits may be remelted to make shielding blocks or cold-rolled to fabricate containers for radioactive waste, and thus recycled within the nuclear industry.

A particularly advantageous consequence of melting is its "decontamination" effect on caesium-137, a volatile element that has a half-life of 30 years. During melting, caesium-137 accumulates in the dust collected by ventilation filters and is removed. The dominant remaining nuclide in the ingots (for most reactor scrap) is cobalt-60. This element has a half-life of only 5.3 years. Other remaining nuclides have even shorter half-lives. Consequently, ingots with reasonably low-activity concentrations may be stored for release in a foreseeable future. Moreover, radiation exposure to foundry workers during the subsequent remelting of ingots is drastically reduced as a result of the removal of the caesium-137. The secondary waste consists of the slag from segmenting and melting, as well as dust from the ventilation filters. This secondary waste only comprises between 1 to 4 per cent of the weight of the melted scrap.

4.5.2 Current melting practices

Limited quantities of metallic scrap thus far have been released from nuclear facilities for melting at conventional facilities. These releases have been permitted on a case-by-case basis and the qualifying release limits for radioactivity have varied from country to country. The prevailing practices and conditions at these conventional foundries during the direct melting of contaminated scrap had previously provided the basis for calculating the exposure to workers and the public.

However, within the last ten years, the melting of contaminated steel in special-purpose plants for recycling has developed as a new industry. Established techniques are being utilised for minimising the quantity of active metallic waste. A number of plants are or have been melting contaminated metals on an industrial scale, including:

- CARLA Plant, Siempelkamp, Germany (start 1989).
- STUDSVIK Melting Facility, Sweden (start 1987).
- INFANTE Plant, Marcoule, France (start 1992).
- Scientific Ecology Group (SEG) Plant, Oak Ridge, USA (start 1992).
- Capenhurst Melting Facility, United Kingdom (start 1994).
- Manufacturing Sciences Corporation (MSC), Oak Ridge, USA (start 1996).

Table 4 illustrates the accomplishments of some of these facilities. All operate in “controlled” areas using safety precautions, including filtered ventilation and health physics supervision. Moreover, the slag and dust collected in the filters are treated as radioactive waste.

Table 4. **Operating melting facilities**

Facility	**Quantity of scrap melted (*t*)**	**Recycled/released**
CARLA	7 000	6 800 t recycled in nuclear industry, 50 t free release
Studsvik	1 500	230 t released, remaining stored for decay (or disposal)
INFANTE	3 600	Stored/Recycling in nuclear industry
SEG	2 000	Recycling in nuclear industry

Table 5 provides some additional details of interest.

Table 5. **Characteristics of operating melting facilities**

Facility	**Furnace type**	**Types of metal treated**	**Charge size**	**Products**	**Radiological limitations**
INFANTE	Electric arc melting furnace	Carbon steel, stainless steel	12 t	Ingots, shield blocks, waste containers	Max. 250 Bq/g for ^{60}Co, other limits for other nuclides
STUDSVIK	Induction for steel, small electric arc for aluminium	Carbon steel, Stainless steel, Aluminium	3 t	Ingots	No specified limits
CARLA	Induction	Carbon steel, stainless steel, aluminium, copper, lead (R&D)	3.2 t	Ingots, shield blocks, waste containers	Max 200 Bq/g for beta-gamma nuclides, Max 100 Bq/g for alpha nuclides, separate limits for uranium

SEG	Induction	Carbon steel, stainless steel, aluminium, (planning to melt copper and titanium)	20 t	Ingots and shield blocks at present, waste containers and reinforcing steel after 1994	Normally < 2 mSv/h, greater dose rates with prior review and approval

At the STUDSVIK Melting Facility, the ingots are stored, if necessary, to permit them to decay until they may be released for remelting at commercial foundries. Prior to release, the material is certified by the appropriate radiation protection authorities. After remelting, the materials may be used without radiological restrictions. Several advantages result from this remelting strategy:

- Volatile nuclides like caesium-137 have been removed in the first melt. Consequently, dust is no longer a radiological problem in further remelting processes.
- There is no surface contamination. As a result, there is no need for further segmentation.
- The slag has been removed as radioactive waste.

4.5.3 Advantages of melting as decontamination technique

Melting presents the particular advantage of redistributing a number of radionuclides among the ingots, slag and filter dust resulting from the melting process, thus decontaminating the primary material.

Melting may provide an essential step when releasing components with complex geometries, simplifying monitoring procedures for radioactive metal characterisation. In addition to its decontamination effects, the problem with inaccessible surfaces is eliminated and the remaining radioactivity content is homogenised over the total mass of the ingot. So melting may be a last step in the decontamination and release of components with complex geometries after these pieces have been decontaminated, for example,by chemical methods, that remove radionuclides, such as cobalt-60, that would remain in the ingot after melting.

4.6 Other decontamination techniques

In special cases, other decontamination techniques (*e.g.*, ultrasonics, laser, high-pressure water jetting or steam spraying, thermal erosion, pastes, gels, foams, etc.) have also been used in decommissioning. Some of them, however, require more or less complex application procedures or still need more development to allow industrial applications.

Chapter 5

CHARACTERISTICS OF SELECTED DECONTAMINATION TECHNIQUES FOR BUILDING SURFACES

5.1 General considerations

When decontaminating building structures, mainly mechanical surface-removal techniques have to be considered. Surface-removal techniques are used when future land-use scenarios include reuse, when it is impractical to demolish the building (*e.g.,* a laboratory within a building), or in view of waste minimisation. The techniques considered in the following sections remove various depths of surface contamination (*e.g.,* floors versus walls), and may be used to reduce the amount of contaminated material for disposal. For example, if a contaminated building is demolished, all the debris is considered contaminated and requires special handling.

However, by first using a surface-removal technique, the volume of contaminant is limited to the removed surface material. The eventual demolition may then be performed conventionally. In this instance, a cost-benefit analysis should be prepared and consider such potential concerns as packaging, shipping and disposal costs involved when using a surface-removal technique as compared to conventional demolition and disposal.

Before any surface-cleaning or surface-removal activity, surface preparation and safety precautions are required. Surfaces to be treated must be free of obstructions (*e.g.,* piping and supports should be dismantled or segmented), and should be vacuumed to minimise release of airborne contamination during application of the surface-removal technique. Moreover, precautions are needed to prevent explosions when treating an area containing combustibles. In this instance, all combustibles should be neutralised, stabilised or removed. Due consideration should be given to industrial hazards associated with the use of these techniques and to unacceptable damage that may be caused.

Finally, contaminated debris (*i.e.,* 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 in which a contaminant has penetrated the material beyond the surface layer, a further treatment may be required.

Most of the surface-removal techniques usually leave an undesirable surface finish. If a smoothly finished surface is required (*i.e.,* if the building is to be reused), a concrete cap or some other surface-smoothing treatment must be applied. Due consideration should also be given to the industrial hazards associated with the use of these techniques and to unacceptable damage that may be caused (stability of the building).

5.2 Basic techniques

Decontamination processes to be used for contaminated concrete depend greatly on the characteristics of the concrete surface to be cleaned. They may vary from very simple hand-based processes to jackhammer or drilling removal techniques. The former is normally used for cleaning painted or smooth surfaces covered by loose contamination and the latter for decontaminating concrete in which the contamination has penetrated deeply.

Simple processes, such as brushing, washing and scrubbing, and vacuum cleaning, have been widely used, since the need for decontamination/cleaning was first noted in the nuclear industry, and each nuclear facility has to some extent a certain practical experience of these kinds of decontamination processes. These processes are generally labour-intensive, but they have the advantage of being versatile. They are often used as a first step (*e.g.,* to vacuum dust and remove loose contamination) before or during dismantling, to prepare items for more aggressive decontamination using stronger processes.

Other, more aggressive techniques are grinding, spalling and drilling, high-pressure water jetting, foam decontamination, the use of strippable coatings, high-frequency microwaves, laser and induction heating. The use of most of these techniques is limited to specific applications in specific cases. Some of them have disadvantages such as spreading of contamination, or produce a lot of undesirable secondary waste. Some of them are also less suitable for industrial applications.

When decontaminating concrete surfaces, mainly mechanical scarifying techniques such as needle scaling, scabbling, or shaving, are used.

5.3 Scarifying

Scarifiers physically abrade both coated and uncoated concrete and steel surfaces. The scarification process removes the top layers of contaminated surfaces down to the depth of sound and uncontaminated surfaces. A decade ago, concrete scarifying was considered a radical approach to decontamination owing to poor tool performance and inability to provide a uniform surface profile upon removal of the contaminants. Today's refined scarifiers are not only very reliable tools, but also provide the desired profile for new coating systems in the event the facility should be released for unconditional use.

5.3.1 Needle scaling

Needle scalers are usually pneumatically driven and use uniform sets of 2, 3 or 4-mm needles to obtain a desired profile and performance. Needle sets use a reciprocating action to chip contamination from a surface. Most of the tools have specialised shrouding and vacuum attachments to collect removed dust and debris during needle scaling with the result of no detectable concentrations above background levels.

Needle scalers are an excellent tool in tight, hard-to-access areas (*e.g.,* pipe penetrations, etc.), and may also be used for wall and ceiling surface decontamination. This technique is a dry decontamination process and does not introduce water, chemicals or abrasives into the waste stream. Only the removed debris is collected for treatment and disposal. Production rates vary depending on the desired surface profile to be achieved.

5.3.2 Scabbling

Scabbling is a scarification process used to remove concrete surfaces. Scabbling tools typically incorporate several pneumatically operated piston heads striking (*i.e.,* chipping) a concrete surface. Available scabblers range from one to three headed hand-held scabblers to remotely-operated scabblers, with the most common versions incorporating three to seven scabbling pistons mounted on a wheeled chassis. Scabbling bits have tungsten-carbide cutters, the bits having an operating life of about 100 h under normal use. Both electrically and pneumatically-driven machines are available. Because scabbling may cause a cross-contamination hazard, vacuum attachments and shrouding configurations have been incorporated, so that scabbling may be done with no detectable increase in airborne exposures.

Before scabbling, combustibles must be stabilised, neutralised, and/or removed. In practice, floor scabblers may only be moved to within some 5 cm of a wall. Other hand-held scabbling tools are therefore needed to remove the last 5 cm of concrete flooring next to a wall, as well as remove surface concrete on walls and ceilings. This technique is a dry decontamination method – no water, chemicals or abrasives are required. The waste stream produced is only the removed debris. Work rates are not easy to predict due to the variety of concrete composition and characteristics as well as to the different types of bits that may be used.

Scabblers are best suited for removing thin layers (up to 15 or 25 mm thick) of contaminated concrete (including concrete block) and cement. It is recommended for instances where:

- airborne contamination should be limited or avoided;
- the concrete surface is to be reused after decontamination;
- waste minimisation is envisaged;
- for instances in which the demolished material is to be cleaned before disposal.

The scabbled surface is generally flat, although coarsely finished, depending on the bit used. This technique is suitable for both large open areas and small areas.

5.3.3 Concrete shaving

As an alternative for floor scabbling, a floor shaver has been developed. This machine is similar to a normal floor scabbling unit. It has a quick-change diamond-tipped rotary cutting head designed to give smooth-surface finish, easier to measure and ready for painting. It is capable of cutting through bolts and metal objects, which would have damaged the scabbling head of a traditional scabbler. Actual cutting performance results in:

- a three-times higher mean working rate for floor decontamination compared to scabbling;
- a 30 to 45 per cent lower waste production than by scabbling with a comparable decontamination efficiency;
- much less physical load on the operators due to the absence of machine vibration;
- end products (concrete dust) that, combined to suitable additives, may be incorporated in a cement matrix with an additional volume reduction factor.

Based on the positive experience with the floor shaver a remote-controlled diamond wall-shaving system has been developed as a solution for concrete decontamination of larger surfaces. The machine consists of:

- a remote-controlled hydro-electric power pack for the remote-controlled shaving unit;
- vacuum systems to fix temporarily vacuum pads holding the horizontal and vertical rails of the shaving unit;
- a simple xy-frame system containing a guide rail, a vertical rail and a carriage for the shaving head;
- a quick-change diamond-tipped rotary shaving head with dust-control cover for connection to existing dust-extraction systems.

The entire system is built up in sections which are portable by one operator. It removes a concrete layer in a controlled and vibration-free manner with the removal depth being controllable between 1 and 15 mm per pass, and producing a smooth-surface finish. The cutting head is designed to follow the contours of the surface being removed, and depth adjustments may be set manually in increments of 1 mm to minimise waste production. With 300 and 150-mm-wide shaving heads, both large areas and awkward corners may be accessed. When the vertical rail is fitted to the wall with the cutting head shaving, the horizontal rail may be disconnected and moved forward, thus ensuring continuous operation.

Production rates vary depending on the structure and the hardness of the concrete, the depth setting, the cutting speed and the type of diamond used. Heads can be used for shaving up to 2 000 m^2.

5.3.4 Hydraulic/Pneumatic Hammering

Cutting and decontamination of concrete structures may be carried out with hydraulic or pneumatic hammers, either hands-on or using an electrically-powered, hydraulically-controlled robot. The latter may be equipped with a hydraulic hammer, an excavator bracket, or other tools, and is well suited for decontaminating floors and walls. A mini electro-hydraulic hammering unit (weighing only 350 kg) is commonly used in areas where contamination has penetrated deeply into the concrete surface, increasing the decontamination possibilities and reducing significantly the workload for the operators.

5.3.5 Dust collection

For dustless decontamination of concrete, scabblers, scarifiers and shavers may be integrated into a system of remotely and manually-operated scarifying equipment. With these systems, dust and debris are captured at the cutting-tool surface, which minimises cross-contamination. For hand scabblers and smaller systems, dust evacuation is carried out using industrial vacuum cleaners (capacities of up to 500 m^3/h), and equipped with absolute filtering systems at the outlet.

Larger scabbling or shaving machines are connected to vacuum systems with capacities of up to 2 500 m^3/h or higher. They incorporate a cyclone to evacuate larger concrete particles, a filtering system with cleanable prefilters and absolute filter, and a vacuum pump. The cleanable filtering system incorporates a fill-seal drum changeout (contamination-free exchange) method that allows the operator to fill, seal, remove, and replace the waste drum under controlled conditions. The unit may accommodate different drum sizes and several scabblers, shavers and needle scalers at longer distances.

5.3.6 Production rates

Typical work rates obtained with needle scalers, scabblers and shavers are indicated in Table 6.

Table 6. **Typical work rates obtained with different kinds of scarifying techniques**

Scarifying technique	**Layer thickness removed** (*mm*)	**Removal speed** (*m^2/h*) (machine working time)
Needle scaler	2	0.1
Hand scabbler (1 head)	2	0.6
Floor scabbler (7 heads)	3	4.6
Wall scabbler (3 heads)	3	4.6
Wall scabbler (7 heads)	4	8.4
Floor shaver	1.5	13.6

Wall shaver	1.5	21

5.4 Guidelines for selecting appropriate decontamination techniques for building surfaces

When selecting an appropriate decontamination technique for building surfaces, some general considerations presented in Sections 2.2 and 4.2.4 should be taken into account. In any case, the use of techniques that would make contamination penetrate further into the substrate should be avoided. In addition, as general rules:

- For decontaminating painted floors and walls, where it may be proved that contamination has not penetrated into the substrate, simple processes as brushing, washing, scrubbing and vacuum cleaning may be used.
- For decontaminating concrete surfaces which are not painted and in which the contamination has slightly or more deeply penetrated the substrate, more aggressive techniques *(e.g.*, scabbling, shaving, jackhammering or drilling) must be considered.

CONCLUSIONS

It was the aim of the Task Group to prepare a state-of-the-art report on decontamination in connection with decommissioning, and to describe some critical elements for the selection of appropriate techniques in order to resolve practical decontamination problems. The work has been focused on decontamination for dose reduction, waste decategorisation and conditional or unconditional release of materials. The decontamination of both metallic and concrete surfaces has been considered.

To achieve this goal, a questionnaire was prepared and sent to different project managers and customers of decontamination techniques who have applied decontamination processes in a radioactive environment. The information requested covered the technical and economical aspects of the selected decontamination techniques.

This report gives an extensive and detailed overview of the data acquired from the survey. It presents a comprehensive list of real case examples for various decontamination techniques and processes applied in decommissioning.

Based on the information gathered, some specific characteristics of selected decontamination techniques for segmented components and for building surfaces have been discussed. In addition, some critical elements of choosing techniques for practical decontamination problems have been given.

The information presented is not exhaustive. Practical experience in decontamination has also shown that a universal decontamination process does not exist. As such, future users should familiarise themselves with the characteristics of proposed techniques, in order to make adequate choices based on specific requirements.

Annex 1

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Annex 2

QUESTIONNAIRE ON DECONTAMINATION TECHNIQUES FOR DECOMMISSIONING

On the next pages is shown the questionnaire on decontamination techniques for decommissioning that was sent to decontamination operators for data collection.

QUESTIONNAIRE ON DECONTAMINATION PROCESSES

Filling date
Name of decontamination process
Description of application
Objective of the application

When
Where
Give two criteria used for the choice of that process for this particular application.
Criteria 1

Criteria 2

What was the dismantling strategy followed in this particular application and at that time?

1. Field of application of the decontamination process for that specific application

1.1 Objectives of the decontamination process Answer YES if applicable.
Reduction of exposure
Waste recategorisation

1.2 Description of decontaminated material Answer YES if applicable.

Metallic	Stainless steel
	C-steel
	Inconel
	Zircaloy
	Lead
	Cu alloys
	Al
	Zr
	Others
Non metal	Brick
	Concrete
	Coatings
	Plastics
	Others

Typical values of quantity of material treated, (*e.g.*, m²/batch or m² for a FSD (give values in m², kg, ...).

Amount:	Surface	m²
	Volume	m³
	Weight	kg

Geometry: Answer YES if applicable.
Flat surface/walls
Tank
Pipe
Pump
Valve
Heat exchangers
Others

1.3 Type of equipment to be decontaminated Answer YES if applicable.

1.3.1 Origin of equipment
Reactor type
PWR
BWR
GCR
FBR
MTR
Candu
Pool reactors
Others
Reprocessing Plant
Indicate nature of fuel.
Indicate the type of process.

Fuel Fabrication Answer YES if applicable.
UO2
MOX
Metalluc U

	Others	
U process facilities		Answer YES if applicable.
	Mining & milling	
	Purif. & Conversion	
	Enrichment	
	Re-enrichment	
Waste treatment facilities		Give a short description of the facility.
	Type of waste treated	
	Activity level & type	
	Treatment type	
Laboratories		Give a short description.
Radioisotope production facilities		Give a short description.
Weapons facilities (maintenance/dismantling)		Give a short description

1.3.2 Original use of equipment to be decontaminated

Give an indication on the source term, e.g. equipment used for mixed oxide fuel fabrication.

Give an indication about the nature of the contamination source,
example: the equipment was contaminated by circulation of primary water or by storage of solid waste

Answer YES if applicable and give an indication of the contaminant nature.

Solid handling
Liquid handling
Gas handling
Transport cask
Others

2. Process description

This chapter describes in detail the decontamination process used.

2.1 Type of decontamination process

Answer YES if applicable.

Full System

Components	In-situ	After dismantling
Pools		
Vessels		
Pumps		
Piping		
Heat exchangers		
Valves		
Tools		
Others		

2.2 Decontamination principle

Answer YES if applicable.

Chemical process

Electrochemical process

Physical process

Combined process
Give the combination used

2.3 Description

2.3.1 Chemical processes

Number of cycles
Number of steps/cycles
For each step, give the values of the following parameters and the nature of products used.

Step
Nature/conc. chemicals

Temperature
Pressure
pH
Hydrodynamic parameters
Reynolds range
Duration
Volume/area ratio
Method of agitation
Ultrasonics
Others

2.3.2 Electrochemical process

Give the values of the parameters used for the process.
Make a table if there are several steps.

Nature/conc. electrolyte

Temperature
Pressure
pH
Current density
Voltage
Polarisation
Duration
Hydrodynamic parameters
Conductivity
Electrode materials
Others

2.3.3 Physical process

Principle of operation	Describe the operating principle of the process.
Wet/dry	
Additive	Give the nature and quantity of additive used. Nature Quantity

Temperature
Pressure
Hydrodynamic parameters
Duration
Others

2.3.4 Combined processes

Give the combination used and make the detailed description in the appropriate part (*e.g.*, physical process followed by chemical decontamination).

2.4 Material compatibility	Which materials are not compatible with the decontamination process (*e.g.*, gaskets who do not resist to given chemicals).
Specific for	Give a list of materials for which this process was developed.
Incompatible with	Indicate the materials, equipment, gaskets which are not compatible with the use of the decontamination products.

Material
Equipment
Gaskets
Others

2.5 Services required for the application of the process

Answer YES if applicable and indicate for which purpose.

Electricity
Water
Steam
Compressed air
Hydraulics
Refrigeration
Preventilation/prefiltration
Ventilation
Gases
Video/audio communication
Others

2.6 Precautions

Identify what are the precautions to be taken during the use of this process.
A list of safety terms are given - answer YES when applicable and explain in a few words (*e.g.,* chemicals are acids and oxidants corrosive and dangerous for the skin).

Hydraulic precautions
Hazards
- Chemical
- Corrosive
- Toxic
- Liquids
- Gases
- Aerosols

Inert atmosphere (N_2 and CO_2)
Fire hazards
Flammability
Explosion
Electric shock
Personnel protection equipment   Indicate type of clothing

Physical precautions
(*e.g.,* abrasive water jet)
Dust/aerosols
Drowning
Others

2.7 Operation

Indications on the decontamination operation: number and qualification of personnel used.
Normal day operation or continuous operation.

Personnel

Indicate the number of personnel used with the respective qualifications;
The personnel is subdivided only in 3 categories defined in the footnote.

Personnel			
Number			
Qualification	Technical	Industrial worker	General worker

Key safety aspects   Give a list of the main safety aspects of the process.

Key parameters

Give a list of the key parameters of the process (e.g., temperature and chemical concentration).

Summary of the operating procedure

Note	Technical	Professional, e.g. engineer, supervisor.
	Industrial worker	Qualified trade man, e.g. welder, fitter, electrician, lab. technician, plant operator, radiation control, ...
	General worker	No specific qualification.

3. Description of the application

3.1 Preparatory work

Radiological inventory

How is the radiological inventory performed?

Mock-up demonstration

Describe the nature of the cold tests and of the training.
Cold testing

Training

Plant modifications

Give a list of the modification necessary for the use of the process.

Predecontamination operations

Give a list of operations needed before starting the decontamination operation itself.
Example: cutting of vessel by plasma arc torch in pieces 50 x 50 cm.
Describe the nature of the operations.

Dismantling

Cutting

Entrance facility (air lock)

Ventilation

Off gases filtration

Others

3.2 Description of the decontamination system/equipment

(Add a schematic diagram if appropriate)

3.3 Consumables

Indicate the type of consumables and the quantity used.
Are the consumables recycled or used once?
Additive

Pieces of equipment
Filters
Ion exchangers
Others

3.4 Consumption of services specific for the process

Quantify the consumption of services directly connected to the decontamination equipment
(example: x kWh for an electrochemical process).

Electricity
Water
Steam
Compressed air
N_2
Refrigeration
Gases
Others

4. Expected results/recorded results

Measurement methods Indicate the method used to characterise the contamination.

Sampling
Direct measurement

Instruments used Indicate the instruments used for the radiochemical characterisation.

Nature of contamination layer Describe the nature of the contamination in detail.

Nuclide composition

Indicate the radiochemical nature of the contamination/give a list of the main contaminants.
Indicate the relative importance of the different type of isotopes taking gamma = 100.
For example beta = 100 means activity level of beta emitters is equivalent to the gamma.

List of isotopes	Relative activity

Gamma	100
Beta	
Alpha	

Measurement of the decontamination efficiency

For each type of measurement, indicate the number of measurements/the area measured/the method used.

Type of measurement	Sampling	Direct measurement	
Number of measurements			
Area measured			
Method used (e.g. smear test)			
Values measured	Before	After	Dose reduction
Dose rate mSv/h			
Range			
Average			

Specify the nature of the emitters (gamma, beta, alpha) measured.

Contamination levels cps/cm²	Before	After	Decontamination factor
Range			
Average			

Contamination levels Bq/cm²	Before	After	Decontamination factor
Range			
Average			

Contamination levels Bq/g	Before	After	Decontamination factor
Range			
Average			

Surface thickness removed µm or mg/cm²

Surface roughness

Removal rate (µm/h or mg/cm²/h)

Radiation dose exposure

Give when available the radiation dose for the operators during the different phases of the operation.
The dose should be given for the different phases of the operation.
Give also when available the number of operators.
And the individual dose exposure for the critical group of operators (max. dose mSv/man).

Collective personnel radiation dose

	man.mSv	Number of operators	Individual dose Range mSv/man	Max. mSv/man
Preparation				
Decontamination process				
Post decontamination operations				
Other operations				

5. Waste treatment aspects

Waste treatment policy

Give a description of the waste treatment policy followed for this particular case,
including the conditioning and the disposal options

Waste quantities produced

The waste produced must be related to a given quantity treated.
Specify the amoun treated, e.g., m^2 decontaminated or weight of material treated.

For each type of waste produced, indicate the volume produced and the total activity.
Indicate also the conditioning method followed and the encapsulation method.
Encapsulation means production of the final waste form suitable for final disposal.
A list of conditioning and encapsulation methods are given in footnote.
For solids, 4 main types were selected.
For liquids, the dry residu content is an important parameter to mention.
For airborne waste, give the treatment system used (see footnote) for the trapping of the activity.
The volume to indicate is the volume of secondary waste produced,
e.g., the volume of filters used ...

Type	Nature	Volume (m^3)	Activity (Bq)	Condition. Method	Encapsulation Method	Waste Volume (m^3)
Solid	Resins					
	Filters					
	Sludge					
	Protective clothing					
	Others					
Liquid						
	Dry residu					

Airborne	Nature	Treatment System	Volume	Condition. Method	Encapsulation Method	Final Waste Volume
	Gas					
	Liquid					
	Aerosols					

Footnotes Examples

Conditioning methods
- Concrete embedding
- Storage in cast iron containers
- Incineration
- Embedding in polymers
- Compaction
- Embedding in bitumen
- Drying
- Vitrification
- Others

Encapsulation = final waste form
- 400 l drum
- 200 l drum
- 1 m^3 concrete
- metal canister
- Others

Treatment systems for airborne Examples
- Charcoal for liquids
- HEPA for aerosols
- Bag filters for dust

Wash column for noxious gases
Others

6. Advantages/disadvantages/limitations

For this application, identify the advantages and disadvantages of this process.
Consider the aspects not only dealing with the decontamination operation itself,
but also the preparartory work and the post decontamination operations.
A list of aspects is given to guide you.

	Aspects	Advantages	Disadvantages
Preparatory work			
Decontamination operation			
	Safety aspects		
	Chemicals		
	Others		
Post decontamination operations			
	Waste		
	Others		

7. Costs

Recommendation: use the ECU currency.
Cost estimation at the date of filling in.
Otherwise note the reference date, e.g. the date of the operation.
All the costs are related to the particular application described.

Operating costs (manhours)	
Consumables	
Licensees costs	
Services costs	
Specific equipment	
Products/reagents	
Waste treatment	
Waste disposal	
Cost savings	Savings due to the recategorisation of the waste for example.
Others	

8. Experiences to date

Give a list of other applications of this process and specify at which scale they were performed.
Lab scale

Pilot scale

Industrial scale

9. Recommendation for areas requiring R & D

10. Availability

Suppliers of equipment/products

Manufacturers of equipment

11. References

Name and company of the author

List of publications

List of customers having used this process