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Empowering Cost Benchmarking: Guidance on Converting General Cost Work Breakdown Structure into the International Structure for Decommissioning Costing

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COMMITTEE ON DECOMMISSIONING OF NUCLEAR INSTALLATIONS AND LEGACY MANAGEMENT

Empowering Cost Benchmarking: Guidance on Converting General Cost Work Breakdown Structure into the International Structure for Decommissioning Costing

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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.

Foreword

The Nuclear Energy Agency (NEA) Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) has provided a mandate for the formation of the Expert Group on Costing for Decommissioning of Nuclear Installations and Legacy Management (EGCDL). The CDLM and EGCDL are part of the current global effort to further enable the generation and reporting of reliable and comparable cost estimations for nuclear decommissioning projects. The EGCDL has three primary tasks: to merge the NEA reports *International Structure for Decommissioning Costing of Nuclear Installations* (NEA, 2012) and *Addressing Uncertainties in Cost Estimates for Decommissioning Nuclear Facilities* (NEA, 2017); to complete a fit-for-purpose review of the International Structure for Decommissioning Costing (ISDC) for complex and legacy sites; and to establish guidance for producing data submissions for cost benchmarking. This report fulfils the latter part of the mandate of the EGCDL.

The aim of this document is to provide guidance on preparing data for cost benchmarking nuclear facility decommissioning projects. The guidance will provide information on:

- the qualitative data that are required to provide high-quality data submissions for cost benchmarking;
- common cost areas to focus detailed data collection (i.e. ISDC Principal Activity containing the majority of the cost and risk);
- ways to convert readily available data into the ISDC format.

This report was approved by the CDLM on 11 November 2024.

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List of abbreviations and acronyms

AGRs	Advanced gas-cooled reactor sites (United Kingdom)
ARAC	Annual Reports and Accounts (United Kingdom)
BoE	Basis of estimate
BWR	Boiling water reactor
BKW	BKW Energie AG (Bernische Kraftwerke Aktiengesellschaft, Germany)
CDLM	Committee on Decommissioning of Nuclear Installations and Legacy Management (NEA)
CERREX	Cost Estimation for Research Reactors in Excel
CNSC	Canadian Nuclear Safety Commission
CPD	Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects
CRPPH	Committee on Radiation Protection and Public Health (NEA)
DETEC	Swiss Federal Department of the Environment, Transport, Energy and Communications
DACCORD	Data Analysis and Collection for Costing of Research Reactor Decommissioning
EC	European Commission
EDF	EDF Energy (United Kingdom)
EGCDL	Expert Group on Costing for Decommissioning of Nuclear Installations and Legacy Management (NEA)
ENSI	Federal Nuclear Safety Inspectorate (Switzerland)
IAEA	International Atomic Energy Agency
ISDC	International Structure for Decommissioning Costing
KHNP	Korea Hydro & Nuclear Power
KINS	Korea Institute of Nuclear Safety
KKM	Mühleberg Nuclear Power Plant (Kernkraftwerk Mühleberg, KKM, Germany)
KINS	Korea Institute of Nuclear Safety
LLWR	Low Level Radioactive Waste Repository (United Kingdom)
LTPs	Lifetime Plans (United Kingdom)
MIR	Swiss MIR Nuclear Research Institute
MOTIE	Ministry of Trade, Industry and Energy (Korea)
NDA	Nuclear Decommissioning Authority (United Kingdom)
NDC	Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle, or Nuclear Development Committee (NEA)
NEA	Nuclear Energy Agency
NRS	Nuclear Restoration Services (United Kingdom)
NSA	Korean Nuclear Safety Act
NSC	Federal Nuclear Safety Commission (Switzerland)
NSSC	Korean Nuclear Safety and Security Commission
NTS	Nuclear Transport Solutions (United Kingdom)
NWS	Nuclear Waste Services (United Kingdom)
ONR	Office for Nuclear Regulation (United Kingdom)
PHWR	Pressurised heavy water reactor
PWR	Pressurised water reactor
POCO	Post Operational Clean Out
RWM	Radioactive Waste Management Limited (United Kingdom)
RWMA	Korean Radioactive Waste Management Act
RWMC	Radioactive Waste Management Committee (NEA)
SEFV	Swiss Ordinance on the Decommissioning Fund and the Waste Disposal Fund for Nuclear Installations
SFOE	Swiss Federal Office of Energy

UFs	Unit factors
WBS	Work breakdown structure
WPMO	Working Party on Management and Organisational Aspects of Decommissioning and Legacy Management (NEA)

Units of measure

kW(th)	kilowatt thermal
MWe	megawatt electric
MWth	megawatt thermal

Executive summary

Accurate cost estimates for decommissioning nuclear facilities are crucial for countries with nuclear installations. Since the 1980s, many countries have faced significant cost and schedule overruns due to factors such as immature radioactive waste management infrastructure, poor site characterisation and changes in national decommissioning policies. Efforts have been made to improve cost estimates and reduce overruns through better waste management, decontamination techniques and workforce development.

From the 1980s to 2003, initial efforts focused on identifying problems and risks in cost estimation. Major studies, such as the *Decommissioning Nuclear Power Plants: Policies, Strategies and Costs* report, highlighted the challenges in comparing decommissioning costs across countries due to differences in work breakdown structures and scope (NEA, 2003).

From 2003 to 2012, the development of the International Structure for Decommissioning Costing (ISDC) aimed to standardise cost reporting. The ISDC categorises decommissioning costs into 11 principal activities.

Since 2012, adoption of the ISDC has remained limited despite its international recognition. The *Cost Benchmarking for Nuclear Power Plant Decommissioning* report found that the nuclear sector lacks effective cost benchmarking capabilities compared to other industries (NEA, 2019).

This document includes a literature review and provides guidance on preparing data for cost benchmarking nuclear facility decommissioning projects, targeting those that are new to the ISDC community. It emphasises the importance of defining project boundaries and capturing assumptions to ensure accurate cost comparisons. It focuses on qualitative information required for high-quality data submissions; key cost areas for detailed data collection; and converting existing data into ISDC format.

Key recommendations and findings are listed below.

- **Barriers to cost benchmarking**: Differences in national policies, regulatory frameworks and labour costs, along with low ISDC adoption and data sharing concerns, hinder effective cost benchmarking.
- **Improving ISDC accessibility**: It is recommended to create summary documents for non-specialists, translate ISDC materials and capture knowledge from retiring experts.
- **Guidelines for data conversion**: A four-stage process for converting non-ISDC data into ISDC format is outlined, emphasising the importance of defining data boundaries, assigning appropriate ISDC levels, collaboratively converting data, and capturing assumptions.

The document includes case studies from Korea, Switzerland and the United Kingdom, highlighting the factors influencing decommissioning cost estimation and the importance of qualitative information in benchmarking.

While significant progress has been made in standardising decommissioning cost estimates, challenges remain. This document aims to help member countries face those challenges by better generating and reporting reliable and comparable cost estimations in nuclear decommissioning.

1. Introduction

Having accurate cost estimates for decommissioning nuclear facilities has long been essential for countries with existing or planned nuclear installations. Since the 1980s many countries have experienced severe cost and schedule overruns on major decommissioning activities (NEA, 1986), usually as a result of:

- low maturity in the radioactive waste management infrastructure, leading to increased waste conditioning costs;
- poor site characterisation masking the complexity of the project; or
- significant changes in national decommissioning policy.

Individually, many countries have since focused on improving national infrastructure by opening more waste management and disposal routes, improving characterisation, decontamination and waste minimisation techniques, and investing in a highly skilled workforce (NEA, 2020). While these measures have reduced the rate at which decommissioning costs are increasing, cost and schedule overruns remain common.

There has been a sustained global effort to improve cost estimates since the 1980s (NEA, 2003; 1996; 1991; 1986). One of the largest studies was completed in 2003, when cost estimation data from 26 countries[1] were analysed to help establish a baseline of global cost estimation efforts. The study was a collaboration between three NEA committees[2], with support from the International Atomic Energy Agency (IAEA), and produced a report entitled *Decommissioning Nuclear Power Plants: Policies, Strategies and Costs* (NEA, 2003). The report found that differences in decommissioning work breakdown structures and scope between countries and operators made comparable responses difficult to obtain. This was despite great care being taken to provide participating countries with a detailed, explicit questionnaire to use.

Following the publication of the 2003 NEA report, successive iterations of committees and working groups have produced numerous investigations and reports. Prominent among these publications is *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations* (NEA, 2012). Building upon the 2003 questionnaire reporting structure, the ISDC project team continued the harmonised international approach to creating a work breakdown structure, which categorises decommissioning costs into 11 principal activities (and further subcategories). The ISDC was produced by a collaboration between the NEA, the European Commission (EC) and the IAEA. The purpose of the ISDC is to provide countries and operators with a standardised format for reporting decommissioning cost data, targeting some of the differences identified in the 2003 report. It is complemented by a 2017 report which describes how uncertainty and risks can be analysed and incorporated in decommissioning cost estimates, while presenting the outcomes in a transparent manner (NEA, 2017). The main contents of the ISDC and uncertainties guidance publications were combined into the *Handbook for Nuclear Decommissioning Cost Estimation*, published in 2023 (NEA, 2023).

[1] Including 9 non-OECD member countries supported by the International Atomic Energy Agency (IAEA).

[2] The Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC), the Committee on Radiation Protection and Public Health (CRPPH) and the Radioactive Waste Management Committee (RWMC).

Although the ISDC is recognised internationally as a common structure for data collection, the use of the ISDC as the primary data collection and reporting structure is uncommon. In 2019 a report was commissioned to analyse the maturity of global cost benchmarking[3] in other major decommissioning industries and compare them against that of the nuclear sector (NEA, 2019). The analysis found that the nuclear sector significantly lacks the capability to effectively cost benchmark major decommissioning projects. It also concluded that a key requirement for implementing cost benchmarking in major industries is the availability of a common cost-reporting structure.

1.1. Scope and objectives

This document aims to provide accessible guidance for the preparation of data for cost benchmarking nuclear facility decommissioning projects. The primary audience for this report is those who are new to the ISDC community and/or have previously experienced barriers in implementing the ISDC. The report will provide information on:

- qualitative information that is required to provide high-quality data submissions for cost benchmarking;
- key cost areas to focus detailed data collection (i.e. ISDC principal activities containing the majority of cost and risk);
- converting readily available data into ISDC format.

1.2. Structure

This document first focuses on literature to provide the background for the work that underpins decisions made in the subsequent sections. The literature review is structured as a timeline and provides a summary of relevant reports on cost estimation within the nuclear sector.

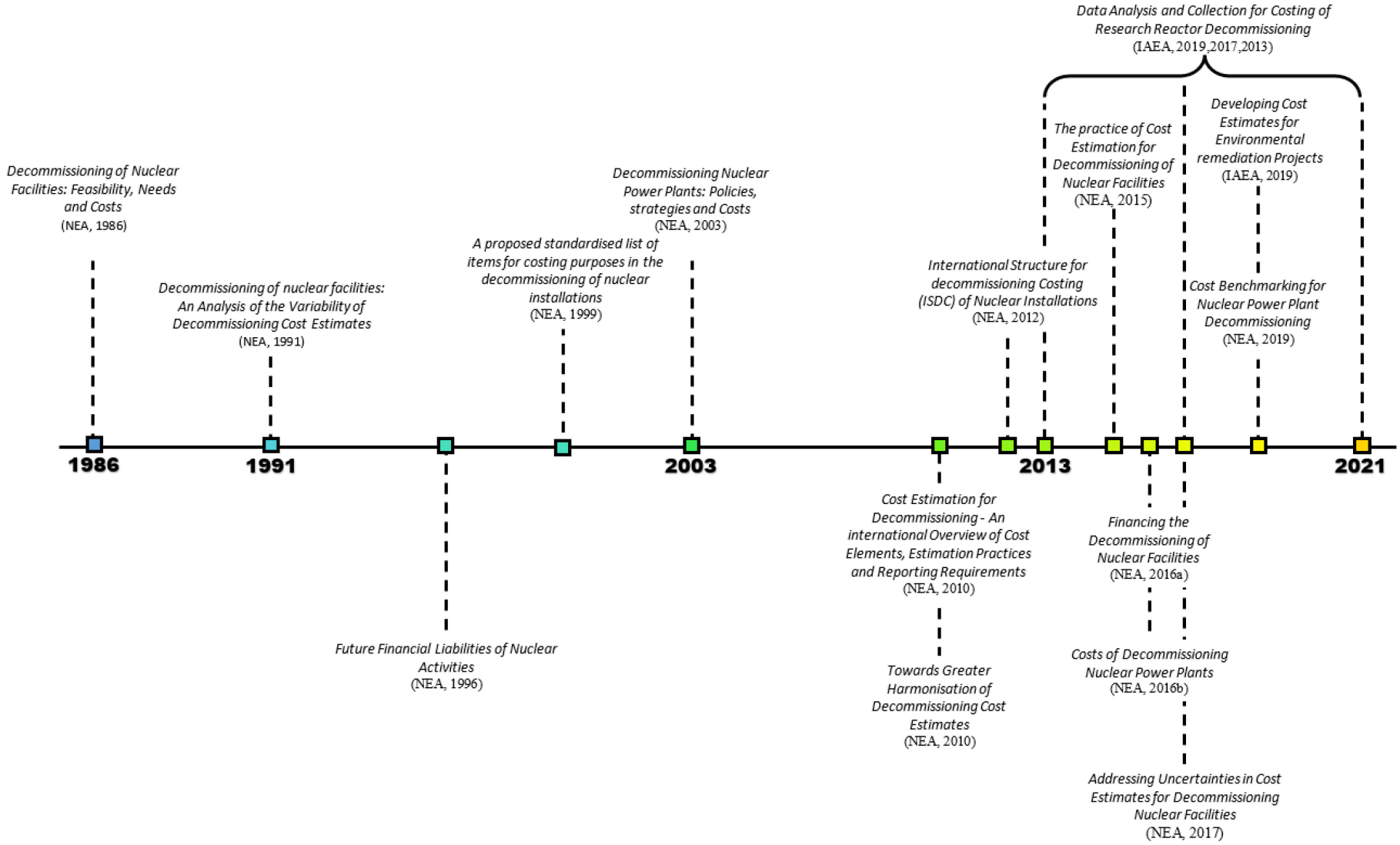
The latter part of this report aims to provide practical and accessible guidance on preparing data for cost benchmarking. Guidance is provided for the translation of generic work breakdown structures of real-life complex projects into the ISDC format, and the description of the metadata required to support cost data reporting and future cost benchmarking activities.

1.2.1. Boundaries

This document is not a "how to" guide for cost benchmarking. This report provides guidance on producing high-quality data submissions (both quantitative and qualitative), consistent with the current international guidance on decommissioning cost estimation, including the treatment of uncertainties (i.e. NEA, 2024; 2017; 2012). Specifically, the aim is to aid future cost benchmarking using the ISDC cost breakdown structure. The task has been limited to converting generic cost breakdown structures of a generic work breakdown structure (WBS) into ISDC principal activities (Level 1). This decision was made to ensure the guidance breaks down known barriers to the implementation and adoption of the ISDC. To complete a fully scoped international cost benchmarking exercise, costing data would be required to ISDC Level 3.

[3] A method used to compare the cost of a product, service or supplier against the market or industry peers.

Figure 1.1. A timeline of publications related to decommissioning costs



2. Cost benchmarking development within the nuclear industry

The reports identified in the timeline can be divided into three groups. Earlier reports focussed on identifying the problems and risks faced when comparing cost estimates. The reports then shifted their attention to problem-solving, with solutions proposed to mitigate the issues and risks associated with cost comparison. Finally, in recent years, the reports' focus has turned to implementing and building industry confidence in the solutions. In this chapter, the aim is not to provide an in-depth review or analysis of cost comparison techniques used within the reports, but to focus on the aims, outcomes and legacy of the work. The combined legacy of prior cost comparison and cost benchmarking reports will form the basis of this guidance and of any suggested further work.

2.1 Identifying and defining the issue

In 1980, there were 253 operating nuclear power plants with 135 000 MWe total capacity in 22 countries; 53 of these had been providing electricity to a grid for 20 years or longer. In addition, around 230 units with more than 200 000 MWe were under construction (Char and Csik, 1987). This was a period where nuclear power investment and confidence was unpredictable, with public acceptance wavering following the Three Mile Island accident. This instability was slowing the rate of new build reactors and causing projects in development to be suspended or cancelled (Char and Csik, 1987).

The main objective of the earliest report identified in the timeline, the NEA report of 1986, was to provide an assessment of the feasibility of, and techniques for, decommissioning large commercial nuclear facilities currently in operation. In this report, the cost estimates were not a key factor in the feasibility assessment and the main calculation performed was estimating what proportion of the decommissioning cost would be funded by the electricity production revenue. In the report it was estimated that decommissioning costs would amount to less than 2% of the total electricity generation costs. The report identified that the level of uncertainty for total decommissioning, the deferment of activities (mothballing), and waste disposal are key factors in providing accurate estimates.

The NEA report published in 1991 supported the majority of the conclusions from the report five years prior. The report, authored by the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC), highlighted difficulties with monetary conversion when comparing data in different currencies, and the use of discounted and undiscounted values. The report stated that discounted rates are useful for internal financial considerations such as comparing various decommissioning strategies for the same facility, and that undiscounted is preferred for understanding differences between different facilities. The 1991 report found that information such as government policy and decommissioning strategy decisions, regulatory costs and principles, and the desired end state for the facility all hinder the ability to find useful conclusions when comparing data.

The main objective of the 1996 report was to discuss the cost implications associated with immediate decommissioning or deferring for 30-100 years. The report found that decommissioning costs are reduced when there is a deferral period in decommissioning. The cost benefit associated is highest with a quiescent period of 30 years. A quiescent

period of 100 years still saw cost reduction benefits, but to a lesser extent. The report stated that conclusion may by impacted by:

- national nuclear strategies;
- facility characteristics;
- protection of health, safety and the environment;
- radioactive waste management;
- future use of the site;
- improvement of decommissioning technology;
- costs and the availability of funds; and
- social considerations.

These three reports highlight a period of development for international cost estimation and comparison. The conclusions made are often on entire project costs and not a breakdown into defined categories; they are also provided with multiple caveats.

In 1999, the basis of the future International Structure for Decommissioning Costing (ISDC) was published in a report entitled *A Proposed Standardised List of Items for Costing Purposes in the Decommissioning of Nuclear Installations* but most commonly referred to as the "Yellow Book" (NEA, 1999). This was the first attempt to put forth a common list to eliminate decommissioning cost evaluation discrepancies and to allow a better information exchange in this area. It was hoped at the time that the list could serve as a basis for existing and future databases to evaluate decommissioning costs in the three co-operating organisations (NEA, IAEA and EC), with the potential benefit of a fast and comprehensive exchange of decommissioning data, thus improving international co-operation.

Finally, the 2003 report aimed to compare countries' decommissioning policies and strategies to clarify to what extend these affect the cost of decommissioning (NEA, 2003). The 2003 report's conclusions were based on an in-depth questionnaire which was itself based upon previous work carried out within the Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD). The questionnaire was highly successful, with contributions from 26 countries (including 9 non-OECD member countries that participated under the IAEA umbrella).

Although the expert group decided to develop a comprehensive questionnaire, it was recognised upfront that the study would not include detailed analyses of decommissioning cost structure or in-depth reviews of differences between the various cost data provided by respondents. The rationale for collecting detailed data was to support the analysis of impacts from policy and strategy choices on various cost items and on cost structure with quantitative examples. The analysis provides some indication of the influence of policy and strategy on these costs. According to the information provided in response to the questionnaire, the two cost elements representing a major share of total costs are dismantling and waste treatment and disposal, accounting for around 30% each. Labour costs represent a significant share of total decommissioning costs, ranging from 20 to 40%. A further breakdown of the cost findings can be seen below in Table 2.1.

Table 2.1. The percentage proportion of costs associated with different decommissioning activities (NEA, 2003)

Decommissioning activity	Percentage proportion of cost
Dismantling	25-35% of total
Waste treatment and disposal	17-43% of total
Security, survey and maintenance	8-13% of total
Site clean-up and landscaping	5-13% of total
Project management, engineering and site support	5-24% of total

The conclusions of the 2003 report specified that although great care had been taken in this study to produce a detailed and explicit questionnaire, further work would be required to have a complete understanding of decommissioning cost variability due to wide variations in many aspects of national decommissioning policies. For example, in 2003, only half of the 26 countries that contributed had a national definition of decommissioning and just over half had a defined endpoint for the decommissioning process. Only seven countries had a mandatory timescale to complete reactor decommissioning and only a third had a defined start point.

2.2 Developing the solution

The period between the 2003 report and the publication of the ISDC in 2012 focused on developing a solution to the variability of cost estimates to inform international benchmarking of decommissioning projects.

The report that was published in 2010, and the main focus of this report, was *Cost Estimation for Decommissioning - An International Overview of Cost Elements, Estimation Practices and Reporting Requirements* (NEA, 2010a). The report findings are based on country responses to a detailed questionnaire. The questionnaire focused on the legal requirements and the responsibilities of the main parties concerned with the preparation and oversight of cost estimates, the main cost elements and associated boundary conditions, cost estimating methodologies, and experiences gained during the process. The report had two goals: to gain a better understanding of the primary cost elements, including their definition and derivation, and to gather learning from where estimates had been incorrect. The underlying study was established on the basis that gaining a better understanding of decommissioning costs should lead to improved cost estimates for existing nuclear power plants and facilities, facilitate funding, and enable better control of decommissioning costs. The report also considered the role of national reporting requirements and the implications of these for comparing different estimates.

The report found that in the period between 2003 and the questionnaire (2008) most countries, either through regulation or by owner preference, had adopted a formal organisation of the cost estimates. A cost breakdown structure is typically used, based either on the Standardised List "Yellow Book" format or on an equivalent national format. There was considerable variability in the format, content and practice of cost estimates, which made it difficult to compare estimates, even for similar types of facility. The reasons were due to different legal requirements in different countries and to historical custom and practice, leading to differences in basic assumptions such as the anticipated decommissioning strategy, the end state of the site, and to different approaches to dealing with uncertainties.

Along with many other findings relating to best and frequent practice, the report concluded that while countries have improved their estimates, there is significant room for progress

through greater standardisation and consistency of estimates, both nationally (where multiple operators are present) and internationally. The authors also stated that attaining such harmonisation across countries would be challenging due to many decommissioning strategies and the associated reporting being rooted in legislation. The authors suggested a standard reporting template onto which national cost estimates could be mapped for the purposes of comparison. Finally, the authors stated that a future challenge would be to find a mechanism to encourage the sharing of best practices and to provide examples of how this can be readily implemented.

The second report released in 2010, *Towards Greater Harmonisation of Decommissioning Cost Estimates*, was a summary report highlighting good practices for cost estimating and dealing with uncertainty and risk (NEA, 2010b). The report reinforced the NEA and IAEA's goal of working together towards the standardisation of the format and content of cost estimates to give greater transparency to the decommissioning process and build regulator and stakeholder confidence in the cost estimates and schedules.

The two 2010 reports focus on harmonisation and collaboration between nations to enable the sharing of best practices. This objective was reiterated in the publication of the *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations* in 2012 (NEA, 2012).

Building upon the recommendation to have a standard reporting template onto which national cost estimates can be mapped for the purposes of comparison, the ISDC was generated as a joint initiative of the NEA, IAEA and European Commission (EC). The ISDC contains 11 principal activities, each of which is broken down into more detail and organised into three hierarchical levels. The structure of the levels is shown in Figure 2.1. Level 3 is also known as the reference level, whereas levels 1 and 2 are the sum of the costs associated with the typical decommissioning activities in level 3.

Figure 2.1. The relationship between levels 1, 2 and 3 of the ISDC and how reference data collected for typical decommissioning activities are grouped to form an overall cost for the activity groups and principal activities

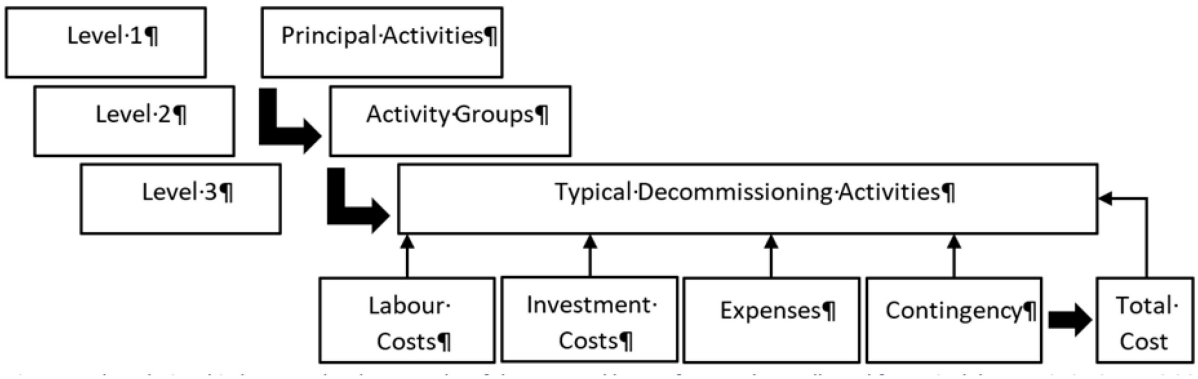


Table 2.2 shows an example of how a principal activity is broken down into the two further activity levels. The activities level is indicated by the numbering following the formula X.YZ where X represents the Level 1 principal activity, Y the associated Level 2 activities and Z the associated Level 3 activities. For example, using the table below, the Level 1 principal activity is 04; therefore, X equals 04. The lines in bold are the Level 2 activities; principal activity 04 has nine associated Level 2 activities; therefore, the Y values range from 01 to 09. Finally, using Activity 04.01 "Procurement of equipment for

decontamination and dismantling" as an example, Activity 04.01 has five associated Level 3 activities and therefore Z ranges from 01 to 05. Level 3 activities are also shown in italics in the table below.

The full list of 11 principal activities broken down into levels 2 and 3 is provided in Appendix A.

In addition to the cost breakdown structure, the ISDC provides a list of boundary conditions and assumptions intended as guidance for users concerning the completeness of the scope of work to be included in the cost estimate. The report also contains Appendix D: *Standardised definitions for cost items* and Appendix E: *Glossary,* to increase process standardisation and avoid ambiguity.

Table 2.2. An excerpt of the ISDC cost breakdown structure to demonstrate the layout of the three activity levels. The example provided is of principle activity 4.

04.0100	**Procurement of equipment for decontamination and dismantling.**
	04.0101 Procurement of general site-dismantling equipment. *04.0102 Procurement of equipment for decontamination of personnel and tools.* *04.0103 Procurement of special tools for dismantling the reactor systems.* *04.0104 Procurement of special tools for dismantling in fuel cycle facilities.* *04.0105 Procurement*
04.0200	**Preparations and support for dismantling.**
	04.0201 Reconfiguration of existing services, facilities and site to support dismantling. *04.0202 Preparation of infrastructure and logistics for dismantling.* *04.0203 Ongoing radiological characterisation during dismantling.*
04.0300	**Pre-dismantling decontamination**
	04.0301 Drainage of remaining systems. *04.0302 Removal of sludge and products from remaining systems.* *04.0303 Decontamination of remaining systems.* *04.0304 Decontamination of areas in buildings.*
04.0400	**Removal of materials requiring specific procedures.**
	04.0401 Removal of thermal insulation. *04.0402 Removal of asbestos.* *04.0403 Removal of other hazardous materials*
04.0500	**Dismantling of main process systems, structures and components.**
	04.0501 Dismantling of reactor internals. *04.0502 Dismantling of reactor vessel and core components.* *04.0503 Dismantling of other primary loop components.* *04.0504 Dismantling of main process systems in fuel cycle facilities.* *04.0505 Dismantling of main process systems in other nuclear facilities.* *04.0506 Dismantling of external thermal/biological shields.*
04.0600	**Dismantling of other systems and components.**
	04.0601 Dismantling of auxiliary systems. *04.0602 Dismantling of remaining components.*
04.0700	**Removal of contamination from building structures.**
	04.0701 Removal of embedded elements in buildings. *04.0702 Removal of contaminated structures.* *04.0703 Decontamination of buildings.*
04.0800	**Removal of contamination from areas outside buildings.**
	04.0801 Removal of underground contaminated pipes and structures. *04.0802 Removal of contaminated soil and other contaminated items.*
04.0900	**Final radioactivity survey for release of buildings.**
	04.0901 Final radioactivity survey of buildings. *04.0902 Declassification of buildings.*

2.3 Implementation of the solution

The publication of the ISDC can be seen as the starting point in implementing international cost benchmarking for nuclear power plant decommissioning.

Following the publication of the ISDC, the NEA Decommissioning Cost Estimation Group, consisting of 11 countries, authored the 2015 report entitled *The Practice of Cost Estimation for Decommissioning of Nuclear Facilities* (NEA, 2015). The aim of the report was to provide guidance for generating cost estimates for the decommissioning of nuclear power plants, principally pressurised water reactors (PWR) and boiling water reactors (BWR), although the guidance could be applied to multiple different nuclear facilities. This report discusses different approaches to cost estimation, such as bottom-up technique and parametric estimating. It describes the four basic elements of producing a cost estimate: basis of estimate (BoE), structure of estimate, work breakdown structure and schedule and uncertainty analysis. This report is a key resource for those new to cost estimation using the ISDC.

One of the most detailed examples of cost analysis performed for nuclear power plant decommissioning project is that of the 2016 NEA report, *Costs of Decommissioning Nuclear Power Plants* (NEA, 2016b). The report is based on the analysis of data gathered through a questionnaire addressed to NEA countries and provides cost analysis using six detailed country case studies as well as analysis on supporting data from ten other NEA members and IAEA and EC contributors. The report provides insight into the cost of decommissioning power plants but also identifies several barriers that limited the size of the cost analysis exercise the authors had hoped to perform. These barriers included hesitation between "competitors" in the decommissioning market to share sensitive financial information, and limited use of the ISDC as a common cost breakdown structure. The report also highlights the effects the qualitative data such as funding and policy strategy, and regulatory framework have on the quality of the cost analysis performed.

For the purpose of improving a common definition, calculation and reporting of uncertainty and risk in relation to cost estimates, the 2017 report entitled *Addressing Uncertainties in Cost Estimation for Decommissioning Nuclear Facilities* was published (NEA, 2017). Authored by the NEA and IAEA, the report aims to develop a consistent and comparable treatment of risk and uncertainty in decommissioning cost estimation to further facilitate comparison between different cost estimates and enhance the overall understanding of and confidence in the estimates themselves. The report provides detailed guidance on establishing the "in-scope" elements of the cost estimate in relation to the originally established BoE. In-scope uncertainties are associated with situations and events that, based on past experience, can be considered sufficiently likely to occur, and thus should be fully reflected in the cost estimate. The report also recommends that "out-of-scope" uncertainties are captured and designated as risk events since they relate to situations that, though not expected to occur, could impact the total project cost. The guidance in this report has since been incorporated into the 2023 issue of the *Handbook for Nuclear Decommissioning Cost Estimation* (NEA, 2023).

The barriers identified in the 2016 report were analysed in the 2019 NEA report, *Cost Benchmarking for Nuclear Power Plant Decommissioning*. This report, aimed at policy makers, regulators, strategists and decision makers, compares the ability to cost benchmark in other major decommissioning industries with that of the nuclear decommissioning sector, and considers related developments in other industries to facilitate a discussion on approaches to cost data sharing and analysis, as well as the development of cost benchmarking approaches that could be implemented for nuclear power plant decommissioning. The report suggests additional information required to support data

submissions. The recommendation following the analysis of several options is for a facilitated member group collection/sharing arrangement and normalisation to be implemented. This would require a critical mass of participants, for example a group of operators and national authorities with significant data, to enter into a legal agreement to share data across international borders. This group would need to select or create an independent organisation to manage and oversee the initiative. The cost benchmarking organisation would establish the database requirements and infrastructure, organise the services around input and output of data, and commence population with any available pre-existing data from participating members. Given the international nature of the envisaged collaboration, the primary option for this organisation would likely be co-operation through some form of international organisation, or in the private sector. The report concludes that the sort of international co-operation envisaged for the option outlined above would likely take a number of years to establish. The document states that the ISDC provides the type of common reporting structure to be used for nuclear power plant decommissioning costs (NEA, 2019).

2.4 Cost benchmarking using the ISDC cost breakdown structure for research reactor decommissioning: DACCORD.

The DACCORD (Data Analysis and Collection for Costing of Research Reactor Decommissioning) project is an example of an IAEA international collaborative project focused on supporting countries in developing preliminary cost estimates for research reactors decommissioning by collecting, analysing and creating benchmarking cost data. Within the DACCORD project, all stages of identifying and defining the problem and developing and implementing the solution are covered. DACCORD has been focused on in this section as an excellent example of international cost benchmarking within the nuclear industry.

The project was launched in 2012 with the scope of sharing knowledge and guidance in developing preliminary cost estimates for research reactor decommissioning. At the end of the original project in 2016, a second phase was launched to extend the sharing of information to the area of planning, characterisation and uncertainties in connection to the cost estimation process.

In Project Phase 1 (2012-2016) benchmarking data were identified and reference cases were developed using the Cost Estimation for Research Reactors in Excel (CERREX) code, thus increasing the experience and shared knowledge in cost estimation among members of the project.

Project Phase 2 (2016-2019), continuing the collecting of new costing cases, was focused on enhancements to CERREX to facilitate its use; better awareness of the impact of decommissioning planning and the impact of characterisation on cost estimating; and developing a more comprehensive understanding of uncertainty and contingency in estimating costs.

Two reports were published: a Phase 1 report in 2017 and a Phase 2 report in 2021 (IAEA, 2021; 2017).

The project collected and analysed cost data relevant to the decommissioning of 20 participating research reactors in 18 countries, comprising actual reported costs or calculated estimates.

The detailed dataset includes reactors in different life cycle stages: some were already decommissioned, several reactors were shut down but not yet decommissioned, and some were still in operation and their decommissioning was still at the planning stage.

Considering the number, typologies and countries involved in the project, costing cases analysed were not of uniform scope, although the majority include only the research reactor and materials directly related to its operation.

During the project all the costing cases were collected and developed on ISDC structure using the CERREX tool, a software developed by the IAEA starting from 2013 to be used for estimating costs for research reactor decommissioning.

CERREX is a Microsoft Excel-based software code based directly on the ISDC cost calculation structure, with the costing method based on unit factors (UFs). The software has been substantially enhanced – as CERREX-D2 – following completion of the first phase of the DACCORD project.

Data collection, sharing information and costing cases developing processes were key aspects of the project. Once all decommissioning cost estimates were assembled and developed on CERREX, the process of data analysis, comparison and benchmarking was started. For this purpose, the application of the ISDC structure to all costing cases, as provided by the CERREX code, proved beneficial. In addition, the unit factor methodology allowed the comparison of decommissioning and waste management unit factors values between all costing cases. A detailed analysis of the unit factors dataset applied to costing cases is presented in both reports.

The reports describe a comparison between the reactors involved in the project of actual or estimated costs at ISDC Level 0 (Total Cost) and Level 1 activities, by cost categories and workforce. It is important to consider that the sets of collected data come from different countries with significantly different regulations, programmes and labour/equipment costs.

Below are examples of some of the analysis performed among 20 costing cases in Project Phase 2. All data and graphs were analysed and commented:

- Relationship of total decommissioning cost/workforce hours (ISDC Level 0) to reactor power.
- Comparison of contributions from ISDC cost categories (labour, investment, expenses, contingency) as a percentage of the total cost.
- Decommissioning cost breakdown by ISDC L1 principal activity as a percentage of the total cost.
- Workforce breakdown by ISDC Level 1 principal activity as a percentage of the total cost.
- Percentage of total cost by ISDC Level 1 principal activity.
- Percentage of total cost for most significant cost groups (ISDC 04+07, 05, 06+08, others) as identified in NEA (2016).
- Total cost and workforce for ISDC principal activities 04, 05, 07 in correlation with reactor power.
- Waste costs for ISDC 05 as a function of reactor power.
- Decommissioning costs by ISDC activity groups as a percentage of total cost in comparison to nuclear power plants costs.

With reference to the decommissioning cost estimate, the project also addressed the following key areas:

- impact of decommissioning planning and characterisation on cost estimates;

- improved understanding of contingency and uncertainty related to the cost estimates.

Two sections of the Phase 2 report describe these fundamental topics, where examples applied to costing cases are presented and commented.

The results of the project in general showed that the cost of decommissioning a research reactor is influenced by various factors, including reactor type, age, operational history, final facility status, and labour/equipment costs in the country where the reactor is located. Estimating decommissioning costs, even in a preliminary type, is challenging without a detailed analysis of the reactor, including its physical and radiological inventory, decommissioning strategy, and waste management plan. Benchmarking activities should consider that decommissioning costs can vary widely, even among reactors with similar designs and power ratings.

The outcomes of analysis performed on the collected data are described in detail in the project reports. Reported below are the main conclusions of the comparison of 20 research reactor decommissioning costing cases, as performed in Project Phase 2:

- "Decommissioning costs and workforce levels show a broadly proportional increase with increasing power levels, with a cost threshold at very low power ratings and for zero power installations (e.g. those below 50-100 kW[th]). There are many factors that affect the cost for a specific reactor (e.g. its type, operational history, end state and waste management strategy), such that individual cost estimations should be done for each research reactor decommissioning project. Careful selection of UFs and reflection of relevant national conditions are of key importance".
- "Analysis of unit cost of dismantling/demolition activities (ISDC 04, 07 – USD/t) shows a general tendency of relative cost reduction with increasing reactor power rating, with high unit cost figures being more applicable to low reactor power costing cases, especially in the case of reactor structures. There are two basic cost components: the dismantling itself, which is broadly proportional to inventory levels, and the preparatory and finishing activities, which are less directly related to inventory levels. The second component increases unit cost for small reactors. The decommissioning cost per tonne of inventory is likely to be significantly higher for research reactors than for nuclear power plants, with comparable levels only being approached at very high thermal power ratings (several tens of MW[th])".
- "Labour cost is the most significant cost category, with an average percentage of around 50% of total cost; consequently, variations in labour rates have a large impact on the total estimated decommissioning cost. Accordingly, non-inventory dependent activities (ISDC 06, 08, 01, 02) represent a significant component of the decommissioning cost and workforce."
- "The analysis undertaken confirms the conclusion of DACCORD Phase 1, where ISDC 04 (dismantling activities), 08 (project management and support), 05 (waste management), 06 (site infrastructure and operation) and 01 (preparatory activities) are identified as the most significant contributors to the total cost."
- "Waste management assumptions – and associated waste management costs – may differ significantly, from a minimalist approach involving putting the waste into storage, to full treatment, conditioning, storage and final disposal".

In general, the application of ISDC (International Structure for Decommissioning Costing) in benchmarking activities has provided valuable experience, confirming the effectiveness of this structure as a reliable basis for comparing decommissioning costs.

In undertaking a cost estimate for decommissioning it is important that the assumptions, exclusions and boundary conditions relating to the decommissioning project are clearly described and recorded, as these are key elements in evaluating differences between cases in benchmarking activities.

2.5. Summary and findings

This section provided a timeline of published reports to outline the key developments in cost estimation, analysis and benchmarking within the nuclear decommissioning industry, focusing on nuclear power plants. This section also reviewed in detail the DACCORD projects as an example of using ISDC in practice for benchmarking cost estimates for research reactors.

Overall, it is clear that many barriers to international cost benchmarking in the nuclear decommissioning industry have been addressed through the production of the ISDC and subsequent guidance; and yet, over 10 years after the publication of the ISDC, international cost benchmarking for nuclear decommissioning projects is not common practice. The primary barriers continue to be the effects of different quantitative data fields such as national policies, regulatory frameworks and labour costs, low adoption of the ISDC, lack of confidence in data sharing and commercial data protection in an open forum such as the NEA expert groups.

Recommendation: Improve the accessibility of the ISDC to non-specialists and decision makers, including by communicating more effectively about its benefits

Countries participating in the EGCDL were asked a question regarding barriers to implementing ISDC as part of a wider question set (provided in Appendix B). The answers supported the view that the ISDC remains unknown outside of the NEA expert group representatives (or other similar international collaborations). This is particularly a problem if non-specialists in cost analysis such as portfolio managers, senior leadership and decision makers are not aware of the structure and/or are not provided with sufficient information to communicate the benefits of using the ISDC format. It is recommended that future expert groups focus on communicating to a non-specialist audience to raise awareness of the structure, such as by creating short summary documents. It is also recommended that translations of the ISDC and short summaries be made available to facilitate the communication of the structure to decommissioning workers.

3. Guidelines for converting non-ISDC generic cost structures into the ISDC format

It has been established that collecting data directly into the ISDC format is not common practice, with many countries having their own cost structures (often based on their particular WBSs) and systems in place for collecting project cost data. As a result, there is a raft of non-standardised cost information that, in its current format, could not be used for the purposes of international cost benchmarking. Standardising the data across countries, operating companies or from similar facilities into one common cost breakdown structure is required. The most established standardised cost breakdown structure available is the ISDC.

In this section the conversion of a non-ISDC generic cost breakdown structure into the ISDC format is discussed. Through this discussion, common practice, barriers and differing country policies that could skew the final cost distribution are highlighted. The conclusion of this section is a set of guidelines and recommendations to help standardise the conversion, enabling the data that countries already hold to be utilised for global cost benchmarking.

3.1 Methodology

To formulate the guidelines and recommendations below, a two-part exercise was completed by contributing countries. First, group members were asked to convert a generic cost breakdown structure into ISDC Level 1. Then, as a group, the same exercise was completed with group members discussing the assumptions made individually. These assumptions were often based on the individuals' understanding of the ISDC within the context of their countries' project management controls. Where opinions differed, these were noted, debated, and a common solution was found.

The generic cost breakdown structure used was provided by the United Kingdom and covers all aspects of nuclear power plants decommissioning, from pre-decommissioning preparation to waste disposal and site remediation. This task could be repeated with additional cases to refine the recommendations further. It is also recommended that this exercise be repeated for other facilities to form a set of guidelines for non-nuclear power plant decommissioning projects.

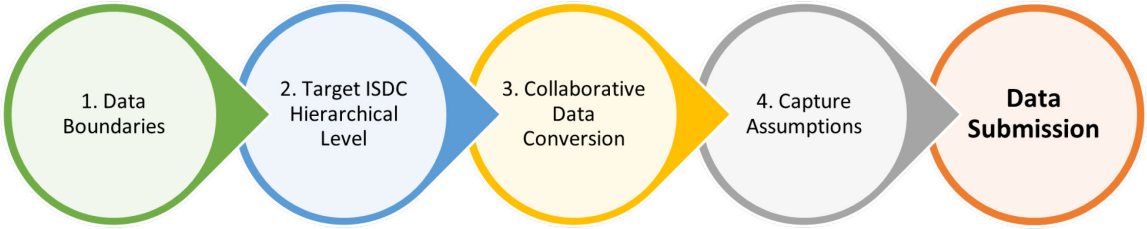
The generic cost breakdown structure was used, and a full breakdown of the discussion is provided in Appendix A.

The guidelines and recommendations were presented to the wider EGCDL membership for comment and agreement is sought through the approval and publication of this report.

3.2 Guidelines

Accurately converting non-ISDC data into an ISDC format data submission can be split into four key stages, as outlined in 3.1.

Figure 3.2 Stages of data conversion into an ISDC format data submission



Stage 1-Defining data boundaries

The initial stage in data conversion is to define the boundaries of the project. It is apparent that across different countries the boundaries in which we define "decommissioning activities" vary; some countries set the boundaries for all decommissioning activity that occurs within the nuclear site perimeter, while others set the boundaries at only decommissioning within the nuclear island (i.e. excluding administration buildings, low and intermediate storage facilities, and in some cases, the turbine hall). While neither is incorrect, the boundaries in which data are collected can have a significant impact on the overall cost of a project and can result in inaccurate, unsubstantiated cost comparisons being made. Areas of differentiation in terms of data boundaries have been identified in the point at which decommissioning activities are initiated, the point at which they are terminated and the types of facilities that are considered as nuclear or conventional decommissioning.

Conversion begins with the definition of the point at which decommissioning activities are initiated. This difference was most readily observed between countries in which the same commercial entity operates and decommissions the nuclear power plants, and countries in which different commercial entities operate the nuclear power plants and undertake the decommissioning. When one commercial entity operates and decommissions the nuclear power plant the time at which decommissioning starts is most commonly earlier in the post operational clean out (POCO) stage of decommissioning. Whereas, when there is a change in commercial owner, decommission costs commonly occur following the POCO and often reactor defuelling and spent fuel waste management are excluded from decommissioning costs as the waste remains under the ownership of the operator.

Further to this, it was observed that some participating countries would include upgrading existing facilities to enable decommissioning activities within the total cost of the decommissioning project. This can include, for example, research into robotic decommissioning capability to conduct contamination surveys in areas that are inaccessible to humans or upgrading the electricity supply to the site following the termination of energy production. The argument for including these costs within the data boundary was that

decommissioning activities cannot proceed without completing the enabling work. Arguments against including these costs note that enabling works are not activities progressing the decommissioning of the site. While both arguments are valid, they both have an impact in the ability to accurately cost benchmark nuclear decommissioning projects and therefore should be captured and reported.

It is equally important to define the end point of the decommissioning activities. Some countries have announced policies to define the target end state for their nuclear power plants sites as greenfield, meaning the end point of the parcel of land that has been utilised for industrial purpose is restored to the conditions existing before the construction of the plant. To achieve this target end state, the cost associated with site remediation will be significantly higher than a project seeking to leave behind a site with future restrictions for use. In addition, many countries include investment in environmental initiatives within the overall cost of the project. While initiatives such as increasing the biodiversity surrounding the site for local wildlife or planting trees to offset carbon emissions are not directly contributing to the decommissioning activities, they can be associated with the site remediation. In addition to the target end state, the pace at which decommissioning occurs will have a significant impact on costs. Some countries plan to have significant dormant periods where only basic asset management and security activities occur prior to final site clearance, while other countries' policies envision a continuous programme of decommissioning without a period of dormancy. Both decommissioning strategies will have additional costs associated with them. For dormant periods the asset management and security costs accumulated during this period are not progressing the decommissioning activity, but account towards the overall cost of decommissioning. Additional costs, such as hiring and training the workforce to complete decommissioning, also account for a proportion of the overall cost of decommissioning. For continuous decommissioning, the cost of research, development and innovation to decommissioning high radiation areas safely will be significantly higher.

While project boundaries will change between projects and countries, the most important aspect is to note these boundaries and report them as supporting data to any future cost benchmarking submissions.

Example 1:

A decommissioning entity (Company 1) has taken over legal liability for the decommissioning of a nuclear power plant. As part of the legal transition, it was agreed that the operating company would complete plant shutdown activities including defueling, managing spent fuel, and draining the spent fuel pond and other open systems. The decommissioning entity completed a data submission in ISDC format and reported a single value of $USDx$ against ISDC Principal Activity 2 at Level 1.

At a second nuclear power plant site there was no transfer of liability, and the same legal entity (Company 2) is completing the decommissioning of the nuclear power plant following site closure. They reported a single value of USDy against ISDC Principal Activity 2 at Level 1, which was significantly higher that USDx.

Exclusively looking at the values it would be unclear why the values differed until reviewing the metadata, as shown below.

Table 3.2.1. Example of defining data boundaries – Company 1

ISDC Principal Activity	Reported value
02 FACILITY SHUTDOWN ACTIVITIES	USDx
02.0100 Plant shutdown and inspection	N/A Activity completed by operator
02.0200 Drainage and drying of systems	N/A Activity completed by operator
02.0300 Decontamination of closed systems for dose reduction	Proportion of USDx
02.0400 Radiological inventory characterisation to support detailed planning	
02.0500 Removal of system fluids, operational waste and redundant material	

Table 3.2.2. Example of defining data boundaries – Company 2

ISDC Principal Activity	Reported value
02 FACILITY SHUTDOWN ACTIVITIES	USDx
02.0100 Plant shutdown and inspection	Proportion of USDx
02.0200 Drainage and drying of systems	
02.0300 Decontamination of closed systems for dose reduction	
02.0400 Radiological inventory characterisation to support detailed planning	
02.0500 Removal of system fluids, operational waste and redundant material	

While this is a simplistic example, it is designed to demonstrate the importance of a clear definition of assumptions and boundary conditions on which the estimate is based. This information must be available before starting the benchmarking process.

Example 2:

Company 1 is decommissioning a facility with large volumes of high dose rate contamination. The companies' policy states that the reactor site will have a safe enclosure period of 60 years where only basic asset management and security operations will be completed. The company predicts that, following the safe enclosure period when all final decommissioning activities are completed down to a site with restrictions, the total project cost will be USD*z*.

Company 2 is decommissioning a similar facility with a very similar fingerprint to Company 1. Their company policy states that they will invest in research and development to enable safe continuous decommissioning. They develop and utilise remote techniques to reduce contamination and to decommission the facility in 25 years. They report that the total predicted cost of the project is USD*z*.

While this situation is of course completely unrealistic, it shows that for a future project with a period of safe enclosure it would be more appropriate to benchmark against the Company 1 cost data submission than Company 2. Again, this example is provided to show how important the supporting metadata are to the accuracy of cost benchmarking.

Stage 2-Assigning target ISDC level

Once the data boundaries are known and assumptions are captured it is appropriate to review the quality of the data collected within the original non-ISDC cost breakdown structure.

Accurately converting data into ISDC is reliant on correctly identifying the ISDC level that is appropriate for the data conversion. Data cannot increase in accuracy after they are captured, a cost breakdown structure can only be converted into the activity level it was

originally collected in. If the original cost breakdown structure was not sufficiently detailed to convert into ISDC Level 2 or below these data cannot be generated through assumptions; however, metadata captured in stage 1 can be utilised to add clarity, as shown in the previous example.

The ISDC document itself provides a basic understanding of ISDC cost elements. Further support for understanding of the content of ISDC items can be achieved by developing more detailed assumptions and boundary conditions in the ISDC format. Below are some examples of ISDC-based assumptions and boundary conditions for decommissioning projects.

Table 3.2.3. Examples of ISDC-based assumptions and boundary conditions for decommissioning projects

Category	Assumption and boundary conditions
ISDC 01	Approaches for planning, costing, characterisation, safety assessment, waste planning, funding of activities.
ISDC 02	Mode of management of spent fuel, cooling down, management of nuclear materials, primary system decontamination, operational, historical, legacy waste, extent of included activities, funding of activities.
ISDC 03	Extent of safe enclosure, duration, activities during the safe enclosure.
ISDC 04	Dismantling strategy of primary components, decontamination and dismantling techniques, contaminated items out of controlled area, approach to final survey of buildings and release criteria; contracting of activities.
ISDC 05	Waste management system for the decommissioning project, external services, waste classification, Waste Management (WM) techniques, containers, end state of WM within the scope of the decommissioning project, disposal facilities, waste acceptance criteria, materials clearance scheme and criteria.
ISDC 06	Approach to security, surveillance and to maintenance, extent of operation of auxiliary systems, radiation and environmental monitoring.
ISDC 07	Dismantling and demolition techniques, level of demolition (-1 m, to the base plate, no demolition), end state of the site, approach for site survey, site release criteria.
ISDC 08	Organisational chart of the project, contracting approach.
ISDC 09	Extent of R&D activities included in the decommissioning project.
ISDC 10	Mode of management of the spent fuel after cooling down period.
ISDC 11	Projects for transition period funded in the frame of the decommissioning projects, types of fees, taxes and insurance included, assets considered in the decommissioning project.

Proper understanding of the relation between non-ISDC and ISDC cost items is a key issue in the transformation of formats. Non-ISDC cost items may in principle include one or more than one ISDC cost items. The conversion is then performed in two modes:

- **One-to-one allocation** of non-ISDC cost items to the relevant ISDC item when the content of the non-ISDC cost item is identical with the content of the ISDC item according to ISDC definitions.
- **One-to-N allocation** of non-ISDC cost items to several relevant ISDC items where the identified content of non-ISDC cost items includes the content of several ISDC cost items according to ISDC definitions.

When converting one-to-N at any ISDC level it is important to consider time management and not to over-scrutinise the conversion of trivial/low-impact line items. The majority of time spent on completing a data conversion exercise should be spent on line items that would have a critical impact on the accuracy of the data submission. A definition of different impact levels and the appropriate action to take is as follows:

- For low-impact items (items that cost <1% of overall project expenditure)
  - Assign all cost to the dominant activity.

- For medium impact items (i.e. 1-5% of overall project expenditure)
    - Assign 50% between two dominant activities.
- Critical impact (>5% of overall project expenditure)
    - Take time to estimate the proportion of costs between 3 to 4 dominant activities and assign cost appropriately.

For all situations any decisions/assumptions should be captured in a decisions log for the purposes of cost benchmarking.

Example 3:

Company 1 is undertaking a data conversion process from an internal cost breakdown structure into ISDC format. The data conversion team is converting into ISDC Level 1 as the internal cost breakdown structure is high-level and does not provide the required information to covert to ISDC Level 2 or below. They have completed a quick sift of the data and have converted all line items they have identified as a simple one-to-one allocation. The remaining line items are as follows:

- Characterisation programme.

It is estimated that this cost is <1% of the overall project expenditure.

- Given the proportion of the overall project expenditure, it was assumed that this line item included both planning the characterisation programme (ISDC Principal Activity 1) and conducting the programme throughout the life cycle of the project (ISDC Principal Activity 6). The activity cost has a low impact on the overall project cost and therefore all activity cost was assigned to the dominant activity and recorded as ISDC Principal Activity 6.

- Site management arrangements, facilities and service contracts.

It is estimated that this cost is <5% of the overall project expenditure.

- The line item does not provide clarity on what exact activities are undertaken and therefore activities are assumed to include staffing costs for facilities and service contracts, e.g. cleaning, catering staff and utility costs such as electricity and water supply, and security contracts. These activities could be split between ISDC categories 6, 8 and 11. The activity cost associated with the line item has a medium impact on the overall project cost. It was assumed that utility costs and security contracts are the dominant activities and therefore the activity cost was reported as 50% ISDC Principal Activity 11 and 50% ISDC Principal Activity 6.

- Regulatory cost.

It is estimated that this cost is >5% of the overall project expenditure.

- The line item does not provide clarity on what exact activities are undertaken. The costs associated also have a large impact on the overall cost of the project. Significantly more information is required to underpin the assumptions made when assigning the activity cost associated with this line item. For example, activities could include authorisation costs (ISDC Principal Activity 8), preparation for new regulatory permissions or the removal of existing permissions (ISDC Principal Activity 1), staff costs for supporting regulatory activities (ISDC Principal Activity 8), staff costs for preparing evidence for removal of existing permissions (ISDC Principal Activity 8), characterisation to support the removal of a permit (ISDC Principal Activity 7), final site survey to support regulatory activities (ISDC

Principal Activity 4), delicencing costs (ISDC Principal Activity 11), and any fines/penalties (ISDC Principal Activity 11). Once more, evidence must be collected to determine the dominant activities to appropriately report the cost.

Stage 3-Collaborative data conversion

A collaborative approach to data conversion is key to identifying and discussing assumptions. Often different levels of knowledge of the non-ISDC cost breakdown structure or the ISDC can lead to assumptions that can impact the accuracy of a data submission. Through discussing the decisions, these assumptions can be identified and challenged. An exercise such as the one undertaken within this report (see section 3.1 Methodology) is recommended. This allows individuals (recommended three participants) to undertake the exercise to increase the consistency of reporting, as the final submission is a group consensus as opposed to an individual's perspective and interpretation of guidance. This is also a way to build expertise in the ISDC elements (at ISDC Level 1, Level 2 or Level 3) and the conversion process – building the subject matter experts of the future.

Recommendation: Ensure knowledge management, including by capturing knowledge from retiring members within the community

It was apparent that group members highly familiar with the ISDC made similar assumptions, whereas those newer to the ISDC interpreted the wording within the document differently. This could be the result of reading the ISDC in isolation and without the additional knowledge gained from prior NEA expert group participation and conversations. This suggests that additional support may be required by new members to the international cost benchmarking community to ensure prior knowledge is shared.

Stage 4-Capturing assumptions

Throughout the data conversion process, many decisions will be made based on best estimates and assumptions. It is paramount to any future cost benchmarking activities that assumptions made during the development of the data submission are captured to ensure that they can be taken into consideration during comparison. The assumptions made are equally as important to the actual data reported. Table 3.2.4 and Table 3.2.5 provide an example of possible information types required to support a cost data submission.

Table 3.2.4. An excerpt of *Cost Benchmarking for Nuclear Power Plant Decommissioning* (NEA, 2019) demonstrating an example of metadata collection required to undertake accurate cost benchmarking

Type of Information	
Facility/project type	
Scope of work planned	
Scope of work delivered	
Metrics defining the facility/project	
Date defining the facility (e.g. inventory database)	
Timeline (schedule) achieved (overall, and by stage)	
Basis of estimate +	
Structure of estimate +	
Work breakdown structure + (or recognised cost-reporting structure, e.g. ISDC)	
Schedule and uncertainty analysis (historic) +	
Decommissioning process	Principal activities*
	Activity groups*
	Activities*
Cost categories	
Definitions for cost items*	
Project performance information (planned and actuals)	
Facility/project delivery strategy (planned and actuals)	
Procurement strategy (planned and actuals)	
Waste management strategy (planned and actuals)	
End-state delivered (planned and actuals)	
Independent validation of cost information; data is traceable	
Assumptions and boundary conditions* (as below)	
Scope of work through to the end-point of the site	
Regulatory requirements, including details of reporting and clearance levels	
Stakeholders' demands	
Characterisation of physical, radiological and hazardous material inventory	
Waste processing, storage and the availability of ultimate disposal facilities	
Disposal of spent fuel/on-site storage prior to emplacement in a permanent (e.g. geological) disposal facility	
Clean structure disposal and use of the site for new developments	
Provisions for estimated uncertainty and risk-application and use in the estimates	
Availability of experiences personnel with knowledge of the plant	
Assumed duration of the dismantling and clean-up activities	

Note: Items marked with a + are identified in "The Practice of Cost Estimation for Decommissioning of Nuclear Installations" (NEA, 2015), and those marked with a * are identified in "International Structure for Decommissioning Costing (ISDC) of Nuclear Installations" (NEA, 2012).

Table 3.2.5. An excerpt of *Costs of Decommissioning Nuclear Power Plants* (NEA, 2016a)

Items included in the scope of the decommissioning estimates	Finland	France	Slovak Republic	Spain	Sweden	Switzerland	United Kingdom
De-fuelling	Y	N	Y	N[1]	N	Y[2]	N
On-site storage of fuel	N	N	Y	N	N	N[3]	N
On-site storage of radwaste from decommissioning	Y	N	Y	N[4]	N	N	N
On-site storage of operational radioactive waste	N	N	Y	N	N	N[5]	Y
Retrieval and packaging of accumulated operational waste	N	N	Y	N[4]	N	Y[2]	Y
Removal of reactor building	Y	Y	Y	Y	Y	Y	Y
Removal of conventional plant/buildings, e.g. turbine halls	N	Y	Y	Y	Y	Y	Y
Removal of non-radioactive structures above ground level	N	Y	Y	Y	Y	Y	Y
Removal of non-radioactive structures below ground level	N	N	Y	Y[6]	N	Y[7]	Y
Transport and disposal of radioactive waste	Y	N	Y	N	N	Y	Y
Disposal or recycling of non-radioactive waste	N	N	Y	Y	Y	Y	Y
Contaminated ground remediation	N	N	Y	Y	Y	N[8]	Y
Landscaping and site de-licensing	N	Y	Y	Y	Y	Y	Y
Final site surveys	Y	Y	Y	Y	Y	Y	Y
De-licensing of the site	Y	Y	Y	Y	Y	Y	Y

1. Costs related with SNF temporary storage on-site are not included in the scope of the estimate. The underlying assumption is to transfer SNF to the future centralised temporary storage before starting the execution of decommissioning project.
2. The costs for defueling and packaging of radwaste are allocated to the post-operational phase that is added to the decommissioning costs. Costs for fuel casks and their storage are allocated to the waste management costs.
3. On-site and central storage of fuel are allocated to the waste management costs, separate from decommissioning costs.
4. Waste processing, storage and disposal cost item only takes into account tasks related with waste processing and temporary storage on-site during the execution of the dismantling activities. Decommissioning cost estimate does not consider any category of radioactive waste (high-, intermediate- and low-level) disposal cost.
5. Central storage of operational radioactive waste costs are allocated to the waste management costs, separate from decommissioning costs.
6. The removal of non-radioactive structures below ground level may be included or not depending on the intended end point of individual decommissioning plans. In principle, non-radioactive structures could remain on-site if they do not constitute an obstacle for achieving the expected goal.
7. Removal of non-radioactive structures below ground level to be executed up to a depth of 2 metres.
8. No ground contamination is assumed.

Recommendation: Structured collection of data assumptions and project information, including by capturing them consistently within a structured table

Participating countries were asked a question regarding data submissions as part of a wider question set (provided in Appendix B). Answers supported the future development of a "standardised cover sheet" to capture project boundaries and decisions/assumptions. This is standard practice internally within many organisations and is described in Chapter 5, The Practice of Cost Estimation for Decommissioning of Nuclear Facilities (NEA, 2015), but there is not one provided as part of the ISDC. A "cover sheet" should include (at a minimum) the initial state of the facility at the beginning of the decommissioning project (presence of spent fuel or historical waste in the facility) and the goal of final state (non-nuclear facility, demolition, etc.), the planned date of the shutdown of the facility, the date of the facility construction (providing an indication of the likelihood to find hazardous materials such as asbestos or lead paint). A "cover sheet" should also allow for the capture of country-specific information such as regulatory and labour costs. For example, the "cover sheet" could also include a standard list of items/activities (see for example Table 3.2.5) whose inclusion or exclusion is clear in the project scope.

4. Case studies

Cost benchmarking nuclear decommissioning projects is often described informally as "comparing apples and oranges" because of the number of differences between two seemingly similar projects. Factors such as public or private ownership, regulatory costs, labour costs, or something as fundamental as the definition used to identify the point in time when decommissioning began can cause major differences in cost estimation and therefore influence the outcome of benchmarking.

The purpose of this section is to identify and highlight the key qualitative information that is required in addition to the quantitative cost data to inform benchmarking decisions.

A request was sent to participating organisations to supply country-level information on costs, risks and uncertainties to inform this work. The information requested was all to be from publicly available sources. Information was received from five countries (France, Italy, Korea, Switzerland and the United Kingdom), in varying levels of detail. The focus here is on three countries to highlight the factors that influence cost estimation and therefore the ability to cost benchmark.

4.1. Korea

The decommissioning of nuclear power plants in Korea is regulated by the Nuclear Safety and Security Commission (NSSC). The NSSC is an independent central administrative and regulatory authority under the prime minister, responsible for ensuring the safety, security and safeguards of nuclear power plants.

The NSSC delegates technical work to the Korea Institute of Nuclear Safety (KINS), which is a regulatory expert organisation established by a Special Act in 1990 to support the NSSC. KINS conducts technical reviews of decommissioning plans and periodic inspections of decommissioning activities, as well as the closure of radioactive waste storage, treatment and disposal facilities and their subordinate facilities.

Korea Hydro & Nuclear Power (KHNP), the sole nuclear power plant operator in Korea, permanently shut down Kori-1 in June 2017 and Wolsong-1 in December 2019. According to the Nuclear Safety Act (NSA), if a nuclear operator intends to decommission its nuclear installation, the operator is required to submit a decommissioning plan within five years of the permanent shutdown and obtain approval from the NSSC.

As of December 2022, the following facilities are either planning or undergoing decommissioning:

- **Kori Unit 1,** the first commercial nuclear power plant in Korea, was commissioned in 1978 and permanently shut down for decommissioning in June 2017 after 40 years of operation. Korea Hydro & Nuclear Power (KHNP) submitted the final decommissioning plan and related documents for Kori Unit 1 in May 2021. KINS completed the document review for adequacy in January 2022, in accordance with the Nuclear Safety Act. Currently, the final decommissioning plan, including safety assessment results of residual radioactivity, decommissioning plan, decommissioning cost, etc., is under review.
- **Wolsong Unit 1**, the second oldest and first pressurised heavy water reactor (PHWR) in Korea, was commissioned in 1983 and permanently shut down in

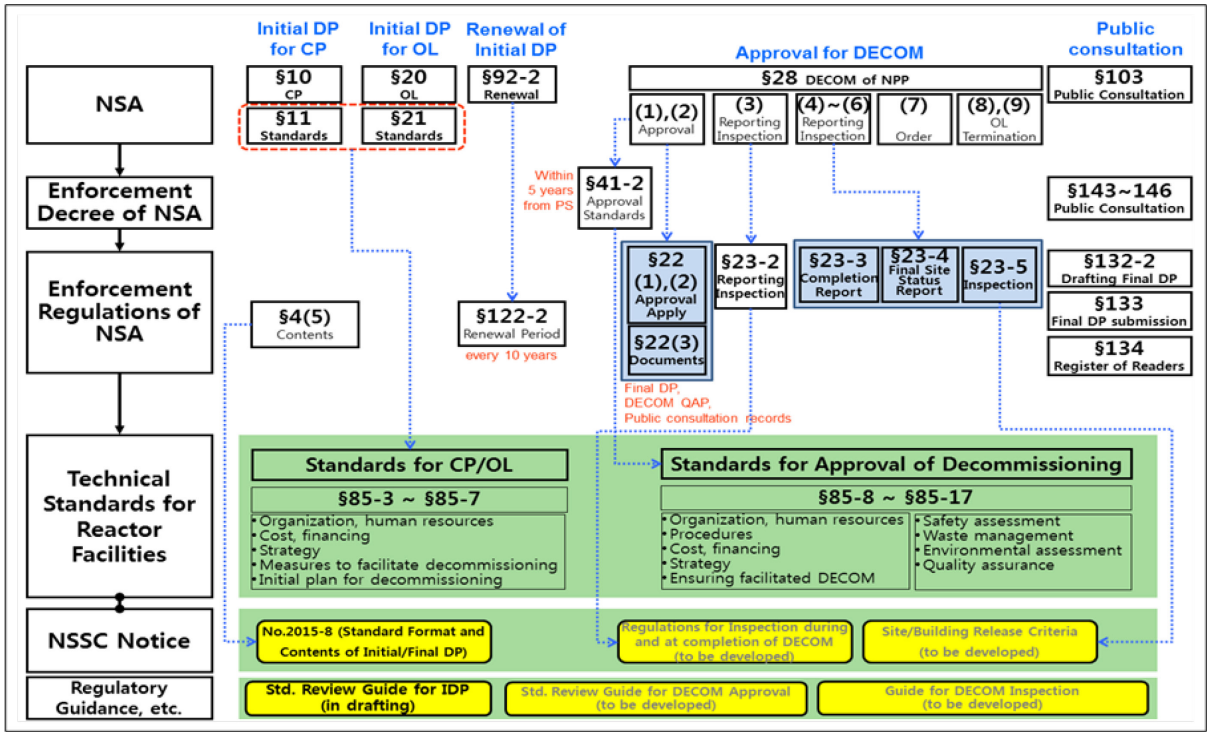
December 2019. KHNP is preparing to submit the final decommissioning plan for Wolsong Unit 1 within five years of its closure.

- **TRIGA Mark-II and III** research reactors, purchased from General Atomics in 1959, were the first nuclear research reactors in Korea, operating for approximately 30 years from 1962 to 1995. The dismantling of facilities affiliated with the reactor began in 1997, and the non-contaminated facilities were completed in 2021. Currently, preparations are underway for the dismantling of the contaminated facilities and site restoration.

Regulatory framework

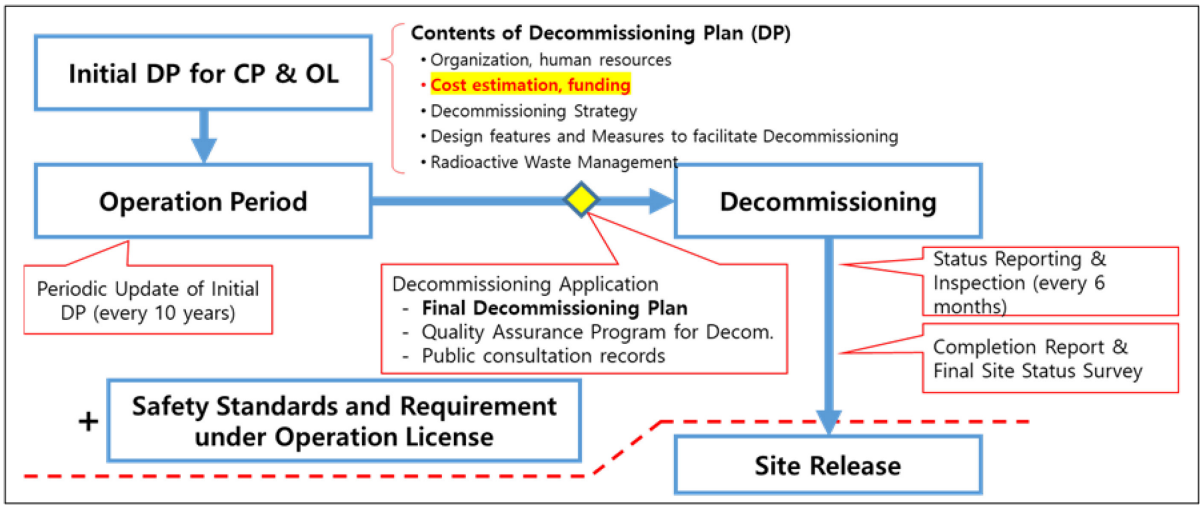
In preparation for the decommissioning of nuclear power plants, the Nuclear Safety Act (NSA) related to decommissioning was revised and promulgated in 2015. The lower statutes, including the Enforcement Decree and Regulation of the NSA, were promptly revised to incorporate decommissioning-related requirements and procedures. Detailed technical standards and regulatory guides on decommissioning, such as the Safety Review Guideline on Final Decommissioning Plans for Decommissioning Approval, were also developed and will continue to be developed to facilitate relevant activities and ensure nuclear safety. As discussed, the framework for permanent shutdown and decommissioning of nuclear facilities has been well established through the successful revision of the NSA in Korea. The figures below illustrate the overall regulations and processes for decommissioning, with the NSSC Notice providing detailed technical standards for decommissioning. For instance, the notice specifies the standard format and content of the decommissioning plan, which has been developed based on the IAEA safety standards.

Figure 4.1.1. Regulatory structure for decommissioning in Korea



Source: NEA (2016c).

Figure 4.1.2. Regulatory process for decommissioning in Korea



Source: Jiyoon Jung, presented at the EGCDL Plenary on 25 June 2024.

Aligning with the NSA, operators of a commercial reactor, research reactor, or nuclear fuel cycle facility that want to get a construction permit, operating licence, business licence, or plan to decommission, must submit a decommissioning plan for approval from the NSSC. The decommissioning plan should include the following:

- organisation, personnel and financial resources for the decommissioning of nuclear facilities;
- decommissioning strategy and schedule of nuclear facilities;
- reflections in design and measures in construction and operation to facilitate decommissioning;
- measures for preventing radiological accidents;
- methods of radioactive materials and contamination removal;
- radioactive waste treatment, storage and disposal methods;
- assessment of environmental impact and protective measures;
- and other measures, as specified by the NSSC.

The operator should revise the initial decommissioning plan every 10 years based on experience and information obtained in the process of operation and management of a nuclear facility as well as the results of assessment related to decommissioning. In addition, the operator should submit the final decommissioning plan to the NSSC to apply for decommissioning after permanent shutdown. At that point, the operator should hold a public hearing to incorporate public opinion in the final decommissioning plan.

During the period of decommissioning, the progress of decommissioning should be reported to the NSSC every six months (Decommissioning Status Report) and the NSSC should verify and inspect the status of decommissioning. When decommissioning is completed, the operator should submit to the NSSC a decommissioning completion report and a final site status report, and the NSSC should conduct a decommissioning completion inspection to verify that decommissioning is properly performed, and then give the operator a written notice of licence termination.

Decommissioning policies, strategy and implementation

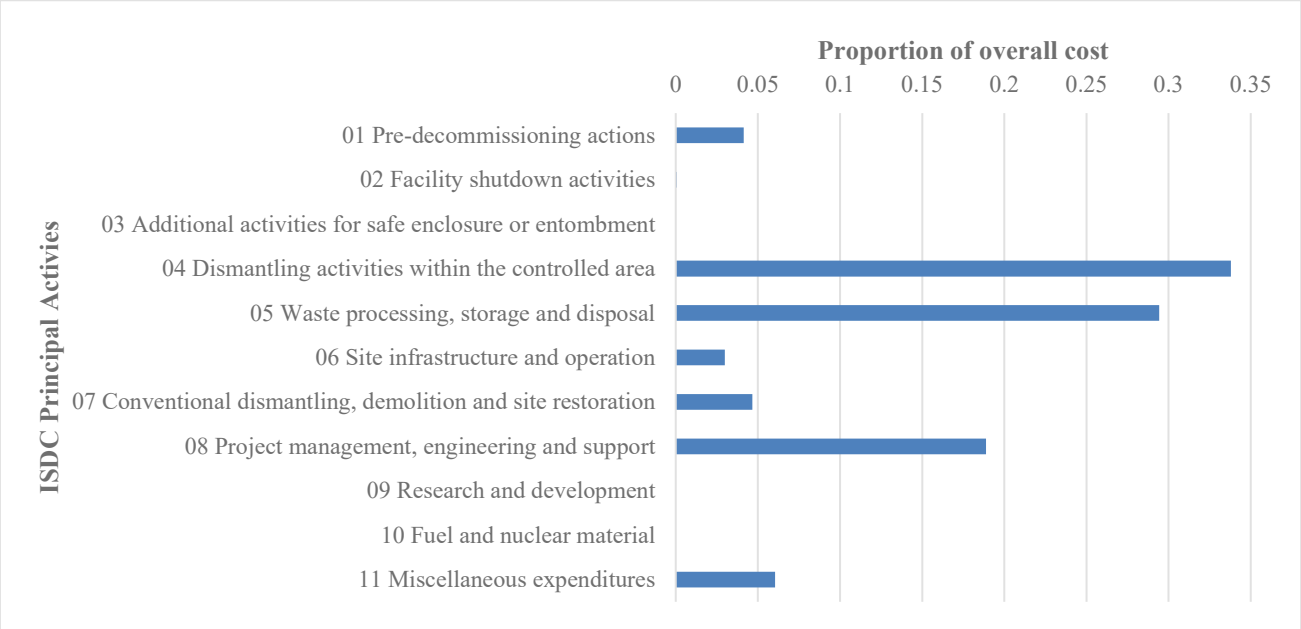
In Korea, the Nuclear Safety Act provides immediate and delayed decommissioning as options for decommissioning strategies. The Nuclear Safety Act requires the licensees of nuclear facilities to select a decommissioning strategy in the decommissioning plan, and most nuclear facility operators/licensees have selected immediate decommissioning as the decommissioning strategy and reflected it in their decommissioning plan.

Decommissioning cost estimation

In order to secure financing for the safe decommissioning of nuclear power plants, the RWMA (Radioactive Waste Management Act) requires a nuclear power plant operator to accumulate a reserve every year for decommissioning of the relevant nuclear power plant, and to prepare a plan for accumulating the reserve and submit it to MOTIE (Ministry of Trade, Industry and Energy) every year. The decommissioning costs of nuclear power plants are following RWMA notices and as of 2022, were USD 662 million per unit. Costs in RWMA do not use the ISDC method but the WBS method.

Unlike nuclear power plants, research reactors and fuel cycle facilities are using the ISDC or WBS for decommissioning cost estimations. The following figure shows the normalised approximate decommissioning cost of a fuel fabrication facility for a specific research reactor that selects an immediate decommissioning strategy.

Figure 4.1.3. Normalised approximate decommissioning cost of a Korean fuel fabrication facility for a specific research reactor that opts for immediate decommissioning



4.2. Switzerland

In Switzerland, there are four nuclear power plants at three sites and one central intermediate storage facility for radioactive waste currently in operation. The disposal facility for radioactive waste is situated in the surrounding areas of the nuclear power plants.

For the first time, a commercial nuclear power plant in Switzerland is being decommissioned.

In October 2013, BKW, a nuclear power plant operator, decided to definitively cease electricity production at Mühleberg Nuclear Power Plant (KKM) by the end of 2019 and subsequently decommission the plant. In December 2015, BKW submitted its decommissioning project to the Swiss Federal Office of Energy (SFOE). In the project, BKW requested that decommissioning work commence immediately upon final shutdown. The decommissioning works shall be completed once the plant no longer poses a radiological hazard (nuclear decommissioning). The conventional dismantling of KKM will be the subject of a further procedure at a later date.

The documents for the decommissioning project were made available to the public in 2016; a total of eight objections were received. In addition, the SFOE obtained comments from the cantons concerned and various federal authorities. The expert opinion on the decommissioning project prepared by the Swiss Federal Nuclear Safety Inspectorate (ENSI) and the statement of the Swiss Federal Nuclear Safety Commission (NSC) were published in 2017. ENSI requested 35 conditions to be included in the decommissioning order to ensure the orderly implementation of the decommissioning of KKM. Both ENSI and the NSC confirmed that, taking these conditions into account, BKW's decommissioning project met all the necessary requirements for issuing the decommissioning order.

Based primarily on the ENSI report and the comments received, the SFOE drafted the decommissioning order, which was issued by the Federal Department of the Environment, Transport, Energy and Communications (DETEC) in June 2018.

The Nuclear Energy Act has been in force since 2005 and regulates the decommissioning: The operators of nuclear power plants must prepare a decommissioning plan (which must be updated every 10 years) and submit it to the SFOE. To apply for the decommissioning order, the operator must submit an application complemented by a decommissioning project. The SFOE then conducts the decommissioning procedure, as the authority in charge of the procedure, with the involvement of the federal authorities and the cantons concerned. At the start of the procedure, the decommissioning project is made publicly available. During the public display period, the persons affected by the decommissioning can lodge an objection. Afterwards, the SFOE prepares a decommissioning order for the attention of DETEC, in which decommissioning is ordered.

A nuclear power plant goes through four licensing phases: Planning (general licence), construction (construction licence), operation (operating licence) and decommissioning (decommissioning order). The Nuclear Energy Act assumes a seamless sequence of these licences.

The decommissioning work is monitored by ENSI. For a long time, ENSI's experts have been following decommissioning projects worldwide; progress in dismantling techniques; and developments in licensing and decommissioning procedures. ENSI also regularly exchanges information with experts from other countries. ENSI's experts assess the plans of the operators of nuclear facilities, supervise decommissioning on site and co-ordinate the involvement of various other authorities, for example in the area of conventional environmental protection and occupational health and safety.

Procedure after final cessation of power operation

After the final shutdown of KKM, work began on establishing the technical post-operation phase. This is necessary to bring the plant into a safe condition for the long-term. The

establishment of the technical post-operational phase includes the transfer of all fuel assemblies to the fuel pool and all technical and organisational measures required for safety reasons. With the completion of the transfer and the implementation of these measures, the plant has achieved final shutdown. From the time of final cessation of power operation, work in preparation for decommissioning ("preparatory measures") shall then be carried out.

After the technical post-operation phase has been established, the decommissioning begins. This is divided into three phases:

Decommissioning Phase 1 (2020-2024): During Decommissioning Phase 1, the same fundamental protection goals as during the operating phase apply. The fuel assemblies are transported in several transport campaigns from the plant to the intermediate high-level waste storage. Activated components and equipment no longer required will be dismantled. The infrastructure for material handling will be set up. Decommissioning Phase 1 ends when the plant is free of nuclear fuel.

Decommissioning Phase 2 (2025-2030): Dismantling continues. Among other things, it includes dismantling work on systems that are still in place (e.g. reactor water purification, ventilation systems, fire protection equipment) and large components (e.g. reactor pressure vessel). Decommissioning Phase 2 ends with the clearance measurement and lifting of the controlled zones, alongside the completion of the evidence-securing measurements on the site.

Decommissioning Phase 3 (2031): After reviewing the final report, ENSI determines that the plant no longer imposes a radiological hazard and that there are no further nuclear safety or security obligations.

Conventional dismantling (2032-2034): This is followed by the second, conventional part of decommissioning. The remaining buildings on the site will be dismantled so that they are not repurposed. This second part of the decommissioning will be the subject of a further procedure.

The Nuclear Energy Act allows for two decommissioning strategies: immediate decommissioning and delayed decommissioning. At the moment, all nuclear operators have selected immediate decommissioning as the decommissioning strategy and reflected it in their decommissioning project.

Financing of decommissioning

The owners of the Swiss nuclear installations are obligated to dismantle their installations following final shutdown. This includes disposing of all radioactive waste from the operation and the dismantling of the installations in deep geological repositories. They are also obligated to bear all costs connected with these tasks. In keeping with the polluter pays principle, Swiss law (Swiss Federal Nuclear Energy Act and the Ordinance on the Decommissioning Fund and the Waste Disposal Fund for Nuclear Installations [SEFV]) regulates funding for the shutdown of nuclear installations and the disposal of the radioactive waste they generate. To ensure the necessary financial resources, two state-controlled funds were set up. Operators of the Swiss nuclear installations contribute to these funds. After the final shutdown of these installations, the funds must have sufficient resources to cover the costs arising from decommissioning and waste disposal. In addition, the owners of the nuclear installations are obligated to make provisions in the accounts for covering waste disposal costs incurred prior to final decommissioning as well as the post-shutdown operations costs (establishing technical post-operation and Decommissioning Phase 1).

The payments into both state-controlled funds (Decommissioning Fund and Waste Disposal Fund) and the provisions for decommissioning and waste disposal that the owners of the nuclear installations enter in their accounts, are based on a comprehensive assessment. This includes the following: the decommissioning and waste disposal costs, the fund value at the beginning of the assessment period and a mathematical model which takes into account the schedule of the working programme as well as the rate of inflation and return. The cost assessment must be conducted every five years as specified in the SEFV. Along with the updating of the studies on decommissioning and waste disposal costs, the post-shutdown operation costs paid directly by the nuclear installations are also recalculated.

While the Decommissioning Fund has existed since 1984, the Waste Disposal Fund was established in 2000.

Disposal costs that arise during operation, such as research and site selection for a deep geological repository, reprocessing of spent fuel, interim storage, and the purchase of transport and storage containers, are not financed by the fund. They must be paid continuously by the owners of nuclear installations. After the final shutdown of a nuclear installation, these outstanding cost items will be covered by the Waste Disposal Fund.

The entitlement of each owner to the two funds is equivalent to the amount paid, including capital earnings, after deduction of cost. In case the entitlement of the contributing party does not cover the cost, the concerned party has to cover the remaining cost from his own financial resources. If the financial resources are insufficient, the funds cover the remaining cost from its overall resource. Owners benefiting from this are obligated to pay additional contribution to the funds. If the beneficiary is unable to repay, the other contributing parties and beneficiaries cover the difference through additional payments in proportion to their contributions. In case the additional payments are not economically viable for the owners, the Federal Assembly decides if and to what extent the confederation will contribute.

The bodies of the funds and their tasks are described in the SEFV: the Administrative Board, the Office and the Auditors. The Administrative Board controls and manages the funds. It decides the Portfolio Strategy and fixes the annual contribution. The Administrative Board has established two committees for dealing with the various tasks: the Investment Committee and the Cost Committee. The duties of these committees are specified in a set of regulations issued by the Administrative Board. The task of the Office is to control the payment of the annual contributions and to manage the meetings of the Administrative Board and the Committees.

The supervisory body is the Federal Council, which appoints the members of the Administrative Board and the Auditors. The members of the Administrative Board and the committees are independent persons as well as operators of nuclear power plants, which are allowed maximally 1/3 of the board seats.

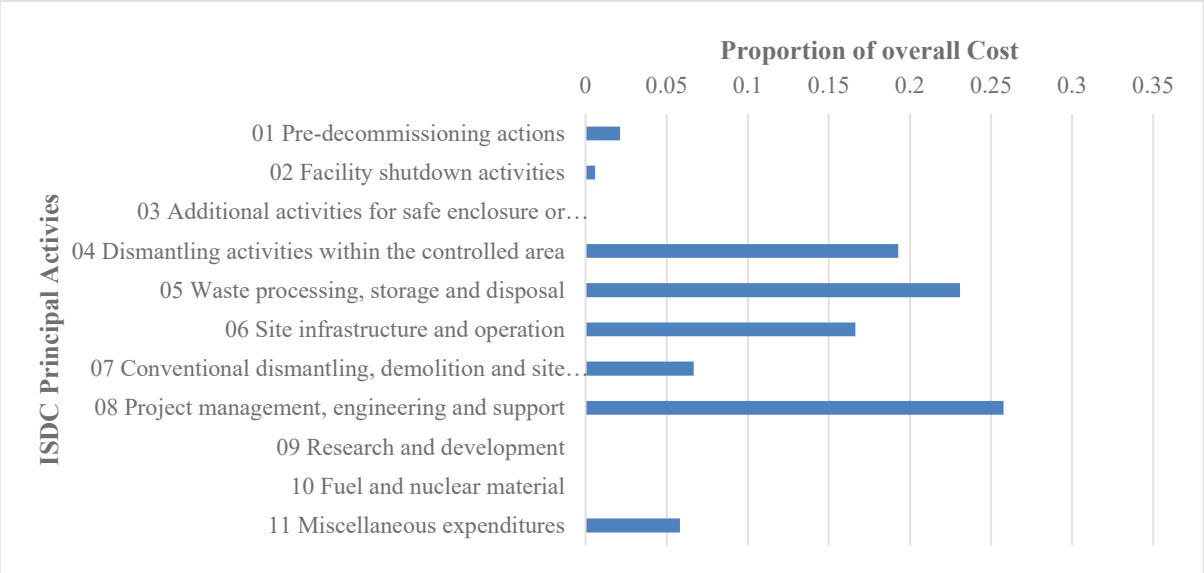
Radioactive waste that arises from the use of radioactive materials in medicine, industry and research (MIR) has to be delivered to the Swiss Confederation; the Confederation charges a fee for this service.

The latest cost estimate was carried out in 2021 and incorporates new knowledge and experiences from the ongoing nuclear decommissioning projects. The insights derived from the recent development of the decommissioning of the Mühleberg Nuclear Power Plant and from the preparatory planning for the decommissioning of the Beznau Nuclear Power Plant are also being considered.

The next cost study will be carried out in 2026.

The figure below shows the normalised results of the Cost Study of 2021 for the decommissioning. The data have been normalised to demonstrate the proportion of the costs reported within each ISDC Principal Activity.

Figure 4.2.1. Normalised results of the Switzerland Cost Study of 2021 for decommissioning



4.3. United Kingdom

Decommissioning in the United Kingdom is managed by the Nuclear Decommissioning Authority (NDA) on behalf of the UK government. The NDA is publicly funded, and expenditure is voted upon annually by UK parliament. The NDA took full management of the UK's 17 earliest nuclear sites (the nuclear legacy) across England, Scotland and Wales in the period of 2016-20.

The NDA is responsible for the decommissioning and clean-up of the publicly owned nuclear sites across the whole of the United Kingdom and the safe and secure management of radioactive waste arising from those sites. It is accountable to both the UK government and Scottish ministers. The NDA also has oversight of the decommissioning plans for EDF Energy's existing fleet of UK-based nuclear power stations, which will be transferred to the NDA for decommissioning once they stop generating power and have been defuelled.

The NDA's mission is to complete the clean-up of UK legacy sites and release them for beneficial reuse. The NDA estate currently comprises 17 nuclear licenced sites as well as organisations that deliver radioactive waste management solutions. The estate includes 4 subsidiaries:

- **Sellafield** is the largest nuclear licenced site in Europe and has played a pivotal role in the United Kingdom's nuclear industry since the 1940s. Sellafield is located in the northwest of England and employs 10 000+ staff, most of whom live in the local area. Following a period of management by a private consortium, the site management was returned to the NDA and direct government control in 2016. At this time the site management company, Sellafield Ltd., became a subsidiary of the NDA. With the closure of nuclear power generation at the site in 2003 and fuel

reprocessing in 2022, the site's primary activities are nuclear waste processing and storage and nuclear decommissioning.

- **Nuclear Restoration Services (NRS)** is responsible for safely decommissioning the first generation nuclear and research sites across the United Kingdom. Formed in 2023, NRS joins together the 12 Magnox sites and Dounreay in Scotland. It also prepares NDA to welcome the seven advanced gas-cooled reactor sites (AGRs), currently managed by EDF, for decommissioning, as well as other future missions. Operating as one decommissioning company, NRS can take a fleet-wide approach to decommissioning such as utilising skills and expertise from the different sites to solve common challenges. While many of the challenges are analogous, NRS sites are located across England, Scotland and Wales, which results in unique socio-economic challenges; it requires fulfilling different devolved government decommissioning policies and remaining compliant within varying environmental regulatory regimes.
- **Nuclear Waste Services (NWS)** brings together the Low Level Waste Repository Ltd, Radioactive Waste Management Ltd and the NDA group's Integrated Waste Management Programme. It oversees waste management activities across the NDA group. The Low Level Waste Repository Limited (LLWR) is responsible for managing the low-level waste disposal facility in Cumbria. The facility, which has been operating since 1959, has safely disposed of the nation's low-level waste for over 50 years. Radioactive Waste Management Limited (RWM) has been given the responsibility for implementing geological disposal of the United Kingdom's most hazardous radioactive waste.
- **Nuclear Transport Solutions (NTS)** is a global provider of safe, secure and reliable nuclear transport solutions. As part of the NDA, NTS supports the use specialist transport and logistics expertise to help customers and partners around the world solve their own complex transport challenges. Alongside providing logistical solutions, NTS provides nuclear shipping and rail freight capabilities.

Decommissioning policies, strategy and implementation

For the most part, the policy for managing radioactive waste and nuclear decommissioning is set by the UK government for the whole of the United Kingdom; however, in some areas, such as waste disposal, the devolved administrations in Northern Ireland, Scotland and Wales are responsible for policy in their respective nations. The UK government and the devolved administrations are in consultation with UK citizens on a new policy document that aims to create clearer and more consistent policy objectives across the United Kingdom by bringing multiple policy documents into one. The desired outcome of this change is to facilitate speedier and more cost-effective decommissioning and radioactive waste management, while maintaining high standards of safety, security and environmental protection.

The NDA works with the government to develop a strategy to deliver the policy. The NDA outlines the strategic approach for the subsidiaries and in turn the subsidiaries create Lifetime Plans (LTPs) that outline the stages of decommissioning that are required, the target end state of the site, the workforce skills requirements to deliver the decommissioning mission, the estimated cost and much more. The NDA has recently changed its position on decommissioning from a care and maintenance (safe enclosure) model to a programme of continuous decommissioning, where appropriate and value for money. This change has had a significant impact on the site LTPs, which are undergoing a period of review and update.

Regulatory framework

In the United Kingdom, nuclear safety, conventional safety on nuclear sites, nuclear security, safeguarding of nuclear material, and transport of nuclear material are regulated by the Office for Nuclear Regulation (ONR). ONR is the principal regulator for the UK nuclear industry regulating the life cycle of the nuclear site from design to decommissioning. ONR was established by law in the Energy Act 2013. The key activities of ONR are the granting of permissions for nuclear activities, particularly by means of site licences for nuclear installations, and inspections for compliance.

Environmental regulation of UK nuclear sites is undertaken by the Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency. These agencies work closely with ONR and have their own regulatory functions. These agencies enforce laws by means of regulation with regard to environmental and human health, covered by the Environmental Permitting Regulations (in England and Wales) or the Radioactive Substances Act (in Scotland). This regulation not only covers radiological activities, but all the other activities associated with the industry that may occur on the sites. Where ONR regulates the accumulation of radioactive wastes, the various environment agencies regulate the disposal and discharge of radioactive wastes.

At the time of writing, the United Kingdom was seeking to amend the regulatory framework for the final stages of nuclear decommissioning. In the final stages of decommissioning and clean-up of nuclear sites, hazards and risks fall to levels comparable to those on non-nuclear industrial sites and the focus is on waste management and land remediation. However, under UK law, nuclear sites in the final stages of decommissioning remain subject to nuclear third-party liability for longer than required by international agreements. In the final stages of decommissioning, the UK government considers that continued regulation by ONR is unnecessary and that former nuclear sites should be regulated in a more proportionate way. In addition, disposal facilities for radioactive waste of nuclear origin are subject to nuclear third-party liability; however, some disposal facilities present a very low level of risk. Adopting internationally agreed standards would allow these facilities to exit nuclear third-party liability and reduce costs for operators. Simplifying the regulatory framework in the United Kingdom to align with international standards is estimated to save at least GBP 500 million (pounds) of taxpayers' money over the next 20 years, with similar savings in the following 40 years. In addition, up to GBP 7.5 billion in additional savings over the next 100 years are estimated as the Sellafield site is decommissioned, although this estimate is uncertain.

Decommissioning cost estimation

The NDA outlines to its subsidiaries the control activities required within the operating companies to enable the NDA to provide assurance, monitor and support performance, and provide support and approvals where required in the following areas:

- Current Year plan - including funding requirement;
- Operating / Business Plan - typically 3-5 years in duration;
- Lifetime Plans (LTP) - up to end state (the approved baseline);
- Sanction of projects - where sanctions fall outside of the operating companies' delegation of authority.

One of the underlying principles of effective project controls is the existence of an identifiable baseline that is the subject of governance and control. Each Operating Company holds a single baseline that reflects their whole LTP.

The LTP is the over-arching set of documents that, for each NDA Operating Company, describes the totality of activities required to take the site/s from their current state and mission to the assumed or agreed end state. It is the means through which the NDA and the operating companies identify the nature of the work to be performed (the scope), when, during the lifetime of the site/s, the work is to be done (the schedule) and how much it is going to cost to discharge the lifetime liabilities (the cost).

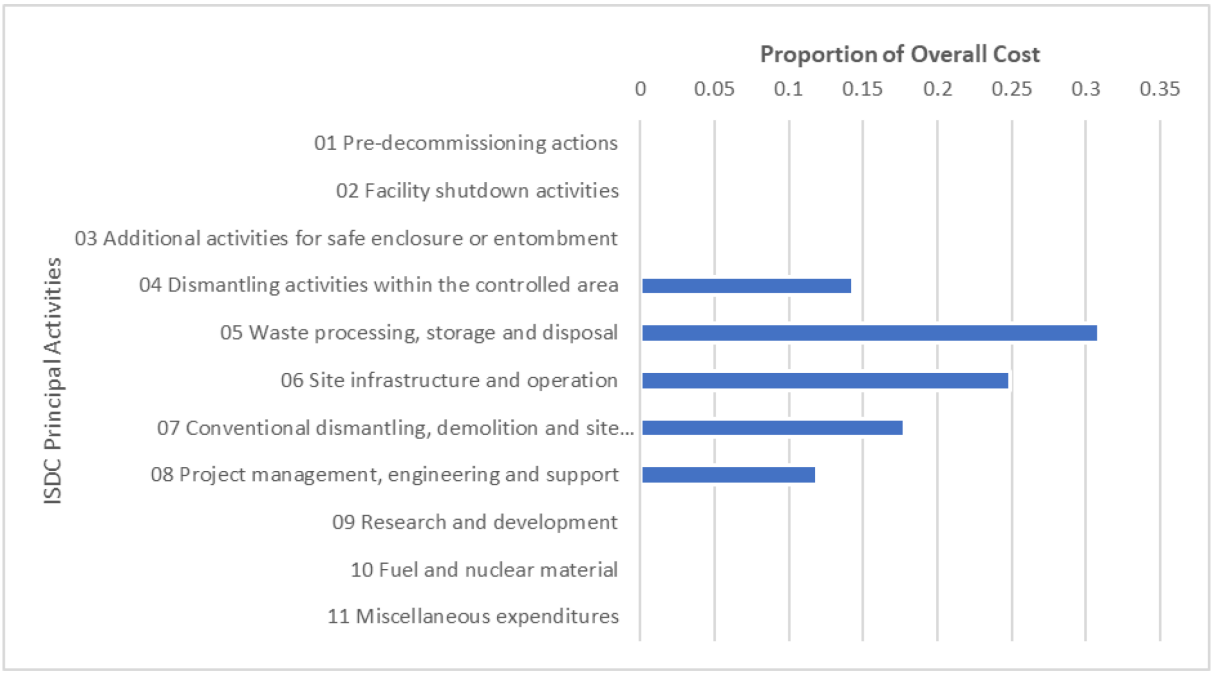
Using the cost to discharge the lifetime liabilities, one of the purposes of the LTP is to provide a financial liability forecast to inform statutory reporting within the Annual Reports and Accounts (ARAC).

As part of the development of the LTP, NDA prescribes the reporting structure and cost elements needed to fulfil their support, assurance and portfolio analysis and reporting obligations. Additionally, any breakdown of cost "types" required by NDA Finance to align with NDA Finance systems and processes will be provided. Operating companies map their internal work breakdown structures (WBS) in a manner that can align with these requirements.

As the internal WBS does not map directly to the 11 Principal Activities, subsidiaries were provided with a definition attached to each principal activity for each subsidiary to map their respective LTP. Taking the lowest level WBS enabled a direct mapping of the activity to one of the 11 principal activities.

Additionally, the initial data capture exercise used information provided to inform the forward assessment of costs for scope-to-go and as published within the Annual Report and Accounts. While this does not reflect costs incurred to-date, it provides a clear reconciliation of the reported position against published costs.

Figure 4.3.1. Normalised results from United Kingdom using cost data from NDA subsidiary lifetime plans as published in 2022



Note: Values do not include data for geological disposal costs.

4.4. Case study remarks

The differences identified within the case studies provide further evidence of the complexity of cost benchmarking within the nuclear industry. They also highlight the importance of international collaboration, standardised methodologies for data conversion, and an independent entity to fully analyse complex data submissions.

The above case studies highlight the differences between regulatory frameworks, decommissioning strategies, cost estimation methods, and specific challenges faced by each country. However, there are some similarities that can be observed in the normalised cost data.

Overall: Across all three countries, significant portions of the decommissioning budget are allocated to waste processing, storage and disposal, as well as dismantling activities.

Project management and support: All three countries allocate substantial resources to project management, engineering and support, highlighting the complexity and need for meticulous planning in decommissioning projects.

Site infrastructure and operation: Maintaining site infrastructure and operations during decommissioning is a notable cost in all three cases, reflecting the ongoing need for safety and security.

Country-specific differences: The United Kingdom allocates a higher percentage to waste processing and site infrastructure compared to Korea and Switzerland, possibly due to differences in regulatory requirements, site conditions and decommissioning strategies.

These figures provide valuable insights into the cost distribution of decommissioning activities, highlighting both common challenges and country-specific approaches.

5. Summary of recommendations

Recommendation: Improve the accessibility of the ISDC to non-specialists and decision makers by ensuring benefits of production of data submission in ISDC format are communicated

Participating countries in the EGCDL were asked a question regarding barriers to implementing ISDC as part of a wider question set (provided in Appendix B). Answers supported the hypothesis that outside of the NEA/IAEA/EC expert group representatives (or other similar international collaborations), the ISDC remains unknown. This is particularly a problem if non-specialists in cost analysis such as portfolio managers, senior leadership and decision makers are not aware of the structure and/or are not provided with sufficient information to communicate the benefits of using the ISDC format. It is recommended that future expert groups focus on communicating to a non-specialist audience to raise awareness of the structure, this could be achieved by creating short summary documents. It is also recommended that translations of the ISDC and short summaries be made available to facilitate the communication of the structure to decommissioning workers.

Recommendation: Knowledge management - ensure knowledge is captured from retiring members within the community

It was apparent that group members highly familiar with the ISDC made similar assumptions whereas those newer to the ISDC had interpreted the wording within the document differently. This could be the result of reading the ISDC in isolation and without the additional knowledge gained from prior NEA/IAEA/EC expert group participation and conversations. This suggests that additional support may be required by new members to the international cost benchmarking community to ensure prior knowledge is shared.

Recommendation: Structured collection of data assumptions and project information, including by capturing them consistently within a structured table

Participating countries were asked a question regarding data submissions as part of a wider question set (provided in Appendix B). Answers supported the future development of a "standardised cover sheet" to capture project boundaries and decisions/assumptions. This is standard practice internally within many organisations and is described in Chapter 5 of *The practice of Cost Estimation for Decommissioning of Nuclear Facilities* (NEA, 2015), but there is not one provided as part of the ISDC. A "cover sheet" should include (at a minimum) the initial state of the facility at the beginning of the decommissioning project (presence of spent fuel or historical waste in the facility) and the goal of the final state (non-nuclear facility, demolition …), the planned date of the shutdown of the facility, the date of the facility construction (providing an indication of the likelihood to find hazardous materials such as asbestos or lead paint). A "cover sheet" should also allow for the capture of country-specific information such as regulatory and labour costs. Further context and evidence in support of this recommendation is provided in earlier NEA documents (NEA, 2019; 2015).

Recommendation for potential updates of the ISDC: Implement lessons learnt and additional recommendations

The ISDC 2012 captures briefly in a graphical form the principal links between the ISDC and WBS elements. Based on lessons learnt, it is recommended that additional guidance be

developed that sets out detailed procedures of conversion of WBS cost formats into the ISDC cost format. Consideration of this issue in this present report is limited to ISDC Level 1, providing examples of principal steps in data conversion. However, there is a need to also consider lower ISDC levels (Level 2 and Level 3) and to address how to split the converted items to ISDC cost categories (labour cost, investment cost, expenses and contingency).

It is also recommended that detailed lists of assumptions and conditions be developed in the ISDC format for ISDC Level 2, i.e. an extension of the table presented in Chapter 3.2, stage 2 of this report. The extended assumptions and boundary conditions would include not only narrative parts related to relevant ISDC elements but also proposals for additional numerical data presented in parallel to cost data. These additional data could be related to the workforce, quantities of inventories or waste quantities. These supporting data may facilitate an understanding of differences in decommissioning costs for the same ISDC items. A similar experience was observed during the IAEA DACCORD project.

Benchmarking is also related to the funding of decommissioning activities. Items of ISDC can be funded from various sources such as decommissioning funds, operator funds and funds contributed by government and other stakeholders for decommissioning activities. Clear allocation of funds to individual ISDC items is recommended (for example, spent fuel cooling down during the transition period may be funded from a specific operator's funds or from a decommissioning fund). Understanding these funding aspects may bring more transparency to the benchmarking of decommissioning costs.

In some cases, the decommissioning may be organised in several sequential or parallel projects. The phasing and sequencing of projects related to overall decommissioning of a nuclear facility may cause the same ISDC items to appear in different projects. Examples of sequential/parallel projects could be the POCO or termination of operation phases, phases related to deferred dismantling, decommissioning projects with multiple phases with licensing of individual phases (e.g. after accident decommissioning projects) or decommissioning with a separate site remediation project. A clear definition of the links between the above-listed projects related to one nuclear facility, including the level of these projects (programme level), will add transparency to benchmarking.

Recommendation for the NEA, IAEA and EC: Provide additional support for application of the ISDC

There is a statement in the NEA (2019) document that other industries have led the way in demonstrating how cost benchmarking can provide valuable insights for managing costs and improving project delivery. This report also states that there are benefits to be gained from submitting data in an ISDC format as a key aspect of cost benchmarking. The NEA, IAEA or EC are encouraged to consider providing additional support for developing ISDC-based data formats that would enhance efforts to implement decommissioning cost benchmarking.

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Appendix A

Figure A.1. Generic cost breakdown structure 1

Row No.	Activities within
1	PRE CLOSURE PREPARATORY WORK (Activity 0)
2	FUEL MANAGEMENT (Activity 01)
3	01.1 Reactor Defuelling and Fuel Despatch
4	01.1.1 Fuel Removal Operations from Reactor
5	01.1.2 Fuel Storage in Cooling Pond
6	01.1.3 Fuel Transfer from Fuel Building Pond to Spent Fuel Interim
7	SITE OPERATION & PLANT PREPARATION (Activity 02)
8	02.1 Making Safe Redundant Systems & Plant
9	02.1.1 Non Maintenance Group Specific
10	02.2 Primary Circuit Decontamination (PCD)
11	02.2.1 PCD Engineering Design
12	02.2.2 PCD Installation and Commissioning
13	02.2.3 PCD Operations
14	02.2.4 PCD Waste Management
15	02.3 Site Plant Maintenance during Decommissioning
16	02.3.1 During Plant Decommissioning
17	02.4 Plant Operations During Decommissioning
18	02.4.1 During Plant Decommissioning
19	MANAGEMENT OPERATIONAL WASTES (Activity 03)
20	03.1 Retrieval, Processing, Transport and Disposal
21	03.1.1 ILW Operational Waste
22	03.1.2 LLW Operational Waste
23	PLANT & REACTOR DECOMMISSIONING (Activity 04)
24	04.1 Nuclear Island (NI)
25	04.1.1 Reactor Building
26	04.1.2 Fuel Building
27	04.1.3 Safeguard Buildings
28	04.1.4 Nuclear Auxiliary Building
29	04.1.5 Other Nuclear Island Buildings
30	04.1.6 Access Building
31	04.1.7 Waste / Effluent Building (HQA / HQB)
32	04.1.8 Backup Diesels
33	04.1.9 Functional Simplification
34	04.1.10 New Works
35	04.1.11 Dismantling Preparation
36	04.1.12 Nuclear Island Demolition Support
37	04.1.13 Nuclear Island Dismantling Secondary Wastes
38	04.2 Conventional Island (CI)
39	04.2.1 Turbine Hall
40	04.2.2 Other Conventional Island Buildings
41	04.3 Balance of Plant (BOP)

42	04.3.1 CW System
43	04.3.2 Other Balance of Plant

Figure A.2. Generic cost breakdown structure 2

Row No.	Activities within WBS	
1	PRE CLOSURE PREPARATORY WORK (Activity 0)	
2	0.1	Strategic Review and Decommissioning Plan Development
3	0.2	Environmental Impact Statement
4	0.3	National & Local Planning Permission
5	0.4	Article 37 Submission
6	0.5	Revise Station Maintenance Schedule
7	0.6	Revise Discharge Authorisations
8	0.7	Programme Management Development
9	0.7.1	Preliminaries
10	0.7.2	Integration Workstreams
11	0.7.3	Workstreams Tranche 1
12	0.7.4	Workstreams Tranche 2
13	0.8	Pre-Closure Planning Staffing Requirements
14	0.9	Environmental Monitoring programme
15	0.9.1	Environmental Monitoring
16	FUEL MANAGEMENT (Activity 01)	
17	1.1	Reactor Defueling and Fuel Despatch
18	1.1.1	Convert Interim Spent Fuel Storage for Autonomous Operation
19	1.1.2	Relicense Autonomous ISFS
20	1.1.3	Interim Spent Fuel Store Operation
21	1.1.4	Spent Fuel Transport and Disposal
22	1.1.5	Interim Spent Fuel Store Decommissioning
23	1.1.6	Spent Fuel Encapsulation Facility Planning
24	1.1.7	Spent Fuel Encapsulation Facility Construction
25	1.1.8	Spent Fuel Encapsulation Facility Operation
26	1.1.9	Spent Fuel Encapsulation Facility Decommissioning
27	SITE OPERATION & PLANT PREPARATION (Activity 02)	
28	2.1	Activity 2 Staffing Levels
29	2.2	Decommissioning Electrical Supply & Electrical Distribution
30	2.2.1	New Decommissioning Site Incoming Electrical Supply
31	2.2.2	New Decommissioning Site Electrical Distribution System
32	2.3	Active Waste Treatment System
33	2.3.1	New Effluent Discharge Arrangements
34	2.4	Site Overheads
35	2.4.1	Site Management & Arrangements, Facilities, Services
36	2.4.2	Operations and Project Support to Decommissioning
37	2.4.3	Records & Knowledge Management for Decommissioning
38	2.4.3	Programme Management and Controls
39	2.4.4	Site Staff Redundancy costs
40	2.4.5	Environmental Management
41	2.5	Corporate Support Costs
42	2.5.1	Corporate Staff Support
43	2.5.2	Regulatory Costs
44	2.5.3	Civil Nuclear Constabulary Costs (armed police force in charge of protecting civil nuclear sites)
45	2.5.4	Nuclear decommissioning fund (Fundco) Operating Costs
46	2.5.5	Department of Energy and Climate Change Charges
47	2.5.6	Insurance Costs During Decommissioning & Spent Fuel
48	MANAGEMENT OPERATIONAL WASTES (Activity 03)	

49	3.1	ILW Interim Storage Facility (ILW ISF)
50	3.1.1	ILW ISF - Store Emptying
51	3.1.2	Interim Waste Storage - Decommission & Demolition
52	3.2	Active Waste Treatment Systems
53	3.2.1	Mobile AETP
54	PLANT & REACTOR DECOMMISSIONING (Activity 04)	
55	4.1	Nuclear Island (NI)
56	4.1.2	Waste / Effluent Building (HQA / HQB)
57	4.2	Conventional Island (CI)
58	4.2.1	Turbine Hall
59	4.2.2	Other Conventional Island Buildings
60	4.3	Balance Of Plant (BOP)
61	4.3.1	CW System
62	4.3.2	Other Balance of Plant
63	SITE CLEARANCE & RELEASE for REUSE (Activity 05)	
64	5.1	Site Delicencing
65	5.1.1	Power Generation Site Area - Delicensing
66	5.1.2	Transferred ISFS Area of Site - Delicensing
67	5.2	Environmental Management
68	5.2.1	Landscaping of Generating Plant Area of Site
69	5.2.2	Landscaping of Interim Spent Fuel Store Area of Site

Appendix B

EGCDL-3 Global Task 3 (GT3) Breakout Session questions

1) Converting non-ISDC WBS to ISDC

During GT3 meetings we have discussed methodologies for converting non-ISDC format work breakdown structures into ISDC (Level 1 principal activities only). For most activities this is a simple exercise with one line item matching directly with one ISDC activity. However, some line items represent more generic activities and must be split between multiple activities. An example of this is the line item "Site overheads: Site Management & Arrangements, Facilities, Services". This activity could be split between Principal activities 6 and 8.

GT3 has discussed the following options as solutions to this problem:

- For low-risk items (Items that cost <1% of overall project expenditure)
  - Assign all costs to the dominant activity.
- For medium-risk items (I.e. 1-5% of overall project expenditure)
  - Assign 50% between two dominant activities.
- Critical items (>5% of overall project expenditure)
  - Take time to estimate the proportion of costs between 3 to 4 dominant activities and assign costs appropriately.

For all situations, any decisions/assumptions should be captured in a decisions log for the purposes of cost benchmarking.

The solution is proposed to reduce the amount of time spent on trivial/low-risk line items.

a. Do you agree with the principal behind the solution proposed?

b. Do you agree with the threshold used set to define a low (<1%), medium (1-5%) or critical item (>5%)?

2) Defining project boundaries

Within the EGCDL GT3 meetings, we have been discussing how project boundaries are set in different countries. We have found that some in the group set their decommissioning project boundaries narrower than others and do not include preparatory tasks that enable the decommissioning work (tasks such as upgrading an interim storage facility to enable defuelling, or R&D to enable facility characterisation/access). While neither method is right or wrong as costs for enabling tasks will be captured elsewhere, there is a risk that

cost benchmarking at a project or facility level will be influenced significantly by project boundaries.

a) If you were submitting data for cost benchmarking, where would you currently capture additional information such as the project boundaries and decisions/assumptions? Is there a need for a standardised cover sheet to capture this information?

b) Please discuss if there is a need to provide guidance on defining project boundaries in a future programme of work.

3) Change of ownership/liability

In some countries when nuclear power plant decommissioning begins there is a change of ownership/liability from the operating company to the company/entity that will decommission the facilities. Within EGCDL GT3 we have differences in procedure when an ownership change occurs. In some countries the minimum required is defuelling and in others it is removal of all operational waste. This difference would affect the cost of future decommissioning as POCO has not occurred in the first situation and therefore would affect project-level cost benchmarking.

Please discuss how this situation is managed in your country so that GT3 can establish a common practice.

4) Communication of ISDC

In the EGCDL GT3 report, we conducted a literature review and produced a timeline of key reports in the development and implementation of the ISDC. This exercise highlighted the global effort that has been put in to produce the ISDC and supporting documents. However, it is not common practice for countries to collect data in ISDC format or to have a set methodology for providing data in ISDC format.

a. What barriers have you faced when trying to implement ISDC in your country?

b. In your country do you believe that the ISDC is known of outside of the NEA expert group representatives?

   i. If so, what steps have been taken to achieve this?

   ii. If not, do you believe there is a need to communicate the benefits of the ISDC/ cost benchmarking in a more accessible format? E.g. a short summary (2 pages max) for communicating to decision makers and/or key stakeholders.