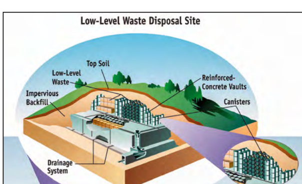
Radioactive Waste Management and Decommissioning
2020

Optimising Management of Low-level Radioactive Materials and Waste from Decommissioning



OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Radioactive Waste Management and Decommissioning

Optimising Management of Low-level Radioactive Materials and Waste from Decommissioning

NEA No. 7425

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 37 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, Colombia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

This work is published under the responsibility of the OECD Secretary-General. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the member countries of the OECD or its Nuclear Energy Agency.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

This document, as well as any data and map included herein, are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Corrigenda to OECD publications may be found online at: *www.oecd.org/about/publishing/corrigenda.htm*.

Cover photos: Low-level radioactive waste facility (United States Nuclear Regulatory Commission); Low-level radioactive waste storage pit (Federal Government of the United States).

Foreword

Managing radioactive waste from the decommissioning of nuclear facilities is integral to the success of all decommissioning programmes worldwide. It is essential that this strong relationship between decommissioning and radioactive waste management be fully explored in the early stages of developing decommissioning strategies. The efficient use of available resources to optimally manage materials and waste with (very) low-level radioactivity is key to ensuring sustainable, safe and cost-efficient decommissioning and will thus avoid imposing undue burden on future generations.

In terms of volume, low-level and very low-level waste represent the vast majority of radioactive waste from decommissioning, although they are only a small fraction of the radiological inventory. The availability of an appropriate waste management infrastructure (including disposal routes) for this waste, along with robust processes, procedures and an optimisation culture, are thus key components of an optimal approach. While recognising that the regulatory framework for the clearance of such materials will differ from country to country, it is equally important to underline that large volumes of waste and materials arising from decommissioning could be deemed to be exempt from control as radioactive waste when the clearance process is undertaken. The clearance process will thus contribute to optimising the volume of radioactive waste from decommissioning that requires management.

It should also be recognised that the capacity for radioactive waste disposal is decreasing faster than expected in some countries, and this capacity may ultimately become insufficient for forecasted volumes of waste. The decrease in capacity comes at a time when the development of new disposal capacity is increasingly difficult because of societal concerns and expanding pressure on land resources. A focus on waste management optimisation, to ensure that facilities are used only for waste that should be consigned to them, is therefore of increasing importance.

Observing the increasingly important role of effective waste management in the delivery of successful decommissioning programmes, the Nuclear Energy Agency (NEA) Working Party on Decommissioning and Dismantling (WPDD) established an expert group in 2016 – the Task Group on Optimising Management of Low-Level Radioactive Materials and Waste from Decommissioning (TGOM) – to examine how different countries manage their (very) low-level radioactive waste and materials arising from decommissioning. The expert group considered all the steps of the waste management life cycle, from generation during dismantling to the final destination, whether it involved clearance, recycling or disposal to a landfill or to a repository.

This report explores the elements contributing to optimisation in national approaches at the strategic level, describing the main factors involved and the relationship between them. It also identifies constraints in the practical implementation of optimisation, based on experience in NEA member countries.

Acknowledgements

The Nuclear Energy Agency (NEA) would like to thank the following experts for their active contributions to this report: Michel Pieraccini (Électricité de France, France); Gerd Bruhn (Gesellschaft für Anlagen- und Reaktorsicherheit [GRS], Germany); Michael Knaack (TÜV Nord, Germany); Kai Möller (Federal Office for the Safety of Nuclear Waste Management [BfE], Germany); Boris Brendebach (GRS, Germany); Tiziano Vignaroli (Società Gestione Impianti Nucleari [Sogin], Italy); Hiroki Hayashi (Nuclear Regulation Authority [NRA], Japan); Ken-ichi Tanaka (Institute of Applied Energy, Japan); Tomas Hrncir (Nuclear and Decommissioning Company [JAVYS], Slovak Republic); Roman Strazovec (JAVYS, Slovak Republic); José Luis Leganés Nieto (Empresa Nacional de Residuos Radiactivos, S.A. [Enresa], Spain); Fredrik De la Gardie (Chair, Swedish Nuclear Fuel and Waste Management Company [SKB], Sweden); Patrik Fors (Vattenfall, Sweden); Karoline Sodergren (SKB, Sweden); Anders Wiebert (Swedish Radiation Safety Authority [SSM], Sweden); Sofia Eliasson (Oskarshamns Kraftgrupp AB [OKG], Sweden); Pascale Kuenzi (Swiss Federal Office of Energy [OFEN], Switzerland); Erwin Neukäter (BKW, Switzerland); Hannah Kozich (Low Level Waste Repository Ltd, United Kingdom); David Loudon (Nuclear Decommissioning Authority [NDA], United Kingdom); Paul Robinson (Environment Agency, United Kingdom); Bill Barley (Pacific Gas and Electric, United States); David Miller (Information System on Occupational Exposure [ISOE]/North-American Technical Centre [NATC], United States); Stuart Walker (Environmental Protection Agency [EPA], United States); Christian Glorennec (International Atomic Energy Agency [IAEA]); Flavio Zanovello (EC Joint Research Centre [JRC] Ispra); Inge Weber and Jihtong Lin (NEA).

The task group also wishes to express its gratitude to the NEA Forum on Stakeholder Confidence (FSC) and the Working Group on Radiological Protection Aspects in Decommissioning (WGDECOM) of the International System on Occupational Exposure (ISOE) for their contributions to the report.

This report is dedicated to David Loudon, who was well regarded, equally for his professional contributions as for his endearing personality. He will always be remembered.

Table of contents

List of abbreviations and acronyms 7

Chapter 1. **Introduction** 9
1.1. Objectives 10
1.2. Scope 10
1.3. Organisation of the report 11

Chapter 2. **Background** 13
2.1. (V)LLW generation during decommissioning 14
2.2. (V)LLW management 17
2.3. The optimisation context 19
2.4. Lessons learnt/success factors and barriers 21

Chapter 3. **Drivers for optimisation** 23
3.1. Safety and environment 23
3.2. Characterisation 31
3.3. Enabling Infrastructure 40
3.4. Stakeholder involvement 47
3.5. Economic and financial aspects of (V)LLW management 51

Chapter 4. **Conclusions** 55

Chapter 5. **Potential future work** 59

References and recommended reading 61

List of appendices

A: Country information 63
B: Case studies 100

List of figures

1-1: Factors influencing radioactive waste management 12
2-1: Graphs of the different aspects of decommissioning waste created during the phases of a project 14
2-2: Simplified decommissioning radioactive waste management process flow diagram 15

2-3: The impact of decommissioning approaches on (V)LLW volumes 16
2-4: The waste hierarchy from the most to least favourable option, together with different options for (V)LLW management at each step 17
2-5: External factors influencing radioactive waste management systems.......20
3-1: Characterisation objectives through a facility life cycle supporting decommissioning and materials, and waste end-states 32
3-2: Radiological characterisation implementation...35
3-3: Typical (V)LLW life cycle 41
3-4: Identification of stakeholder involvement..48
3-5: Different levels of stakeholder involvement...49
AB-1. Distribution of waste volume in relation to activity content: Impact assessment and decision making..104

List of abbreviations and acronyms

AECL	Atomic Energy of Canada Limited
ALARA	As low as reasonably achievable
ALARP	As low as reasonably practicable
BAT	Best available technique
BWR	Boiling water reactor
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
CNL	Canadian Nuclear Laboratories
EC	European Commission
EDF	Électricité de France
HLW	High-level waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate-level waste
JNFL	Japan Nuclear Fuel Limited
KHNP	Korea Hydro & Nuclear Power Co Ltd
L&ILW	Low- and intermediate-level radioactive waste
LL	Long lived
LLW	Low-level waste
MDA	Minimum detectable activity
NDA	Nuclear Decommissioning Authority (United Kingdom)
NEA	Nuclear Energy Agency

NPP	Nuclear power plant
NRA	Nuclear Regulation Authority (Japan)
OECD	Organisation for Economic Co-operation and Development
OPG	Ontario Power Generation (Canada)
POCO	Post-operational clean-out
PWR	Pressurised water reactor
RD&D	Research, development and demonstration
SFR	Final Repository for Short-lived Radioactive Waste
SKB	Swedish Nuclear Fuel and Waste Management Company
SL	Short lived
SSM	Swedish Radiation Safety Authority
TGOM	Task Group on Optimising Management of Low-level Radioactive Materials and Waste from Decommissioning (NEA)
(V)LLW	Low-level and very low-level waste
VLLW	Very low-level waste
WAC	Waste acceptance criteria
WPDD	Working Party on Decommissioning and Dismantling

Chapter 1. Introduction

Since the beginning of the commercial nuclear industry in the 1950s, a total of 188 civilian nuclear power reactors have ceased operation in 20 countries (International Atomic Energy Agency [IAEA] Power Reactor Information System [PRIS], May 2020). These reactors are mainly commercial power reactors, but they also include prototypes and experimental reactors of differing technologies. A range of other types of nuclear facilities – including those that form part of the nuclear fuel cycle, those for waste treatment and processing, and laboratories and research facilities – will also require decommissioning.

Radioactive waste is generated during operations and during the decommissioning of nuclear facilities. In terms of volume, low-level and very low-level waste (hereafter referred to as [V]LLW) represent the vast majority of radioactive waste from decommissioning, although they are only a small fraction of the radiological inventory. The availability of an appropriate waste management infrastructure (including disposal routes) for waste, along with robust processes, procedures and an optimisation culture are therefore key components of an optimal approach. While the clearance of materials undergoing a clearance process differs from country to country, large volumes of waste and materials arising from decommissioning could nonetheless be deemed to be exempt from control as radioactive waste, after having been cleared through the clearance process. The clearance process can thus contribute to optimising the volume of radioactive waste from decommissioning requiring management.

It should also be recognised that capacity for radioactive waste disposal is decreasing faster than expected in some countries, and this capacity may ultimately become insufficient for the forecasted arisings. The decrease in capacity comes at a time when the development of new disposal capacity is becoming more difficult because of societal concerns and increasing pressure on land resources. A focus on waste management optimisation, to ensure that these facilities are used for the waste that should be consigned to them, is therefore of increasing importance.

Effective radioactive waste management is integral to the success of decommissioning programmes, and the strong relationship between them should be fully explored when developing decommissioning strategies. The efficient use of available resources to optimally manage (V)LLW is key to ensuring sustainable, safe and cost-efficient decommissioning. The impact of (V)LLW should thus be minimised in terms of dose to workers and to members of the public, and the impact on the environment must also be limited so as not to pose undue burden on future generations.

1.1. Objectives

The objective of this report is to provide policy makers, regulators, strategy owners and decision makers with high-level guidance for developing and tailoring strategies for optimising the management of (V)LLW arising during decommissioning. The report aims to explore optimisation factors through the steps of the radioactive waste management life cycle, from generation during dismantling to final disposal (whether clearance, recycling, or disposal to landfill or a repository).

Particular focus is given to providing the context for these key factors and describing the relationships between them. They are addressed from a perspective of optimising the management of waste, while also optimising safety and environmental objectives.

1.2. Scope

The term optimisation can be defined as "making the best or most effective use of a situation or resource". Globally, optimisation is a process to manage the (V)LLW in the best way possible within a facility or site decommissioning programme. There are a number of drivers that may influence optimisation, including waste volumes, cost, decommissioning schedules, clearance levels, recycling options, dose and discharges or making the best use of the available infrastructure. These considerations do not exist in isolation and may influence each other. They will also vary from country to country, depending on the policy, strategy and regulatory environment, and on individual country constraints (such as limited disposal capacity or stakeholder concerns).

This report draws on the experience of Nuclear Energy Agency (NEA) member countries in optimising the management of (V)LLW arising from decommissioning to identify relevant factors that should be considered when developing decommissioning strategies.

The focus is on describing strategic level factors rather than the technical aspects of optimising waste management. Although optimisation is mainly considered in terms of minimising the radioactive waste resulting from decommissioning, the report aims to provide a comprehensive overview of all relevant factors that may contribute to overall optimisation. It provides examples of good practice to support the development of waste management strategies, with particular focus on incorporating and applying solutions for handling and minimising radioactive waste arising from the decommissioning process.

As noted previously, (V)LLW will be used throughout the report to describe very low-level (VLLW) and low-level waste (LLW). The IAEA[1] defines VLLW and LLW (IAEA, 2009) as all waste that may have a risk of radioactive contamination (i.e. that cannot

1. Countries have many varied definitions for VLLW and this is an area for future work. For convenience, this report applies the definition advanced by the IAEA.

be administratively excluded from being contaminated), but which may be suitable for disposal in a landfill facility (for VLLW) or a near-surface repository (for LLW). It should be recognised that each country has its own definitions of VLLW and LLW, which must be considered by the generators of radioactive waste in that country. In addition, some countries use the term "material" in the same context, for example if it is going to be reused. In this report, such materials are included in the definition of (V)LLW.

The concepts described in this report are intended to be universally applicable when decommissioning a nuclear facility, and when overseeing the associated waste management processes; although some differences in the planning, preparation and/or procedures may occur for legacy sites and/or historical waste. Readers of this report may identify certain parts of the report as being more relevant than others, depending on their specific situation.

The term *end-state* for a site is used in this report to mean the point at which the site is released or partially released from regulatory control. It will, in part, be determined by the country's policy, strategy and regulations, as well as by the future use defined for the site. The defined end-state may change during the life of the decommissioning programme; and waste management optimisation may be one aspect that could influence the site end-state.

1.3. Organisation of the report

National approaches to decommissioning and the associated management of (V)LLW are driven by a range of factors. Some of these are external, setting the course and providing the boundary conditions for radioactive waste management in a country; and some are internal to the organisation, site or facility. Appendix A provides specific information on NEA member countries' waste management programmes.

The radioactive waste management system is influenced and determined by many factors that should be considered when developing an appropriate strategy. Figure 1-1 (page 12) shows an overview of factors influencing radioactive waste management, all of which are discussed in this report.

It is important to recognise that these factors are interconnected; and therefore, the optimum solution for a particular situation requires a consideration and balancing of all the factors.

Chapter 2 provides the background and context for (V)LLW generation, management and optimisation. Chapter 3 describes the key factors to be considered within the radioactive waste management process when seeking its optimisation during decommissioning. The sections of Chapter 3 are designed as standalone sections.

Key conclusions are summarised in Chapter 4 and areas of potential further work identified in Chapter 5. Appendix A gives detailed information on the approaches taken in individual NEA member countries and serves as a basis for specific country examples used in this report. Finally, Appendix B contains a number of case studies as examples of optimisation practice.

Figure 1-1: **Factors influencing radioactive waste management**

Source: OECD/NEA.

Chapter 2. Background

Experience from decommissioning programmes to date demonstrates that proper preparation is key to delivering optimised decommissioning, from both a technical and financial perspective, as well as from the perspective of ensuring public acceptance. It has also shown that quality decision making requires clear responsibilities, transparency throughout the process and the trust of stakeholders, which can be challenging in a multidimensional decommissioning environment. Decision makers need to maintain a wide perspective on these complexities; navigating between aspects such as dose calculations, waste acceptance criteria, decommissioning and dismantling techniques, conventional worker safety, incentive mechanisms, and changes in organisational structures, as well as between the cultures required when moving from operations to decommissioning.

Key for decommissioning success is a focus on reviewing the scope of work to be done at a site so as to deliver the defined site's end-state. This includes consideration of the safe and efficient management of radioactive waste generated during the work. Inadequate focus on the waste management process can lead to cost escalations, delays, safety risks and a loss of trust among stakeholders.

Early in a decommissioning programme, the prerequisites for an efficient waste management process should thus be established by ensuring that:

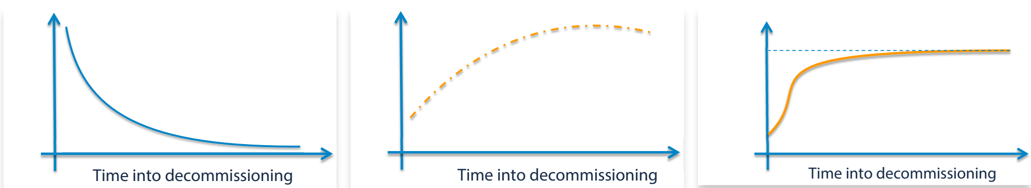
- Characterisation information is made available from the operational phase of the site and that characterisation activities are undertaken early in the decommissioning project, so that waste management options are not foreclosed.
- Sufficient and suitable treatment and disposal capability is available to enable the decommissioning work to be carried out in accordance with the programme schedule.
- Suitable national legislation, regulation, policies and strategies, including clearance allowance, are in place to enable a flexible and fit-for-purpose waste management approach. This approach could include the implementation of a radioactive waste classification system that supports efficient management of the large volumes of waste that will be generated.
- Ownership of the waste throughout the life cycle is clearly defined – especially important in countries where the responsibility for the waste moves from one organisation to another during the waste management life cycle.
- Funding mechanisms are established early on in the process to enable and support effective life cycle planning and decision making.

2.1. Low-level and very low-level waste generation during decommissioning

As nuclear facilities across the world cease operation and enter the decommissioning phase, significant volumes of radioactive waste will need to be managed.

The most radioactive parts of a facility are usually removed in the early stages of decommissioning (including during the last months of the operational phase) to reduce background radiation levels in accordance with the "as low as reasonably achievable" (ALARA) principles. As a result, the level of radioactivity remaining in the facility will decrease as the dismantling process proceeds and the amount of Low-level and very low-level waste ([V]LLW) will increase, making the management of this waste stream key for optimised decommissioning. Figure 2-1 shows a schematic representation of (V)LLW generation during a decommissioning project.

Figure 2-1: **Schematic representations of the different aspects of decommissioning waste created during the phases of a project**



Source: OECD/NEA.

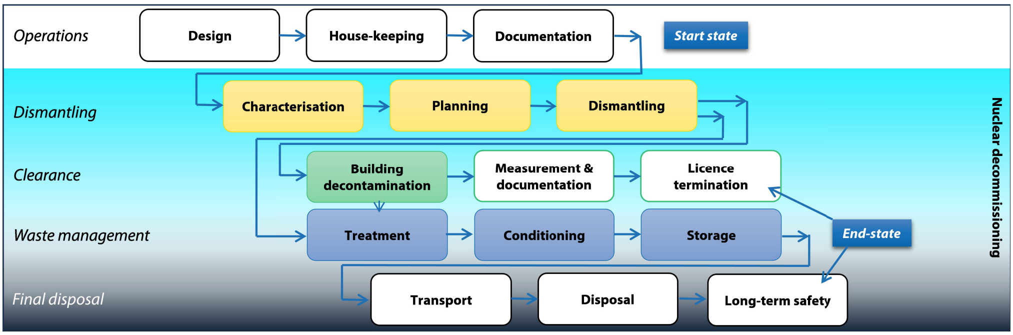
The (V)LLW generated during decommissioning arises from two sources; i) primary (V)LLW from the existing systems, structures and components of the facility at shut down, and ii) secondary waste generated during dismantling and decontamination activities.

The amount of primary waste is determined by the extent of contamination at the start of decommissioning and is governed by the facility design, the history of events and the housekeeping policies implemented during operations. The volumes of primary (V)LLW can be lowered by decontamination to below clearance levels, a process in which the radioactivity is removed and attached to another carrier of smaller volume, such as ion exchange resin or a filter.

Significant amounts of secondary waste are generated as work is carried out in the facilities. The secondary waste typically consists of protective clothing, wipes and used tools, as well as items such as filters and ion exchange resins used for decontamination purposes. The generation of secondary waste is inevitable for radiation protection purposes to reduce the risk of spreading contamination and to concentrate the radioactivity into a form more suitable for final disposal. However, since the volume of secondary waste generated can become a significant cost driver, it should be carefully monitored to avoid creating unnecessary waste volumes.

Figure 2-2 shows a process flow diagram for decommissioning and radioactive waste management.

Figure 2-2: **Simplified decommissioning radioactive waste management process**



Source: OECD/NEA.

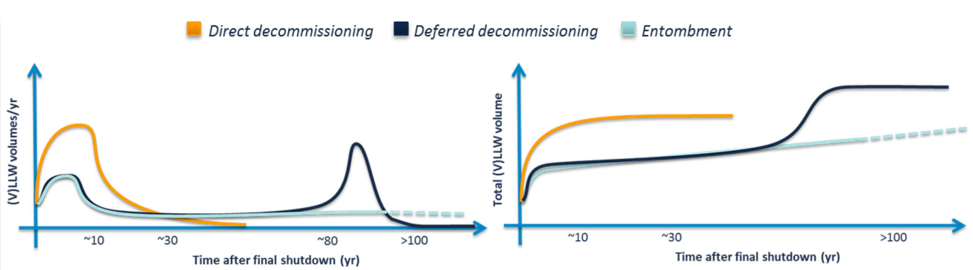
As depicted in Figure 2-2 above, decommissioning, dismantling and clean-up activities are preceded by the planning and characterisation stages; these, together with the documentation available at final shut down, should allow decommissioning and dismantling plans to be developed before waste generating activities commence. In addition, having a sufficient understanding of the waste management and clearance processes before decommissioning starts will reduce the risk of having to undertake unnecessary decontamination or waste treatment activities; and can reduce the risk of spreading contamination as dismantling proceeds. Proper preparation can thus prevent the creation of unnecessary secondary waste and mitigate against the risk of having to undertake remedial activities as a result of inadequate planning. These remedial activities can be more complex and therefore costlier than had the activities been completed correctly in the first place. Sufficient planning is thus the cornerstone of optimised (V)LLW management.

The overall decommissioning strategy, as well as the start state of a facility inherited from the operations phase, will govern both the timing and volume of (V)LLW generated during a decommissioning programme. Figure 2-3 shows a general schematic representation of (V)LLW volumes generated if a facility is subject to three different decommissioning approaches. (Specific circumstances may alter the curves in Figure 2-3.)

- **Immediate decommissioning**, starting as soon as possible after operations have ceased. The good condition of the facility's systems, structures and components, together with available information about the facility, should offer the best opportunity to optimise the decommissioning process from a waste generation perspective. As a result, a direct decommissioning strategy should give rise to the lowest total amount of (V)LLW, despite the relatively short period for radioactive decay and the facility's associated relatively high initial activity levels.

- **Deferred decommissioning** will give rise to secondary waste during the care and maintenance phase, from maintenance activities associated with preservation of plant integrity. There is also a risk that a loss of knowledge of plant status and history, and the deterioration of the systems and structural integrity, may lead to additional production of (V)LLW. For most facilities this additional waste volume would not be compensated for by the physical decay of the radionuclides in the primary waste as a result of in situ decay storage. Hence, a deferred decommissioning strategy will generally give rise to a larger total (V)LLW volume than a direct decommissioning strategy, despite the lower total amount of radioactivity when finally decommissioning the facility.
- **Entombment** is defined by the International Atomic Energy Agency (IAEA) as "*in situ disposal* (*entombment*) *where the nuclear facility is disposed wholly or partly at its existing location* and an alternative which may be considered acceptable only under exceptional circumstances". Depending on the level of hazard posed by the entombed structure, it can be a burden to future generations as it may require ongoing care and maintenance, as well as surveillance. At first sight, it may seem that an entombment strategy would generate lower volumes of (V)LLW than a deferred decommissioning strategy; however, it is likely that an entombment strategy will, over the life of the strategy, generate more waste than other approaches. This is because at some point either the accumulated waste volume will have to be treated and sent off site for disposal or it will effectively become in situ disposed. Since, in general, more than 90% of the materials in a commercial reactor are not contaminated at the end of the operational period; the total radioactive waste volume is increased, by an order of magnitude, by the act of entombment because it would all be managed as in situ disposed radioactive waste. In addition, entombment is considered to be the least preferred approach from a public acceptance and stakeholder perspective; and should therefore only be considered in severe accident scenarios. As a consequence, entombment will not be addressed further in this report since it is not considered to deliver waste management optimisation.

Figure 2-3: **The impact of decommissioning approaches on (V)LLW volumes**



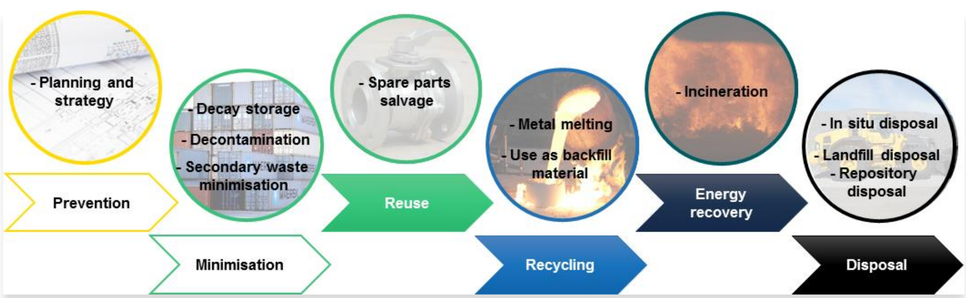
Source: OECD/NEA.

2.2. (V)LLW management

Multiple options exist for the management of decommissioning (V)LLW. In general, the more contaminated the waste is, the more likely that it will require disposal to a repository. There are a range of activities that could be undertaken to optimise the waste requiring disposal, including treatment to improve the final waste form, and/or steps to reduce its volume (such as decontamination or incineration). The treatment options deployed will vary, depending on existing regulations and local knowledge. However, some common principles can be applied:

- Waste hierarchy: the principle that waste generation and management should consider impacts on the environment is the first common principle when managing (V)LLW generated during decommissioning (see Figure 2-4).
- Clearance: the clearance level definitions are almost always associated with the waste hierarchy. The associated clearance threshold values typically allow the recycling and reuse of 90% of decontaminated materials, whether in the civil or nuclear industry (depending on local regulations).

Figure 2-4: **Waste hierarchy from the most to least favourable option ,options for (V)LLW management**



Source: OECD/NEA.

The waste hierarchy is relatively well established and similar approaches can be seen worldwide, but clearance levels are defined in national legislation and national interpretations of international standards. Continuous improvement of clearance levels and standardisation worldwide, as well as harmonisation of respective regulations, may be central to facilitating successful, long-term decommissioning waste management optimisation, since standardisation and harmonisation between countries are the foundation of:

- waste management optimisation;
- public acceptance;
- stakeholder confidence;
- productivity gains improving technical and financial management during decommissioning.

As a consequence, having standardised regulations and uniform clearance levels could not only foster the sharing of good practices, reinforcing technical and financial management during decommissioning, but it could also avoid potential confusion, potential loss of public acceptance and the possibility of decreased credibility of authority representatives.

The management of (V)LLW can be considered to follow the same waste hierarchy principles as those for non-radioactive waste, through the use of different treatment methods. As with non-radioactive waste management, the main driver is to prevent unnecessary (V)LLW from being created. However, recognising that, in decommissioning projects, the generation of (V)LLW is unavoidable, the main focus should therefore be to limit the volumes and complexity of the (V)LLW created as far as reasonably practicable.

Decommissioning (V)LLW can generally be divided into one of the following main radioactively contaminated waste types:

1. able to be incinerated (organic material, plastics, cellulose based material, liquids, etc.);
2. metal (carbon steel, stainless steel, aluminium, copper, titanium, etc.);
3. inert (concrete, sand, contaminated soil, mineral insulation, etc.).

Many mixed-material components exist; and additional complexity arises because conventional hazardous materials can also be present in radioactive waste. (V)LLW would therefore need to be separated into a number of waste streams to enable fit-for-purpose management; and early characterisation activities such as in situ gamma spectrometric measurements and gross gamma measurements, and hazardous material inventories are valuable tools to support such activities. Regardless of the segregation strategy used, the available treatment options can generally be explained by the three waste types listed above; all of which are used here.

Waste that is able to be incinerated is mainly generated as secondary waste from a decommissioning project; is generally hard to decontaminate and, because of its unfavourable surface structure, is almost impossible to measure as free from surface contamination. There are no practicable reuse or recycling options for these waste streams, and so volume reduction and energy recovery through incineration offers the preferred route from a waste hierarchy perspective; with nuclear waste incinerators existing in many countries (for this option to be preferred from an environmental perspective, energy should be recovered during the incineration process). The main alternative to incineration is disposal (except for organic waste in some countries), either directly or after treatment (using compaction or super compaction); this option can offer both good radiation safety and low costs.

Contaminated metal arising from a decommissioning project is predominantly primary waste. Prevention and minimisation is best achieved during the construction and operation of the facility, which is beyond the scope of this report. Some metal components can be reused, although this generally represents an insignificant volume in a large-scale decommissioning programme. Metal components can also be surface decontaminated, although the success of this technique is dependent upon the geometry of the component. Optimised (V)LLW metal treatment is often best achieved by melting the material; and facilities exist in a number of countries, including France, Germany, Sweden and the United States. Melting can be considered an advanced decontamination technique, as volatile radionuclides (typically ^{137}Cs) are removed and captured by an off-gas system; and other radionuclides (such as alpha nuclides, and partially, some beta gamma nuclides) can be distributed into the slag phase, although a portion will remain in the melt. New experiments could be undertaken to optimise the benefits from this aspect of the radionuclide characteristics, including magnetic properties. Carrying out several cycles of melting could also improve the decontamination ratio, as long as the required number of melt cycles achieves an economic balance with regard to waste treatment cost. ^{60}Co does have a short half-life (5.27 years) and so the resulting waste could be easily managed through decay storage. The metal in the ingot will have a homogeneous distribution of the remaining radionuclides, which can be measured, and, if the ingot has low enough specific activity, allow clearance (direct or after decay storage) as a result of the dilution of the contaminants with the bulk material. Experience shows that this kind of treatment achieves a volume reduction of between 14 to 21 times the initial volume. In some countries, such as Spain, metal melting is a legal requirement. Direct disposal of contaminated metals can be safe and cost-efficient and may be the choice for more contaminated, or mixed (V)LLW.

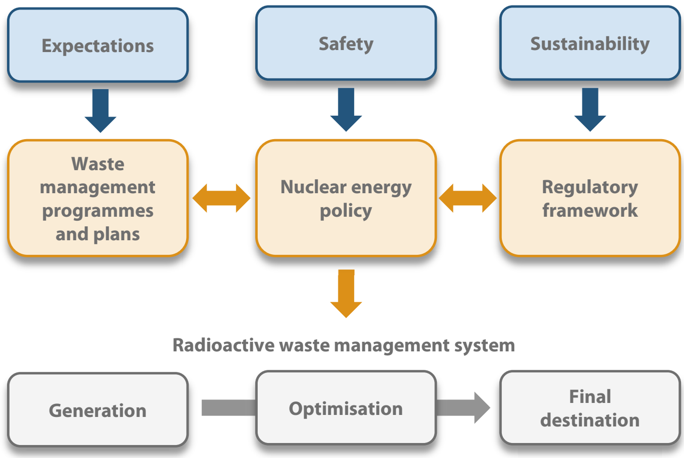
Inert (V)LLW from decommissioning projects is, by volume, mainly concrete. Where significant spills or leaks have occurred during operations, contaminated soil may also contribute to the inert (V)LLW. Contamination can have spread to the structures during both operations and decommissioning; and the (V)LLW can therefore be a mixture of primary and secondary waste. Concrete, soil and sand (V)LLW can be used as backfill or as a construction material in a repository, or for road building in some countries; but otherwise it is difficult to find an alternate use for it because it has low commercial value and the impact of CO_2 from transport makes it economically difficult to be recycled (except locally). Inert (V)LLW can also be disposed of in a landfill, a repository or, in the case of concrete and sand, in situ if national regulations permit (see Section 3.3 for further discussion).

2.3. The optimisation context

The process of optimisation involves making judgements about the different aspects of (V)LLW management (for example, radiological risk, non-radiological hazards, safeguards, environmental detriments, technology maturity and availability, financial or societal concerns) and their relative importance to decision makers. In accordance with the definition in Chapter 1, optimisation is about delivering the best possible joint outcomes for both decommissioning and waste management, from the decommissioning start state to the desired site end-state. The optimisation of (V)LLW management should thus positively influence and impact decommissioning programme schedules and costs, as well as safety and environmental objectives.

Figure 2-5 shows the external factors influencing radioactive waste management. The main driver of all nuclear energy policies is safety. Protection of current and future generations is of paramount concern and safety is recognised as the first pillar of trust when discussing the principles of operation and decommissioning of nuclear facilities, as well as the management of associated waste.

Figure 2-5: **External factors influencing radioactive waste management systems**



Source: OECD/NEA.

The nuclear industry is generally expected to make a commitment that the generations using nuclear installations have an obligation to ensure that the financial, technical and scientific resources needed for the safe decommissioning of the facilities are available, and that radioactive waste is managed safely (NEA, 2006). In addition, these expectations are based on:

- The polluter pays principle, with the aim of preserving safety and not imposing an undue burden on future generations.
- Optimisation of radiological protection, also referred to as the ALARA principle. According to the International Commission on Radiological Protection (ICRP) "Optimisation of protection is a source-related process to keep the likelihood of exposures…the number of people exposed and the magnitude of individual doses as low as reasonably achievable, taking economic and societal factors into account" (ICRP, 2007).

The concept of sustainability has been introduced in most national nuclear energy policies, given the long time frames involved in decommissioning and radioactive waste management, and it is also a pillar of radioactive waste management optimisation.

The national regulatory framework and legislation will influence (V)LLW management optimisation; and each country has developed its own arrangements for undertaking decommissioning and waste management. A summary of key information for each of the NEA countries is summarised in Appendix A. In addition, the different drivers behind the optimisation are presented and discussed in detail in Chapter 3.

2.4. Lessons learnt/success factors and barriers

Lessons learnt from waste-oriented decommissioning shows that the design and construction of new facilities should include consideration of waste minimisation during operations and decommissioning (and is a legal requirement in many countries). Strategic waste management planning should take place throughout the whole decommissioning programme or project life cycle. A strong project planning process, which includes consideration of waste arisings and their management at all stages of the project, along with suitable logistics and data management systems, is identified as a success factor during decommissioning planning. However, there may also be safety, financial or schedule constraints to optimising the management of radioactive waste and materials.

Lessons learnt also show the importance of understanding the initial state of the facility after permanent shutdown. Effective characterisation processes enable categorisation of waste and should be carried out at the right time and to the right extent. Characterisation also enables early and robust inventories of radioactive waste to underpin project plans and to allow external service providers to make commercial decisions on supporting infrastructure investments. Constraints relating to the initial state of a facility include difficulties with estimating hard to measure radionuclides and the availability of reliable inventories of (V)LLW and of radiologically contaminated land (both the quantities and waste).

When identifying an optimal end-state, the planning and decision-making process should engage stakeholders from the start of the process. An optimal end-state may reduce the amount of (V)LLW generated. Lessons learnt also show the need for flexibility in the process; information gaps regarding the (V)LLW inventory and extent of radiologically contaminated land may lead to a review of the selected end-state. There may be legislative, financial, political or scheduling constraints that impact the selection of the optimal end-state.

Applying the waste hierarchy has been shown to be a success factor; initially seeking to avoid waste generation, and then to minimise disposed volumes through reuse and recycling of materials, as well as having waste treatment facilities available to enable reuse and recycling. Having supporting capability in place to enable effective application of the waste hierarchy, such as characterisation laboratories and appropriate transport and packaging solutions, has also been identified as a success factor, as has the use of "optioneering" and analysis tools, including best available technique (BAT) assessments, which facilitate the selection of appropriate waste treatment, conditioning and disposal routes over the entire waste management life cycle.

Flexibility and different management alternatives provide the ability to undertake safe in situ disposal of suitable radioactive waste on a site, to align with the defined site end-state. It is also possible to use decay storage as a waste management tool (for example for short half-life period radionuclides – typically ^{60}Co). Conditioning, treatment and disposal facilities should be available when required (whether on-site or through the supply chain), with clear and appropriate enabling waste acceptance criteria. Suitable packaging and transport resources should also be available to enable a flexible approach, including an appropriate waste transport legislative framework.

Clearly defined responsibilities and the right skills and knowledge for waste management within the site, facility and project are clear success factors. The ability to send waste for treatment to another country is dependent on international agreements, including transboundary transport and the harmonisation of rules.

Having appropriate policies, strategies and a suitable regulatory framework in place have been shown to be key success factors. A strong industrial nuclear fabric, a stable nuclear industry structure, and detailed regulatory frameworks and guidelines facilitate the process for the plant owners. A change in the regulatory environment during a decommissioning programme could, for example, cause problems.

Stakeholder involvement should be considered early in the project. Robust stakeholder engagement and communication processes are also seen as success factors. The relationship with government, the general acceptance of public opinion towards the nuclear industry and public acceptance of (V)LLW management solutions have all been shown to be crucial for a successful decommissioning project.

Chapter 3. Drivers for optimisation

As noted in Chapter 1, developing and optimising waste management strategies requires finding and maintaining a balance between a range of factors, including the national nuclear energy policy, and the regulatory framework and national waste management programmes, while also considering the entire waste management process, from generation to final disposal (see Figure 2-2).

This chapter describes the key factors to be considered within the radioactive waste management process when seeking its optimisation during decommissioning.

3.1. Safety and environment

Safety in the context of optimising the management of Low-level and very low-level waste ([V]LLW) requires consideration of both the radiological and industrial hazards – in relation to staff undertaking decommissioning work, the wider public and the environment – during decommissioning and waste management activities. The ultimate objective will be the release of the site from regulatory control.

The comparatively low radiological dose derived from the treatment of (V)LLW may mean that the dominant risks associated with its management and optimisation are the industrial hazards associated with the demolition of structures, excavation of soils, and waste handling and transport. Consideration of radiological and industrial hazards will extend beyond the site boundary and should include the transport and disposal of waste.

Decommissioning of a plant means that the total amount of radioactivity generated during operation has to be managed, either as radioactive waste or as cleared material, and be transported off site. A safety case may be developed to support radioactive materials that will remain on the site after the termination of regulatory control. Key factors influencing these disposal routes and approaches relate to local and national conditions and controls, and include:

- the availability of disposal options, with or without interim storage;
- the breadth of available waste acceptance criteria;
- the scope for clearance of materials for reuse, reutilisation and disposal as waste;
- public and stakeholder acceptance of the different disposal pathways;
- the site end-state and restoration requirements;
- the significance and acceptability of environmental impacts resulting from radioactive and non-radioactive waste and discharges.

With a focus on safety, a holistic optimisation process should be utilised, including the consideration of the waste hierarchy and the industrial hazards.

Safety

The management of decommissioning waste will need to take place within a comprehensive safety framework that takes account of the legal framework, sustainability and cost drivers to optimise waste, as well as the practical challenges associated with decommissioning waste optimisation. Tensions may exist between the regulatory requirements for dose reduction and the need to work in controlled areas, or challenging working environments.

It is essential that a safety culture is maintained and developed during decommissioning, which is in line with the radiological protection principle of as low as reasonably achievable (ALARA), i.e. to keep the likelihood of exposures, the number of people exposed, and the magnitude of individual doses ALARA, economic and social factors being considered. The safety culture in place during the site's operational period will need to change upon entering decommissioning and through post-operational clean-out (POCO), dismantling and demolition.

The radiological protection culture in (V)LLW management is driven by the need to balance and optimise:

- dose reduction versus waste minimisation, taking a life cycle approach to optimisation;
- the length of interim storage and timing of final disposal availability;
- disposal capacity availability and the extent of waste minimisation;
- common dose concepts and specific activity levels needed for disposal and clearance.

It is assumed that preparatory decommissioning activities will be performed by the former facility operator as a first part of the transition from operation to decommissioning or POCO. In all aspects of decommissioning, safety requirements must be met, and consideration taken for cost and practical constraints within the process. The use of novel and bespoke solutions to decommissioning challenges may assist in delivering decommissioning while meeting safety objectives. In comparison with the operational period, the safety framework for the decommissioning period will need to:

- be more flexible and reactive, changing as the site is decommissioned;
- deliver efficient and effective logistics because of higher waste volumes and throughput;
- put in place training and re-skilling of staff for the new work challenges;
- seek to implement a new staff mind-set, recognising that their jobs will have a finite duration;
- enable adaptation of site systems for completely new tasks associated with decommissioning;
- adjust to the decrease in hazards while decommissioning is progressing.

To support decommissioning, the safety culture should not be static and will need to evolve, taking into account the nature of the challenges and the status of the workforce.

Industrial hazards in the management of (V)LLW include asbestos, polychlorinated biphenyls (PCBs), mercury, hydrocarbons and any materials that exhibit hazardous properties other than radioactivity. Decommissioning activities should be carried out within safe systems of work, which take account of these hazards. If there is a combination of industrial hazardous material with radioactivity, then the priority should usually be focused on the radiological hazards, although this does not negate the need to deliver conventional safety measures.

Optimising radiological safety should be carried out using a life cycle approach. There are different steps for optimisation at different stages in the process. Keeping the dose both to the public and to the staff as low as reasonably possible should not be competing aims, if a practical approach is adopted.

The principal condition for clearance is to meet an established level of safety. According to the International Commission on Radiological Protection (ICRP), the applicable dose constraint is of the order of some 10 µSv/a (the "de minimis" concept). Different dose pathways overlapping each other have to be considered, resulting in a 10 µSv/y approach for a single pathway. By calculation of radiation doses for different exposure scenarios, this dose is transferred into nuclide specific Bq/g values as clearance limits. The clearance process and the single measures within it are usually checked by regulatory bodies to ensure safety. Optimisation of protection should also be considered.

Early segregation and decontamination is one of the approaches used to achieve clearance for a larger portion of material; and is therefore essential for optimisation of (V)LLW management. Special attention must be paid to α emitting nuclides requiring measures against incorporation (inhalation). Protection against radiation from β and γ emitters can be applied by the usual radiological protection measures, like shielding (if possible), limiting the time for work and keeping as much distance as possible from the material. The treatment of radioactive waste for clearance and the conditioning for final disposal to a repository will cause dose to workers but reduce doses to the public.

Radiological hazards associated with an operational power plant will be significantly reduced once the reactor is shut down, with a further reduction as the nuclear fuel is either stored safely on-site (e.g. dry cask storage) or removed from site. This change means certain site-wide safety requirements can be reduced, allowing the proportional application of safety systems corresponding to the reduced radiological hazard.

The safety culture up to the time of site clearance should consider dose reduction within (V)LLW management. The radiological dose consequences associated with the optimisation of (V)LLW management are likely to reduce significantly during decommissioning and demolition as the more hazardous radioactive materials are managed or disposed of.

Environment

All activities associated with the clearance of waste and materials will take place within a waste management framework covering site activities and the off-site consignment, either as reuse of waste and materials or disposal.

Doses to the environment may occur from a range of different pathways reflecting the activity being undertaken, including:

- clearance;
- releases to water and air;
- storage, whether on- or off-site;
- surface and geological disposal;
- transport (dose rates for transport are limited by the legal framework, where hazards to public are taken into account when defining these limits).

Prior to the end of the operational period, the operator should seek to identify the nature of the safety constraints so that appropriate environmental optimisation can take place. Throughout the site clearance and aftercare period (if required), all activities will need to meet relevant local and national radiological safety requirements.

The optimisation of (V)LLW during decommissioning and site clearance can deliver significant environmental benefits by allowing the timely return of the nuclear site to other uses and the minimisation of the quantities of backfill materials requiring importation to achieve the site end-state. The application of the waste hierarchy and the demonstration of the best available technique (BAT) can provide an effective framework in which the optimisation of (V)LLW can be delivered, while keeping the likelihood of exposures, the number of people exposed and the magnitude of individual doses ALARA.

The environmental consequences associated with both specific items and general site-wide disposal and reuse of materials or waste should be described and assessed within an environmental safety case (ESC), since the ESC will provide a framework within which the optimisation of (V)LLW can be carried out. The ESC will:

- identify environmental receptors requiring protection;
- provide a framework for the optimisation of (V)LLW;
- demonstrate that (V)LLW is being disposed of on-site safely;
- show that any residual contamination present in buried structures is safe;
- allow the development of waste acceptance criteria (WAC) for on-site waste disposal facilities;
- provide clean-up objectives for contaminated land and in situ structures;
- consider the environmental context of (V)LLW optimisation on a site-wide basis;
- demonstrate that regulatory controls can be removed from the site at some point in the future.

As with safety, the nature and extent of environmental challenges will change with the move from operations to decommissioning, site clearance and eventual licence termination. An optimised solution will consider all environmental impacts associated with the management and disposal of (V)LLW throughout the life cycle of the waste, with the best overall solution identified. Effective and early waste and material characterisation combined with the application of the waste hierarchy and optimisation of radiological protection provides a means of delivering an optimised decommissioning programme that can ensure the minimisation of environmental discharges and waste disposal during decommissioning. Optimisation will also need to consider all significant environmental impacts resulting from waste treatment, storage and transport on- and off-site.

(V)LLW, cleared material and discharges resulting from decommissioning, as well as those materials left after release, should be optimised to ensure an optimal level of protection to human health, wildlife, organisms and the wider environment, while complying with relevant dose limits and constraints stated in national regulations.

Optimisation of environmental impacts will also need to take account of the timescales over which the environmental and human health hazard remains.

A key objective for decommissioning is bringing the site to a condition at which it can be released from regulation (licence termination). This needs to take account of resources, socio-economics, environmental impact and safety to deliver an optimised solution. It should be done through a process that will keep the radiological risks to individual members of the public and the population as low as reasonably achievable, but still practical (pragmatic, proportional, fit-for-purpose and flexible).

The production of waste that cannot be safely disposed of (known as orphan waste) should be avoided. Existing and new disposal routes should be maintained and protected to support site decommissioning objectives. The optimisation of waste disposal will need to take account of the potential to leave materials and waste on site where appropriate, while taking into account the identified future use of the site.

The optimised solution should seek to prevent the mixing of radioactive waste with other materials, including other radioactive waste, where such mixing might compromise subsequent effective management or increase environmental impacts or risks.

Optimisation should take place within national regulations for the management and disposal of conventional waste.

If disposal as radioactive waste is the optimal solution, the environmental implications of its management must be considered, including its safe transport, interim storage (if necessary) and final storage and disposal, taking account of the potential lack of a suitable repository and any uncertainty associated with the repository's waste acceptance criteria.

In order to achieve site release, the management of safety during decommissioning and site release should:

- maintain country specific regulatory requirements both before and after the release of the permit;

- be flexible, so as to accommodate a wide range of activities (some novel), often only occurring only once on the site;
- be pragmatic, taking account of the benefits delivered by optimised decommissioning and site clearance and the reduced overall site hazard;
- be proportionate to the nature of activity being undertaken;
- take account of internal and external learning from experience;
- take account of the change in site operations; since the site's primary business will now be dismantling and management of the resulting waste;
- ensure that all staff are appropriately trained, re-skilled and motivated for the job at hand;
- maintain site-specific knowledge;
- take account of safety issues associated with the transport of large volumes of materials on- and off-site;
- provide a safety framework for waste treatment and disposal on- and off-site.

A successful safety framework will take account of the changing nature of radiological and industrial hazards during the ongoing decommissioning, allowing the optimisation of (V)LLW management and the timely release of the site. Success will be defined by the effective application of optimisation benefits delivered without compromising safety.

Examples of safely managing hazards

Some examples of how specific hazards could be safely managed are provided below:

- **Asbestos management at a nuclear site**. Asbestos gives rise to significant human health impacts. During decommissioning it is essential that the operator carries out appropriate characterisation of all aspects of the components and building structures, including those which have been subject to radioactive contamination or activation. Removal techniques and disposal routes for the management of radiologically clean asbestos are well established; however, in many countries disposal and management routes for radiologically contaminated asbestos may not exist. It is therefore vital that sufficient characterisation and decontamination (if possible) is carried out to minimise the amount of radiologically contaminated asbestos, while at the same time minimising exposure to both asbestos fibres and radiological contamination.

- **Buried structures and infrastructure**. Below ground building structures and infrastructure associated with the operational facility may have been contaminated during the site's operation. The removal of all radioactive contamination below ground may involve extensive excavations and difficult demolition techniques. Optimisation should be carried out in order to balance the radiological and industrial hazards associated with the complete removal of any contamination against long-term safety and environmental impacts associated with leaving the contamination and structures in place after site closure.

- **Reactor core graphite**. The timing of the removal of reactor graphite (and activated core internals) should be optimised to take account of the balance between the worker doses associated with the removal and packaging of the graphite, the availability of downstream treatment capacity and the need to remove the reactor pressure vessel to facilitate site clearance. The use of remote decommissioning techniques may influence this consideration.
- **Conditional clearance**. According to the ICRP, the applicable dose constraint is of the order of 10 µSv/y (the "de minimis" concept) considering different and overlapping pathways. Specific radionuclide values (Bq/g) are calculated taking conservative approaches to the overall possible exposure scenarios to derive a clearance limit. The use of a conditional clearance limit has to be licensed by the competent authority and is usually checked by the regulatory body. This route is not available in every country.

Strategic implications and considerations

The optimisation of (V)LLW, and the decommissioning and release of nuclear sites, will take place within the specific country's policy and strategy framework. The strategy will determine and limit the nature and extent of the opportunities for optimisation, the timing and progress towards site clearance, the waste management infrastructure available and the funding to deliver an optimised solution.

The process of optimising the management of (V)LLW must be carried out within a comprehensive safety framework, which takes account of radiological and industrial safety. A balance should be maintained between safety requirements and the requirement to optimise the management of (V)LLW. Optimisation should provide a means to consider doses to both operators and future exposed groups, finding a balance between these two dose impacts during waste management.

The outcome of optimisation will influence the decommissioning strategy, which should demonstrate a balance between dose impacts, waste volumes, socio-economic implications and costs, with waste management optimisation undertaken on an iterative basis to take account of learning and knowledge gained from site operations, industry best practice and stakeholder involvement.

The extent of remediation should be driven by the consideration of radiological and industrial safety, the environmental impact of remediation and the expectations of stakeholders. This consideration should include the amount and doses associated with any radioactive or hazardous material left on-site at the end of regulatory control.

The application of the waste hierarchy should take account of dose implications; recognising that the R in ALARA stands for "reasonable" and should also include practical.

The delivery of an optimised end-state enables release of the site from regulatory control (licence termination). The release should be carried out in a safe manner with consideration of environmental issues during decommissioning and waste management. Where country specific regulations allow, the end-state may include leaving some radioactivity on the site as long as it is an optimised solution that meets appropriate safety and environmental requirements. This option should be achieved through a process that keeps the radiological and other risks to individual members of the public and the population as a whole as low as reasonably achievable and practical.

Conclusions

It is essential that the management of safety during decommissioning is considered in a holistic way, from before the decommissioning process begins until site release and licence termination is achieved. Consideration should be given to safety aspects including:

- the significant increase in the quantities of waste arising within a short period of time, often with discrete peaks in waste production;
- the increased range of radiological and chemical waste types and resulting hazardous properties;
- the need to safely manage and dispose of (V)LLW requiring off-site and on-site disposal;
- the move from a highly controlled operational work environment to one where a wide range of bulk industrial processes, including demolition, occur;
- the need to undertake hazardous demolition on a nuclear licensed site;
- the different hazards to both workers and members of the public during and after decommissioning and waste management;
- the different skill sets, technologies, procedures, systems and approaches to waste management and clearance needed.

At a strategic level, the operator will need to optimise the management of (V)LLW by balancing a number of safety and environmental factors:

- justification of worker dose against the need to apply the waste management hierarchy and deliver BAT;
- radiological safety versus industrial safety during decommissioning activities;
- the amount and nature of radioactivity (waste) remaining on the site after site release;
- early hazard reduction versus deferred decommissioning/hazard reduction;
- interim storage and decay of waste versus timely disposal and site release;
- on- or off-site management and disposal of waste;
- conditioning, processing and treating waste versus raw waste disposal;
- any limitations or possibilities resulting from the site's proposed future use.

3.2. Characterisation

Characterisation of a waste means the determination of its physical, chemical and radiological properties to establish the need for further treatment or conditioning, or its suitability for handling, processing, storage or disposal.

A life cycle approach to characterisation provides the opportunity to consider the characterisation objectives and the timing of characterisation activities across the life cycle of a nuclear facility; from design, construction, operation, transition (including POCO), through to decommissioning and waste management so as to deliver the desired facility end-state.

For decommissioning purposes, buildings and site areas are defined as belonging to one of two categories: either non-radiological (conventional) or radiological. This categorisation is based on design and historical data and knowledge from the operational life of the facility.

Systematic characterisation activities should be considered an important, ongoing, high-priority process for the radiological areas; some verification measurements are also needed to prove the lack of residual activity in non-radiological areas. Characterisation consists not only of sampling, measurement and analysis of the results, but also involves evaluation of information from the operating history, from calculations, from existing data and from other sources.

The full range of waste properties are important to consider when seeking to manage (V)LLW; thus, characterisation should be considered in its widest sense and should include determination of the following properties:

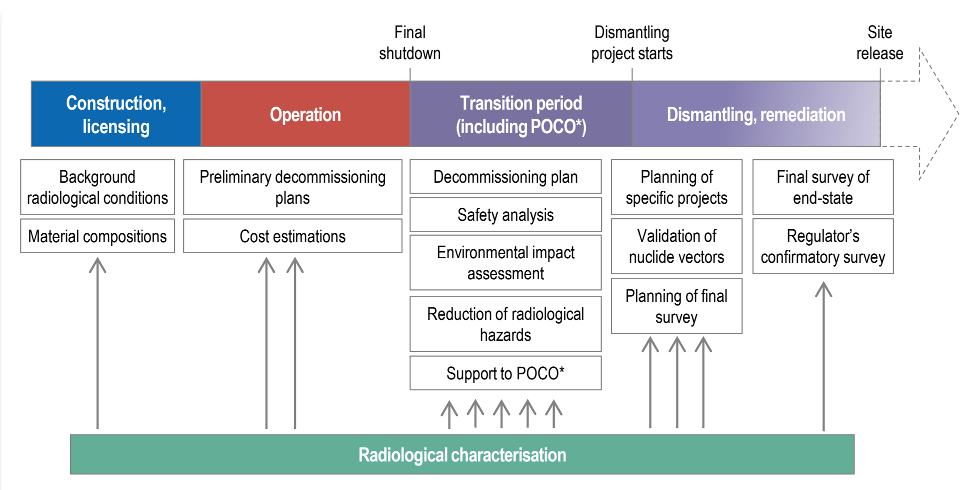
- **Radiological**: the nature, location and concentration of radionuclides, along with the mass or volume of the different types of waste.
- **Physical**: the physical dimensions and condition of a facility. This physical dimension should include the volume and mass of contaminated and potentially contaminated materials, its physical form, structure, geometry and the physical properties of the waste, including the industrial hazards associated with waste characterisation.
- **Chemical**: the chemical characteristics of a nuclear facility and its associated solid waste can significantly impact the decommissioning programme and the optimisation of waste segregation and disposal plans. Chemical components arise from the composition of the original construction materials, chemicals used in operational processes, and chemical spills or incidents associated with the facility. Understanding these characteristics is important for both worker safety and for meeting the WAC of candidate waste treatment and disposal routes.
- **Biological properties** may also be important, particularly where decommissioning has been deferred.

A graded approach can be applied to the radiological characterisation process. For example, in Germany significant characterisation work is undertaken to demonstrate that waste can be cleared from controlled areas. The characterisation work must verify that activity levels are below those defined in the EU Basic Safety Standards (BSS) for unconditional clearance, which can require extensive measurement. However, there is also the ability to conditionally clear materials. Here, the activity levels would be in excess of the BSS values, but the waste could go to conventional landfill – for melting or for restricted use – and in this way the characterisation activities would be less onerous. When considering materials or buildings in unrestricted areas, use can be made of the historical information available, combined with a few direct measurements to demonstrate that there are no hot spots, which is once again less onerous. With this graded approach, the complexity of the characterisation need will differ, depending on the origin and destination of the waste.

The radiological characterisation process can also be executed at a number of levels such as analysis of an area or a building, and of samples, packages or containers. This will depend on the context and the characterisation objective.

Figure 3-1 shows how information generated throughout the life cycle of nuclear facilities can be important in underpinning the radiological characterisation activities, particularly for decommissioning and waste management.

Figure 3-1: **Characterisation objectives through a facility life cycle supporting decommissioning and materials, and waste end-states**



* Post-operational clean-out – the removal of operational materials and waste.

Source: NEA, 2017b.

Characterisation as an enabler to (V)LLW optimisation

There are a range of reasons why characterisation is a key contributor to enabling (V)LLW optimisation during decommissioning. These include:

- **Supporting facility dismantling**: characterisation is central to the planning, implementation and optimisation of decommissioning projects, supporting BAT analysis, determining task durations and risk, etc.
- **Management of (V)LLW arisings**: good facility characterisation, used to support facility decommissioning plans can allow decommissioning to take place in a manner that prevents/minimises the generation of radioactive waste.
- **Material classification**: it is important to determine the volume/mass of the different types of material that will be generated, whether conventional or radiological, with the latter including clearable materials and radioactive waste. This information supports the design of suitable treatment facilities to meet the requirements of the disposal routes.
- **Protection of workers, risk assessment**: radiation doses to workers must be below legal limits and, through a process of optimisation (considering measures such as time, distance, shielding and personal protective equipment), reduced to as low as reasonably practicable.
- **Transport requirements**: when transporting (V)LLW for either treatment or disposal, the consignor must demonstrate compliance with transport regulations (European Agreement concerning the International Carriage of Dangerous Goods by Road, ADR).
- **Protection of the public**: radiation doses to the public must be below legal limits and reduced to as low as reasonably practicable.
- **Protection of the environment**: characterisation plays a key role in environmental management; for example, by informing the development and maintenance of an environmental aspects register.
- **Cost estimation**: there are two main aspects to cost estimation: the cost of the characterisation activities themselves and the potential to avoid costs from unplanned tasks during decommissioning, which could compromise the budget. In addition, legacy waste is generally more complex to characterise, because of a lack of sufficient or reliable information (whereas decommissioning waste is generally produced within a waste management system, ensuring compliance and data traceability). Recovering lost information by opening waste packages, re-sampling or sorting can be extremely expensive, as well as being against good practices in radioprotection.
- **Suitability of routes and meeting WAC**: characterisation information enables the waste producer to demonstrate compliance with treatment or disposal WAC, and thus influence the steps in the waste management process. WAC at disposal facilities can have an important influence on decommissioning strategies; for example, in many facilities the capacity for specific nuclides with a long half-life, such as C-14, is limited, which may

exclude part of the inventory from being disposed of at these facilities. The possible disposal options for cleared waste will also influence the efforts undertaken to decontaminate materials.

- **Waste inventory**: information generated from characterisation activities is used as input into the national radioactive waste inventory, as well as to support waste management planning.
- **Clearance**: clearance information can provide public reassurance and confidence that the waste meets WAC for waste treatment and disposal routes; or meets the requirements for conventional disposal of cleared waste.
- **Lack of disposal routes**: certain types of waste may have no identified disposal route, and the characterisation of this waste may result in the identification of alternate processes to transform the waste into a form suitable for disposal or provide important information for the development of alternative disposal solutions.
- **Decontamination processes**: decontamination processes that potentially reduce the classification of waste from intermediate-level waste (ILW) to low-level waste (LLW) or very low-level waste (VLLW) need information from characterisation to evidence the suitability of the process.
- **Decommissioning strategies and plans**: the classification and characterisation of waste is closely connected to decommissioning and waste management plans. National regulations on clearance not only influence the way materials are managed on-site, but changes in the regulation, for example to clearance levels, can lead to significant changes in the amount of waste that needs to be managed as radioactive waste (see case study in Appendix 2). These changes can also influence the required storage, treatment and disposal capabilities, as well as the characterisation activities required. Indeed, a national strategy for disposal may be challenged if the amount of radioactive waste becomes greater than the planned capacities for disposal, which also means that changes in the national disposal strategy may influence the strategy for decommissioning. Clearance levels also influence the decommissioning strategy since they may determine how different waste streams need to be separated to prevent the contamination of materials that are to be cleared. The decommissioning strategy can also be vulnerable to changes in public acceptance of the disposal of cleared radioactive waste.

Implementation of characterisation during decommissioning

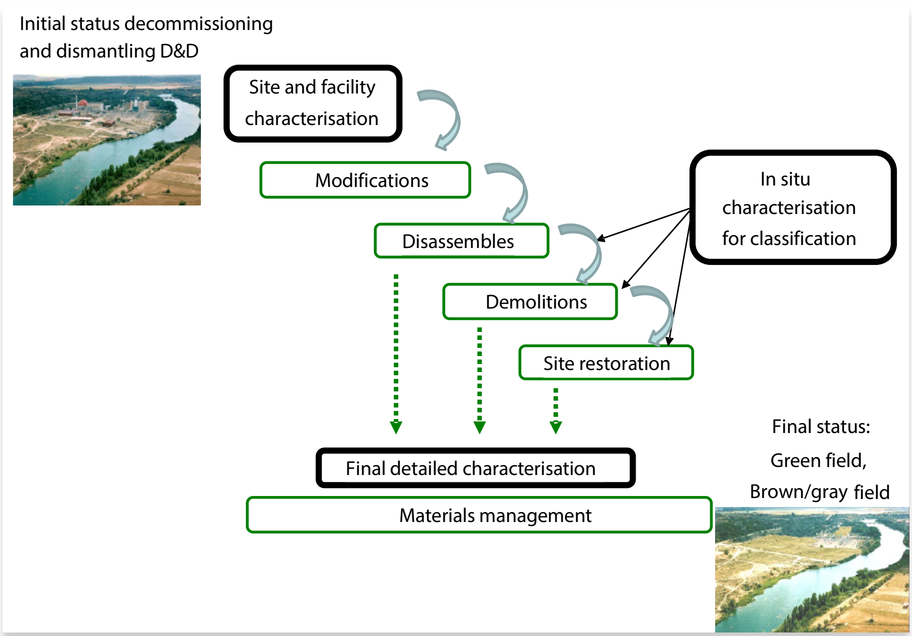
As noted above, adequate radiological characterisation is of crucial importance to the optimisation of (V)LLW management at all stages of a decommissioning project; and the planning and prioritisation of characterisation activities is essential to ensure that the process is optimised and the need for rework – and potential delays to the decommissioning programme – is minimised or eliminated. The NEA Working Party on Decommissioning and Dismantling (WPDD) has produced reports on radiological characterisation (NEA, 2017b and 2013) that provide guidance on the selection and tailoring of strategies for radiological characterisation, as well as an overview of good practice.

Once the decommissioning phase starts, there are different, possible ways of undertaking characterisation activities, depending on the schedule and the specific processes to be undertaken. These include:

- Site and facility characterisation: where the objective is to obtain a radiological understanding of the whole installation, or at least the locations accessible for characterisation work.
- In situ characterisation for classification: this is a high-level characterisation process that allows the segregation of waste in the different categories (ILW, LLW, VLLW) and also allows a practicable approach to classifying the materials to facilitate, for example, disassembly or cleaning activities.
- Final detailed characterisation for final assignment/assessment: this is a thorough characterisation activity that confirms the final destination of the (V)LLW or enables the clearance of materials and fulfils the regulatory requirements for disposal.

These characterisation processes must all be undertaken during the decommissioning programme, and their sequence will depend on a range of factors such as the facility characteristics or the regulatory requirements. Figure 3-2 shows how these activities fit within the overall decommissioning cycle for a site or facility.

Figure 3-2: **Radiological characterisation implementation**



Source: Enresa, Jose Cabrera NPP D&D.

Three activities can be used during decommissioning, which could directly influence the optimisation of (V)LLW:

- Material release: during radiological dismantling activities, a large volume of material is generated from controlled zones, which could pass a clearance process and therefore reduce the volume of material that would need to be managed as radioactive waste.
- Surface release: surface decontamination can be undertaken with the aim of releasing the building being decommissioned and enabling it to be demolished.
- Site release: this is the final process to release the site for either unrestricted or restricted, future use.

As a result, several, ongoing processes could take place in parallel during the decommissioning programme, generally involving in situ characterisation for classification of the material generated.

Site and facility characterisation

Before starting the main decommissioning activities in a radioactive area, it is useful to undertake an analysis of the historical data collected during the operational life of the facility to estimate the scope of the radiological characterisation work required. This analysis should include not only consideration of radiological issues but also of any aspects related to incidents, changes in function of the area, etc., which could have an influence on radiological classification, including the determination of whether buildings are radioactive or non-radioactive. The results of this analysis will allow the site and facility characterisation work to focus on radiological area.

The main objective of site and facility characterisation is to obtain as holistic a radiological picture of the installation as possible. The characterisation plan should take into account the nature of the building materials and likely contamination; the availability of an applicable radionuclide fingerprint; the accessibility of the contamination; and the level of confidence needed. Depending on the historical data available, the characterisation could be carried out in one or several of the following ways:

- calculations based on design and historical neutron flux;
- dose rate measurements;
- total beta and alpha measurements;
- gamma spectrometry;
- sampling programmes.

In addition to supporting the determination of waste management activities, the results can also inform the strategies developed by other parts of the organisation, such as radiological protection, engineering and the operational dismantling function.

The characterisation plan should enable sampling optimisation, with the aim of saving costs while improving confidence. An approach could be implemented that takes the following items into consideration:

- Classify the samples by both origin and the simplest or easiest values measured, such as dose rate, total alpha or beta.
- For each sampling area, generate composite samples from those which are inside predefined interval ranges, making sure they are homogeneous in relation to the measured parameter.
- Send for radiochemical analysis the least possible number of composite samples, while trying to cover as wide a range of values as possible, with enough activity to ensure that values greater than the minimum detectable activity (MDA) will be obtained.

Radionuclide vectors can be used for all radiological waste classifications encountered during decommissioning.

It should be recognised that it might be necessary to keep some of the samples stored to support future analysis during and after the decommissioning activities in order to optimise future processes if questions are raised.

In situ characterisation for classification

In situ characterisation is the process carried out during the dismantling period to classify the waste generated. It is assumed that site and facility characterisation has been completed and that the only remaining task after in situ characterisation for classification would be the final assessment of the activity.

The common in situ characterisation activities in a decommissioning programme, connected to the main volume optimisation activities (material release, surface release and site release), are:

- material characterisation during the disassembly activities;
- characterisation of large items or equipment;
- surface characterisation of building walls;
- soil characterisation during site remediation.

These activities are, to some extent, undertaken in sequence: for example, it is not worth measuring the building walls before removing the system structures; and it is not worth remediating the site while having operating systems that could impact the level of soil contamination. Early surface characterisation of the building walls or the soil would, however, support planning of the remediation activities.

In order to make the process effective, a robust in situ characterisation approach should be used to deliver good quality information while enabling a practical process. This approach could be achieved using portable devices to measure dose rates, total counts, etc.

Characterisation work will enable waste to be packaged into containers; these would then be monitored for the final assessment of activity. The number of rejections seen in the process will provide a measure of the effectiveness of the entire process, from initial generation of the material to the final measurement. It should therefore be an iterative activity, with the ability to use feedback to improve the whole process.

Characterisation for final assignment/assessment

The final characterisation process has three main objectives:

- For packages and large components: the final assessment of activity and therefore its final classification; and the final assessment to demonstrate that release or other disposition criteria have been met.
- For building surfaces: final assessment to demonstrate that release criteria have been met.
- For site soils: final assessment to demonstrate that end-state criteria have been met.

It is important to use the right instrumentation to obtain a final value in agreement with the requirements and to demonstrate that classification limits or clearance levels have been met. Differing levels of radioactivity and types of materials require the use of different instrumentation to ensure the accuracy of the results.

Generally, packages, large items or small rooms would be measured using gamma spectrometry or dose rate measurements. In this case, little statistical analysis is required, with measurement error the only uncertainty parameter to consider. However, other approaches are required for characterisation of surfaces or soil, because of the large surface area or volumes involved. Here, it would be reasonable to use suitable statistical methods to demonstrate that the activity meets the requirements for release. The mean value is obtained by taking a number of measurements at specific locations, either equally or randomly distributed over the surface under study. It would also be necessary to either have appropriately estimated the activity of the remainder of the surface under consideration or to have demonstrated that its activity is below the limits.

When estimating the residual activity between measured points, and when the data is structured, geostatistics can be used since these are designed to find correlation between measured data and to use this information to infer the mean distribution of the residual activity. When the data is not structured, a geostatistical approach is of no additional benefit over classical statistical approaches, and estimation is not possible from non-correlated measured data. Here, dynamic scanning of the surface can be used to ensure that no point with activity values above the limits is present and that the remaining activity is distributed in a homogenous way (without hot spots). Dynamic scanning does not quantify the residual activity of the surface measured but provides a threshold of activity detection that allows assurance that the residual activity is either below or above that threshold. As a result, for surfaces, a good approach combines detailed statistical measurements at a number of points on the surface, followed by a dynamic scan of the surface.

In addition to the surface characterisation methods described above, further activities have to be undertaken to determine the activity at depth. Borehole campaigns can be used to quantify the depth of the activity as well as its extent. Here, the only available tool to estimate the mean residual activity between boreholes at different depths is geostatistics, which can optimise the process, potentially avoiding the need to treat large volumes of soil. The uncertainty of the estimated residual activity between boreholes could be used to determine the optimum number of boreholes. This information is obtained from data correlation between boreholes, and it is used to minimise uncertainty to an acceptable level.

Another consideration when determining the best approach to characterisation of contaminated soil is the difficulty of obtaining representative values of residual activity at different depths or intervals in the borehole material itself. Often the borehole material is very heterogeneous, containing gravel, sand and very fine particles with different degrees of contamination as a function of the material concerned. As a result, it can be difficult to assign a value of activity through the depth of the borehole from laboratory measurements. An alternative to measuring the borehole material itself is to measure the hole left by the borehole using gamma spectrometry, providing a cylindrical average source term at every depth.

An in situ characterisation process on material excavated during the remediation process, as the soil is excavated, should be undertaken to determine its classification (releasable, VLLW, LLW or ILW); and detailed characterisation of the containers produced will decide their final destination.

In order to optimise the volume of (V)LLW, it is recommended that a decontamination process is used, if possible, on the remediated soil. This decontamination process is usually carried out using a soil washing plant, which separates the material in three components: the gravel, sand and the finer particles that carry most of the more soluble contamination (such as ^{137}Cs). A plant of this type is currently being used in Spain as part of the decommissioning programme.

Once the remediation of the site is complete, a final status survey must be carried out to demonstrate that there are no values above the limit, both at the surface (the first 15 cm) and at depth.

Conclusions

Radiological characterisation involves the determination of the nature, location and concentration of radionuclides, as well as the mass/volume of different types of waste. Properties of the waste other than the radiological ones are important, and therefore characterisation activities should include consideration of the radiological, physical, chemical and biological properties.

Characterisation is a key process for delivering optimisation within a decommissioning programme; with many aspects of the process directly influenced by the characterisation outcomes, including the radiological protection of workers and the public; transport requirements; cost estimates; and engineering work; as well as the classification and volume of waste generated; and verification that it meets the WAC of treatment or disposal facilities. The characterisation approach should therefore be carefully considered early in the decommissioning and waste management planning process; and should be iterated over the life cycle of the decommissioning programme to ensure it remains effective.

3.3. Enabling infrastructure

Since the decommissioning of nuclear sites will result in the generation of significant quantities of (V)LLW, optimising its management is essential to ensure that its impact is minimised in terms of dose to workers and members of the public and in terms of the impact on the environment. The infrastructure available to decommissioning sites will therefore significantly impact their ability to optimise the management of (V)LLW.

Enabling infrastructure requirements and availability will vary from country to country, depending on the scale of the decommissioning challenge the specific legislative requirements and the availability of appropriate waste management routes. Some countries may have specific policy and regulatory requirements indicating that the waste hierarchy should be applied where it is practicable to do so and that volumes of waste disposed of at repositories should be minimised where possible. This can only be achieved where there is sufficient infrastructure and capability to manage waste and materials by alternative routes.

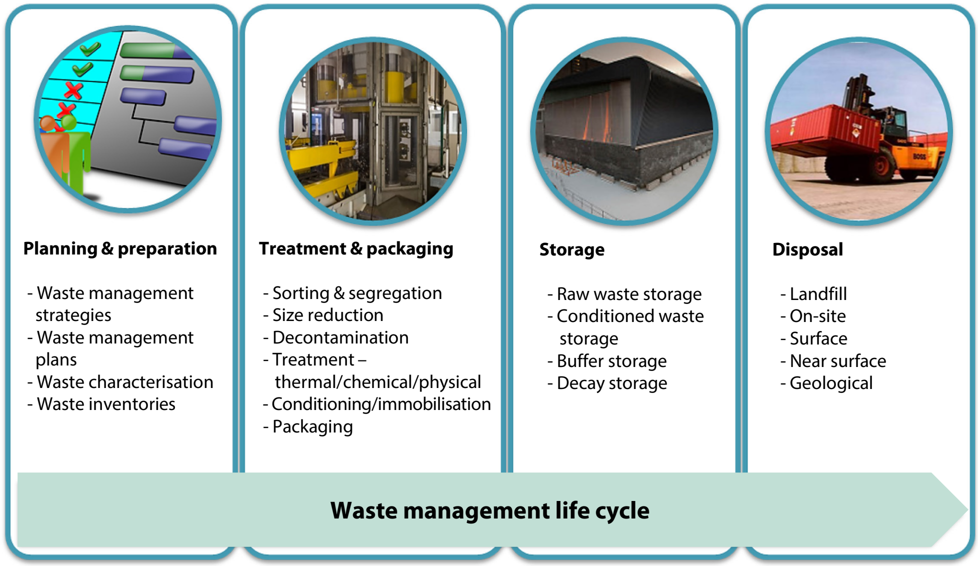
The availability of enabling infrastructure can therefore have a significant impact on both the approach and the outcomes of (V)LLW management during decommissioning; but its influence is also impacted by country specific policies and the regulatory environment.

Aspects of optimisation

The management of (V)LLW typically comprises several stages, although it should be noted that different countries have different classification definitions, and clearance may be unconditional/conditional or not practised in some countries. The NEA Co-operative Programme for the Exchange of Scientific and Technical Information on Nuclear Installation Decommissioning Projects (CPD) report *Recycling and Reuse of Materials Arising from Decommissioning of Nuclear Facilities* (NEA, 2017c) provides a summary of clearance practices from several countries, as well as a range of case studies detailing recycling and the reuse of materials.

A typical radioactive waste and material management life cycle is shown below in Figure 3-3. Transport infrastructure may be needed to enable treatment, storage and disposal operations.

Figure 3-3: **Typical (V)LLW life cycle**



Source: OECD/NEA.

Planning and preparation

Decommissioning waste volumes are typically much higher and potentially different than operational waste; therefore, having appropriate waste management plans in place is an important aspect in the management of radioactive waste and materials. Ensuring that waste infrastructure has the capacity and capability to handle increasing volumes can be a logistical challenge. The use of integrated waste management strategies and waste management plans during operational and decommissioning activities help to articulate the waste management requirements and costs over the life cycle of the decommissioning programme, as well as to identify any gaps in knowledge, skills or infrastructure requirements, which in turn may facilitate research and development. It is important to note that planning and preparation is an iterative process and is applicable throughout all stages of the waste management life cycle.

In the United Kingdom, Magnox Ltd. uses an integrated decommissioning and waste management strategy to define the strategy for the 12 Magnox sites; and Sellafield Ltd is also developing an integrated decommissioning and waste management strategy. In France, the site (or plant) waste management strategy is linked with the dismantling strategy, which are simultaneously reviewed by the nuclear regulator.

The information in the integrated waste management strategies, waste management plans and inventories is useful for a range of external stakeholders:

- waste planners, responsible for ensuring waste facilities, meet local and national needs;
- supply chain organisations that process waste materials;
- researchers and academics developing innovative technologies and processes for managing radioactive waste and materials.

Many legacy facilities were not designed in accordance with decommissioning and waste management principles and this imposes an additional challenge in terms of optimisation of waste management. New facilities tend to be designed and constructed such that the potential spread of contamination is minimised, reducing quantities of waste generated. In France, the design and operation principles for a new facility should fulfil the following objectives:

- to reduce the quantity and volume of radioactive waste remaining in the facility when it is time to decommission;
- to limit the occupational exposure in accordance with ALARA, when considering future decommissioning and dismantling activities;
- to implement specific arrangements and procedures during the operational life of the facility, to reduce contamination and facilitate future clean-up.

Radiological characterisation plays an important role in the decommissioning of nuclear facilities. It is the basis for radiological protection, identification of contamination, assessment of potential risks, cost estimation, planning and implementation of decommissioning, dismantling strategy, waste strategy, radiological worker protection and other matters (see Section 3.2). At all stages of a decommissioning project, adequate radiological characterisation is of crucial importance. The planning and prioritisation of characterisation is essential to ensure that the process is optimised and the need for rework and delays to the decommissioning programme is minimised or eliminated. The NEA report, *Radiological Characterisation for Decommissioning of Nuclear Installations* (NEA, 2013) provides guidance on the selection and tailoring of strategies for radiological characterisation and an overview of good practices.

Treatment and packaging

The aim of waste treatment and packaging is to process raw waste into a form that is suitable for disposal, where routes are readily available, or for long-term storage pending the development of suitable disposal routes. Typically, this process will cover several steps and technologies, including:

- sorting, segregation and size reduction;
- decontamination;
- treatment;
- conditioning/immobilisation;
- packaging.

Any treatment must be in line with the later disposal acceptance criteria – waste should not be created that cannot be disposed of later.

- Sorting, segregation and size reduction

Segregation and size reduction of (V)LLW enables optimisation according to physical, chemical or radiological properties, and it facilitates onward management and/or disposal. The need for sorting, segregation and size reduction is typically driven by the waste hierarchy, optimisation of radiological protection, and acceptance criteria for waste disposal and cost. Size reduction can enable optimisation both from the ability to reclassify waste, and also from increasing packing efficiency. Sorting and segregation could either be carried out at source as the waste is generated or in a separate facility. The option undertaken will depend on site-specific issues such as space and dose controls although it is generally accepted practice that sorting and segregation at source, where this is possible, provides a more appropriate approach.

Size reduction can be carried out either on the site where the waste/material is generated or at the treatment/processing facility; for example, metal melting facilities require metals to be size reduced to fit into the furnace for treatment. In some cases, size reduction may be necessary for large items that cannot be transported whole and need to be size reduced to fit into a transport container. In addition, metal melting operations have an important decontamination effect for some specific radionuclides (especially for alpha emitting nuclides).

- Decontamination, conditioning, treatment

Many wastes or materials require some form of conditioning or treatment prior to final disposal. This could include a range of decontamination options either to decontaminate so as to allow reuse or to reduce radioactivity so as to increase the available range of management options, including clearance. Conditioning requirements are typically stipulated in the WAC or in conditions for acceptance, which are specific to each storage or disposal facility. Conditioning typically means the conversion of waste into a solid form suitable for interim storage or final disposal (2016 International Atomic Energy Agency [IAEA] Safety Glossary) and most sites accepting LLW grout the waste into the containers prior to disposal. Contaminated soil and rubble can, in some countries (such as the United Kingdom), be disposed of in suitably permitted conventional landfill sites.

Treatment can take many forms and can include:

- Physical treatment, e.g. shot blasting metal/concrete to decontaminate the material by removing surface contamination; the removal of contamination "hot spots" by cutting; or compaction to reduce waste volumes.
- Chemical, e.g. the use of gels, wipes or chemical reagents to remove surface contamination.
- Thermal, e.g. incineration, vitrification and metal melting.

Conditioning/treatment infrastructure is typically a combination of on-site and supply chain infrastructure. Some sites have most of their waste management infrastructure on site (such as the Bohunice plant in the Slovak Republic); while others may only have some infrastructure, e.g. Sellafield in the United Kingdom has on-site super compaction capability. Some countries also have access to mobile conditioning facilities provided by supply chain companies. These mobile conditioning facilities may not have the capacity to manage the volumes of waste generated during decommissioning; and it may be necessary to develop capability and capacity within a decommissioning site to ensure that waste conditioning/treatment is optimised. Commercial companies operating in an international market, e.g. Cyclife, GNS, Siempelkamp and Energy Solutions, provide metal melting capability. Incineration capability is usually provided by supply chain companies; however, some sites do have small scale capability for their operational waste.

- Packaging

Once waste is generated, it needs to be packaged for storage, transport or disposal. The availability of suitably licensed packages is necessary to safely transport materials for treatment and eventual disposal. The types of packaging used tend to be dictated by the type of waste being packaged and the activity of the waste. VLLW packages typically tend to be drums or flexible packaging with no specific shielding requirements. LLW destined for disposal tends to be packaged in robust steel or concrete containers that may have some shielding incorporated into the package, or it may be placed in a shielded transport container. In the United Kingdom, LLW Repository Ltd has developed a wide range of packages to meet the needs of the waste producers and the various waste management routes. These include reusable transport packages and limited reuse disposal packages, as well as a range of waste boxes designed to fit inside standard transport packages. This range of options allows waste producers to optimise their packaging arrangements. In France, the National Agency for Radioactive Waste Management (Andra) has a number of approved package designs for specific waste that can be used by all producers. In Sweden, the approach is to minimise the range of packages that operators use, and the packages are suitable for most of the waste management approaches e.g. the repository or other end-state alternatives.

The package specification is typically related to the WAC for storage or the disposal facility; and it must meet a range of criteria e.g. activity limits, surface dose rate and accident scenarios. It should be noted that, if the packaged waste needs to be transported to the storage or disposal facility, it must also meet transport regulations, which may be more restrictive than the requirements for storage or disposal.

- Storage

In most countries, (V)LLW tends to be disposed of as the waste is produced, and interim storage is limited. Some countries such as Italy, utilise interim storage either while a final disposal solution is being developed or for the purposes of decay storage, where the waste is stored in a way that allows short-lived waste to decay so as to meet levels suitable for disposal as either LLW or VLLW. Interim storage may also be used in cases where the rate of waste production is low and waste is consolidated to minimise transport activities.

Disposal

Most countries either already have a range of disposal routes available for (V)LLW or have plans in place to develop and implement disposal solutions. Types of disposal facilities range from conventional landfill facilities to concrete vaults, and in some cases, underground repositories (of varying depths).

Where countries have LLW repositories, these tend to be large national facilities that are either funded by the state or by a decommissioning and waste management fund established by nuclear power plant operators.

Some countries, e.g. Germany and the United Kingdom, utilise commercial landfill sites for the disposal of some VLLW; however, in some cases, there are limited capacities available. The United States is unique in that commercial sites are available for the management of LLW. Many countries also have on-site disposal capability e.g. Sweden, United States DoE sites and Sellafield in the United Kingdom. On-site facilities range from VLLW-type landfills to concrete vault repositories, and they typically only manage waste from the site on which they are located. In some countries the same organisation is responsible for decommissioning and the management of the repository.

Transport

The transport of radioactive materials is carried out under regulations developed by the IAEA, Regulations for the Safe Transport of Radioactive Material (IAEA,2018). These regulations establish standards of safety that provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment, which are associated with the transport of radioactive material. Specific regulations are also in place for transboundary shipments of waste and materials.

The availability of transport infrastructure and capacity is a key enabler to successful waste management. Transport of (V)LLW is typically by road or rail; however, sea transport routes are used for transport to metal melting facilities in Germany, Sweden and the United States. Most (V)LLW transport is executed by commercial transport companies.

Ownership and responsibility

The ownership and responsibility for decommissioning and waste management varies from country to country, and a range of examples are provided below:

- In France, nuclear operators are responsible from the design, construction and commissioning of the nuclear power plant to the decommissioning of the plant and the clean-up of the site. The management of the waste and materials is the responsibility of the owner of the company, even if the actions of waste management (sorting, packaging, etc.) are carried out by another operator. Andra is the public body charged with the long-term management of radioactive waste in France and the provision of disposal capacity.

- In Germany, the nuclear power plant operators are responsible for decommissioning, but the federal state is responsible for the implementation, financing and operation of interim storage and the disposal repositories.
- Italy, Spain and the Slovak Republic have state-owned companies that have responsibility for the decommissioning of nuclear installations and the management of all radioactive waste, including the development and management of final disposal repositories.
- In Japan, the Federation of Electric Power Company of Japan (FEPC-J) decided to conduct centralised management and disposal for ILW(L1) and LLW(L2) through the Japan Nuclear Fuel Limited (JNFL, established by the FEPC-J) and also decided that each operator should dispose of VLLW(L3) at the nuclear power plant (NPP) site (on-site disposal). The operators and JNFL take primary responsibility for the planning, implementation and completion of decommissioning and waste disposal.
- In Sweden, nuclear power companies have jointly formed the Swedish Nuclear Fuel and Waste Management Company (SKB) in order to transport and dispose of radioactive waste. Responsibility for the waste, however, remains with the licence holder of the power plant (waste generator) until the repository is finally sealed. The management of waste and decommissioning are financed by the power companies where fees being deposited into the nuclear waste fund.
- In the United Kingdom, the Nuclear Decommissioning Authority (NDA) is a non-departmental government body responsible for the decommissioning and waste management of all civil, UK nuclear sites that were in state ownership in 2004. This covers 17 nuclear sites in the United Kingdom. The remaining eight operational reactors are in private ownership (EDF Energy), and their future decommissioning costs are managed through the Nuclear Liabilities Fund, which is funded by the site operator.

The finance and funding of decommissioning and waste management can, as shown above, vary from country to country. In the United Kingdom, the decommissioning and waste management funding for older, legacy facilities is funded by the state, whereas operators of newer nuclear power plants pay into a decommissioning fund to cover decommissioning and waste management liabilities when the sites are eventually decommissioned. Other countries, such as France and Sweden, have a similar approach, where operators are required to have a decommissioning and waste management fund; in France, the proper management of these funds is verified by government.

The approaches to ownership and responsibilities, and the available waste management infrastructure, all influence how waste management optimisation is achieved.

Conclusions

The optimisation of the management of (V)LLW is heavily influenced by technical, operational and organisational aspects. A key driver for many countries is reducing the volumes of waste or materials requiring disposal to a final repository, either to minimise costs or to reduce storage volumes and associated costs as final disposal routes are not available. Most countries have regulatory drivers to ensure that optimisation occurs, and these are typically linked to BAT, waste hierarchy and ALARP/ALARA decision making. These regulatory drivers are either in the form of national policy/strategy statements or site permitting/licensing requirements.

Key to successful optimisation is having a robust infrastructure in place, ensuring that appropriate management and disposal routes are available and accepted by the public and all other stakeholders. The use of radioactive waste or material clearance methodologies is identified as an enabler to optimisation in that it allows for some waste and materials to be cleared from radiological facilities and managed through conventional routes.

The lack of clearance routes was identified as a key issue for countries that do not have them; along with waste acceptance criteria limits, lack of specific infrastructure and stakeholder perception regarding management of (V)LLW or cleared waste or materials.

3.4. Stakeholder involvement

Introduction

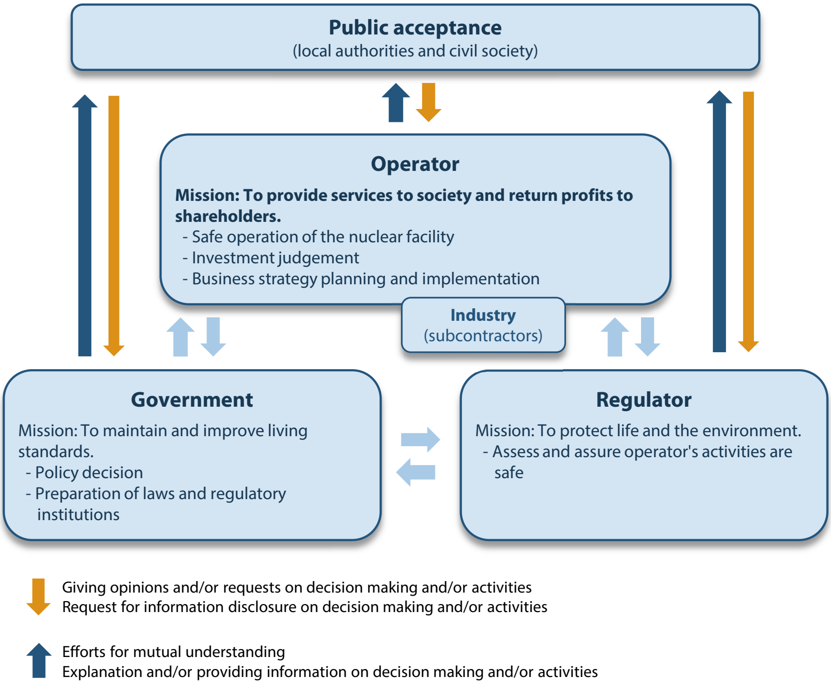
As mentioned in Chapter 1, stakeholder involvement is one of the five key factors enabling and influencing effective and efficient decommissioning and associated management of radioactive materials.

Within legal frameworks, compliance with stakeholder involvement requirements has become an important consideration for those responsible for decommissioning and waste management plans, programmes or specific activities. The Aarhus Convention is increasingly used to influence stakeholder engagement; setting out citizens' rights to information, participation and justice. However, compliance with international and national obligations may not be sufficient. The involvement of additional stakeholders, with a proportionate commitment to allow stakeholder involvement in optimising the management of (V)LLW arising during decommissioning, can increase and strengthen public acceptance.

In previous NEA reports dealing with waste management arising from decommissioning (see for example, NEA, 2017c), several examples demonstrated that greater levels of direct communication between operators and regulators can lead to increased trust and better alignment of objectives.

Figure 3-4 shows the roles of different stakeholder groups and how information flows between them.

Figure 3-4: **Identification of stakeholder involvement**



Source: OECD/NEA.

The identification of stakeholders

The involvement of stakeholders in societal decision making is appropriate and advisable to enhance the credibility, legitimacy and final quality of any decisions. Stakeholders should be involved early in the chronology of a specific project; but just as importantly, they should also be engaged while project options are being considered and before the final project scope has been determined.

Inspired by the Aarhus Convention, the NEA definition of a "stakeholder" is "any actor – institution, group or individual – with an interest or a role to play in the radioactive waste management process" (NEA, 2015b). The identification of stakeholders is therefore a crucial first step. When convening a stakeholder involvement initiative, it is necessary to identify the target population, which may be very broad in the early stages of decision making (at the level of policy, plans or programmes) and then become more precise as decisions come to bear upon local projects or activities. Stakeholders have both different contributions to make and different involvement needs at each stage of a decision-making process.

Stakeholders may have different interests, and engagement should be adjusted to the contexts which create differing needs, programme phases or formal requirements; as well as to national or local processes and cultures. When considering which stakeholders to engage, at minimum the operator (the promoter of the project) should identify institutions, groups or individual groups towards whom the organisation has legal, financial or operational responsibilities; who are affected by the organisation's operations; and who are likely to influence the organisation's performance.

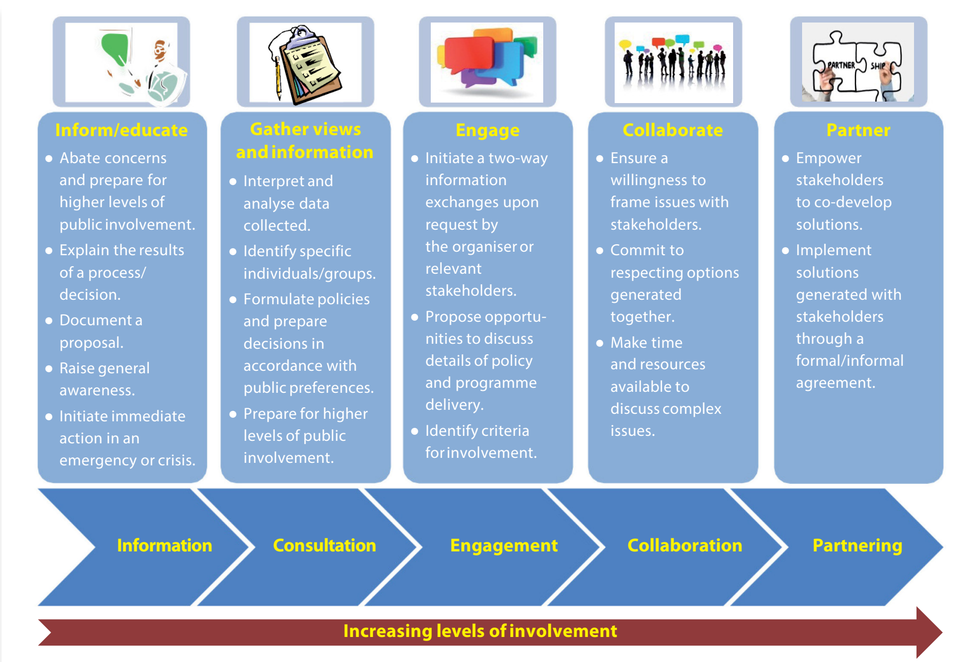
Besides the obvious stakeholders, additional stakeholders may include scientific experts/consultants, municipalities and local communities, elected representatives, technical experts and NGOs. It is not only about those who are potentially affected, but also about those who feel affected: stakeholders whose fears and concerns are not heard, considered or left unanswered may become opposed to the project

The identification of stakeholders is thus a crucial step that should take place at an early stage of a programme; it can be a complex task that requires openness, flexibility and responsiveness (NEA, 2015c).

Methods and levels of stakeholder involvement

There is no typical approach to stakeholder involvement – engagement strategies must respond to the political, legal and cultural context, as well as stakeholders' needs. Different methodologies are described in the NEA report *Stakeholder Involvement in Decision Making: A Short Guide to Issues, Approaches and Resources* (NEA, 2015c).

Figure 3-5: **Different levels of stakeholder involvement**



Source: Based on the Health Canada Policy Toolkit for Public Involvement in Decision Making (Ministry of Public Works and Government Services, Canada).

Stakeholder involvement may take different forms at different phases and can include information and education, gathering views, engagement, collaboration and partnering. Moving away from the historic approach of "decide, announce and defend", recent stakeholder involvement approaches try to increase the levels of involvement, as shown in Figure 3-5. The involvement may vary considerably, from simply providing information to real partnering within the project.

An example of stakeholder involvement, from Belgium, is provided in Appendix B.

Guiding principles for stakeholder involvement

Several factors contribute to stakeholder confidence in the safe and secure management of radioactive waste, in accordance with societal values and expectations. These confidence factors can be described via the following themes (as provided in NEA, 2014 and 2017a):

- **Decision-making process**: A stepwise approach to decision making is advised, combining a technical and societal focus. It should consider and empower the full range of stakeholders (public, local authorities, government, regulators, operators, industry), fostering mutual learning. It should embrace ethical considerations concerning future generations and the potential socio-economic impacts on communities, as well as health, safety and environmental concerns.
- **Framework for oversight**: A clear framework should be in place that defines the roles and responsibilities of the stakeholders (the public, local authorities, government, regulators, operators, the industry).
- **Stakeholder obligations**: It is important that all stakeholders assume their responsibilities, and that local (e.g. local authorities and the public) and national (e.g. government and regulators) actors work together towards mutually agreed solutions. Trust in the national regulatory bodies and the promoter of the project (operator) is crucial.
- **Transparency**: A core value that has been acknowledged in all areas of governance, both at the national and international levels, is transparency. Transparency is an important goal and should be practised systematically in the field of radioactive waste management. It can only be achieved within an ongoing process if stakeholders are given access to information about the progress of the project and the opportunity to provide their input.

Conclusions

Even though stakeholder involvement can be resource intensive, it is necessary and can deliver significant benefits. Some of the benefits are: more pertinent choices from the environmental, economic and technical point of view; agreements or tolerated consensus; increased legitimacy of the decision-making process; more transparent decision making and social learning; constructive dialogue and better co-operation, as well as more socially acceptable choices. Known barriers and constraints include resource constraints (financial, staff and time); unclear definition of roles and objectives of the stakeholders; a lack of transparency by the government/regulator or the promoter of the project; and a lack of responsiveness to the concerns of stakeholders.

3.5. Economic and financial aspects of (V)LLW management

(V)LLW management has the potential to significantly affect the budget for decommissioning since, although the cost per cubic metre may be less than that for higher activity waste, the total volumes involved can result in this waste form being the highest total waste cost. For this reason, funding considerations around (V)LLW management require careful attention. This waste form very often appears later in the decommissioning process; can have significant uncertainty associated with the volumes to be generated; and the time from initial cost estimates to the waste being generated can all result in erroneous cost assumptions.

It should also be recognised that there are costs which are shared with other aspects of decommissioning, such as the training of personnel, and decommissioning management overheads. These can either be accounted for in waste funding by apportioning them out or can remain within the overarching decommissioning budget.

To understand how costs related to waste management can be minimised, it is important to identify all the cost elements, accounting for 100% of the cost. The costs will be split between fixed (or overhead) and variable (or operational) costs.

Cost items

The life cycle cost of radioactive waste management is made up of several factors; which will vary from country to country and from one operator to another with potentially different objectives in the waste management chain. To correctly evaluate waste management costs, a clear definition of the waste management boundaries must be developed since, in some financial planning systems, budgets for decommissioning and waste management are kept separate. There is a risk that a swapping of financial liabilities could occur if a clear distinction between the two cost elements is not maintained. It is important to recognise, however, that real optimisation can only be achieved if the whole waste management life cycle is considered, from creation through disposal.

Cost optimisation of single cost items or groups of them (like processing and disposal) may result in a final overall cost that is different from the one that would be achieved if the optimisation process was performed in a more holistic and broader manner. As an example, extensive segregation and/or size reduction can reduce treatment or disposal costs but could also require significant, initial effort. The problem is even greater if different entities, funded from different budgets, perform certain steps of the waste management life cycle; in this case, each entity may try to optimise their steps, potentially increasing costs for the following steps. Much of this is dependent on how waste management is organised in each country; the number of players involved; the type of funding for each organisation, etc. In some countries, such as Spain, waste management is undertaken by a single organisation, which is responsible for the majority of the process; in many of these countries this organisation is nationally owned, whereas in others the private sector is involved.

There are several cost elements, which are summarised below:

- **Fixed costs** include all costs that are not directly related to the volume of the waste managed, and on a per unit basis, are inversely proportional to the volume of waste managed. If the volume of waste to be managed is low, most try to avoid incurring this type of cost by choosing alternative strategies. The following are examples of fixed costs:
  - licensing;
  - construction of waste management facilities;
  - maintenance of waste management facilities;
  - overhead or management of waste management contracts;
  - rental of equipment or land lease;
  - security costs (decommissioning duration dependent).
- **Variable costs** include those costs related to waste management, ranging from characterisation, treatment, conditioning, packaging, temporary storage, transport and final disposal. The costs vary considerably from country to country and for different operators; each operator must understand very clearly which drivers influence the cost of each item in their system (country, market, etc.) and adopt a coherent strategy. Technical, contractual and strategic choices may significantly influence the overall life cycle cost of waste management; therefore, work planning for waste should be as holistic as possible.
- **Characterisation costs**: Characterisation is the first step in planning for (V)LLW management and is central to the optimisation process. Based on the volumes and radiological activity present in the different forms of waste, decisions can be made between the various options for segregation, decontamination, packaging, transport and disposal. Where total characterisation is not possible, alternate pathways may be developed based upon information gathered as the work progresses.
- **Treatment costs**: Treatment may include temporary storage, size reduction, decontamination, and/or volume reduction, as well as any activities required to enable the (V)LLW be in an acceptable form for packaging and final disposal. This could include the decontamination of a structure prior to demolition; volume reduction processes such as incineration; special encapsulation for hazardous waste, or chemical conditioning of the waste. As appropriate, costs anticipated for any planned treatment must be factored into the overall costs.
- **Packaging costs**: (V)LLW usually does not require additional shielding or very robust packaging, with the exception of those items that may damage the packaging during transport. The packaging should be chosen to minimise the weight and volume added to the disposal package, while

taking into consideration the transport mode (road or rail) and also minimising the cost of the packaging itself. Since (V)LLW has low specific radiological activity, larger packaging may be utilised to facilitate the handling of bulk volumes with readily available handling equipment. The total cost of the packaging, equipment purchases or rental, and the manpower, should be included in the cost estimate.

- **Interim storage costs**: Because of the large volumes of (V)LLW, it may be problematic to achieve "just-in-time" transport. Therefore, it may be beneficial to consider interim storage capability, to facilitate smooth transport scheduling to the final disposal location. As with the packaging, sophisticated storage of packaged (V)LLW is usually not required, but the packages mainly need to be protected from the weather.
- **Transport costs** associated with waste treatment, characterisation, or interim storage should be allocated to that waste management step, to enable a comprehensive assessment of the true cost for each aspect of waste management planning. Transport costs for (V)LLW are generally proportional to the volume/weight and distance travelled to the final disposal location. Where rail access is available, it will often provide the safest and most cost-effective transport solution. If a railhead is not directly available at the dispatching or receiving site, a multi modal (road and rail) solution could be adopted.
- **Final disposal cost**: (V)LLW disposition varies from country to country; however, the safest, most cost-effective and regulatory compliant disposal option should be utilised. Generally, if inexpensive disposal solutions are available, the driver for volume reduction is limited, whereas if the disposal solutions are expensive, volume reduction could be a financial necessity.

Timing and availability of funding

The waste funding for the entire project life cycle should be secured, the forecast expenditure profile planned, and metrics developed to track expenditure and to ensure corrective action is taken if the actuals deviate substantially from the estimate. It is also beneficial to avoid building large accumulations of waste, where inflation could cause cost escalation in the future.

Where there are specific controls on the release of funding, the project should plan to have funds available when required, with an understanding of the time required to complete the approval process.

Methods of funding and work execution

Decommissioning funds previously accumulated should be available to cover the estimated (V)LLW costs. Where previous funds have not been accumulated, for example at legacy waste sites, the costs should be accounted for in the funding mechanism established for the site clean-up and closure.

In either case, contracts for (V)LLW processing, packaging, shipping, disposition and burial should involve due diligence in terms of the selection of the contractors and should include incentives to ensure optimisation.

When appointing contractors, consideration of waste optimisation and secondary waste production minimisation should be included in the process for awarding contracts. Selection criteria could include consideration of previous experience in waste management within the contractor's proposed organisation; or their proposals for the management of avoidable waste.

Conclusions

(V)LLW is usually a substantial portion of the waste volume generated and not an insignificant portion of the decommissioning cost. Up front waste analysis, and planning and cost accounting can result in the identification of optimisation strategies to reduce volumes, better reduce and track costs and assist with metrics to incentivise waste contracts.

Chapter 4. Conclusions

As more nuclear facilities enter decommissioning around the world, it is important that the management of (very) low-level radioactivity (or [V])LLW) is optimised since it represents the vast majority (by volume) of radioactive waste generated during decommissioning and dismantling. A number of factors have been identified as influencing the ability of a site or facility to optimise its (V)LLW management, and these include strategy and planning, safety and the environment, characterisation, enabling infrastructure, stakeholder involvement, and financial and economic aspects.

This report has explored how all of these factors enable the optimisation of (V)LLW. Safety, financial or schedule constraints have also been recognised as having a potential impact on the optimisation of (V)LLW management, and a balance between such issues must therefore be achieved when seeking to optimise (V)LLW management for any given situation.

To support (V)LLW optimisation, the report identifies key learning from experience in member countries of the Nuclear Energy Agency (NEA), which include:

- It is important to have the appropriate radioactive waste management policies and strategies in place, as well as a suitable regulatory framework, with a stable nuclear structure. Effective regulatory frameworks and guidelines ease the decommissioning process for nuclear power plant owners, and a change in the regulatory environment during the decommissioning project can cause problems.
- Having clearly defined responsibilities is key to successful decommissioning programmes; as is ensuring that those intervening have the right skills and knowledge for waste management of a site, facility or project.
- Ownership of the waste throughout the life cycle should be clearly defined, which is especially important in countries where the responsibility for the waste moves from one organisation to another during the waste management life cycle.
- It is important to understand the initial state of the nuclear facility before decommissioning starts. Effective and early characterisation should be carried out to develop and maintain robust waste inventories, which can be used to underpin decommissioning planning, to execute plans, to determine the site end-state and to allow external service providers to make commercial decisions on infrastructure investments. It is important to regularly assess physical and radiochemical inventories during the operational phase so as to underpin decommissioning planning. Characterisation is an iterative process

that continues during the decommissioning programme to inform both effective (V)LLW management and wider activities, such as radiological protection and engineering.

- Strategic waste management planning should take place throughout the entire decommissioning programme life cycle; and a strong planning process should be in place, which includes consideration of waste arisings and their management throughout the programme, along with suitable logistics and data management systems.
- The application of the waste hierarchy can support (V)LLW optimisation; initially seeking to avoid waste generation and then to minimise the volume of waste requiring disposal through reuse, recycling and volume reduction technologies. To facilitate waste minimisation, supporting infrastructure must be in place, such as characterisation laboratories and appropriate transport and packaging solutions. Robust optioneering and analysis tools, including best available technique (BAT) assessments, facilitate the selection of appropriate waste treatment, conditioning and disposal routes over the entire waste management life cycle.
- Conditioning, treatment and disposal facilities should be available when required (whether on-site or through the supply chain), with enabling waste acceptance criteria. The ability to send waste for treatment to another country is dependent on international agreements, including transboundary transport and the harmonisation of regulations.
- Safety should be holistically considered for the public, workers and the environment, from both a radiological and conventional risk perspective.
- It is important to recognise and respond to the change in culture, skills and knowledge necessary when transitioning from an operational to a decommissioning environment, building knowledge and skills in effective waste management and recognising that waste is the key product from decommissioning.
- Transparent and continued stakeholder engagement should be planned early on in the project to build and maintain societal acceptance of the decommissioning and waste management approach, as well as of the optimal site end-state. As a consequence, nuclear operators need to demonstrate the robustness of their capability, as well as their technical, financial, environmental and social capability to safely undertake decommissioning.
- It is important to consider the costs associated with (V)LLW management within decommissioning funding; in addition to having an adequate amount of funding for (V)LLW management, it is also important to have it available when needed.
- The site end-state and future use of the site should be defined as early as possible, recognising that the decommissioning process, the radiological inventory and the extent of radiologically contaminated land might have an impact on the site's final end-state. There may also be legislative, financial,

political or schedule constraints, which could influence the selection of the optimal end-state. When determining the end-state for the site, proper planning and decision-making processes should involve stakeholders from the very beginning which may influence the amount of (V)LLW generated.

- Flexibility and different management alternatives may enable safe, in situ disposal of suitable radioactive waste on-site, in alignment with the defined site end-state. It is also possible to use decay storage as a waste management tool (for example, for short half-life radionuclides, such as ^{60}Co).
- The design and construction of new facilities should include consideration of waste optimisation during operations and decommissioning (and is a legal requirement in many countries), as well as consideration of the ability to replace all major components.
- The opportunity to clear materials can optimise the volume of (V)LLW requiring management; recognising, however, that this is not possible in some countries, or that there may be limited or no markets for cleared materials.

Chapter 5. Potential future work

During the development of this publication, and in the meetings of the Nuclear Energy Agency (NEA) Working Party on Decommissioning and Dismantling (WPDD), a number of areas were identified for potential future work, including:

- The topic of life cycle extensions of nuclear power plants and their impact on (very) low-level waste ([V]LLW) – and all waste in general – has not been addressed to date. Although overall waste generation resulting from life extensions may not change volumes significantly, through greater utilisation of the facility, there could be an overall reduction in volume generated per year across the nuclear fleet due to the fact that less fleet will be built.
- New power plant designs should focus on the replacement of all major components so as to optimise the waste emanating from decommissioning. Such an improvement could allow sensible lifetime extensions of nuclear facilities, and the reuse of buildings with new components. As a consequence, the amount of waste generated from decommissioning could be significantly reduced, minimising the related environmental and social impacts, as well as the schedules and costs. Major optimisation of the design could mean moving decommissioning from a definitive shutdown to a large maintenance phase.
- While the present report focuses on the management of (V)LLW, there is an opportunity to consider the optimisation of intermediate-level waste (ILW) as well. Although the volumes of ILW are less, the hazards and costs for treatment, packaging, control and disposal, as well as its impact on dismantling work, are greater. A report exploring good practice in ILW optimisation may thus be of interest.
- It has been recognised that, because of the amount of decommissioning anticipated in the near future, there will be a shortage of experienced personnel to manage and perform this work. Plans and methods for increased training and development of staff could be explored to assist sites starting decommissioning programmes.
- The benefits of harmonising clearance levels between countries has also been recognised, as has potential improvements to available instrumentation that demonstrates that established clearance levels have been achieved.
- There are a number of new volume reduction methods where the certification of waste forms produced could be investigated; plasma arc technology, which produces a concentrated waste form with a significantly reduced volume, is one example.

References

ICRP (2007), *The 2007 Recommendations of ICRP. Annals of the ICRP 37(2-4)*, ICRP Publication 103.

IAEA (2018), *Regulations for the Safe Transport of Radioactive Material*, IAEA Safety Standards Series No. SSR-6 (Rev.1), IAEA, Vienna.

IAEA (2009) *Classification of Radioactive Waste*, IAEA Safety Standards Series No. GSG-1, IAEA, Vienna.

IAEA (2005), *Financial Aspects of Decommissioning*, TECDOC-1476, IAEA, Vienna.

IAEA (2003), *Radioactive Waste Management Glossary*, IAEA, Vienna.

NEA (2018), *Preparing for Decommissioning During Operation and After Final Shutdown*, NEA No. 7374, OECD Publishing, Paris.

NEA (2017a), "How the Forum on Stakeholder Confidence serves as a platform to build and share knowledge about stakeholder confidence in radioactive waste management", Flyer, www.oecd-nea.org/rwm/fsc/docs/fsc_identity_flyer_a4.pdf, OECD Publishing, Paris.

NEA (2017b), *Radiological Characterisation from a Waste and Materials End State Perspective*, NEA No. 7373, OECD Publishing, Paris.

NEA (2017c), *Recycling and Reuse of Materials Arising from Decommissioning of Nuclear Facilities*, NEA No. 7310, OECD Publishing, Paris.

NEA (2016a), *Costs of Decommissioning Nuclear Power Plants*, NEA No. 7201, OECD Publishing, Paris.

NEA (2016b), *Financing the Decommissioning of Nuclear Facilities*, NEA No. 7326, OECD Publishing, Paris.

NEA (2015a), *Fostering a Durable Relationship between a Waste Management Facility and its Host Community: Adding Value through Design and Process*, 2015 Edition, NEA No. 7264, OECD Publishing, Paris.

NEA (2015b), "How can Stakeholder Involvement be Improved?", Flyer, www.oecd-nea.org/rwm/fsc/docs/a4-stakeholder_involvement.pdf, OECD Publishing, Paris.

NEA (2015c), *Stakeholder Involvement in Decision Making: A Short Guide to Issues, Approaches and Resources*, NEA No. 7819, OECD Publishing, Paris.

NEA (2014), "Stakeholder Confidence and Transparency in Radioactive Waste Management", Flyer, www.oecd-nea.org/rwm/fsc/docs/transparency-a4.pdf, OECD Publishing, Paris.

NEA (2013), "Radiological Characterisation for Decommissioning of Nuclear Installations", NEA/RWM/WPDD(2013)2, OECD Publishing, Paris.

NEA (2010a), *Cost Estimation for Decommissioning: An International Overview of Cost Elements, Estimation Practices and Reporting Requirements*, NEA No. 6831, OECD Publishing, Paris.

NEA (2010b), "The Partnership Approach to Siting and Developing Radioactive Waste Management Facilities", Flyer, www.oecd-nea.org/rwm/fsc/docs/FSC_partnership_flyer_EN_A4.pdf, OECD Publishing, Paris.

NEA (2008), *Release of Radioactive Materials and Buildings from Regulatory Control: A Status Report*, OECD Publishing, Paris.

NEA (2006), *Decommissioning Funding: Ethics, Implementation, Uncertainties: A Status Report*, OECD Publishing, Paris.

NEA/IAEA (2017), *Addressing Uncertainties in Cost Estimates for Decommissioning Nuclear Facilities*, A Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, NEA No. 7344, OECD Publishing, Paris.

NEA/IAEA (2012), *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations*, ISBN 978-92-64-99173-6, OECD Publishing, Paris.

Appendix A: **Country information**

Canada	
National policy and strategy for radioactive waste management	The 1996 government of Canada *Policy Framework for Radioactive Waste* sets the stage for institutional and financial arrangements to manage radioactive waste in a safe, comprehensive, environmentally sound, integrated and cost-effective manner. The framework specifies that: • the government of Canada is responsible for developing policy and regulating and overseeing radioactive waste producers and owners to ensure that they comply with legal requirements and meet their funding and operational responsibilities in accordance with approved long-term waste management plans; • waste owners are responsible, in accordance with the "polluter pays" principle, for the funding, organisation, management and operation of the facilities required to safely manage their waste over the short and long term. The framework recognises that arrangements may be different for the four broad categories of radioactive waste found in Canada: spent fuel, low-level radioactive waste, intermediate-level radioactive waste, and uranium mine waste rock and mill tailings.
National Programme document?	In addition to the 1996 government of Canada *Policy Framework for Radioactive Waste*, federal legislation used to regulate and oversee the nuclear industry, including the management of radioactive waste and spent fuel, comprises the *Nuclear Safety and Control Act*, the *Nuclear Fuel Waste Act*, the *Nuclear Liability and Compensation Act* and the *Nuclear Energy Act*.
Regulatory framework	In addition to the policy framework and federal legislation listed above, the Canadian Nuclear Safety Commission (CNSC) publishes regulatory documents. The following regulatory documents apply to radioactive waste management and decommissioning: • REGDOC-2.11.1, *Waste Management Volume II: Assessing the Long-Term Safety of Radioactive Waste Management* which replaces previous CNSC regulatory documents, G-320, *Assessing the Long-Term Safety of Radioactive Waste Management* and P-290, *Managing Radioactive Waste*. • G-219, *Decommissioning Planning for Licensed Activities*. The Canadian Standards Association (CSA) group is a not-for profit organisation composed of representatives from the government, industry and consumer groups. The following CSA Standards are relevant to radioactive waste management: • N286, *Management system requirements for nuclear facilities*. • N292.0, *General principles for the management of radioactive waste and irradiated fuel*. • N292.2, *Interim dry storage of irradiated fuel*. • N292.3, *Management of low – and intermediate – level radioactive waste*. • N292.5, *Guideline for the exemption or clearance from regulatory control of materials that contain or potentially contain, nuclear substances*. • N294, *Decommissioning of facilities containing nuclear substances*.

Canada	
Definition of low-level waste (LLW) and very low-level waste (VLLW)	The radioactive waste classification system is organised according to the degree of containment and isolation required to ensure safety in the short and long term. The classification system also takes into consideration the hazard potential of different types of radioactive waste. As outlined in CSA Group standard N292.0-14 *General principles for the management of radioactive waste and irradiated fuel*, the following are definitions of LLW and VLLW: Low-level radioactive waste: LLW contains material with radionuclide content above established clearance levels and exemption quantities, and generally limited amounts of long-lived activity. LLW requires isolation and containment for up to a few hundred years. LLW generally does not require significant shielding during handling and interim storage. Very-low-level radioactive waste: VLLW is treated as a sub-category of LLW, VLLW has low hazard potential but is above the criteria for exemption. VLLW includes large volume bulk material such as low-activity soil, rubble and some uranium waste. It does not need a high degree of containment and near-surface repositories are generally suitable. In Canada, licensees are responsible for safely managing their own waste. They must demonstrate to the CNSC how they propose to fulfil this obligation. CSA standard N-292.0-14, which defines the Canadian waste classification system, did not provide definitive numerical boundaries, as it was developed to provide licensees with a degree of flexibility – according to their operational and organisational needs – in developing waste management plans.
Definition of clearance	The CNSC's *Nuclear Substances and Radiation Devices Regulations* (NSRDR) define two clearance levels that may be applied to materials, including radioactive waste: unconditional and conditional. Unconditional clearance means the unrestricted release of materials from regulatory control (i.e. there are no restrictions regarding the disposition of the material). The unconditional clearance levels in the NSRDR are applied when the quantity of material involved is greater than 1 tonne per year per nuclear facility. The unconditional clearance levels in the NSRDR align with IAEA RS-G-1.7, Application of the Concepts of Exclusion, Exemption and Clearance. Conditional clearance applies to specified types of materials and disposition routes. As such, conditional clearance levels are developed by CNSC licensees and submitted to the CNSC for review and approval. The conditional clearance levels are therefore specific to each submission for specified types of materials and disposition paths. The dose criteria on which conditional clearance levels are based are the same as the unconditional clearance levels, namely an annual effective dose of 10 μSv due to realistic scenarios and parameters and an annual effective dose of 1 mSv due to low probability events (referred to in IAEA RS-G-1.7, Application of the Concepts of Exclusion, Exemption and Clearance). In addition to the clearance levels discussed above, exemption quantities are defined in the NSRDR that may also be used to clear radioactive waste if the inventory of material involved is less than or equal to 1 tonne per year per nuclear facility. The exemption quantities in the NSRDR align with the established exemption levels in Schedule I of the IAEA's GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. In addition; a CSA Group standard, N292.5-11 (R2016) – Guideline for the exemption or clearance from regulatory control of materials that contain, or potentially contain, nuclear substances, has been developed to provide guidance on approaches to the clearance of materials consistent with Canadian and international recommendations.

<table>
<tr><th colspan="2">Canada</th></tr>
<tr><td>Waste generators (number and types of facilities)</td><td>Status of decommissioning at Canadian facilities
Hydro-Québec:
- Gentilly-2 Nuclear Generating Station – the station was placed in a guaranteed shutdown state and decommissioning activities are being undertaken. Hydro-Québec has adopted a deferred decommissioning strategy approach. This current phase, planned from 2015-2020, consists of completing the transfer of spent fuel stored in the pool to the dry storage facility at the generating station's secure site.
Atomic Energy Canada Limited owned facilities:
- Whiteshell Laboratories – Canadian Nuclear Laboratories (CNL) has continued to decommission the facility, the licence to decommission expires December 2018 and CNL is proposing to move up site closure to 2024 and decommission using in situ decommissioning – Licence renewal hearing are expected to proceed fall 2018.
- Gentilly-1 Waste Management Facility – A three-phase approach has been established for reactor decommissioning. Phase 1 brought the facility to a safe, sustainable shutdown state. Phase 2 is a period greater than 30 years of storage with surveillance. Final decommissioning, approximately 10 years, occurs in Phase 3. The Gentilly-1 Waste Management Facility is currently in Phase 2.
- Douglas Point Waste Management Facility is presently in the storage with surveillance phase of a deferred decommissioning programme.
- Nuclear Power Demonstration site – CNL has not yet submitted its licensing application or safety case in support of in situ decommissioning for regulatory review. A licensing hearing to consider this proposal is expected to occur later in 2018.
- Chalk River Laboratories decommissioning activities – To date, the pace of decommissioning at Chalk River Laboratories has been constrained by the availability of waste routes. Priority has been given to hazard reduction and risk mitigation of facilities representing high hazard and risk, as well as to demolition of low-hazard structures for which waste routes are available.
AREVA Resources Canada Inc.
- Cluff Lake Project – Cluff Lake is the most recent of the northern Saskatchewan uranium mines to move into decommissioning.</td></tr>
<tr><td>Organisation(s) responsible for decommissioning</td><td>The licensees (waste owners such as Ontario Power Generation (OPG), Hydro-Québec, NB Power and Atomic Energy of Canada Limited (AECL), uranium mines and mills including Cameco and Areva) are responsible for decommissioning of their facilities.</td></tr>
<tr><td>Funding</td><td>Licensees of nuclear facilities, including spent fuel and radioactive waste management facilities and uranium mines and mills, must provide guarantees that adequate financial resources are available for the decommissioning of these facilities and managing the resulting radioactive waste, including spent fuel. Subsection 24(5) of the Nuclear Safety and Control Act provides the legislative basis for this requirement. Paragraph 3(1)(l) of the General Nuclear Safety and Control Regulations stipulates that, "an application for a licence must contain a description of any proposed financial guarantee related to the activity for which a licence application is submitted." CNSC regulatory guide G-206, Financial Guarantees for the Decommissioning of Licensed Activities, covers the provision of financial guarantees for decommissioning activities.
Financial guarantees must be sufficient to fund all approved decommissioning activities. These activities include not only dismantling, decontamination and closure but also any post-decommissioning monitoring or institutional control measures that may be required, as well as subsequent long-term management or disposal of all waste, including spent fuel. To ensure that licensees are required to cover the costs of spent fuel only once, the money in the trust funds set up under the Nuclear Fuel Waste Act is considered part of the licensee's total financial guarantee to the CNSC.</td></tr>
</table>

Canada	
Expected volumes of radioactive waste	For the expected volumes of (V)LLW please refer to the Inventory of radioactive waste report in Canada 2016 from Natural Resources Canada Section 4.0 for LLRW projections. www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/uranium-nuclear/17-0467%20Canada%20Radioactive%20Waste%20Report_access_e.pdf
Availability and description of intermediate and final storage/ disposal solution(s)	The owners of low- and intermediate-level radioactive waste (L&ILW) are licensed by the CNSC to manage and operate storage facilities for their radioactive waste. In addition, the two major waste owners, OPG and AECL/CNL, are pursuing long-term management solutions. OPG: - L&ILW from OPG owned CANDU (CANada Deuterium Uranium) reactors (including Bruce A and B) is safely stored in a central location at the Western Waste Management Facility at the Bruce nuclear site in Kincardine, Ontario. - OPG's plan for the long-term management of its L&ILW is the Deep Geologic Repository, which has undergone environmental assessment; however, no regulatory decision has been made. NB Power and Hydro-Québec: - NB Power and Hydro-Québec have their own facilities for the interim storage of L&ILW at their reactor sites. AECL/CNL: - For waste from research and development, AECL/CNL have waste storage facilities at two sites – Chalk River Laboratories (CRL) and Whiteshell Laboratories – as well as at its three prototype reactor sites. - Activities dealing with legacy radioactive waste and decommissioning liabilities at AECL sites are being advanced by CNL under a government-owned, contractor-operated (GoCo) arrangement. - A near-surface disposal facility with a total planned disposal capacity of 1 million cubic metres is proposed to be available by 2020 for disposal of LLW and other suitable waste streams (pending regulatory decision). The L&ILW generated by decommissioning, environmental remediation, ongoing operations and L&ILW accepted from third-party generators will also be managed in these facilities. AECL/CNL – Port Hope Area Initiative: - Canada has significant volumes of LLW from past practices (referred to as historic waste). - The Port Hope Area Initiative (PHAI) involves the clean-up and long-term management of historic LLW in Port Hope, Ontario, which accounts for the bulk of Canada's historic LLW. The objectives of the PHAI is to safely manage the historic LLW in two above-ground mounds that are being constructed in the local communities. The construction and commencement of these projects is underway. - These initiatives are under the responsibility of AECL, with the work being delivered by CNL under a GoCo model.
Main decommissioning strategies	Decommissioning strategies (prompt decommissioning, deferred decommissioning, in situ confinement or a combination of decommissioning strategies) are not prescribed by the CNSC. Proponents must propose their preferred strategy as part of their preliminary decommissioning plan and must support it with a safety case. The preliminary decommissioning plan is updated periodically during the life cycle of the facility. A detailed decommissioning plan which specifies the work programme, safety and environmental protection procedures, and management system to be followed during decommissioning is finalised and filed with CNSC for appropriate licensing actions prior to the beginning of decommissioning activities. Any proposed decommissioning strategy will be assessed by the CNSC against regulatory requirements to ensure the protection of health and safety of the public and the environment. Once approved by the CNSC, the detailed plan will be incorporated into a licence prior to decommissioning authorisation.

<table>
<tr><th colspan="2">Canada</th></tr>
<tr><td>End-state strategies</td><td>As outlined in CSA Standard N294-09 Decommissioning of facilities containing nuclear substances, a description of the final radiological, physical and chemical end-state objectives should be provided in the detailed decommissioning plan. The final end-state shall be considered reached when the planned decontamination, demolition and dismantling are completed, and when all materials, waste, equipment and structures have been dispositioned as outlined in the detailed decommissioning plan. Final surveys of residual radioactive and hazardous materials shall be performed and a final end-state report shall be prepared.</td></tr>
<tr><td>Country definition of optimisation</td><td>Canada does not have a formal definition of optimisation. As outlined in G-219 Decommissioning Planning for Licensed Activities, when a decommissioning strategy is not immediately apparent, alternative strategies should be compared using a simple detriment-benefit evaluation method. The evaluation method should ensure that the relative advantages and disadvantages of the remaining strategies can be objectively compared in a systematic and traceable fashion.</td></tr>
<tr><td>Principles enabling optimisation</td><td>As outlined in G-219 Decommissioning Planning for Licensed Activities the factors that may be relevant to the evaluation of alternative decommissioning strategies include:
- forms and characteristics of radioactive and conventional contaminants;
- integrity of containment and other structures over time;
- availability of decontamination and disassembly technologies;
- potential for recycle or reuse of equipment and materials;
- availability of knowledgeable staff;
- potential environmental impacts;
- potential worker and public doses;
- end-state objectives and site redevelopment pressures;
- potential revenues, costs and available funding;
- availability of waste management and disposal capacity;
- regulatory requirements;
- public input.</td></tr>
<tr><td>Barriers and constraints to optimisation</td><td>As outlined in G-219 Decommissioning Planning for Licensed Activities the factors that may be relevant to the evaluation of alternative decommissioning strategies include:
- forms and characteristics of radioactive and conventional contaminants;
- integrity of containment and other structures over time;
- availability of decontamination and disassembly technologies;
- potential for recycle or reuse of equipment and materials;
- availability of knowledgeable staff;
- potential environmental impacts;
- potential worker and public doses;
- end-state objectives and site redevelopment pressures;
- potential revenues, costs and available funding;
- availability of waste management and disposal capacity;
- regulatory requirements;
- public input.</td></tr>
<tr><td>Options for waste minimisation – treatment, disposal, etc.</td><td>The Canadian nuclear sector practices waste minimisation by:
• implementing material control procedures to prevent materials from unnecessarily entering into radioactive areas;
• implementing enhanced waste monitoring capabilities to reduce the inclusion of non-radioactive waste in radioactive waste;
• implementing improvements to waste handling facilities;
• enhancing employee training and awareness.</td></tr>
</table>

Canada	
Main drivers for waste minimisation	Canada has adopted IAEA waste minimisation practices as described in CNSC policy document P-290, *Managing Radioactive Waste,* which expects that the "generation of radioactive waste is minimised to the extent practicable." (For more information on P-290, see Section B.5.) Waste minimisation is also a key principle of the CSA Group's industry standard CSA N292.3, *Management of low- and intermediate-level waste*, and CSA N292.0, *General principles for the management of radioactive waste and irradiated fuel*. In addition, CNSC regulatory guide G-219, *Decommissioning Planning for Licensed Activities*, indicates that waste management plans should include "specific plans for the reuse, recycling, storage or disposal of that waste." Canada has also developed the industry standard CSA N294, *Decommissioning of facilities containing nuclear substances*, which indicates that strategies for waste management must consider and prioritise" the potential for recycling or reuse of equipment and materials."
Stakeholder engagement	CNSC licensees have a regulatory requirement to have extensive public information and disclosure programmes, and many licensees conduct outreach activities including engagement with Indigenous communities and consultation with municipal governments and local stakeholders. The CNSC conducts public hearings in an open and transparent manner – it conducts hearings throughout the life cycle of the facility, and there are regular opportunities for public participation throughout the licensing period. The CNSC Participant Funding Program (PFP) gives the public, Indigenous communities and other stakeholders the opportunity to participate in CNSC's regulatory process; PFP does not influence the nature of the public intervention at hearings or meetings.
Lessons learnt (positive/negative)	- Social acceptance is key. - The CNSC licence to decommission is required before any decommissioning activities are to take place. - CNSC Licensees have a regulatory requirement to have extensive public information and disclosure programmes. - Public hearings are conducted throughout the life cycle of the facility and there are regular opportunities for public participation throughout the licensing period. - Preliminary decommissioning plans are developed and updated progressively throughout the life cycle of the facility to reflect the appropriate level of detail required for the respective licensed activities.

France	
National policy and strategy for radioactive waste management	• The legal and regulatory framework on decommissioning has been updated and detailed by the Act No. 2006-686 dated 13 June 2006. • Act on the energy transition No. 2015-992 dated 17 August 2015 (aims to strengthen the framework for a quick dismantling after the final shutdown of the facility). • The decommissioning process is regulated by decree No. 2007-1557 dated 2 November 2007. Management of radioactive waste and other industrial waste is subject to the general legal framework prescribed by Article L.541 of the Environment Code (following Act No. 75-633 of 15 July 1975), and the associated decrees about recycling of materials and disposal of waste. The basic principles enshrined in this Environment Code concern the prevention of waste production, from generation to reuse, recycle or safe disposal, and interactions between inter-dependent waste management operations. In addition, it is only when waste cannot be reused or recycled under current technical and economic conditions that it must be disposed of (concept of final waste). • Regarding the policy for waste management, broad guidelines were set out in Article L.542 of the Environment Code, following the Waste Act of 30 December 1991 and the Planning Act concerning the sustainable management of radioactive materials and waste of 28 June 2006. • The order of 7 February 2012 provides additional provisions applicable to the decommissioning related aspects (decommissioning plan, final state, human and organisational factors, etc.).
National Programme document?	In 2017, France published The French National Plan for the Management of Radioactive Materials and Waste, 2016-2018.
Regulatory framework	Four main guides support the regulations described above: • Guide No. 6 (decommissioning). • Guide No. 14 (clean-up methodology for structures of Basic Nuclear Installations [BNI]). • Guide No. 23: Waste Zoning Plan in BNI. • Guide No. 24: Management of polluted soils by BNIs activities.
Definition of LLW and VLLW	• VLLW: Average around 10 Bq/g. • LLW > 100 Bq/g. • LLW Short life (<31 years). • LLW Long Life (>31 years).
Definition of clearance	No clearance levels (no free release).
Waste generators (number and types of facilities)	• In 2016, 33 BNI were undergoing a decommissioning process. • Two installations have completed the decommissioning process and were released from regulatory control in 2015 (BNI 106 LURE and BNI 20 SILOE). BNI 65-90 (SICN) will soon complete the decommissioning process. • Dismantling of EDF Chooz A pressurised water reactor (PWR), Creys-Malville Fast Breeder Reactor, and Brennilis heavy-water reactor are in progress, as well as the dismantling of 12 research installations of the French Alternative Energies and Atomic Energy Commission. • EDF announced in March 2016 that the decommissioning of the first six generation graphite gas-cooled reactors would be delayed until 2030 as EDF decided to change its industrial scenario for this type of nuclear reactor technology mainly due to the unavailability, on time, of the dedicated graphite disposal scheduled by the law.

France	
Waste generators (number and types of facilities)	• The application for the decommissioning decree is currently being reviewed for three installations (INB 71 PHENIX, INB 105 COMURHEX Pierrelatte, INB 94 AMI CHINON). • Other decommissioning application dossiers are in technical discussions (in particular INB 93 EURODIF, INB 33 and 38 UP2-400). • <1 000 "ICPE" small facilities involving radioactive materials.
Organisation(s) responsible for decommissioning	Each nuclear operator (EDF, Orano [formerly Areva], French Alternative Energies and Atomic Energy Commission) is responsible for the decommissioning of their nuclear installations. There is a specific agency – Andra – responsible for the management of all radioactive waste.
Funding	Operators are responsible for financing the management of their waste and the dismantling of their nuclear installations. Each nuclear operator manages its respective fund, which stays inside the company as provisions backed by dedicated assets of sufficient security and liquidity. Apart from this scheme that concerns only long-term liability of waste producers both in terms of dismantling and waste management cost, the necessary R&D and the economic development scheme of the local municipalities and districts concerned by the project of a geological repository are financed through additional INB taxes, as prescribed by the 2006 Planning Act.
Expected volumes of radioactive waste	• ~25 000 m^3/year of VLLW. • ~12-15 000 m^3/year of LLW (SL+LL). Operational and decommissioning waste at the end of the presently operated or licensed facilities: • VLLW: 2.2 million m^3. • LIL-SL: 1.8 million m^3.
Availability and description of intermediate and final storage/ disposal solution(s)	Two final disposal facilities in operation: One for VLLW and one for LL-SL/IL-SL. Since 2003, very low-level waste has been disposed of at the Andra CSTFA disposal facility, the first disposal facility in the world for this type of waste. Situated in the Aube district, it is designed to accommodate 650 000 m^3 of waste. Once conditioned, waste batches are labelled and emplaced in successive horizontal layers inside several metre deep disposal vaults excavated in clay. Once the disposal vault is filled, it is closed definitively and then capped with a compacted clay layer. This compaction process aims at restoring the initial low permeability to the clay material. In order to get the most out of the repository capacity and reduce volumes to be disposed of, waste generators must take action to optimise waste processing and conditioning. Since 1992, low- and intermediate-level short-lived waste has been disposed of at the Andra CSFMA waste disposal facility. Situated in the Aube district, it was designed to accommodate 1 000 000 m^3 of waste. Waste is disposed of at the surface in reinforced concrete cells. Once filled, these cells are closed with a concrete slab and then sealed with an impermeable coat. Finally, the cell will be capped with a several metre thick layer of clay, to ensure the long-term confinement of the waste. As prescribed by the 28 June 2006 Planning Act, Andra has been studying the concept of shallow disposal for low-level long-lived waste and is developing a 500-metre deep disposal concept for intermediate-level long-lived waste (ILW-LL) and high-level waste (HLW).

France	
Main decommissioning strategies	Immediate decommissioning: the decommissioning process is regulated by decree No. 2007-1557 dated 2 November 2007, which requires that permanent shutdown and decommissioning shall be licensed by a specific decree. This decree has been amended by decree No. 2016-846 dated 28 June 2016, which prescribes the time frame for the application for decommissioning. The decree of 28 June 2016 established the principle of dismantling of nuclear installations (INB) "at the earliest" after final shutdown as set by Article 127 of the energy transition law. An installation which ceases to operate for a continuous period of two years shall be deemed to be permanently shut down. The operator will have to dismantle it "in a time frame as short as possible," in economic conditions and with respect for the environment.
End-state strategies	After completion of the decommissioning actions and the clean-out of the site, the Nuclear Safety Authority fosters a return to the public sector (for uses which may or may not be restricted), subject to possible adjusted encumbrances. It is only when waste cannot be reused or recycled under current technical and economic conditions that it must be disposed of (concept of final waste). Final disposal should be developed for all categories of final waste.
Country definition of optimisation	• Minimising environmental impact. • Preservation of natural resources as well as storage capacities. • The French public health code requires that exposure from ionising radiation resulting from a nuclear activity must be maintained as low as reasonably achievable, taking into account technology, economics and social factors.
Principles enabling optimisation	Waste zoning plan; reuse of materials by melting within the nuclear industry.
Barriers and constraints to optimisation	No clearance level.
Options for waste minimisation – treatment, disposal, etc.	Sorting by waste zoning plan, reuse and recycling using waste treatment facilities (lead, metals, fuel, etc.), disposals.
Main drivers for waste minimisation	• Environmental impact and social acceptance. • The final disposal capacity. • Cost in an overall approach.
Stakeholder engagement	• Commitment between major French nuclear operators. • Discussion and compromises defined in co-operation with French regulator and its TSO (IRSN). To obtain a decommissioning licence, the operator must follow a procedure requiring stakeholder information and participation. The operator must provide a file application to the French ministry in charge of nuclear safety, who refers to the local Préfet (local French government representative), in charge of planning a public inquiry. The ministry also refers to the Environmental Authority. In addition, a part of this file is placed on the website of the local prefecture.
Lessons learnt (positive/negative)	• Physical and radiochemical inventories have to be updated regularly. • Lab capacities have to be strengthened. • Social acceptance is the key. • Waste management and decommissioning have to be taken into account from the design and conception phases onwards. • Transition management has to be considered (resources, skills, etc.)

Germany	
National policy and strategy for radioactive waste management	• The legal requirement for waste management is that prior to disposal, all steps of treatment of the radioactive waste are subjected to the polluter pays principle. • Disposal itself is the responsibility of the federal government. • Deep geological disposal for all kinds of waste.
National Programme document?	Germany published its National Programme document, "Programm für eine verantwortungsvolle und sichere Entsorgung bestrahlter Brennelemente und radioaktiver Abfälle (Nationales Entsorgungsprogramm)" in 2015.
Regulatory framework	The legal basis for licensing procedures for the decommissioning of nuclear facilities is the Atomic Energy Act [1A-3], as well as the associated statutory ordinances promulgated on the basis of the Atomic Energy Act and general administrative provisions. § 7, para. 3 Atomic Energy Act contains the basic requirement for the licensing of decommissioning. It stipulates that for any facility that has been Incensed according to § 7, para. 1 Atomic Energy Act, the decommissioning, safe enclosure or dismantling of that facility or of parts thereof shall require a licence once operation has been permanently suspended. Here too, a consideration of the state of the art in science and technology is retained as a guiding principle. The safety provisions and regulations of the Atomic Energy Act and associated ordinances are further embedded by general administrative provisions, guidelines, safety standards of the Nuclear Safety Standards Commission (KTA), recommendations by the Reactor Safety Commission (RSK), Commission on Radiological Protection (SSK) and Nuclear Waste Management Commission (ESK), as well as conventional technical standards.
Definition of LLW and VLLW	• LLW is part of non-heat generating waste. • VLLW is not considered to be radioactive waste.
Definition of clearance	Restricted or unrestricted clearance is possible.
Waste generators (number and types of facilities)	• Since the 2011 final shutdown of ten nuclear power plant (NPP) reactors, preparation for decommissioning is under way. • 2018-2022: remaining seven NPP reactors to be taken out of operation.
Organisation(s) responsible for decommissioning	Operators are responsible for the decommissioning and waste treatment of their facilities.
Funding	While operators are responsible for the decommissioning of their facilities, the state will be responsible for the implementation and financing of interim storages and the disposal repositories.
Expected volumes of radioactive waste	3 000-5 000 m^3 per reactor.
Availability and description of intermediate and final storage/disposal solution(s)	• Interim storage facilities will be constructed on sites; some centralised storage facilities, collecting facilities of the federal states (Länder). • All non-heat generating waste will be disposed of in the Konrad disposal facility, which is under construction and will be available in 2027. • Disposal of heat generating waste: one repository planned; site selection procedure according to Site Selection Act.
Main decommissioning strategies	• Dismantling of the facility and release of all buildings and land areas from the obligations under the Atomic Energy Act. The current and preferred practice for NPPs is immediate dismantling.

Germany	
Main decommissioning strategies	• Within the context of the decommissioning concept, the operator plans the decommissioning procedure, assuming that any residual quantities of radioactive waste treated at the facility have been removed beforehand. The decommissioning concept also incorporates the requirements with regard to decontamination and dismantling methods and thus the radiological protection of the personnel. • For clearance, various clearance options are available, which are listed in § 29, para. 2, subparts 1 and 2 StrlSchV, in conjunction with the requirements outlined in Appendix IV StrlSchV. Important clearance options include the unrestricted clearance of all types of solid or liquid material, as well as rubble, excavated soil and soil surfaces, clearance for disposal (in a conventional landfill or in a thermal waste treatment plant), the clearance of rubble or excavated soil for recycling (e.g. in road building), the clearance of scrap metal for recycling, and the clearance of buildings for demolition or subsequent use. • Insofar as specific provisions of the StrlSchV on clearance are not available or no clearance values have been defined in the StrlSchV, a so-called Einzelfallnachweis (case-by-case decision) on the compliance with an effective dose in the range of 10 µ Sv per year for members of the public may be carried out. In such cases, the dose is determined on the basis of boundary conditions relating to the site of the intended use, recycling or disposal of the material. • Deliberate mixing or dilution of the materials in order to achieve clearance is not permitted.
End-state strategies	Clearance, reuse or disposal.
Barriers and constraints to optimisation	Technical limits and the as low as reasonably achievable (ALARA) principle.
Options for waste minimisation – treatment, disposal, etc.	• Clearance (limited and unlimited) is most important in minimising decommissioning waste. Every reactor in decommissioning will produce no more than 3 000-5 000 m^3 or radioactive waste. • Cleared material is disposed of in conventional landfill sites. • Various treatment options are used to minimise existing waste like high-pressure compaction, recycling and use of contaminated concrete to fill empty space in waste packages. • Facilities in other European countries are also utilised for waste management. Radioactive waste generated from the operation of nuclear facilities is delivered to Sweden for conditioning and subsequently returned to Germany. • Both central and decentralised storage facilities are available for the interim storage of radioactive waste with negligible heat generation from nuclear power plants and the nuclear industry. For waste generated from the use and handling of radioisotopes in research, industry and medicine, land collecting facilities operated by the Länder are available for storage.
Main drivers for waste minimisation	• The disposal capacity does not allow for more than 5 000 m^3 per reactor. • Decades of interim storage may be necessary. • The disposal costs will be EUR 10 000-20 000 per m^3.
Stakeholder engagement	• All licences for waste management facilities require public participation. • First steps have been taken for stakeholder involvement concerning the disposal of cleared materials.
Lessons learnt (positive/negative)	• Plan ahead to have disposal option ready when needed. • Plan for enough disposal capacity. • Develop a robust plan and acceptance for the disposal of cleared material.

Italy	
National policy and strategy for radioactive waste management	National policy is based on the general principles indicated in Article 4 of the 2011/70/Euratom Directive. The following assumptions constitute the general objectives of the national policy and strategy: 1. Implementing the decommissioning of nuclear installations. 2. Update the national inventory of radioactive waste and spent fuel yearly. 3. Safely dispose of the radioactive waste generated in Italy, as priority, on the national territory, as established by Directive 2011/70/Euratom. 4. Define the location, construct and operate the national repository for radioactive waste generated in the country, as specifically defined in Article 27 of Legislative Decree 31 of 15 February 2010. 5. Dispose of low and medium activity radioactive waste in the national repository, when these originate from civilian activities. 6. In a long-term provisional capacity, store within this national repository the high activity radioactive waste and spent fuel from the previous operation of nuclear plants, when originating from civilian activities. 7. Transport abroad the spent nuclear fuel generated by the operation of decommissioned nuclear power plants, still present in the country, to be treated and reprocessed, pursuant to specific government directives/agreements, except for particular cases in which management will nevertheless follow the aforementioned principles of the 2011/70/Euratom directive. Upon completion of the treatment, the radioactive waste originating from specific contracts/ agreements for reprocessing of spent nuclear fuel will be returned to Italy. 8. Ensure respect for the commitments between Italy and Euratom on the management of radioactive waste in the Joint Research Centre located in the municipality of Ispra (VA). 9. Establish a programme for research and development activities that is exclusively aimed at the secure management of spent fuel and radioactive waste in line with the contents of the National Programme. 10. As a priority aimed at reaching the aforementioned objectives, implement a correct, objective and accurate disclosure process to ensure transparency and actual participation by the public in the decision-making processes concerning the management of spent fuel and radioactive waste.
National Programme document?	The information processes will be defined, as required in the EU and national law, to increase the efficacy of the National Programme. Based on the Preliminary Report describing the possible impacts from the implementation of the National Programme, the implementing authority (MISE/MATTM) shall consult with the Ministry of the Environment (the competent authority) and all the entities competent in terms of environmental issues, to define the range and the level of detail of the information to be included in the Environmental Report. The competent body for approval is the Presidency of the Council of Ministries. To ensure transparency/sharing of National Programme and related Environmental Report, they will be disseminated via a complete set of documents, including a non-technical synthesis, to allow the information to be disseminated as broadly as possible, and not be limited only to a technical audience, to increase the degree of awareness of the issues covered by the National Programme and the opportunity for active participation by providing opinions and proposals. The outcome of the consultation will be supplemented with a strategic environmental assessment, and consequently, it will contribute to the conclusive definition of the National Programme prior to its final adoption. The results of the monitoring will be published according to the procedures and the instruments provided by the law, or which have been specifically identified during the consultation processes with the competent bodies.

Italy	
Regulatory framework	• Legislative Decree No. 230/1995 modified to: Legislative Decree No. 187/2000, Legislative Decree No. 241/2000, Legislative Decree No. 257/2001, Legislative Decree No. 151/2001 "Implementation of EC Directives Euratom 89/618, 90/641, 92/3/ and 96/29 on ionising radiation" Ordinary Supplement OJ, 13 June 1995, No. 136. • Legislative Decree No. 45, which entered into effect on 10 April 2014, implementing the provisions contained in the 2011/70/Euratom Directive. • Law No. 282/2005 promulgating the ratification of Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. • Legislative Decree No. 31/2010 and subsequent amendments defining steps and time frames, including public consultation, for the siting procedure and the realisation of the national repository for the LLW disposal and for the ILW/HLW long-term storage. • Law No. 1860 of 31 December 1962 on the Peaceful Uses of Nuclear Energy. • Decree 7 August 2015 on the Classification of Radioactive Waste.
Definition of LLW and VLLW	• VLLW: radioactive waste with a radioactivity concentration ≤ 100 Bq/g and alpha emitters ≤ 10 Bq/g • LLW: radioactive waste with a radioactivity concentration within the following limits: ○ Short half-life radionuclides ($T_{½}$ ≤ 31 years) ≤ 5 MBq/g ○ Long half-life radionuclides ($T_{½}$ > 31 years) ≤ 400 Bq/g ▪ ^{59}Ni and ^{63}Ni ≤ 40 kBq/g
Definition of clearance	No clearance levels established by law for the release, reuse or recycling of materials from dismantling of nuclear installations; but the waste must comply with the defined exemption criteria. Specific requirements for clearance are typically included in the authorisation for the decommissioning of the individual nuclear installation.
Waste generators (number and types of facilities)	• Trino NPP (PWR, 270 MWe); • Caorso NPP (boiling water reactor [BWR], 870 MWe); • Latina NPP (Magnox, 210 MWe); • Garigliano NPP (BWR with steam drum and secondary steam generators, 160 MWe); • IPU (MOX fuel fabrication plant, Casaccia); • OPEC (post irradiation hot cells, Casaccia); • ITREC (U-Th reprocessing and fabrication plant, Rotondella); • FN (LWR fuel fabrication plant, Bosco Marengo); • EUREX (pilot reprocessing plant, Saluggia); • JRC (European Commission Joint Research Centre, Ispra).
Organisation(s) responsible for decommissioning	In 1999, the liabilities and assets connected to nuclear power were assigned to a newly established company, named SOGIN (Società Gestione Impianti Nucleari), whose shareholder is the Ministry of Economy and Finance, while the strategic and operational objectives were given by the Ministry of Economic Development. The primary mission of SOGIN is the decommissioning of all Italian nuclear installations and the safe management of the spent fuel and radioactive waste related to those installations, including the development and management of the final disposal repositories.
Funding	A fund for financing decommissioning and waste management activities is provided for through a specific levy on the price of electricity.
Expected volumes of radioactive waste	The national repository is expected to receive an overall amount of about 60 000 cubic metres of radioactive waste deriving from nuclear plants.

Italy	
Availability and description of intermediate and final storage/ disposal solution(s)	Temporary storage facilities on the sites of origin, waiting for a national repository for the (V)LLW disposal; and for ILW/HLW, long-term storage. It is important to recognise that, in relation to the new classification of radioactive waste, medium activity waste will also be stored on a long-term provisional basis in the National Repository, which, in relation to the content of the long-life radionuclides, cannot be placed in the medium and low-level disposal facility, as the radioprotection objectives set for this facility would not be fulfilled. During the transitional period of the national repository when the high activity radioactive waste remains in the National Repository, the most appropriate disposal solution within a geological site for ILW/HLW will be identified, also taking into account the opportunities provided within the context of possible international agreements that could be concluded within the same period.
Main decommissioning strategies	Single step strategy.
End-state strategies	Release of the sites without restrictions of a radiological nature.
Country definition of optimisation	(V)LLW management optimisation is aimed at: • minimisation of volume of conditioned waste (final packages); • maximisation of quantities of cleared and released solid materials.
Principles enabling optimisation	• minimisation of volume of conditioned LLW (final packages); • maximisation of quantities of cleared and released solid materials; • sorting, segregation, decontamination, application of waste hierarchy; • reducing the amount and activity of radioactive waste to a level as low as reasonably achievable by reducing waste generation at source; • recycle and reuse.
Barriers and constraints to optimisation	• lack of disposal facilities and waste acceptance criteria; • stakeholder acceptance of recycling and reuse of materials.
Options for waste minimisation – treatment, disposal, etc.	• incineration for suitable solids (including spent resin and sludge); • size reduction and collection into metallic drums (non-burnable waste); • collection into metallic drums and super compaction (non-burnable waste); • liquid – solidification by cement encapsulation; • organic liquid – absorption and incineration.
Main drivers for waste minimisation	• waste acceptance criteria; • waste route; • resources.
Stakeholder engagement	Stakeholder engagement activities in progress: • national survey on waste management and national repository awareness; • Scientific Committee (advisory body); • web campaign on waste management and repository awareness, social media; • press and institutional trips to European repositories; • public events and fairs; • advertising on TV, newspapers, etc.

Italy	
Lessons learnt (positive/negative)	• socio-economic impact of radioactive waste management is strongly related to decision making; • good quality of decision making requires clear responsibilities, transparency through the processes, trust among stakeholders; • the respect of the schedule for decommissioning activities increases stakeholders' confidence and public acceptance.

(Main references: "National Programme for spent fuel and radioactive waste management – Preliminary Report"; "Implementation of Council Directive 2011/70/Euratom of 19 July 2011 Establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste – First Italian National Report, 2015"; "Sogin – Bilancio di sostenibilità 2017").

Japan	
National policy and strategy for radioactive waste management	In Japan, it is encouraged that clearance materials and non-radioactive materials generated from decommissioning, as well as conventional waste, are reused. Compliance with Japanese laws and ordinances, the operators of decommissioning, who are the electric power companies and generators of LLW, promote the management and disposal of LLW on their own initiative.
National Programme document?	Not applicable (European Commission requirement under Article 11 of Council Directive 2011/70/Euratom).
Regulatory framework	The Nuclear Regulation Authority (NRA) regulates each decommissioning/clearance/disposal activity based on the "Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (the Reactor Regulation Act)". For decommissioning, the Reactor Regulation Act requires licensees to develop and obtain NRA approval of the decommissioning plan. The decommissioning plan has to include the following description: • the decommissioning processes; • volume estimation of radioactive waste; • capacity for temporary storage of the radioactive waste; • provisions to prevent spreading contaminants; • disposal of contaminated materials; • the amount of funds required; • the funding plans; • the organisational structure for the decommissioning. Unrestricted clearance materials with extremely low radioactivity concentration will be able to be released after approval and confirmation by the NRA. This system targets not only reactor facilities but also other nuclear fuel cycle facilities. For radioactive waste disposal, upper limits of radioactivity concentrations of the waste and the safety function of the facility, depending on each disposal level, are required by Japan Atomic Energy Commission for Enforcement of the Reactor Regulation Act and "the NRA Ordinance on Activity of Category 2 Waste Disposal of Nuclear Fuel Material and Materials Contaminated by Nuclear Fuel Material (the Category 2 Waste Disposal Ordinance)" for Category 2 waste disposal (corresponds to ILW, LLW and VLLW disposal of IAEA definition) stipulated in the Reactor Regulation Act.

Japan	
Definition of LLW and VLLW	According to the Category 2 Waste Disposal Ordinance, upper limits of radionuclide concentrations for each disposal level are defined as following: • six + alpha nuclides for LLW disposal (near-surface pit disposal); • three nuclides for very low-level waste [VLLW] disposal (near-surface trench disposal); Among the electric power companies that are operators of decommissioning and waste management facilities, they commonly refer to these three types of classification of disposal in Category 2 as L1, L2 and L3, respectively. The three types are as follows; • L1 (relatively high level of low-level waste [ILW]): "Subsurface disposal", waste will be disposed of in underground more than 50 m depth; • L2 (relatively low level of LLW): "Pit disposal", near-surface disposal with engineering barriers and artificial constructs; • L3 (VLLW): "Trench disposal", near-surface disposal without engineering barriers nor artificial constructs.
Definition of clearance	Only unrestricted clearance is available under the Reactor Regulation Act. According to the Act and related Ministerial Ordinances, the materials/waste not exceeding the order of 10 µSv/y can be released from the nuclear facility through approval and confirmation by NRA. This clearance system targets not only reactor facilities, but also other nuclear facilities.
Waste generators (number and types of facilities)	Eleven power plants (one gas-cooled reactor, four BWRs, four PWRs, one advanced test reactor and one fast breeder reactor). One reprocessing plant and others.
Organisation(s) responsible for decommissioning	Main players of decommissioning are electric power companies (EPCs) who are licensees of and the operators of decommissioning. Main players of waste management are as follows: • L1 and L2: A waste management company (Japan Nuclear Fuel Limited [JNFL]) established by nine electric companies, Japan Atomic Power Company (JAPC) and others. • L3 and CL (Materials of Clearance Level): the electric power company that operates the decommissioning of its nuclear power plant. The electric companies decided to conduct centralised management for L1 and L2 by JNFL and also decided for each operator to dispose L3 on the site of the NPP, which is called "on-site disposal". The operators (EPCs) and JNFL take primary responsibility for planning, implementation and completion of decommissioning and waste disposal.
Funding	The operator is requested to estimate the decommissioning cost, including the costs of waste management, and to fund the decommissioning cost. The cost of waste management incudes: • pre-processing of the waste; • packaging of the waste; • transport of waste packages to the disposal site; • disposal*. * The operator will pay the cost of disposal to the implementer according to the volume for each classification of waste.

<table>
<tr><th colspan="2">Japan</th></tr>
<tr><td>Expected volumes of radioactive waste</td><td>The table below shows the estimated amount of waste generated from the decommissioning of NPPs.
Uint:ton
<table>
<tr><th colspan="2">Disposal level</th><th>GCR</th><th>BWR</th><th>PWR</th></tr>
<tr><td rowspan="3">LLW</td><td>L1 waste</td><td>~ 1,600</td><td>~100</td><td>~200</td></tr>
<tr><td>L2 Waste</td><td>~ 8,700</td><td>~900</td><td>~1,800</td></tr>
<tr><td>L3 Waste</td><td>~ 12,300</td><td>~11,900</td><td>~4,100</td></tr>
<tr><td colspan="2">Sub-total</td><td>~ 22,400</td><td>~12,800</td><td>~6,000</td></tr>
<tr><td colspan="2">CL materials</td><td>~ 41,100</td><td>~28,500</td><td>~11,700</td></tr>
<tr><td colspan="2">Non-radioactive materials</td><td>~ 128,700</td><td>~495,500</td><td>~477,300</td></tr>
<tr><td colspan="2">Total</td><td>~ 192,200</td><td>~536,700</td><td>~495,000</td></tr>
</table>
BWR: boiling water reactor, PWR: pressurised water reactor, GCR: gas-cooled reactor.</td></tr>
<tr><td>Availability and description of intermediate and final storage/ disposal solution(s)</td><td>The following disposal site/facilities exist:
• an L3 (VLLW) test disposal (closed);
• an L3 (VLLW) disposal site (under NRA review);
• an L2 (LLW) disposal site (operating: only LLW from NPP normal operation);
• a radioactive waste interim storage (from research facilities).</td></tr>
<tr><td>Main decommissioning strategies</td><td>A document published by the decommissioning committee of Ministry of Economy, Trade and Industry (METI) provides “Standard procedure of decommissioning in Japan”. The standard procedure requires the licensees to complete decommissioning within 30 to 40 years. The strategy to complete decommissioning in such a period would be categorised as “deferred dismantling”, which is one of decommissioning strategies defined by the IAEA.
The document provides “scope of decommissioning”.</td></tr>
<tr><td>End-state strategies</td><td>Although there is no clearly determined strategy in Japan, the site after completion of decommissioning will be reused as some kind of industrial facility, which could include a nuclear facility.</td></tr>
<tr><td>Country definition of optimisation</td><td>In the waste management area, the term “minimisation” indicates two measures.
One is to reduce the amount of waste of higher disposal levels. It is possible to decrease the disposal level of waste either by reducing residual radioactivity of SSCs over time, by decontaminating SSCs, or in combining both approaches. By appropriately applying these measures, wastes of L3 or of higher disposal levels would become materials of clearance level, which are not “wastes” but “resources”
Another is volume reduction of any waste of each disposal level. The volume reduction is very effective for the reduction of transport cost and disposal cost. And it is also effective for the rational design of disposal sites for each level.
Appropriate combinations of these two measures enable the optimisation of waste.</td></tr>
</table>

Japan	
Principles enabling optimisation	• Decommissioning activities, which are decontamination, dismantling, and waste management, must be optimised in terms of cost (and of course, in terms of safety). • The cost of waste management is the sum of the costs of waste pre-processing, transport and disposal. The volume reduction of waste whose disposal level has lowered due to the appropriate measures is much more effective for the reduction of transport cost and disposal cost. • In the optimisation of waste management, minimisation of waste indicates lowering the disposal level and volume reduction of the waste.
Barriers and constraint to optimisation	A main constraint of the management of waste generated from decommissioning is cost. One of the most important factors for the operators to carry out decommissioning is cost efficiency. Decommissioning activities must be optimised in terms of cost (and also in terms of safety). Technical studies and/or designs have to be reviewed from an economic point of view (and also a safety point of view) and optimisation of decommissioning activities must be made both in terms of technology and cost.
Options for waste minimisation – treatment, disposal, etc.	Because of the reduction of transport cost and disposal cost, and the rational design of the disposal site for each disposal level, the implementers set minimisation as having a higher priority in waste management. The standard and the guideline, which are published by AES-J, will provide methodologies leading to the optimisation of waste management. In these publications, the methodologies will be shown stage by stage in decommissioning as follows: (1) stage of preparatory tasks; (2) stage of decontamination of SSCs in decommissioning activities; (3) stage of dismantling of SSCs in decommissioning activities; (4) stage of pre-processing of waste in decommissioning activities.
Main drivers for waste minimisation	The operators who generate radioactive waste from decommissioning are promoting waste minimisation in terms of cost minimisation.
Stakeholder engagement	• According to the Administrative Procedure Act, the NRA invites public comment when an ordinance or a review standard will be set or amended. In addition, the NRA voluntarily invites public comment as appropriate (e.g. when a new safety evaluation report for licence application will be summarised). • Interrelations between the main drivers and the public: since electric power companies, which are the operators of decommissioning, are positioned as public utility businesses under laws in Japan, the persons concerned are citizens as a whole. As a responsibility of the public utility business, the operators must take the best measures in terms of social and economic acceptability. In addition, operators shall endeavour to gain the understanding of the local government and the residents where the site is located.

Japan	
Lessons learnt (positive/negative)	• Positive results: Conducting sufficient preliminary surveys and predictive evaluations for the facility to be decommissioned, which is the plant characterisation, have made it possible to reliably estimate the amount of waste. Reliable amounts of waste for each level generated from decommissioning, and a reliable prediction of the amount of time required, have made it possible to streamline and to optimise waste management. • Difficult challenges: Because of the 3.11 Fukushima Daiichi NPP accident, it is becoming difficult to obtain public acceptance of siting for the disposal site. In order to eliminate the aversion to nuclear energy and radiation and to gain an understanding of waste disposal, much time and much effort will be needed in the future. • Other opportunities that could be implemented in the country: In Japan, decommissioning will become full-fledged in the coming five to ten years, and the expectation is that lessons will be learnt through this activity.

Korea	
National policy and strategy for radioactive waste management	The national policy and strategy for radioactive waste management is made by the Ministry of Trade, Industry & Energy (MOTIE) and resolved by the Atomic Energy Promotion Committee by the Radioactive Waste Management Act (RWMA). There are two national policies, the first is the "Basic Plan for LILW Management Plan" and the second is the "Basic Plan for HLW Management Plan".
National Programme document?	Not applicable (European Commission requirement under Article 11 of Council Directive 2011/70/Euratom).
Regulatory framework	• The Nuclear Safety Act (NSA) was enacted as a main regulatory law concerning the safety regulations for radioactive waste management. • In the framework for nuclear safety regulation, the Nuclear Safety & Security Commission (NSSC) has absolute authority with regard to overall nuclear safety regulations (including radioactive waste safety regulation). • The Korea Institute of Nuclear Safety (KINS), which was established in order to strengthen expertise in matters regarding nuclear safety regulation, is engaged in regulatory services concerning nuclear safety entrusted by the NSSC, including areas such as safety reviews, inspections, training and R&D based on expert knowledge concerning nuclear safety regulations and accumulated experiences.
Definition of LLW and VLLW	• VLLW is greater than the radioactivity for clearance and less than 100 times the radioactivity for clearance, which is defined the NSSC Notice No 2014-3. • LLW is greater than VLLW and less than the limit of radioactivity defined by the NSSC Notice.
Definition of clearance	Unrestricted and restricted release of radioactive waste or material in a manner of incineration, landfill and reuse after the regulatory review. There is a regulatory requirement on clearance, for example a clearance level based on the IAEA GSR Part 3, which is stipulated in the NSSC Notice No. 2014-3.
Waste generators (number and types of facilities)	The Korea Hydro & Nuclear Power Co Ltd (KHNP, the NPP operator), the nuclear fuel manufacture company and other RI users. For example: • twenty-five nuclear power reactors; • a research reactor in operation and a research reactor under decommissioning.

Korea	
Organisation(s) responsible for decommissioning	KHNP, as operator of the NPPs.
Expected volumes of radioactive waste	KHNP is evaluating the volume of radioactive waste from the decommissioning of Kori unit 1, which will be permanently shut down in June 2017. The goal of the volume of radioactive waste from Kori unit 1 by the KHNP is about 14 500 drums (200 L drum equivalent).
Availability and description of intermediate and final storage/ disposal solution(s)	In Korea, the facilities related to storage and disposal of radioactive waste are: • temporary storage buildings in each NPP; • Wolsong LILW Disposal Facility which is operated by KORAD.
Main decommissioning strategies	KHNP has the immediate dismantling strategy for Kori unit 1.
End-state strategies	Unrestricted or restricted use.
Country definition of optimisation	With a consideration of cost-benefit analysis and other factors, the optimisation could be defined to find the best option or solution.
Principles enabling optimisation	Consideration and evaluation of economic factors include the disposal option and the waste treatment technology.
Barriers and constraints to optimisation	• regulatory issues (strict regulatory framework for clearance of radioactive material); • selection of the technology for waste treatment and conditioning; • disposal options; • stakeholder engagement, public objections.
Options for waste minimisation - treatment, disposal, etc.	As usual, various options are taken for waste minimisation. • material control, which could be radioactive waste in a radiation zone; • segregation by waste characteristic; • volume reduction (super compactor); • clearance of radioactive material.
Main drivers for waste minimisation	• One of the main fundamental principles for the "Radioactive Waste Management Plan" is the minimisation of radioactive waste generation. • In Korea, disposal cost of radioactive waste is relatively high so waste generators always need to consider their volume of waste generation.
Stakeholder engagement	There is no regulatory requirement concerning the stakeholder in terms of the radioactive waste management of waste generators. However, the operator applying to the regulator for decommissioning approval should take the comments and opinions of the residents into account for the official release of its decommissioning plan and public hearing.
Lessons learnt (positive/negative)	• Regarding radioactive waste management, especially for VLLW, clearance would be a very useful and helpful way to deal with it. • Co-operation between the generator and disposal facility operator is necessary for effective radioactive waste management.

Slovak Republic	
National policy and strategy for radioactive waste management	The national strategy for back-end – approved by the government in 2014. The national policy objectives include: • safe and reliable decommissioning of nuclear installations; • minimisation of waste; • selection of appropriate fuel cycle type; • safe storage; • implementation of safe radioactive waste and spent fuel management; • implementation of nuclear safety principles; • application of a graded approach; • the "polluter pays" principle; • objective decision-making process.
National Programme document?	The Board of Governors of State Nuclear Fund prepared the National Programme for handing of spent nuclear fuel and radioactive waste and it was approved by the Slovak government in 2015.
Regulatory framework	• Atomic act, public health protection act, radiation protection act, regulatory authority regulations. • The National Programme for handling of spent nuclear fuel and radioactive waste in the Slovak Republic. • In general, the regulatory framework for radioactive waste management is well established. • There is a need for detailed guides for specific issues, especially in the field of conditional clearance, recycling within nuclear industry and release of sites.
Definition of LLW and VLLW	In 2012, revision of legislation, VLLW class was added in accordance with IAEA recommendations regarding waste classifications. Slovak waste classification is in line with IAEA recommendations: • VLLW, whose activity is slightly higher than the limit value for their introduction to the environment, mainly contain radionuclides with a short half-life, or also a low concentration of radionuclides with a long half-life, which during storage require a lower degree of isolation from the environment through a system of engineered barriers, as in the case of surface-type radioactive waste repositories. • LLW, whose average specific activity of radionuclides with a long half-life, especially radionuclides emitting alpha radiation, is less than 400 Bq/g, maximum specific activity of radionuclides with a long half-life, especially radionuclides emitting alpha radiation, is locally less than 4 000 Bq/g, does not produce residual heat, and following treatment meet safe operating limits and conditions for surface-type radioactive waste repositories. Derived waste acceptance criteria for both VLLW and LLW repositories are available.
Definition of clearance	Clearance for unrestricted use – a legislation framework exists including general clearance levels, which are in line with Council Directive 2013/59/Euratom. The application of concepts of conditional clearance or recycling and reuse within the nuclear industry is a subject of ongoing discussion among regulatory bodies, implementers/operators and other interested parties, such as technical support organisations.

Slovak Republic	
Waste generators (number and types of facilities)	• A1 NPP (KS 150 reactor type – gas-cooled, heavy water moderated, natural uranium) and V1 NPP (VVER 440 reactor type) under decommissioning; • V2 NPP and EMO1,2 NPP (VVER 440 reactor type) in operation; • institutional radioactive waste producers.
Organisation(s) responsible for decommissioning	The state-owned joint-stock type company called JAVYS is responsible for decommissioning, radioactive waste and spent fuel management, and the related disposal of radioactive waste in the Slovak Republic. JAVYS is in charge of the development of the national project for a deep geological repository. Moreover, JAVYS is responsible for the centralised collection of institutional radioactive waste, including disused, sealed radioactive sources, orphan radioactive waste and/or nuclear materials, as well as their subsequent management in the Slovak Republic.
Funding	The costs of radioactive waste management from decommissioning of nuclear energy installations shall be covered in general by the State Nuclear Fund. In case of V1 NPP, Bohunice International Decommissioning Support Funds (BIDSF), administered by the European Bank for Reconstruction and Development, is used as well. The cost of radioactive waste management from operation of NPPs shall be covered from the operating costs of the producers of radioactive waste.
Expected volumes of radioactive waste	The vast majority of LLW and VLLW generated in the near future is expected to be decommissioning waste: • A1 NPP: more than 10 000 Mg of VLLW (mainly concrete rubble and contaminated soils); more than 2 000 Mg – LLW (metals, other solid waste and treated secondary waste). • V1 NPP: more than 500 Mg of VLLW (mainly concrete rubble); more than 2 000 Mg of LLW (metals, other solid waste and treated secondary waste).
Availability and description of intermediate and final storage/disposal solution(s)	• Certified stores on the premises at A1 NPP. • Integral radioactive waste store in operation since 2018. • Interim store for spent fuel (wet type), plans for building of new dry type storage. • Both LLW and VLLW repositories located at National Radioactive Waste Repository site in Mochovce (near-surface repository). • Ongoing project for siting of deep geological repository (preliminary stage).
Main decommissioning strategies	Immediate dismantling. • V1 NPP – two stages (currently at the 2nd stage – dismantling of primary circuit, large components and reactor itself); normal operation; based on plans, decommissioning works should be finished in 2025. • A1 NPP – five stages (currently at joint 3rd and 4th stage – dismantling of primary circuit); shutdown after an accident (INES 4); based on plans, decommissioning works should be finished in 2033.
End-state strategies	Currently, the only implemented end-state is unrestricted use ("green field"). Application of the restricted use ("brown field") is currently being discussed. However, there are no special guides for release of sites; the same criteria are applied as in the case of clearance of materials. This is another topic for discussion within the regulatory bodies and other stakeholders. Based on the strategy, the planned end-state of V1 NPP site is further industrial use; selected equipment and buildings of A1 NPP will be transferred to another nuclear facility called RAW Processing and Treatment Technology.
Country definition of optimisation	Optimisation is a process leading to selection of the best available solution taking into account several criteria such as safety, technical, economic and other aspects.

Slovak Republic	
Principles enabling optimisation	• Cost-benefit analysis (economic considerations). • Analysis for using an existing or selecting/developing a more appropriate waste treatment, conditioning and disposal option (technical, safety and waste management considerations; effective use of the disposal capacities). • Availability of technology and manpower needed (schedule considerations).
Barriers and constraints to optimisation	• Need for detailed regulatory framework/guides in special fields (e.g. conditional clearance, site release). • Limited knowledge and experience regarding the aforementioned specific issues. • Need for enhancement of existing or application of new incentives to be more effective from an economic point of view. • Stakeholder engagement process, addressing the public attitude and perceptions.
Options for waste minimisation – treatment, disposal, etc.	In general: • Minimisation of waste by separating materials before releasing them into the environment (in particular building material), their reprocessing (crushing) and utilisation. • Use of available technology for processing and treatment of metal radioactive waste (e.g. high-pressure compacting, cementation). Planned construction of melting facility addressing the increased metal radioactive waste generation (recycling and clearance). The low-activity metal waste shall be treated by fragmentation and decontamination with a subsequent release of decontaminated material into the environment. • Use of an incineration technology for combustible waste and high-pressure compaction for compactable waste to significantly decrease the volume of final products to be disposed of. • Appropriate management of inorganic liquid radioactive waste, e.g. by using an evaporator or adding into cement grout. Already implemented: • sorting based on appropriate characterisation; • general clearance for unrestricted use; • treatment leading to a decrease in the volume of waste. JAVYS owns various radioactive waste management facilities: • Bohunice treatment centre for radioactive waste management includes facilities for sorting, incineration, high-force compaction, concentration and cementation. • At the Mochovce site, there is final processing of liquid radioactive waste through concentration, cementation and bituminisation. • At the A1 NPP (Jaslovske Bohunice) site, there are facilities for vitrification, fragmentation, decontamination, sludge fixation, etc. • A melting facility is being constructed (finished environmental impact assessment process; ongoing project; expected operation from 2019). To be discussed with stakeholders in the near future: • direct reuse of devices, tools, etc., within the nuclear industry; • recycling of materials within the nuclear industry; • conditional clearance; • release of sites.

Slovak Republic	
Main drivers for waste minimisation	Economical aspects, optimisation of use of disposal capacities, overall effectiveness of the decommissioning process.
Stakeholder engagement	• Implemented, especially within the environmental impact assessment process, citizens information committee and JAVYS contribution to public awareness. • A great deal of work to be done to communicate the specific issues such as possible conditional clearance or restricted release of sites. • Need for public attitude surveys on above mentioned specific topics, including the siting of a deep geological repository as well.
Lessons learnt (positive/negative)	• Modification of legislation and the strategy to address a particular waste stream may bring benefit (i.e. to be more flexible and fit-for-purpose). • Implementation of VLLW class in legislation – easier, cheaper and a "fit-for-purpose" way to dispose of slightly radioactive waste (mainly contaminated soils) safely. • Refurbishment, modernisation and development of technological facilities and methods – effective characterisation, improved classification of waste (e.g. reclassification from LLW to VLLW class), overall enhancement of waste management system.

Spain	
National policy and strategy for radioactive waste management	• Enresa is the national agency of waste management in charge of radioactive waste from nuclear installations and small producers. • Also, Enresa is in charge of the decommissioning projects. At the present time and in the future for the decommissioning of the NPPs, ENRESA considers the immediate decommissioning strategy and to achieve level 3.
National Programme document?	Spain published its National Programme document "*Sexto Plan General de Residuos Radiactivos*" in 2006.
Regulatory framework	• For the El Cabril repository, there are waste acceptance criteria for both L&ILW and VLLW. • Regulatory body requirements and guidelines for material clearance and site release.
Definition of LLW and VLLW	VLLW <100 Bq/g for Beta, <10 Bq/g Alfa.
Definition of clearance	The process that demonstrates the fulfilment of the release limits for the residual activity of the materials/surfaces/soils involved.
Waste generators (number and types of facilities)	Six operating NPP (five PWR, one BWR); one temporary shutdown (BWR); one dismantled (Level 2) Latency Period (UNGG); one dismantling (Level 3) PWR.
Organisation(s) responsible for decommissioning	Enresa is responsible for the decommissioning of nuclear installations and the management of all radioactive waste, including the development and management of the final disposal repositories.
Funding	In Spain, by law Enresa is in charge of the dismantling processes of nuclear installations and the funds come in advance from the producers by means of taxes.
Expected volumes of radioactive waste	Based on experience from Vandellos 1 NPP and José Cabrera NPP, the percentage of radioactive waste volume as a function of the classification is VLLW: 80%; L&ILW: 20%; HLW: <1%. The percentage of VLLW would be much greater if no release projects were implemented.

Spain	
Availability and description of intermediate and final storage/disposal solution(s)	• El Cabril Repository for L&ILW and VLLW. • Under the licensing process, the centralised interim storage of HLW, spent fuel and HLW.
Main decommissioning strategies	• Enresa has the funds from producers in advance in order to be able to face a complete decommissioning process in a relative short period of time (five to ten years). • Based on previous and current experience in these issues, a global plan is developed which covers the whole decommissioning project, trying to optimise at the most all the main features involved, namely, the means and resources for the characterisation process, optimisation of waste to be generated, material release projects, site release plan, radiological protection issues, safety, costs and schedules.
End-state strategies	In general, the end-state is a brown/grey field for industrial use afterwards, and even green field is also foreseen.
Country definition of optimisation	A methodology that best improves a process (maximum or minimum).
Principles enabling optimisation	Maximising desired factors and minimising undesired ones. In comparison, maximisation means trying to attain the highest or maximum result or outcome without regard to cost or expense.
Barriers and constraints to optimisation	• waste acceptance criteria of repository; • transport criteria; • radiological protection issues; • health and safety issues; • legal aspect for the contract of team workers; • schedule fulfilment; • engineering issues for dismantling difficult structures; • budget.
Options for waste minimisation – treatment, disposal, etc.	• previous characterisation and in situ segregation; • decontamination processes as chemical or physical ones; • release projects; • site restoration.
Main drivers for waste minimisation	• Waste Management Agency: Enresa (El Cabril Repository). • Nuclear Regulatory Council Producers: nuclear power plants, radioactive installations.
Stakeholder engagement	Local authorities, students, general public and media (TV, radio and press).
Lessons learnt (positive/negative)	• Radiological and health safety for workers and of course for the public, volume optimisation of waste. • The combination of schedule and safety with the main objective of dismantling.

Switzerland	
National policy and strategy for radioactive waste management	A Sectoral Plan for Deep Geological Repositories (DGR) was approved by the Federal Council in 2008: In stage 1 of the process, different siting regions for DGR were proposed and approved by the Federal Council. In stage 2, additional geological and safety-based investigations were carried out resulting in a reduction of proposed sites. Stage 2 was concluded in November 2018 with the decision of the Federal Council. Activities in stage 3 include in-depth geological investigations in the remaining siting regions. The results will provide the basis for selecting the final sites for the DGR. The Swiss Federal Office of Energy is in charge of the site selection procedure according to the Sectoral Plan. Two DGRs for low- and intermediate-level waste (ILW) and high-level waste (HLW) are assumed, either at two different sites depending on the geological situation, or at the same site as a "combined repository" (in which case the infrastructure could be shared). Waste disposal in repositories for ILW (HLW) is expected during 2050-2065 (2060-2074).
National Programme document?	Not applicable (European Commission requirement under Article 11 of Council Directive 2011/70/Euratom).
Regulatory framework	• Nuclear Energy Act (of 21 March 2003, Status as on 1 July 2016); • Nuclear Energy Ordinance (of December 2004, Status as on July 2016); • Radiological Protection Ordinance (of 22 June 1994, status as of 1 January 2014); • Guidelines by the Swiss Federal Nuclear Safety Inspectorate (ENSI).
Definition of LLW and VLLW	Under the Nuclear Energy Act, the general definition for radioactive waste is radioactive material or radioactive contaminated material without further use. Definitions under the Nuclear Energy Ordinance (Art. 51): Categorisation: a) High-level radioactive waste (HLW): spent fuel which is no longer used and vitrified fission product solutions resulting from the reprocessing of spent fuel. b) Alpha toxic waste: waste in which the content of alpha emitters exceeds 20 000 Bq/g of conditioned waste. c) Low- and intermediate-level waste (ILW): all other radioactive waste.
Definition of clearance	Clearance limits for unrestricted clearance stated in the Radiation Protection Ordinance: • mass specific values (nuclide specific) according IAEA RP-G-1.7; • dose rate in 10 cm distance less than 0.1 µSv/h; • standard values for the contamination (nuclide specific).
Waste generators (number and types of facilities)	• Beznau NPP, two PWR units; • Gösgen NPP, one PWR unit; • Leibstadt NPP, one BWR unit; • Mühleberg NPP, one BWR unit; • interim storage facility ZWILAG; • medicine and industry; • research centres (major centres: PSI, CERN).
Organisation(s) responsible for decommissioning	The responsibility for waste disposal lies with the waste producers, who have entrusted a national co-operative company (Nagra) with performing all tasks associated with the implementation of the DGR. Nagra will have the role of later owner and operator of a final repository.

Switzerland	
Funding	For financing waste management activities up to the shutdown of nuclear facilities two funds have been established: a decommissioning fund and a waste disposal fund for putting aside the financial reserves by the owners. The costs of the decommissioning and waste disposal (and the annual payments to the funds) have to be estimated every five years in a cost study.
Expected volumes of radioactive waste	Expected volumes for 60 years of NPP operation (NPP Mühleberg, 47 years) and production of waste from medicine, industry and research until 2065: • ILW: 82 000 m^3; • alpha toxic waste: 1 100 m^3; • HLW: 9 400 m^3; • Total: 92 500 m^3.
Availability and description of intermediate and final storage/disposal solution(s)	• ZWILAG: Interim storage facility for all types of radioactive waste from operation and decommissioning of NPPs (HLW, alpha toxic waste, ILW). • ZWIBEZ: Facility for interim storage of radioactive waste (HLW, alpha toxic waste, ILW) of NPP Beznau. • BZL: Facility for interim storage of ILW and alpha toxic waste from industry, medicine and research.
Main decommissioning strategies	Direct dismantling. In general, deferred dismantling or dormancy is possible, but has to be justified to the authority.
End-state strategies	Green field, brown field.
Country definition of optimisation	Minimisation of radioactive waste (volume, activity) according to the nuclear energy act and nuclear Energy Ordinance. ALARA from the radiological protection point of view.
Principles enabling optimisation	Clearance of materials as much as possible and justified by dose and money. Decay storage for 30 years as non-radioactive waste.
Barriers and constraints to optimisation	Regulations for conditioning of radioactive waste with respect to acceptance criteria of the interim storage; permission from the authority necessary.
Options for waste minimisation – treatment, disposal, etc.	• minimisation of the source term; • decontamination at the source (chemical system decontamination); • decontamination and clearance; • decay storage; • plasma melting facility for radioactive waste at Zwilag, minimisation of volume.
Main drivers for waste minimisation	• legal requirements; • cost-benefit calculation (clearance, decontamination, conditioning as radioactive waste, interim storage volumes and costs, final repository volumes and costs); • ALARA.
Stakeholder engagement	• The Swiss Federal Office of Energy (SFOE) is in charge of the regional participation according to the Sectoral Plan for Deep Geological Repositories. In all siting regions, so-called regional conferences have been established and extensive collaboration has been ongoing since the beginning of stage 2.

Switzerland	
Lessons learnt (positive/negative)	Positive results: • interaction between all the stakeholders is taking place concerning the final repository. Challenges: • keeping the timetables; • changing conditions for processing the radioactive waste to meet the safety standards for interim and final storage; • decreasing clearance levels.

Sweden	
National policy and strategy for radioactive waste management	The key fundamental principles implemented in the Swedish legislation include: • A party that has generated spent nuclear fuel and radioactive waste is also required to bear the costs for managing these residual products. • The main responsibility for radiation safety in the management and final disposal of spent nuclear fuel and radioactive waste rests with the licensee of the facility that generated the waste. • Radioactive waste production shall be limited as far as reasonably possible. • Spent nuclear fuel and radioactive waste shall be managed without unnecessary delay with due regard to all the following management steps. • The Nuclear Activities Act and the Environmental Code stipulates requirements that radioactive and conventional waste shall be managed in a way that gives the best protection of human health and the environment, as long as it is not unreasonable. The state has the ultimate responsibility for the management of spent nuclear fuel and radioactive waste generated in Sweden. • Each country is to be responsible for management of spent nuclear fuel and radioactive waste generated from nuclear activities in that country. Exceptions to this policy require special considerations. The general, current strategy is: • Slightly contaminated materials are cleared. • Contaminated waste (surface dose rate <0.5 mSv/h) to shallow land disposal facilities for radioactive waste (presently the most cost-efficient solution for VLLW). • Contaminated waste (surface dose rate >0.5 mSv/h) to the Final Repository for Short-lived Radioactive Waste (SFR). • Ability to clear VLLW metals (<0.1 mSv/h) after treatment. • Long-term storage of long-lived intermediate-level waste, packed to enable future reconditioning. • Decontamination for reclassification of waste only when technically/financially motivated.
National Programme document?	• The Swedish Radiation Safety Authority (SSM) published the National Plan in 2015. The National Plan, with its main references, constitutes the established Swedish National Programme notified under the Council Directive 2011/70/Euratom. • The licensees for the Swedish nuclear reactors and Swedish Nuclear Fuel and Waste Management Company (SKB) present plans for research, development and demonstration every third year in the research, development and demonstration (RD&D) programme as required in the Nuclear Activities Act.

Sweden	
Regulatory framework	National policy: • Environmental Code; • Radiation Protection Act; • Act on Nuclear Activities. Under the Act on Nuclear Activities, the party that holds a licence to conduct nuclear activities in Sweden has an obligation to ensure that the nuclear material, spent nuclear fuel, and nuclear waste generated by the operations, which are not intended to be reused/recycled, are safely managed and disposed of in a repository. This obligation signifies an extensive commitment on the part of a licensee until a final disposal facility for this waste has been ultimately closed. When all obligations have been performed and approved by the government of Sweden, the long-term liability will rest with the state. Main regulations: • SSMFS 2008:1, The Swedish Radiation Safety Authority's Regulations and General Advice concerning Safety in Nuclear Facilities. • SSMFS 2008:37, The Swedish Radiation Safety Authority's Regulations Concerning the Protection of Human Health and the Environment in Connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste. • SSMFS 2008:21, The Swedish Radiation Safety Authority's regulations concerning safety in connection with the disposal of nuclear material and nuclear waste. • SSMFS 2018:3, The Swedish Radiation Safety Authority's regulations and general advice concerning clearance of materials, rooms, buildings and land in practices involving ionising radiation.
Definition of LLW and VLLW	VLLW: Contains small amounts of short-lived radionuclides with T1/2 <31 years, surface dose rate <0.5 mSv/h, with limited amounts (low percentage) of long-lived radionuclides T1/2 >31 years. LLW: Contains short-lived radionuclides T1/2 <31 years, surface dose rate <2 mSv/h, with limited amounts of long-lived radionuclides T1/2 > 31 years.
Definition of clearance	Legislation (SSMFS 2018:3) exists to regulate the clearance of material, rooms, buildings and land from practices involving ionising radiation. In addition, the nuclear industry has compiled a methodology-report (SKB R-16-13) on clearance during decommissioning and dismantling of nuclear installations, which has been well received by the regulating authority.
Waste generators (number and types of facilities)	• Forsmark NPP, 3 BWR units – all units in operation. • Oskarshamn NPP, 3 BWR units – unit 3 in operation, units 1 and 2 have been shut down (service operation). Decommissioning planning is ongoing for unit 1 and 2 due to early shutdown decisions. • Ringhals NPP, 1 BWR, 3 PWR units – decommissioning planning is ongoing for unit 1 (BWR) and 2 (PWR) due to early shutdown decisions. • Barsebäck NPP, 2 BWR units – both units have been shut down (service operation). Segmentation and packing of internals is ongoing. • The Studsvik site, RnD, material testing and waste management site – several facilities in operation, but the research reactors (R2/R2-0) have been shut down and decommissioning is ongoing. The central laboratory (ACL) has been decommissioned. The licensees on-site consist of SVAFO, Cyclife and Studsvik. • Ranstad, Uranium mining and milling facilities – shut down and ongoing decommissioning. • Ågesta NPP, pressurised heavy-water reactor – one unit that has been shut down (service operation), decommissioning planning is ongoing.

Sweden	
Waste generators (number and types of facilities)	• Westinghouse Electric Sweden fuel factory – in operation. • Research reactor (R1) at the Royal Institute of Technology in Stockholm – has been decommissioned. • Final repository for LILW (operational waste), SFR – in operation. • Interim storage facility for spent nuclear fuel, CLAB – in operation.
Organisation(s) responsible for decommissioning	The licensees of the nuclear facilities (including power reactors) are responsible for their decommissioning and the management of waste. Parties licensed to own or operate a nuclear power reactor are subject to a particular obligation to carry out the following in consultation with other licensees of nuclear power reactors: • Preparing a programme for the comprehensive research, development and demonstration work and the other measures necessary for safe management of nuclear waste and spent nuclear fuel, in addition to safe decommissioning and dismantling of nuclear facilities (i.e. the RD&D Programme). • Preparing a cost estimate as input for calculating the fees to be payed to the Nuclear Waste Fund for management of these liabilities from nuclear activities (i.e. the Plan Cost Estimates). In order to fulfil these obligations, the reactor licensees established the Swedish Nuclear Fuel and Waste Management Company (SKB) as the company to be in charge of preparing and submitting to the authority the nuclear power industry's joint RD&D programme and cost estimate. Today, SKB is also the licensee responsible for handling, management, transport and interim storage of spent nuclear fuel and nuclear waste outside the nuclear power facilities, including operations of the facilities Clab (interim storage for spent fuel) and SFR.
Funding	Nuclear power licensees are obliged to bear the costs for decommissioning and radioactive waste management.
Expected volumes of radioactive waste	The following quantities were in storage as defined by SKB's waste classification scheme as for the year 2013: • Approx. 20 000 m^3 of VLLW present in shallow land disposal facilities for nuclear waste or awaiting disposal in such facilities. • Approx. 20 000 m^3 of short-lived, LLW and ILW in the SFR repository's sections BLA (waste vault for low-level waste) and BTF (waste vault for concrete tanks), or present at Swedish nuclear facilities awaiting final disposal in SFR. The projected future quantities of waste that will be in storage in the 2070s (within the parameters of the present reactors' lifetimes) are as follows: • Approx. 70 000 m^3 of short-lived operational waste in the SFR repository. • Approx. 80 000 m^3 of waste from dismantling and demolition in SFR (after the facility has been extended). VLLW expected: approximately 50 000 tonnes. Cleared material, expected: approximately 500 000 tonnes.
Availability and description of intermediate and final storage/ disposal solution(s)	Facilities in operation for final disposal of short-lived operational waste: • Final Repository for Short-lived Radioactive Waste (SFR) for LLW and ILW in Forsmark. • Three shallow land disposal facilities for VLLW at sites of the nuclear power plants in operation (Forsmark, Ringhals and Oskarshamn). • The shallow land disposal facility at the Studsvik site is permanently closed. • SKB is presently applying for permission to expand the SFR to give room for short-lived, low- and intermediate-level decommissioning and operational waste.

Sweden	
Availability and description of intermediate and final storage/ disposal solution(s)	• Work for the dismantling and decommissioning of the first seven reactors is planned to start before the extended SFR is commissioned. The licensees therefore plan to store short-lived decommissioning waste at the power plant sites or at another site. VLLW is also kept in interim storage on sites pending campaigns for final disposal. • Long-lived LLW and ILW is stored at several existing and planned storage facilities awaiting construction of the final repository for long-lived waste (SFL), which is planned to be taken into operation in the 2040s.
Main decommissioning strategies	• direct dismantling; • decommissioning and demolition separate from waste management; • removal of spent fuel to interim storage as soon as possible (within 1-2 years); • early removal of high activity components, ALARA; • proven and available technology; • heavily entrepreneur dependent; • use of existing Swedish system for WM.
End-state strategies	The licensees propose that the sites shall be cleared for conventional, industrial use after demolition of the last (nuclear) unit.
Country definition of optimisation	The Nuclear Activities Act and the Environmental Code stipulates requirements that radioactive and conventional waste shall be managed in a way that gives the best protection of human health and the environment, as long as it is not unreasonable. VLLW should be generated and managed with the aim of achieving the best protection of human health and the environment, while achieving cost and time efficient decommissioning and radioactive waste management. Means of reducing radiation and conventional hazards, as well as applying other goals from an environmental point of view (e.g. sustainability), should thus be put in relation to costs and economic risks for the different available management options. Nuclear activities must be carried out in a way so that ensures that the quantity of nuclear waste and its content of radioactive substances are limited as far as reasonably possible.
Principles enabling optimisation	1) Thorough knowledge of the facility and its radiological status. 2) Thorough investigations of different options for decommissioning and waste management. 3) Multiple available treatment routes for each waste category.
Barriers and constraints to optimisation	Waste treatment need to comply to ALARA, best available technique (BAT) and the waste hierarchy. • At the moment no licence for decommissioning waste in an existing geological repository (SFR) or a shallow land disposal facility. • For dose rate criteria, see national policy and strategy section above.
Options for waste minimisation – treatment, disposal, etc.	• Well planned use of consumables (materials, quantities, etc.). • Segregation at source, minimised cross-contamination. • Decontamination of surfaces before demolition. • < 0.5 mSv/h potential for cost-efficient conditional clearance. • < 2 mSv/h potential for more efficient sorting and conditioning. • Controlled incineration and smelting of nuclear waste is commercially available within the country.

Sweden	
Main drivers for waste minimisation	Key drivers for optimisation (*not minimisation*) with no mutual priority: • overall decommissioning and waste management costs; • economic risks (flexibility); • time to licence termination; • BAT requirements; • ALARA requirements; • HSSE aspects; • environmental aspects (e.g. waste hierarchy, sustainability); • best use of resources; • PR and brand values.
Stakeholder engagement	Generally good acceptance for nuclear power and radioactive waste management: • long-term involvement of stakeholders during development of back-end system (RD&D Programme); • local safety committees; • continuous dialogue with regulators; • dialogue and openness towards the public (guided tours and facility visits, dialogue with neighbours, public hearings during licensing processes); • training course in waste management open to stakeholders (e.g. authorities), new course in decommissioning.
Lessons learnt (positive/negative)	Positive results: • proactive communication is key to acceptance; • flexible back-end lowers the overall cost. Potential challenges: • public acceptance for large quantities of materials from nuclear sites entering the conventional material cycles; • general movement in EU towards higher waste-hierarchic demands influences VLLW management; • changed clearance levels for release of materials (for specific nuclides, e.g. ^{137}Cs). Opportunities: • conditional free release followed by cost-efficient and safe off-site treatment/use of the residual materials.

United Kingdom	
National policy and strategy for radioactive waste management	There are a number of government policies and strategies for radioactive waste management: • Policy for the Long-Term Management of Solid Low Level Radioactive Waste in the United Kingdom, published by government in 2007. • UK Strategy for the Management of Solid LLW from the Nuclear Industry, published in 2016 by DECC. • Implementing Geological Disposal – 2014 White Paper (England and Wales). • Scotland's Higher Activity Radioactive Waste Policy, published in 2011.
National Programme document?	The UK published its National Programme document, Lead Document setting out the United Kingdom's National Programme for the Responsible and Safe Management of *Spent Fuel and Radioactive Waste* in 2015 to meet the requirements of Articles 11-15 of the Euratom 2011/70 Directive.
Regulatory framework	• Nuclear safety and occupational radiation protection aspects of radioactive waste management on nuclear site through the Health and Safety at Work (etc.) Act 1974; the Energy Act 2013; provisions in the Ionising Radiation Regulations 1999; and those parts of the Nuclear Installations Act 1965 concerning licensing and safety. • The Office for Nuclear Regulation (ONR) is responsible for the regulation of nuclear safety, conventional safety and nuclear security on nuclear licensed sites. • Environmental protection and public exposure to radioactive substances in the environment is controlled through the Radioactive Substances Act 1993 (RSA93) in Scotland and Northern Ireland; in England and Wales through Schedule 23 of the Environmental Permitting (England and Wales) Regulations 2016. • The environmental regulators in the United Kingdom are the Environment Agency (England), Scottish Environmental Protection Agency, Natural Resources Wales and the Northern Ireland Environment Agency. • For waste producers, the environment regulators regulate liquid and gaseous discharges and the off-site disposal of solid LLWR and VLLW. • For disposal and treatment facilities, the environment regulators permit the disposal or treatment of solid, liquid or gaseous effluents. • All waste producers and disposal facilities require planning permission from the local planning authority. Activities associated with the generation, management and disposal of LLW and VLLW require planning permission.
Definition of LLW and VLLW	LLW contains levels of radioactivity not exceeding 4 GBq/tonne of alpha activity, or 12 GBq/tonne of beta/gamma activity. VLLW is a sub-category of LLW: • Low volume VLLW ("dustbin loads") – waste that can be safely disposed of to an unspecified destination with municipal, commercial or industrial waste, each 0.1 cubic metre of material containing less than 400 kBq (kilo-Becquerels) of total activity, or single items containing less than 40 kBq of total activity. There are additional limits for carbon-14 and tritium in waste containing these radionuclides. • High volume VLLW (bulk disposals) – waste with maximum concentrations of 4 MBq (mega-Becquerels) per tonne of total activity. There is an additional limit for tritium in waste containing this radionuclide. ILW – radioactive waste exceeding the LLW limit where heat generation does not have to be considered. HLW – radioactive waste exceeding the LLW limit which is heat generating.

United Kingdom	
Definition of clearance	Waste that has such low levels of radioactivity that it is deemed to be outside the scope of regulation. Clearance: The process to confirm that an article or substance is clean (free from radioactivity) or excluded or exempt from further control under all relevant legislation on the basis of its radioactivity).
Waste generators (number and types of facilities)	• Eleven Magnox NPPs (in decommissioning). • Three reactor research sites (Harwell, Winfrith, Dounreay). • Seven AGR NPPS (operational). • One PWR NPP (operational). • One reprocessing site (Sellafield). • One disposal site (LLW Repository). • One fuel enrichment site. • One fuel manufacturing site. • Defence sites. • Small producers (hospitals, etc.).
Organisation(s) responsible for decommissioning	• The Nuclear Decommissioning Authority (NDA) is the non-departmental government body responsible for the decommissioning and waste management of all the civil UK nuclear sites that were in state ownership in 2004. This covers 17 nuclear sites. • EDF Energy Nuclear Generation (EDFE) is responsible for decommissioning the eight operating reactors in their ownership.
Funding	The UK government funds the NDA and the future decommissioning costs for the eight operating reactors managed through the Nuclear Liabilities Fund, funded by the site operator.
Expected volumes of radioactive waste	Forecast arisings in the United Kingdom until 2130: • 1 080 m^3 HLW. • 286 000 m^3 ILW. • 1 370 000 m3 LLW. • 2 840 000 m^3 VLLW.
Availability and description of intermediate and final storage/ disposal solution(s)	• One national LLW disposal site – the LLW Repository site in Cumbria, operated by LLW Repository Ltd. • One LLW disposal facility at the Dounreay site in Scotland, for Dounreay and the adjacent Vulcan site waste. • One on-site site disposal facility for lower activity LLW at Sellafield. • Three commercial landfill sites with permits to accept lower activity LLW for disposal.
Main decommissioning strategies	• As part of the NDA contractual arrangements, every site licence company is expected to develop and implement a site-specific decommissioning strategy for the whole life of the site. The decommissioning strategy will cover the management of LLW and VLLW generated during the operation, decommissioning and clean-up of the site. • The Office for Nuclear Regulation and environmental regulators would assess the appropriateness of these strategies in delivering decommissioning, keeping safety and the environment in mind. • The timing, volume and composition of waste derived from individual decommissioning strategies are linked to national waste disposal infrastructure capacity.

United Kingdom	
End-state strategies	• The NDA (see the NDA Strategy) has asked each of the site licence companies to produce an end-state strategy for each site. The site end-state strategy should take account of: ○ partial or full clean-up and release (zonation); ○ local land use; ○ designated land use; ○ local business needs; ○ link between after use and clean-up requirement. • The site end-state would need to take account of national polices and strategies as well as national priorities. A key stakeholder in the end-state strategy will be the local planning authority. The end-state strategy will need to take account of the local planning authority requirements for site end use. • The regulators currently set out safety and environmental requirements for the de licensing and surrender of safety and environmental permits. • There are also site-specific, integrated decommissioning and waste strategies.
Country definition of optimisation	The UK's high-level definition of optimisation is: "all exposures to ionising radiation of any member of the public and the population as a whole resulting from the disposal of radioactive waste are kept ALARA, taking into account economic and social factors". This is based on ICRP 2007 ICRP recommendations and enacts the requirements of the Basic Safety Standard Directive. Optimisation is incorporated into safety environmental and safety regulations as ALARP, BPM or BAT. These principles are incorporated into waste producers and waste disposal operators environmental and safety permits and licences. Mechanisms to deliver ALARP, BPM or BAT for LLW and VLLW would include: • application of the waste management hierarchy;. • use of the most appropriate technologies and disposal routes; • impacts from the disposal activity throughout the whole life of the waste. The requirement to undertake optimisation using iteration.
Principles enabling optimisation	The UK regulatory framework provides a framework in which optimisation can be delivered. In addition, the nuclear industry has sought to share and develop technologies, approaches and frameworks to allow the optimisation of LLW and VLLW waste. The main mechanisms enabling optimisation include: • Permits requiring the application of BAT, BPM and ALARA. This encourages the use of the waste management hierarchy for the management of LLW and VLLW. • Abatement and treatment technology development and delivery. • Development of a range of disposal routes and infrastructure. • Robust characterisation framework and technologies.
Barriers and constraints to optimisation	• Waste acceptance criteria of treatment and disposal facilities. • Availability and long-term certainty of treatment and disposal infrastructure. • Decommissioning programmes (schedule, budgets). • Current planning permissions and permits.

United Kingdom	
Options for waste minimisation – treatment, disposal, etc.	Sharing of waste minimisation best practice and technologies, in part through the UK's National LLW Programme: • Industry best practice and code of practice for the minimisation of waste. • Cross industry training and learning from experience. • Cross industry sharing forums. Range of treatment facilities available to UK radioactive waste producers: • One UK commercial facility and one on-site facility for surface decontamination of metallic waste. • Three commercial metal melting facilities available to UK waste producers – in Sweden, Germany and the United States. • Five commercial incinerators for suitable waste (four in the UK, one in Sweden). • Two super compaction facilities to support volume reduction of waste requiring disposal to the LLW Repository. • Waste producers seek to minimise the volume of materials taken into active areas to avoid waste generation. • Asset transfer system available to try to reuse redundant assets.
Main drivers for waste minimisation	BAT, capacity constraint at the LLW Repository; cost; schedule. • Regulatory requirement/expectation. • Cost incentive. • Strategic management of the LLW Repository volumetric and radiological capacity.
Stakeholder engagement	• Individual nuclear sites have arrangements for stakeholder management, including site stakeholder groups. • The NDA has a range of stakeholder engagement strategies. • In the LLW arena, the National Waste Programme (responsible for implementing the LLW Strategy) has a set of governance arrangements for engaging with stakeholders (meeting, reporting, etc.). • National interaction with non-governmental organisations and key national stakeholder representatives (e.g. local authorities [NuLEAF]).
Lessons learnt (positive/ negative)	Positives: • A clear government led policy position provides an effective basis for change. • A clear government led strategy and roadmap determining how it is to be delivered provides a powerful driver to change. • The availability of a supply chain which can provide safe, cost-effective alternate treatment and disposal solutions. • A structured programme, with good stakeholder oversight provides focus and energy to implement the strategy. • The permits held by the sites enable waste producers to be flexible in where they can send their LLW for treatment or disposal, while ensuring that they make a robust case for their routing decisions. • The use of BAT/BPM/ALARP as a means of delivering environmental and safety objectives. • The alignment of disposal facility waste acceptance criteria with the anticipated LLW/VLLW inventory. • Effective co-operation between site operators, government and regulators. Barriers: • The significant change in thinking and in the practical arrangements by waste producers to allow them to divert waste from the LLW Repository. • There may be a significant cost for a new entrant into the commercial supply chain – thus the opportunities for the supply chain need to be visible. • Good inventory information is needed to support the case for change. • Effective packaging solutions are required to transport the waste for treatment or disposal.

United States	
National policy and strategy for radioactive waste management	The controls of radioactive waste are set by the government, but the implementation is through private enterprises for commercial waste.
National Programme document?	Not applicable (European Commission requirement under Article 11 of Council Directive 2011/70/Euratom).
Regulatory framework	• Nuclear Regulatory Commission (NRC) sets policy for commercial waste. • NRC and agreement states implement the policy.
Definition of LLW and VLLW	There is just LLW and HLW, although LLW is divided into classes A, B, and C, with different controls for shallow land burial.
Waste generators (number and types of facilities)	• Approximately 100 power reactors in operation, SAFSTOR, or decommissioning. • Thousands of hospitals, universities and laboratories using radioactive materials.
Expected volumes of radioactive waste	Up to a million cubic metres per year.
Availability and description of intermediate and final storage/disposal solution(s)	• High-level waste being stored at generation sites for the most part. • Almost all LLW going directly to one of four permitted shallow radioactive landfills or to other disposal based on specific exemption.
Main decommissioning strategies	• Although there is some effort to efficiently package waste, segregate waste types and unconditionally release valuable tools and equipment; for the most part, use of decontamination and release is not attempted. • For decommissioning sites, use of clearance levels for land and structures to remain on-site are used to restrict waste generation.
Country definition of optimisation	There is no national specific definition, each licensee optimises between cost and waste volume in their waste strategy.
Principles enabling optimisation	Cost-benefit analysis is used with, at times, incorporation of non-quantifiable issues such as safety, public perception or other risks.
Barriers and constraints to optimisation	No clearance level for off-site unconditional release of material.
Options for waste minimisation – treatment, disposal, etc.	Available treatment facilities have limited capacity and are typically only used for smaller volumes of costly mixed (hazardous and radioactive) or other specific costly waste.
Main drivers for waste minimisation	Strictly cost since there are many options currently for LLW disposal.
Stakeholder engagement	Very little public concern or interest in volumes of LLW at the current time.
Lessons learnt (positive/negative)	Positives: • For decommissioning sites, what contaminated soils and concrete can be cleared to the site's dose model clearance level should be retained on-site to the extent possible. Negatives: • Unconditional release of volumetrically contaminated material is very difficult. • Although metals (other than activated) are easier to unconditionally release, there is public opposition to this pathway.

Appendix B: **Case studies**

Case study 1: **Stakeholder involvement – the "Belgian partnership approach"**

The search for a long-term solution for Category A waste

In 1998, the Belgian Council of Ministers entrusted the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) with the task of developing methods for local integration of a disposal project, in consultation with the population. ONDRAF/NIRAS developed this participation by establishing three local partnerships, together with the municipalities that were willing to talk about a repository: STOLA (in Dessel), MONA (in Mol) and PALOFF (in Fleurus and Farciennes). Dessel and Mol are two neighbouring municipalities. All four municipalities already had nuclear activity on their territory.

Each partnership was given the task of developing an integrated, preliminary design for a disposal project on the municipality's territory: a technologically sound repository that would be accepted by the population. This procedure gave the population's concerns in the area of safety, environment and health a prominent place in the pilot study of the disposal project. The partnerships were also asked to develop a broader social and economic project proposal, with long-term added value for the region.

The three partnerships were organised in such a way that they could live up to their role as a representative, transparent, open and independent local platform for discussion. The local partnerships assembled not only local politicians, but also delegates from environmental, cultural, social, economic and other locally based organisations. These representatives from the local civil society were chosen for their different views on both waste issues and local community life.

The municipal council, however, had the final decision to either accept or refuse the proposal. The Dessel and Mol councils were the only ones that agreed to the proposal developed by the partnership (in January 2005 in Dessel, and in April 2005 in Mol), and two options remained: surface disposal and deep disposal. After studying the final dossiers of the partnerships and ONDRAF/NIRAS' final report, the Federal Council of Ministers decided on 23 June 2006 to dispose of Category A waste in a surface disposal facility in the Dessel municipality.

Development of an integrated repository project

Since the Council of Ministers' decision to opt for the STOLA-Dessel proposal, both partnerships (STOLA had since been renamed STORA) remained privileged partners of ONDRAF/NIRAS in the delivery of the integrated disposal project. The role of the partnerships is very diverse. STORA and MONA primarily remain the representatives of their respective communities and critically oversee the implementation of the conditions they laid down. At the same time, volunteers actively participate in the delivery of the various subprojects.

In a co-design process, all decisions regarding the implementation of the conditions are taken jointly. This is a labour-intensive working method that, however, creates a project that is supported by all, as well as a strong sense of ownership among the various partners. In the partnerships, ONDRAF/NIRAS finds an ally to maintain and strengthen public support for the disposal project. The partners act as ambassadors of the project, partly through their own communication channels.

The next project phase

Once the repository is in operation, there will be continued involvement and participation. At this stage, it is important to continue to maintain public support. The partnerships remain a privileged partner and a sounding board for ONDRAF/NIRAS. Because of the nature of the conditions laid down, their implementation will also require ONDRAF/NIRAS to make a lasting commitment, and the partnerships will continue to play an active role. However, the way in which the partnerships are organised and the co-operation with ONDRAF/NIRAS will evolve over time, according to the needs of the project and society.

Case study 2: **The Scottish, English and Welsh environmental regulators approach to achieving the end-state and the release of nuclear sites from regulatory control**

The Scottish Environment Protection Agency, Environment Agency and Natural Resources Wales (the Scottish, English and Welsh environmental regulators) have developed and published guidance to support the delivery of an optimised and environmentally safe end-state for nuclear sites; titled *Management of radioactive waste from decommissioning of nuclear site: Guidance on Requirements for Release from Radioactive Substances Regulation* (GRR). The development of the GRR has been informed by learning and experience from three trial sites: Dounreay, (Scotland) Winfrith (England) and Trawsfynydd NPP (Wales).

The final stages of decommissioning and clean-up involve managing large amounts of solid radioactive waste, as well as other conventional waste. Operators are encouraged to take a joint approach to managing both radioactive and conventional waste in order to comply with their environmental obligations. Waste with higher levels of radioactivity will need to be moved into secure stores until dedicated disposal facilities are built. These stores might be on the site that produced the waste, or require transport to another site.

Once the environmental regulators are satisfied that radioactive waste has been managed safely and the site has been left in a suitable condition, the environmental regulators can release the site from radioactive substances regulation.

The regulators have encouraged operators to have early discussions about their proposals for decommissioning and clean-up, with the expectation that operators will engage early and widely with:

- local communities;
- the general public;
- other regulators and planning authorities.

The GRR requires operators to:

- produce a waste management plan covering all waste that will be generated up until the end-state, including waste removed from the site;
- produce a site-wide environmental safety case, which seeks to demonstrate that the condition of their site meets standards for protection of people and the environment, now and into the future.

Operators are expected to keep the risks of radiation exposure to people as low as reasonably achievable (ALARA), taking account of economic and social factors using optimisation. With the principal of optimisation central to the guidance, every operator must apply optimisation when developing and carrying out its waste management plan. This means the operator must produce a waste management plan that strikes the best overall (optimal) balance between:

- the safety of the public, workers and the environment;
- other factors such as costs, potential future uses of the site, or the impacts of transport of waste and materials.

The operator must assess all reasonable options for their site to manage every:

- batch of radioactive waste;
- area of radioactive contamination.

The full range of options that the operator chooses, and the way the operator carries them out, must keep risks to people as ALARA. Waste management plans must be optimised to each site's individual circumstances. This means that at different nuclear sites, it might be optimal to use either one of the approaches below or a combination of both:

- remove all radioactive waste and contamination from that site and transport it for disposal to another suitable site(s);
- dispose of all radioactive waste and leave all radioactive contamination on that site.

The environmental regulators will only authorise disposal of radioactive waste on a site when they are satisfied that the operator has developed an optimal waste management plan, and that the final condition of the site, and the work to be done to reach that condition, are safe for people and the environment.

The environmental regulators have set standards for public and environmental protection to be consistent with international and domestic law, guidelines and policies. These standards limit the:

- level (dose) of radiation that people and the environment are exposed to while the site is being regulated;
- risk of exposures to radioactive substances dispersed through the environment after the site is released from regulation;
- level (dose) of radiation that people are exposed to from local concentrations of radioactive substances after the site is released from regulation.

The site will only be released from regulation when the regulators are satisfied that the operator has completed all work involving radioactive substances, met all safety standards and can demonstrate this in their site-wide environmental safety case.

Case study 3: **Generic case study for unrestricted release criteria reduction**

This generic case study aims to illustrate the various interrelations between outside drivers and key influencing factors built up around a scenario involving the change of a single boundary condition. For this generic case study, it is assumed that the nuclide specific clearance levels change (and are reduced) in an existing radioactive waste management system.

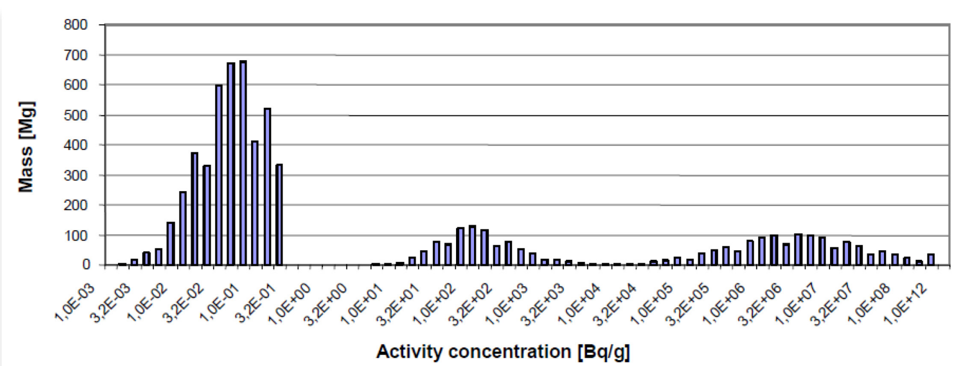
This scenario is realistic since the evolution of the regulatory framework has historically seen a reduction in the allowable dose burden to operators and the population, with a resulting influence on the clearance levels. Clearance levels and acceptance criteria specifications are under the authority of national regulators. Although several international organisations, including the International Atomic Energy Agency (IAEA) and the European Commission (EC) have issued recommendations, the differences between them are significant. As an example, the EU has issued, through Council Directive 2013/59/Euratom, a basic safety standard, including a list of clearance levels, aligned with IAEA RS-G-1.7 and with values different from recommendation no. 122. Higher limits may be defined by EU member states for specific situations, materials or specific pathways, taking community guidance into account, including, where appropriate, additional requirements in terms of surface activity or monitoring requirements.

Effect of changes to clearance levels on (V)LLW management

Optimisation of (V)LLW is significantly impacted by the reduction in clearance levels for unrestricted release. As most of the volume of materials coming from decommissioning of nuclear facilities is characterised by low concentrations of radioactivity, the reduction of unrestricted clearance levels can result, if other strategies are not implemented, in higher volumes of (V)LLW, requiring larger or additional disposal facilities.

The starting point in these considerations is the overall distribution of activity on the material or in the building prior to any decontamination. This distribution can usually be approximated by one log-normal distribution or a superposition of two or three log-normal distributions. The lower values usually originate from airborne (background) contamination that is present almost everywhere in the controlled area of a facility, the higher values can be attributed to contamination from spills, leakages, etc., and in the case of metallic components from reactors, activation. An example is shown in Figure AB-1. Because of the form of log-normal distributions, there is a range of values of specific activity where changes in clearance levels will impact large volumes of material (around the maximum of the distribution), while in the tail range of the distribution only small volumes will be affected. This means that reducing clearance levels for key nuclides from 1 Bq/g to 0.5 Bq/g has a much greater effect than reducing them from (an already high value of) 10 Bq/g to 5 Bq/g. Practical implications change if a single nuclide, a mixture of them, surface or volumetric levels is considered, but the general principle does not change. Moreover, the nature of clearable material from decommissioning is generally different from that of the waste classified as (V)LLW, with more building rubble and metal. Therefore, the primary effect of a reduction in clearance levels is to change the volume (mainly) and nature of the (V)LLW arisings.

Figure AB-1. **Distribution of waste volume in relation to activity content impact assessment and decision making**



Source: NEA (2008).

Stakeholders involved in (V)LLW management should evaluate the impact of any change in clearance levels and consider strategies to mitigate against the impact of the change. When evaluating options, the possibility of finding alternative or optimised paths for clearance and/or optimising the management of the newly classified waste should be taken into account. It is likely that the right balance will be found by trying to increase the volumes of materials cleared and optimising the management of the remaining additional volume of waste.

When assessing the options, the following should be considered:

- Additional resources would be needed to manage the increased volume of waste; whether for characterisation, treatment, transport or disposal; as well as people, planning and funding; recognising that these resources may not be available.
- If optimisation considerations determine that the volume increase can be efficiently tackled by further processing (sorting, size reduction, treatment) further processing capacity would need to be made available.
- The focus on the application of the waste hierarchy should be strengthened to reduce the waste routed for disposal as much and as early as possible.
- Management of increased volumes of waste will lead to additional secondary waste generation.
- The existing, usable capacity of disposal sites to meet the new needs of the radioactive waste industry should be assessed. Simplified disposal facilities with lower costs than engineered facilities could be made available to accept the increased volumes of waste.
- The characterisation effort and spending needed to meet reduced clearance limits may not result in the desired outcome as clearance levels reach the technological limits of available measurement techniques and statistics.
- Costs for clearing material will increase. A specific cost model, developed for a specific case (site, country or organisation) could be developed to compare waste management costs to the cost of clearing materials with different clearance levels scenarios. The model should be reviewed during the decommissioning programme as new experience is gained, and estimates can be replaced with actual costs.
- The funding system in place may not be appropriate to manage substantial amounts of unplanned waste. If this is the case, the sources, volumes and timing of funds shall be revised.
- A clear communication strategy should be implemented to explain to the public the advantages of reducing the amount of material for unrestricted release and the concurrent increase in waste routed for disposal, together with a graded approach to disposal options.
- If waste volumes increase the supply chain for containers and transport would need to respond to the new situation.
- For many of the isotopes involved, it is time consuming to detect for clearance level and requires costly laboratory techniques. This would need to be addressed through more thorough characterisation and use of surrogates in field measurements; achieving the right balance between the increased, cleared volume and the increased resources (both financial and people) needed, which is not an easy task as it would involve expert judgement, experience and knowledge of statistics. Moreover, reduced clearance levels may approach natural or background levels in some materials, making them difficult to sort.

Methods to meet new clearance levels

There are a number of methods that could be used to enable the revised clearance levels to be met:

- **Increased use of conditional clearance (case-by-case process)**. The ability to undertake specific pathway analyses to demonstrate compliance with a dose-based limit, and approval processes such an exemption. Unlike unrestricted release, conditional clearance may require relatively long time frames to get approval because of the additional scrutiny or regulatory control.
- **Strict segregation of material to prevent cross-contamination**. This would require more pre-characterisation work to identify (V)LLW from non-contaminated waste, and demolition techniques would need to be adjusted to prevent cross-contamination.
- **Metal melt of surface contaminated metal to meet the volumetric limits**. This could require new melting facilities; and publicly acceptable routes for the final metal would need to be identified. Increased, recycled metal volumes can raise the level of concern among the public, and public acceptance may require improved education along with pathways that will restrict recycled material from entering the public domain.
- **Extended decontamination of surface contaminated material to meet the new clearance criteria**. This would mainly be applicable to metal surfaces of non-activated metals; but could also be applied to concrete where penetration of contamination is limited to a centimetre or less.
- **Rubbleisation of surface contaminated material to meet volumetric limits**. This would be a method of averaging and would be most suitable for concrete where, through the demolition process used and by appropriate sizing of the rubble, a releasable material could be obtained that could be used as road base or other non-habitat structural purposes. Mass or surface clearable units differ from country to country; larger clearable units allow for more averaging techniques while smaller units require more characterisation effort.
- **Improved characterisation techniques and statistical methods**. Where mixtures of nuclides are expected in releasable material, the sum of fraction rule could be put in place to evaluate the combined effect of the presence of the different nuclides. It is important that the minimum detectable activity (MDA) of each nuclide (taking account of measurement uncertainty, statistical uncertainty and scaling factors for HTM nuclides) is at least one order of magnitude less that the clearance limits; a reduction in clearance limits would demand lower MDAs and thus improved measurement techniques. This can be achieved through a combination of longer measurement times, an increased number of samples, smaller clearable units, etc. In all cases, the improved material clearance system will result in an increased cost for each cleared unit.

Conclusions

In the event of a change in clearance levels, the impact of the change on the resulting volumes of (V)LLW and cleared materials should be assessed and mitigating actions identified, where possible, to optimise the volumes of waste and materials managed through each category. It is important that, as the changes in the process are implemented, learning is gathered to continuously improve the approach.

NEA PUBLICATIONS AND INFORMATION

The full catalogue of publications is available online at www.oecd-nea.org/pub.

In addition to basic information on the Agency and its work programme, the NEA website offers free downloads of hundreds of technical and policy-oriented reports. The professional journal of the Agency, NEA News – featuring articles on the latest nuclear energy issues – is available online at www.oecd-nea.org/nea-news.

An NEA monthly electronic bulletin is distributed free of charge to subscribers, providing updates of new results, events and publications. Sign up at www.oecd-nea.org/bulletin.

Visit us on Facebook at www.facebook.com/OECDNEA or follow us on Twitter @OECD_NEA.

Optimising Management of Low-level Radioactive Materials and Waste from Decommissioning

Low-level and very low-level waste represent the vast majority of radioactive waste by volume from decommissioning activity at nuclear facilities around the world, but they are only a small fraction of the radiological inventory. The availability of the appropriate waste management infrastructure, including a robust process and procedures for managing waste, waste disposal routes and an appropriate safety culture, are key components of an optimal approach to decommissioning. Recognising the important role of an effective waste management strategy in the delivery of a successful decommissioning programme, the former NEA Working Party on Decommissioning and Dismantling (WPDD) established an expert group in 2016 – the Task Group on Optimising Management of Low-Level Radioactive Materials and Waste from Decommissioning (TGOM) – to examine how countries manage (very) low-level radioactive waste and materials arising from decommissioning.

This report explores elements contributing to the optimisation of national approaches at a strategic level, describing the main factors and the relationships between them. It also identifies constraints in the practical implementation of optimisation based on experience in NEA member countries.

Nuclear Energy Agency (NEA)
46, quai Alphonse Le Gallo
92100 Boulogne-Billancourt, France
Tel.: +33 (0)1 73 21 28 19
nea@oecd-nea.org **www.oecd-nea.org**

NEA No. 7425