Radioactive Waste Management
2015

The Practice of Cost Estimation for Decommissioning of Nuclear Facilities

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NEA No. 7237

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- 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;
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The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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Foreword

Decommissioning of nuclear facilities used for both commercial and research purposes is expected to increase significantly in the coming years, and the largest of such industrial decommissioning projects could command considerable budgets. Several approaches are currently being used for decommissioning cost estimations, with an international culture developing in the field. The present cost estimation practice guide was prepared in order to offer international actors specific guidance in preparing quality cost and schedule estimates to support detailed budgeting for the preparation of decommissioning plans, for the securing of funds and for decommissioning implementation. This guide is based on current practices and standards in a number of NEA member countries and aims to help consolidate the practice and process of decommissioning cost estimation so as to make it more widely understood. It offers a useful reference for the practitioner and for training programmes.

The primary focus of the guide is on nuclear power plants, including both pressurised water reactors (PWRs) and boiling water reactors (BWRs). Although it mainly addresses single-unit sites, the approach is applicable to multiple-unit sites as well. With appropriate adjustments for the physical and radiological differences, and nomenclature and process modifications, the guide may be applied to any nuclear facility including research reactors, fuel fabrication facilities, reprocessing plants, accelerators and other sites.

The Decommissioning Cost Estimation Group (DCEG) of the NEA Working Party on Decommissioning and Dismantling (WPDD) produced this guide to accompany the DCEG guide to peer reviews of decommissioning cost studies. The emphasis in this guide is placed on peer reviews that are based on a reference methodology and are carried out and documented in a transparent manner.

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1. At the NEA until July 2014.
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1. Introduction

Organisations are required to produce three main types of decommissioning cost studies in order to obtain authorisation to perform decommissioning. They are namely for the purpose of:

- securing funding;
- preparing a decommissioning plan within the context of licensing;
- budgeting a baseline for decommissioning implementation.

These cost studies are updated at different stages of the lifecycle of a nuclear facility. Three observations can be made in this regard:

1. Each decommissioning cost study may be different in its details.
2. It is preferable to make comparisons between cost estimates over time, and it is important to have a stable structure for each cost study.
3. Consideration should be given to co-ordinating the updates of decommissioning plans and funding schemes in relation to updates in the cost studies.

This cost estimation practice guide was prepared in order to offer international actors specific guidance in preparing quality cost and schedule estimates to support detailed budgeting for the preparation of decommissioning plans, for the securing of funding and for decommissioning implementation. The guide is based on current practices and standards in a number of NEA member countries.

The aim of this guide is to help consolidate the practice and process of decommissioning cost estimation in order to make it more widely understood. It offers a useful reference for the practitioner and for training programmes.

This guide was produced to accompany the *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations* (NEA, 2012). The ISDC is recommended by the NEA, the International Atomic Energy Agency (IAEA) and the European Commission (EC) to act as a common platform for presenting cost estimates for decommissioning projects and to facilitate comparisons between cost estimates of decommissioning activities or groups of activities. The ISDC has been developed as part of a long-term international effort undertaken in recognition of a need to improve the presentation of cost estimates for decommissioning projects and consistency in the ways in which costs are estimated.

The ISDC sets out a standardised structure of cost items for decommissioning projects and provides general guidance on developing a decommissioning cost estimate. The ISDC presents a matrix of typical decommissioning activities (organised in three hierarchical levels) and cost categories for each element in the ISDC hierarchy. Thus, the ISDC focuses mainly on using the cost itemisation structure to ensure that all costs within the planned scope of a decommissioning project are reflected through the identification of all typical activities of any decommissioning project. The ISDC also addresses some aspects of contingency provisions, quality assurance and the traceability of data. The ISDC may also be effectively used as the base for a decommissioning cost calculation structure.

The ISDC should also enhance understanding of the individual decommissioning cost items.[1] Such a common tool is central to further improving transparency, auditability and reliability of decommissioning cost estimates. Accordingly, countries which have not adopted this structure are invited to do so and to apply it in their estimation practices.

This guide takes such aspects of the ISDC into account.

1.1 Objective

The objective of this guide is to provide a detailed process to describe quality estimates in terms of cost classifications; the basis of estimates; the structure of estimates; risk analyses of costs and schedules and contingencies; and quality assurance requirements followed by the licensee to ensure the estimate conforms to the requirements of its quality assurance (QA) programme.

1.2 Scope of the cost estimate guide

The primary focus of this guide is on nuclear power plants – both pressurised water reactors (PWRs) and boiling water reactors (BWRs). Although the guide mainly addresses single-unit sites, the approach is applicable to multiple-unit sites as well. With appropriate adjustments for physical and radiological differences, as well as nomenclature and process modifications, the guide may be applied to any nuclear facility including research reactors, fuel fabrication facilities, reprocessing plants, accelerators or other sites.

The scope of this guide includes presenting the attributes of a quality cost estimate and the content of cost estimates.

1. The ISDC and its predecessor, the "Yellow Book" (*A Proposed Standardised List of Items for Costing Purposes*, IAEA, EC, NEA, 1999) set out a generally accepted standardised decommissioning costing structure in order to enhance transparency, traceability, auditability and the comparability of costs.

1.3 Organisation of the guide

The remainder of report is divided into the following chapters:

- Chapter 2 covers the purpose and nature of decommissioning cost estimates, approaches to cost estimation and the major elements of a cost estimate.
- Chapter 3 examines the development of the integrated schedule of the activity-dependent work scope and the determination of the project critical path.
- Chapter 4 describes the attributes of a quality assurance programme applicable to cost estimation and the use and cautions of benchmarking the estimate from other estimates or actual costs.
- Chapter 5 describes the pyramidal structure of the report, and the scope and content that should be included in the cost study report to ensure consistency and transparency in the estimate underpinnings.
- Chapter 6 provides some observations, conclusions and recommendations on the use of this guide.

2. Cost estimation

This chapter addresses the purpose and nature of cost estimates, approaches to cost estimation, the structure of a cost estimate and the concepts of risks and contingencies.

2.1 Purpose and nature of decommissioning cost estimates

Decommissioning cost estimates may serve a variety of purposes. They may vary depending on the stage in the facility's lifecycle when the estimates are made, and the intended use and user of the estimates. For example, an estimate may be prepared for an operator's own planning or other internal need, or it may be produced for an external party, for example to satisfy a regulatory requirement or concerned stakeholders, who need a reassurance that the necessary funds to cover decommissioning costs will be available when needed, even in the event of a premature shutdown of the nuclear facility. Similarly, in the case of estimates undertaken at the conceptual design stage of a project, the two main purposes may be *i)* to enable designers and client organisations to establish overall project costs; and *ii)* to inform the long-term financing process to provide for future funds when a facility will be decommissioned. Later, when the decommissioning project planning has advanced as a facility nears the end of its period of operation, the cost estimate forms part of the basis for the detailed planning of the dismantling and site clean-up operations.

It is important to note that cost estimates should fit their intended purpose and be appropriate for the stage of the facility's lifecycle for which they are produced. Accordingly, decommissioning cost estimates should identify the purpose for which the estimates are prepared and describe the nature of the estimate, including the degree of detail and level of reliability of the information and the resources used to prepare the cost estimate. This description should be supported by the provision of sufficient information for a reader to understand the necessary limitations to the estimate. In addition, as noted in Section 4.2 below, an awareness of the broader context in which a given estimate is produced is also important to interpret the estimate.

As with all projects that evolve from their infancy (conception) through maturity (detailed definition), the degree of completeness and accuracy of a decommissioning cost estimate improves as more definitive information becomes available with each progressive phase. One way to describe this evolution of cost estimates is by reference to a system of classification. Various organisations use the concept of classification or class of estimate in order to describe the quality of the underpinning data, the completeness and reliability of the estimate. While a selected classification may be somewhat subjective, it provides guidance to the reader or reviewer as to what to expect from the estimate and underlying data. A number of these classification references are described in Appendix A. Where a particular classification is used to describe a particular estimate, the reader may need to be able to verify that the content of the estimate and the underlying data are appropriate for that particular classification.

2.2 Approaches to cost estimation

There are five recognised approaches to cost estimating:

1. **Bottom-up technique:** Generally, a work statement and specifications or a set of drawings are used to extract ("take off") material quantities required to be dismantled and removed and unit cost factors (UCFs) (costs per unit of productivity – per unit volume or per unit weight) are applied to these quantities to determine the cost for removal. Direct labour, equipment, consumables and overhead are incorporated into the UCFs.

   The process involves breaking the project down into its smallest work components or tasks, assigning the work into a work breakdown structure (WBS), estimating the amount of labour, materials and consumables to accomplish each task, the duration of each task and then aggregating them into a full estimate. Determining the overall duration in a bottom-up approach requires sequencing and resource levelling to be done as part of the scheduling process. A detailed breakdown into elementary work activities may also be done based on a detailed itemisation of the ISDC below the level of generic definitions together with linking the ISDC items to WBS items, as presented in NEA, 2012, Section 4.2.

2. **Specific analogy:** Specific analogies depend on the known cost of an item used in prior estimates as the basis for the cost of a similar item in a new estimate. Analogous estimating uses a similar past project to estimate the duration or cost of the current project.

   Adjustments are made to known costs to account for differences in relative complexities of performance, design and operational characteristics. It may also be referred to as ratio-by-scaling.

   Specific analogy estimating requires a detailed evaluation of the differences between a similar past project and the current project. Adjustment for these differences is an important element of this approach. It includes size differences, complexity differences, labour cost differences, inflation/escalation adjustments and possibly regulatory differences.

3. **Parametric:** Parametric estimating requires historical databases on similar systems or subsystems. Statistical analysis may be performed on the data to find correlations between cost drivers and other system parameters, such as units of inventory per item or in square metres, per cubic metres, per kilogramme, etc. The analysis produces cost equations or cost estimating relationships (CERs) that may be used individually or grouped into more complex models.

A parametric cost estimating model is made up of one or more algorithms or CERs that translate technical and/or programmatic data (parameters) about an activity into cost results. The algorithms are commonly developed from regression analysis of historical project information however other analytical methods are sometimes used. The models are very useful for cost and value evaluations early in the project life cycle when not much is known about the project scope. The models are dependent on the many assumptions built into the algorithms. Also, the validity of the model is usually limited to certain ranges of parameter values. For example, size differences of 100% between the past project and the current project would not be reasonable. Due to these limitations and constraints, it is incumbent upon the user to thoroughly understand the basis of a parametric model.

4. **Cost review and update:** An estimate may be constructed by examining previous estimates of the same or similar projects for internal logic, completeness of scope, assumptions and estimating methodology. This approach applies to updating a previous estimate to the current estimate and generally does not involve size difference considerations.

5. **Expert opinion:** This may be used when other techniques or data are not available. Several specialists may be consulted iteratively until a consensus cost estimate is established.

Table 1 provides a comparative overview of the estimating methods and their advantages and disadvantages.

Table 1: Estimating method comparison

Estimating method	Advantages	Disadvantages
Bottom-up	Most accurate as it accounts for site-specific radiological and physical inventory. Relies on unit cost factors (UCFs).	Requires detailed description of inventory and site specific labour, material and equipment costs for the UCFs.
Specific analogy	Accurate if prior estimates are appropriately adjusted for size differences, inflation and regional differences in labour materials and equipment.	Adjustments as noted may require detailed documentation and introduce approximations that reduce accuracy.
Parametric	Suitable for use for large sites where detailed inventory is not readily available. Suited for order of magnitude estimates.	Approximations based on areas or volumes introduce additional inaccuracies. There is no way to track actual inventory. Not suited for project planning of work activities.
Cost review and update	Suitable for large sites where detailed inventory is not available. Suited for update of previous estimates, or order of magnitude estimates.	There is no way to track actual inventory. Generally not suited for project planning of work activities.
Expert opinion	Suitable when expert opinion of the specific work is available. Can be used for estimating productivity of smaller tasks based on expert's experience.	Expert opinion may not be specific to the work activities. May not reflect the radiological limitations of the project.

The method most widely adopted internationally in estimating is the bottom-up technique, based on a building block approach known as the WBS. This building block approach follows the same logic whether the estimate is being generated to support a construction or demolition scenario. Using this approach, a decommissioning project is divided into discrete and measurable work activities. This division provides a sufficient level of detail so that the estimate for a discrete activity can apply to all occurrences of the activity. The building block approach lends itself to the use of UCFs (described later) for repetitive decommissioning activities. This estimating approach was originally developed and presented in the Atomic Industrial Forum/National Environmental Studies Project (AIF/NESP) Guidelines (LaGuardia, 1986).

2.3 Elements of cost estimates

There are four basic elements to a cost estimate: basis of estimate (BoE), structure of estimate, work breakdown structure and schedule and uncertainty analysis. These four elements are described in detail in the following sections.

2.3.1 Basis of estimate (BoE)

The basis of estimate is the foundation upon which the cost estimate is developed. It is based on the currently applicable decommissioning plan or decommissioning concept for the facility. Consistent and accurate cost estimates rely upon the documentation and underpinning contained in the basis of estimate. A typical list of items that might be included in the basis of estimate are shown in the following:

1. assumptions and exclusions;
2. boundary conditions and limitations – legal and technical (e.g. regulatory framework);
3. decommissioning strategy description;
4. end point state;
5. stakeholder input/concerns;
6. facility description and site characterisation (radiological/hazardous material inventory);
7. waste management (packaging, storage, transportation and disposal);
8. spent fuel management (activities included into a decommissioning project);
9. sources of data used (actual field data vs. estimating judgement);
10. cost estimating methodology used (e.g. bottom-up, specific analogy);
11. contingency basis;
12. discussion of techniques and technology to be used;
13. description of computer codes or calculation methodology employed;
14. schedule analysis;
15. uncertainty and management of risk.

Additionally, funding approaches, funding schemes and estimation of contributions to decommissioning funds may be required in the frame of cost estimation as part of the final item. Due to the specific nature of funding, it is not the subject of this document.

1. *Assumptions and exclusions*

A detailed list of all the assumptions and exclusions upon which the estimate is based is important in understanding the scope of the estimate. For example, assumptions may identify which buildings are included in the estimate and the extent to which they will be demolished, the disposition of radioactive and non-radioactive materials, transport distances to waste disposal facilities and the extent to which site restoration will be performed. Exclusions may comprise the disposition of electrical switchgear and transformers, transmission lines and certain roadways that may have a use in the future site application.

2. *Boundary conditions and limitations*

Legal and technical limitations and regulations under which the decommissioning work is expected to be performed should be identified. Guidance provided by the government's regulatory framework should be referenced or included as necessary.

3. *Decommissioning strategy description*

The selected decommissioning strategy for the facility should be identified and any reference studies leading to the selection should be included. Project management approach and involvement of contractors in the decommissioning project should be identified.

4. *End point state*

The intended end point state should be described in sufficient detail to clearly establish the facility and site conditions upon completion of decommissioning and termination of the licence.

5. *Stakeholder input/concerns*

The results and commitments from any stakeholder meetings and agreements should be clearly identified and incorporated as part of the estimate. Stakeholder input has had a significant effect on the planning and implementation of decommissioning projects. Cost considerations associated with stakeholder interests should be accounted for in the cost estimate.

6. *Facility description and site characterisation*

The facility being decommissioned should be described sufficiently to understand the scope of the estimate and the extent to which the facility is dismantled and demolished. The physical inventory of the equipment and structures should be included. A key part of this description should be the results of a facility and site characterisation programme, included by reference to the characterisation report.

The characterisation should address both the radiological and hazardous/toxic material inventory. The radiological inventory should include both contamination of components and structures and neutron activation of the reactor vessel components.

7. Waste management

The method for handling and disposition of waste including packaging, storage, transportation and disposal, should be defined including the types of packaging, storage facilities, transportation methods and disposal options. Historical and legacy waste should be presented separately to follow the ISDC structure.

8. Spent fuel management

Activities for spent fuel management included into the decommissioning projects should be identified such as management of the spent fuel during the termination of operation and management of the spent fuel after transportation from the reactor building. Use of the ISDC principal activities 02 and principal activities 10 may help to identify the activities related to the spent fuel management.

9. Sources of data used

The sources of data used to develop the estimate should be stated, as to whether actual field data were used versus estimating judgement. If field data were used, specific references as to the source of data should be included. Similarly, if estimating judgement was used the experience of estimators should be identified either through copies of their resumes or through a summary listing.

10. Cost estimating methodology used

The estimating methodology used should be identified as bottom-up, specific analogy, or any other recognised method. If specific analogy was used, references should be provided as to the source of scaling information. Use of the ISDC should be identified.

11. Contingency basis

There is inconsistent use of terms in the literature concerning "contingency" and "uncertainty" (see also Item 15). In this guide by the term contingency we address "potential increases in the defined cost of an activity item and is specific to that item" (NEA, 2012). When such increases occur these are mainly due to typical events during the work activities (tool or equipment breakdowns, delays, inclement weather, etc.) and the novelty of some of the tasks. Using this definition of contingency, it is expected that contingency funds will be fully spent during the project.

Contingency can be treated as a certainty based on field experience related to actual dismantling and appropriate contingency values, e.g. in terms of cost percentages, need to be advanced. Contingency costs could also be embedded within the risk analysis (Item 15).

12. Discussion of techniques and technology to be used

A brief discussion of decommissioning and dismantling (D&D) techniques and specific technologies upon which the estimate was based should be included. The detail should be sufficient to understand the concepts and special tooling, without constraining the potential substitution of other tools that might be applied. For example, segmentation of the reactor vessel internals might be performed using thermal torches, mechanical cutting, high-pressure abrasive water-jet cutting.

13. Description of computer codes or calculation methodology employed

A description of all computer codes used in the estimate, including any activation analysis codes, should be included. Any special calculation methodology employed, such as structural analysis or cost benefit analysis, should be identified.

14. Schedule analysis

The methods used and computer codes used to develop the schedule should be identified. Any special scheduling considerations, such as timing constraints imposed by operating facilities that could affect the start and completion of decommissioning, should be included.

15. Uncertainty and management of risk

In this guide, "uncertainty" is the word used to refer to cost variations from causes inside and outside the control of the project (NEA, 2012). Uncertainty inside the project scope is generally addressed as contingency and allowances. Contingency as noted earlier refers to events that occur during the work activities (tool or equipment breakdowns, delays, inclement weather, etc.) and the novelty of some of the tasks, and will be fully spent. Uncertainty outside the project scope is generally considered and addressed as risks, and include such events as currency exchange fluctuations, unexpected inflation rates, regulatory changes, availability of new technologies or disposal routes, etc.

Uncertainty contributes to risk in the cost estimate and may be addressed using probabilistic analyses.

The method used to develop a risk analysis should be included, and the approach to develop a risk register, mitigation techniques, and quantitative risk analysis should be identified. A comprehensive risk analysis should include "opportunity issues", where a positive effect might conceivably be encountered. As risks for decommissioning are a site-specific consideration, the Risk Analysis Team Workshop is an important element of risk planning and mitigation.

2.3.2 Structure of estimate

The following structure applies for any type of nuclear facility. The same estimating approach is applicable, although the data base of equipment and structures inventory would be specific to the facility.

It is constructive and helpful to group elements of costs into categories to better determine how they affect the overall cost estimate. To that end, the work scope cost elements are broken down into activity-dependent, period-dependent, and collateral costs as defined in the following paragraphs. Contingency, another work scope element of cost, may be applied to each of these elements on a line-item basis (as will be described separately) because of the unique nature of this element of cost. Scrap and salvage are other elements of cost where non-contaminated materials may be recycled for reuse, but it must be clear what these terms mean and whether credit was taken for a cost reduction.

1. *Activity-dependent costs*

Activity-dependent costs are those costs associated with performing decommissioning (hands-on) activities. Examples of such activities include decontamination, removal, packaging, transportation and disposal or storage. These activities lend themselves to the use of UCFs (described later) due to their repetition. Work productivity factors (or work difficulty factors – described later) can be added and applied against the physical plant and structures inventories to develop the decommissioning cost and schedule.

2. *Period-dependent costs*

Period-dependent costs include those activities associated primarily with the project duration: programme management, engineering, licensing, health and safety, security, energy and quality assurance. These are typically included by identifying the functions and services needed, including the associated overhead costs based on the scope of work to be accomplished during individual phases within each period of the project.

3. *Collateral and special item costs*

In addition to activity- and period-dependent costs, there are costs for special items, such as construction or dismantling equipment, site preparations, insurance, property taxes, health physics supplies, liquid radioactive waste processing and independent verification surveys. Such items do not fall in either of the other categories. Development of some of these costs, such as insurance and property taxes, is obtained from applicant-supplied data.

4. *Contingency*

Contingency is defined by AACE International (formerly known as Association for the Advancement of Cost Engineering International [AACEI]) (AACEI, 1984) as "a specific provision for unforeseeable elements of cost within the defined project scope, particularly important where previous experience relating estimates and actual costs has shown that unforeseeable events that increase costs are likely to occur."

The cost elements in a decommissioning estimate are typically based on ideal conditions where activities are performed within the defined project scope, without delays, interruptions, inclement weather, tool or equipment breakdown, craft labour strikes, waste shipment problems, or disposal facility waste acceptance criteria changes, or changes in the anticipated plant shutdown conditions, etc. However, as with any major project, events occur that are not accounted for in the base estimate. Therefore, a contingency factor needs to be applied.

Early decommissioning cost estimates included a contingency of 25% that was applied to the total project cost. However, as the composition of the estimates changed over time the need for contingency also changed. More recent estimating models apply contingencies on a line-item basis, yielding a weighted average contingency for the cost estimate which describes the types of unforeseeable events that are likely to occur in decommissioning and provide guidelines for application.

As noted earlier in Section 2.3.1, some estimators use risk analyses to determine contingency. This fact highlights the importance of describing how contingency was developed.

5. *Assets*

The cost estimate should consider the asset value, i.e. from scrap and/or salvage, from materials that were determined to be clean, or that were never exposed to radioactive or hazardous material contamination. The evaluation should be based on recent cost data obtained from scrap metal prices published daily in business newspapers and journals, and from salvage equipment companies. Some materials from operation period may have significant value in total decommissioning cost balance, as an example the heavy water.

Scrap is defined as removed materials that are certified to be clean, and may be sold to a scrap dealer for ultimate recycling as a raw material. Examples of scrap materials are copper wire and bus bars, stainless steel plates and structural members, carbon steel and stainless pipe, carbon steel structural shapes, beams, plates, etc. Salvage is defined as removed materials that have an identified market for resale or reuse in their current form at a specific facility (e.g. pumps, motors, tanks, valves, heat exchangers, fans, diesel engines and generators).

For metal scrap, material is sold on an as-is, where-is basis. There are no warrantees or representations as to the reusability of the item. Market prices are quoted as delivered to a specific city or port.

The market for salvageable materials from nuclear facilities is limited, owing to the very specific purpose for which they were intended. Market prices fluctuate depending on the buyer's expense to remove the component intact and to package it and transport it to its new application in reusable condition. These expenses reduce the resale value of salvaged materials.

- Unit cost factors

As noted in Section 2.2 the bottom-up cost estimating method lends itself to the use of UCFs modified by experience to account for work productivity (or work difficulty) factors. UCFs identify the activity task (cutting pipe, removing pumps, etc.), the labour duration and costs for the task, the equipment required and its cost, consumables used and any subcontractor mark-up costs. These elements of the task cost are then related to the unit being worked on such as per metre of pipe, or per kilogramme of pump weight. Work difficulty factors include any working constraints additional to ideal working conditions for which the UCFs are referenced. These UCFs are then applied to the entire inventory of systems and structures to determine the activity costs and the duration to perform them in a defined sequence. These UCFs are further described in Appendix B.

- Non-repetitive activity cost estimates

Non-repetitive or unique activities, such as reactor vessel and internals segmentation, steam generator and pressuriser removal (for large nuclear power plants), hot cell decontamination and demolition and glove box decontamination and removal, are typically estimated using a level of effort (LOE) crew man-hour and schedule duration methodology. Some guidance on the duration of these specialised activities may be extracted from reports of actual reactor vessel and internals segmentation activities at large and small power reactors, such as the US projects of Yankee Rowe, Connecticut Yankee, Maine Yankee and Big Rock Point. Similarly, activity durations for removal of steam generators and pressurisers may be extracted from actual records of the successful removal and disposition of the Trojan units and other NPPs. Unfortunately, specific data on crew-hours is generally not available for proprietary data reasons, and the estimator can at best compile an estimated crew size and composition (supervisors, foremen, craftsmen, equipment operators and labourers), and apply any actual duration information derived from the literature. Other international experience in France, Germany, Switzerland, Japan, etc., may provide source data for this experience. As new and updated information is received from similar projects, validated data should be incorporated into this cost estimating methodology periodically.

2.3.3 Work breakdown structure and schedule

The WBS is used to categorise cost elements and work activities into logical groupings that have a direct or indirect relationship to each other. The work groupings are usually related to the accounting system or chart of accounts used for budgeting and tracking major elements of the decommissioning costs.

1. *WBS levels*

The WBS elements are generally arranged in a hierarchal format. The topmost level of the WBS would be the overall project. The second level would be the major cost groupings under which project costs would be gathered. The next level would be the principal component parts of each direct or indirect cost category for that cost grouping. Subsequent levels are often used to track details of the component parts of the grouping so that a clear understanding of all the cost bases can be made.

2. *WBS dictionary*

The WBS should include a WBS dictionary which describes the associated activities performed or events occurring in the decommissioning programme.

3. Chart of accounts

The project management or accounting software used on major projects usually identifies categories of costs in terms of a chart of accounts. The chart of accounts is where the individual cost items of labour, equipment, consumables, capital expenditures, recycle services, transportation or disposal services are budgeted and cost-controlled on a rigorous basis. The ISDC defines typical decommissioning activities but also the cost categories (labour cost, investment, expenses and contingency), so the ISDC may be used for the identification of a chart of accounts in the decommissioning project. Principles for linking of ISDC cost categories are presented in the ISDC document (NEA, 2012) in Section 4.1.6.

In this context, it is important to distinguish between the role of the WBS and the ISDC. The WBS is a tool for organising the work in the decommissioning project, while the ISDC is a general list of typical decommissioning activities. It means that the same ISDC items (decommissioning activities) may be repeated in WBS items; while the WBS is unique structure for the decommissioning project. Typical distribution of ISDC Principal Activities in decommissioning projects is presented in the ISDC document (NEA, 2012) in the Section 4.1.3. This principal distribution may be further specified in the WBS of the decommissioning project.

The WBS items and the ISDC may be linked to facilitate transferring cost items calculated in the WBS-based cost calculation structure into the ISDC cost presenting format. Principles for linking these are presented in the ISDC document (NEA, 2012) in Section 4.2.

- Project phases

Decommissioning projects are usually performed in phases or periods describing specific activities of work. Typically, three phases are identified for immediate dismantling: Pre-decommissioning planning, D&D activities, and facility and site restoration. If deferred dismantling is selected, the phases may include: Pre-decommissioning planning, preparations for and operation of safe storage, deferred D&D, and facility and site restoration. The International Structure for Decommissioning Costing (NEA, 2012) follows this breakdown of decommissioning into ISDC Principal Activities that have been paraphrased and/or modified herein. The following paragraphs describe typical decommissioning project phases of work upon which the WBS is built.

1. Pre-decommissioning planning

The preplanning phase of the project, which can be early even before the facility is permanently shut down, involves the preliminary assessment of decommissioning options, conceptual cost estimates and schedules, waste generation and disposition estimates, and exposure estimates to workers and the public. The objective is to select a decommissioning strategy and funding approach that will meet the applicant/licensee needs and satisfy regulators. During this phase detailed engineering evaluations are performed on the methodologies and technologies to be used for decommissioning. This phase includes interaction with regulators and stakeholders for acceptance of the approach, particularly the proposed facility end point state.

Facility decommissioning follows deactivation; that is, after the processes of shutting down operations and removing legacy wastes such as large quantities of high risk, readily accessible radioactivity (spent fuel, sealed sources, etc.) or highly hazardous reactive chemicals such as bulk quantities of acids and bases. After shutdown the residual radiological and hazardous material will be stable and can be inventoried by measurement and calculation. This site characterisation phase is critical to identifying the scope of work to be performed. If the applicant/licensee elects to subcontract the decommissioning management to a Decommissioning Operations Contractor (DOC), the applicant/licensee will solicit bids from prospective DOCs, and select the DOC to perform the work.

2. *D&D activities*

This phase is the actual hands-on activities for decommissioning. It may also involve decontamination, removal, packaging, transportation and disposal or storage of systems and structures to meet end-state objectives. For example, for a nuclear power plant, this would include removal of the steam generators, pressuriser, reactor coolant pumps, reactor vessel and internals, all safety-related systems and structures, the turbine-generator, condensate system, feed water systems, water cooling systems, fire protection systems and, finally, building dismantling. For fuel cycle facilities, this would involve the removal of the main process systems and equipment.

A final site survey will be performed to ensure all residual radioactivity has been satisfactorily removed to meet licence termination criteria.

3. *Facility and site restoration*

During this phase redundant buildings and structures are dismantled and demolished, and the site is prepared to meet the desired end point state.

The reuse of facilities following decommissioning is encouraged when possible to conserve natural resources and to take advantage of the site infrastructure of equipment and structures. It is not truly a decommissioning activity. Unless there is a cost credit accrued to decommissioning in the form of an income source or sale of property, it is generally not included in decommissioning cost estimates.

4. *Preparations for and operation of safe storage*

This phase for the deferred dismantling strategy involves preparations to place the facility in safe storage for the dormancy period. Legacy wastes from operations are disposed of, systems are drained and de-energised, and areas of high radiation or contamination are sealed or locked to prevent inadvertent intrusion. Security measures are reviewed and modified as needed.

5. *Deferred D&D*

This phase following Safe Storage involves the re-activation of any electrical or mechanical systems needed to support decommissioning. The remaining work is similar to D&D as described earlier.

- Project management approach

The management organisation is the applicant/licensee staffing assigned to the administrative and technical oversight of the project. It includes the Project Manager, Assistant Project Manager, administrative managers (Security, Personnel/Human Resources, Financial/Accounting, Public Relations, Janitorial and others as appropriate), technical managers (Engineering and Planning, Cost and Schedule Control, Licensing, Waste Management, Health Physics and Radiological, Quality Assurance, Operations and Maintenance and others as appropriate). Below these levels are typically the superintendents in each discipline who oversee the subcontractor crews performing the work in the field or in the field office.

If the applicant/licensee elects to self-perform (sometimes called self-direct) the field decommissioning work, they may "subcontract" the field work to an in-house division which then provides its own project management staff, with comparable levels as above. The subcontracted group will report to the applicant/licensee organisation above. If the applicant/licensee elects to subcontract the field work to an external DOC, the DOC will establish its own management staff from its Project Manager on down through superintendents and foremen to direct the field work. Use of ISDC Principal Activities 06 and 08 may help to identify these activities.

Some estimates separate the management organisation from the hands-on work, as most management contracts (or subcontracts) are on a level-of-effort cost basis (that is, the organisation is reimbursed for all its costs plus a fixed or incentive fee).

2.3.4 Risk analysis – cost and schedule

Risk analysis is a means of dealing with decommissioning project problems that extend beyond the project scope, the risk potentially causing an increase in cost or an opportunity potentially resulting in a decrease in costs. Risk analysis has become an integral part of cost and schedule estimating in recent years.

Contingency, as defined earlier, addresses problems within the defined project scope, such as delays caused by inclement weather, interruptions caused by late delivery of equipment and supplies, on-site industrial accidents causing project stand-down for safety investigations, tool or equipment breakdown, craft labour strikes, waste shipping problems such as improper documentation or vehicle road safety concerns, or unanticipated plant shutdown conditions. These conditions are handled by a contingency line-item percentage based on experience, or a single value percentage on a bottom line cost.

Risk analysis addresses problems that are beyond the project scope, such as a change in regulations regarding worker exposure limits, site release limits, waste transportation and a change in waste disposal acceptance criteria, an extraordinary increase in costs for labour, equipment and consumables, exceptionally difficult decontamination campaigns, extraordinary difficult remote vessel internals segmentation campaigns, or delays caused by stakeholder intervention. These conditions are handled by a risk analysis as discussed herein.

Some estimators include contingency as part of the baseline estimate in-scope costs as these costs will be fully incurred. Risk analysis is then used to deal with the out-of-scope conditions. Other estimators combine the in-scope and out-of-scope problems in its risk analysis, and use the risk analysis to specify the amount of contingency. In either case, it is crucial to identify how contingency and risk are being applied.

The elements of a risk analysis generally consist of four parts, sometimes leading to an assessment or estimate of project contingency as discussed earlier. In general, the quantitative risk management process involves those parts and associated activities for each new or existing project of major financial value. The four parts are:

- qualitative (risk register);
- quantitative (Monte Carlo analysis);
- sensitivity analysis of major cost drivers;
- cumulative probability curve.

Qualitative risk analysis

1. Assemble a risk management workshop of personnel familiar with the project.

2. Develop a qualitative risk register of all potential risks (negative outcomes) and opportunities (positive outcomes) by:

- describing the potential risks/opportunities;
- assigning a probability to each risk/opportunities;
- assessing the severity should the risk/opportunity occur;
- giving each risk/opportunity a score (probability times severity).

3. Plan how you will prevent risks happening (or manage them if they occur). The highest scoring risks need to be considered and planned for in more detail.

Quantitative risk analysis

Quantitative risk analysis is a method of quantifying risks in order to determine the probability of achieving cost and schedule objectives and should be considered when (but not limited to):

- projects/estimates that require a contingency reserve for the schedule and budget;
- large, complex projects that require "go/no go" decisions (the "go/no go" decision may occur multiple times in a project);
- projects/estimates where upper management wants more detail about the probability of completing the project on schedule and within budget.

There are many quantitative risk analysis tools and techniques, for example:

- scenario analysis;
- decision-tree analysis;
- Monte Carlo analysis;
- sensitivity analysis;
- optimism bias.

In recent years, Monte Carlo analysis has become a popular choice which is a risk modelling technique that presents both the range, as well as the expected value, of the collective impact of various risks. It is useful when there are many variables with significant uncertainties. It can be a useful technique but expert advice is required to ensure it is properly applied, especially when risks are not independent of each other. Before undertaking or commissioning such an analysis, it is useful to know how data will be fed into the model, how the results will be presented, and how decisions may be affected by the information generated.

In addition, specific care needs to be taken when trying to analyse changes to the baseline assumptions or a manifestation of remote probability risks with very high consequences, e.g. early site shutdown, wide spread contamination. These types of events would normally present themselves as a complete change to the fundamental premise of the baseline plan and as such cannot sensibly be incorporated into a statistical risk model centred on a plan with defined start and end points built up using a pre-determined suite of baseline assumptions which is the case within the Funded decommissioning programme or FDP (normal station operations and closure).

Typically this type of event must be treated as a scenario rather than a contingency provision, complete with a high-level plan of what this scenario may look like if it occurred and what the cost consequences would be as the assumptions and their impacts will change any distribution profiles. This will result in a different cost probability distribution compared to the normal closure case. This would be particularly apparent if say the early closure was a consequence of a major plant event which significantly increased the complexity and costs of decommissioning the site. Once a scenario has been developed the gap between the baseline plan and the scenario could be utilised to underpin any quantitative analysis.

In summary, there is no right or wrong method and in fact it could be viewed as more of an art than a science. However, irrespective of the chosen technique, the critical factors required are to clearly document the purpose or expectation of the analysis, how the chosen method meets that expectation, and also to demonstrate a clear relationship with the estimate, assumptions and risk register.

3. Estimated schedule

The duration of a decommissioning project affects its cost importantly through the period-dependent costs and the selected technology for the activity-dependent work. The project schedule is an integral part of a detailed cost estimate. These two interrelated elements must be maintained in balance when preparing an overall cost and schedule estimate.

3.1 Activity-dependent schedule

The activity-dependent schedule draws from the cost estimate database to establish durations for each of the activities in the schedule. Each of the UCFs provides a duration estimate to perform the activity. The activity duration multiplied by the quantity of an item in the inventory provides an estimate of the overall duration to perform that activity. The UCFs also provide a manpower estimate to perform that activity. The number of labour hours multiplied by the quantity of an item in inventory provides an estimate of the overall manpower resources to perform that activity. These two elements, activity duration and activity manpower, are the input factors to the project schedule.

3.1.1 Schedule basis of estimate (SBoE)

In a similar manner for cost estimating, the schedule should identify the schedule basis of estimate (SBoE). The critical path duration of activity-dependent costs is used to establish the overall schedule for application of the period-dependent costs (project management). The cornerstone of project planning and schedule preparation and development is a formal SBoE, including:

- scope statement;
- assumptions;
- project constraints;
- work breakdown structure;
- assignment of labour resources.

3.1.2 Breakdown by phase

The breakdown by phase ties together all related activities in a chronological sequence to better define the work scope and schedule. Section 2.3.3 describes these phases in detail.

3.2 Schedule development

The preparation of a schedule is a well-developed process. The availability of proven software programmes greatly simplifies the work.

3.2.1 Work process flow chart (precedence diagramming method – PDM)

Activity sequencing requires the determination and documentation of the relationship between activities. The precedence diagramming method (PDM) is typically used to structure the relationship between activities. Sequencing usually begins with a chronological ordering of activities, based on a logical progression of events. For convenience, the estimator may choose to divide the decommissioning programme into individual periods or phases to track similar kinds of activities. Within each period the estimator would sequence the activities consistent with known schedule drivers. Individual durations for these activities would come from the estimator's experience, or from experience at other decommissioning projects.

Activity definition requires the combination of the scope statement and the use of the WBS to develop discrete activities that are unique and can be associated with a deliverable. The schedule work breakdown structure should be the same as the cost estimate work breakdown structure. Each activity in the work process flow chart has a predecessor and corresponding successor activity. A complex decommissioning programme would involve multiple parallel paths, to reduce the overall schedule of the programme.

Resources other than people can also be planned and analysed as part of the schedule development, and are routinely included in project schedules. Other resources could include radiation exposure limitations, critical pieces of equipment, use of stationary cranes, or utilities. Including these resources in the schedule will identify whether there are critical resource restraints during particular periods of time.

Once all resources are loaded into the schedule, critical analysis of the resource constraints and resource profiles will show the time-phased consumption of resources. Schedule development involves an iterative process of analysing start and finish dates, activity relationships, activity durations, resource availability and work calendars to optimise the overall schedule and project goals.

3.2.2 Determination of the level of detail in the schedule

This is a critical decision. If the schedule is prepared at too fine a level, the project runs the risk of being overwhelmed with data that project control staff is unable to maintain. On the other hand, a schedule with too little detail is insufficient to use in tracking progress, anticipating problems, or developing risk strategies. As a general rule, the estimator should schedule activities only at the level needed to control the work. This may be somewhat judgemental and depends on the skill of the project team, its past experience, the complexities of the activities and the risk involved in each activity.

For reporting purposes of the cost estimate for management/funding purposes, a summary level schedule may be provided that includes the principal activities to describe what work is being performed. A more detailed schedule may be included in an appendix.

3.2.3 Evaluation and optimisation of critical path schedule

The critical path is the longest sequence of activities in the work process flowchart. The critical path controls the overall length of the project. Any incremental change to any critical path activity will result in a corresponding change in the overall schedule. The estimator and the project management team should evaluate the critical path to determine what technological changes, parallel path changes, or duration estimate changes can be made to shorten the critical path. The overall schedule duration is one of the major cost drivers in a decommissioning project.

Once adopted by the estimator and project management team, the schedule becomes the baseline schedule for the project. It is against this schedule that project performance will be measured. It requires applicant/licensee buy-in and a commitment of management resources to support it.

3.2.4 Development of management staff

The applicant/licensee management staff is one of the major cost drivers in the estimate. Management costs are period-dependent; that is, the costs are a function of the duration of the overall programme. The applicant/licensee management organisation to oversee the programme must reflect the level of activities being performed during each period. Similarly, the DOC staff is also a major cost driver in the estimate. It is also a period-dependent cost and must reflect the activities being performed during each period.

3.2.5 Applicant/licensee staff

The applicant/licensee management staff is determined for the specific function needed to support the decommissioning programme. It should include force account labour (its own in-house crew employees) and all team members from the project manager through supervisors. The management team should review the specific project positions and the number of personnel in each position for the duration of each period.

3.2.6 Decommissioning operations contractor staff

The DOC staff must also be estimated to develop the overall cost estimate and budget for the project. In a similar manner to the applicant/licensee staff, the DOC staff positions are identified for each function and for each period.

3.2.7 Software and flexibility

There are several project management software systems and schedule systems on the market today including Oracle’s P6 and Microsoft’s Project. These systems are specifically designed for scheduling and resource loading management.

4. Quality assurance programme

Quality assurance (QA) in the nuclear industry is normally associated with safety-related design, procurements and operation activities, the objective being to ensure that systems, structures and operating procedures will perform their safety-related functions in normal and accident conditions. However, equally important is assurance that cost and schedule estimates for decommissioning (or design, etc.) are prepared accurately using approved plans and procedures for checking the estimates before they are used to establish funding mechanisms and to manage the project. An element of a quality estimate is one that has been developed in accordance with a rigorous QA programme. This section describes company-specific QA programmes and the use and precautions of benchmarking to validate estimate results. It is important that QA is applied both to the data and to processing data (through the cost estimation model applied). Assumptions should be made explicit and the basis of the calculations transparent.

4.1 American Society of Mechanical Engineers nuclear quality assurance-1 certified programmes

The American Society of Mechanical Engineers (ASME) established a nuclear quality assurance (NQA)-1 programme (ASME, 2008) to certify the design, procurement and operation activities for nuclear plants. The programme consists of a series of implementing procedures that describe the requirements for each element of nuclear plant design through operation. To be sure, its requirements are far in excess of what is needed to provide quality estimates but the principles upon which the programme is built constitute the core elements of a quality cost estimating programme. For cost estimating, most companies will prepare a quality assurance project plan (QAPP) specifically identifying how the company will implement quality principles for its estimates.

4.1.1 Company-specific QA programmes

The organisation (applicant/licensee or consultant) preparing the cost estimates and schedules should provide evidence that it has followed its company-specific QA programme for estimating. Typically, a copy of the QAPP may be provided with the estimate, or a synopsis of its major features described in the estimate report. The important features of a QAPP should include the following:

- Pre-estimating meeting of the estimating team to discuss the scope, objectives, methodology, sources of data, validated versions of computer programmes to be employed and expected output.

- Quality checking of the input data for the estimate, including physical inventory, radiological inventory, hazardous and toxic materials present, source of labour rates, purchased material, and services (packaging, transport and disposal).
- Any hand calculations (or spreadsheet analyses) should include the statement of the problem, method of analysis, source of data and the originator's signature and date of completion.
- Mid-project meeting of the team to discuss status of the estimates, problems encountered in use of the data, additional information required to complete the work and expected estimate completion date.
- Initial results meeting of the team to discuss estimate results and any unanticipated problems. Comparisons to similar cost and schedule estimates can provide valuable insight as to the accuracy of the estimate results.
- Final checking of the input and output results by personnel not previously assigned to the project for an independent evaluation of accuracy. All checking should be initialled and dated by the checker. Significant corrections must be incorporated into the final calculations.
- Final editing of the estimate reports prior to submittal to the customer (reviewer).

The above should be considered as an iterative process to achieve the desired quality of the cost estimate.

As noted earlier, the estimator may submit its QAPP prior to initiation of the work and provide a synopsis of the programme in its final report.

4.1.2 Quality of the data

The importance of the quality of the input data and source data for costs cannot be overemphasised. The input data, consisting of the physical description of equipment and structures and the radiological and hazardous materials inventory, should be obtained from actual plant specifications and reports. If there is any question as to the physical inventory, a site visit to spot check the major components and structures should be made.

The source data for development of UCFs, consisting of local labour, equipment and consumable materials costs, should represent the actual rates for that region of the country or be corrected by local indices from other local cities. Productivity rates used in UCFs, such as the number of metres of piping removed in a defined sequence (metres of pipe per hour) or cubic metres of concrete demolished per day, should be documented as to the source of this data, such as from a previous project or a well-accepted handbook of norms. In the absence of field source data, a detailed description of the task to be performed, estimated time to perform the task, crew size and composition, local labour costs and local equipment and material costs used in developing the UCF should be provided. Adjustments for work difficulty factors should be explained and justified.

Finally, a cross-check of the results to other cost estimates or actual cost data from field experience is an important step to ensure the validity of the estimate. This is discussed in greater depth in the next section.

4.2 Benchmarking

Benchmarking is to "measure the quality of something by comparing it with something else of an accepted standard" (Cambridge Dictionaries online, n.d.). There is no internationally accepted decommissioning cost standard. The NEA (2013b) indicates that, when comparing costs, "cost figures should not be taken at face value unless these ten elements and their history are specified in comparative tables". The ten elements are:

- 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 disposition facilities;
- disposition of spent fuel and on-site storage prior to emplacement in a deep geological repository;
- clean structure disposition and disposal of the site for new developments;
- contingency application and use in the estimates;
- availability of experienced personnel with knowledge of the plant;
- assumed duration of the dismantling and clean-up activities.

In the literature, one can easily find reported values that exceed or are lower than one's own project. Therefore, the quality of an estimate cannot in general rely on comparisons with other projects. Reviewers will require compelling evidence for the quality of the comparison.

Yet it can be a valuable exercise to compare cost and schedule against actual field decommissioning experience. Benchmarking may be accomplished by several methods including:

- comparisons with other studies;
- comparisons to actual field experiences;
- comparisons to decommissioning costing formulae.

The selected method for, and the quality of, the comparison will depend on the quality of the information available and the degree of detail provided for comparison. When possible, all three methods should be used.

Comparison with other studies is the most direct method for experienced estimators to validate the cost and schedule estimates. Generally, estimating consulting companies have an inventory of previous estimates that were prepared for other clients and can review those estimates against the current estimates. Other applicant/licensee estimators may have to rely on published information in literature, papers presented at conferences, or handbooks.

When making comparisons to other studies it is important to ensure the baseline estimates conform to the same assumptions and boundary conditions as in the estimate under review, or to be aware of how any differences in these may impact on the estimates being compared. The basis of estimate for both studies must be compared in detail and any differences noted for the comparison.

4.2.1 The importance of context in decommissioning cost estimation

An awareness of the context in which a decommissioning cost estimate is produced is an important consideration in understanding and interpreting the estimate. This is because the context both defines the nature of the estimate required (in short, what its purpose or function is within the system) and is also a fundamental cost driver, as it determines a number of key factors (assumptions, exclusions, boundary conditions, the attitude towards of risk and uncertainty) on which the estimate is based.

When seeking to make comparisons between decommissioning cost estimates, especially decommissioning cost estimates coming from another country, it is important first to analyse a wide range of different considerations. Although it is very difficult to precisely weigh the impact on the cost estimates of all these factors, their influence on the level and on the confidence of the cost estimate are fundamental, and therefore these have to be analysed in detail before any comparisons are attempted. The specific considerations may vary from country to country and over time and thus any listing in this report can be only indicative and will need to be adapted to be appropriate for the specific comparisons being made. Key considerations include:

- The overall policy framework governing nuclear energy in the country where the estimate was produced: the relationships with government, the strength of the industrial nuclear fabric, the response of the different stakeholders to decommissioning activities, the support (or otherwise) given to making progress on developing the nuclear waste infrastructure, including final repositories, the clearness of the strategy to be followed for decommissioning and waste management, etc.
- The regulatory framework for decommissioning: the regulatory framework under which decommissioning projects are to be undertaken has a great impact on the decommissioning scenario to be followed, the relative ease (or difficulty) that may be encountered in satisfying the regulatory requirements in order to progress in decommissioning projects, the specific end-state to be attained, as well as on a number of risks or uncertainties that may need to be taken into account in the cost estimate. Therefore consideration of the precise regulatory requirements is fundamental to the development and understanding of the decommissioning cost estimate. Specific considerations include: the regulatory philosophy applied; the completeness of the regulatory framework and level of detail in the regulations;

experience in application of the regulations for decommissioning and confidence in how these will be applied in practice.

- The experience gained from earlier decommissioning projects concerning both technical and financial aspects: positive or negative experiences from previous decommissioning projects will strongly impact the degree of confidence in the decommissioning cost estimates, the attitude towards risk and uncertainty and, therefore, the level of financial provision required to cover any perceived additional risk and uncertainties. The possibility to rely on feedback from earlier projects is also a key element to give confidence in the technical options set out in the decommissioning scenario used as the basis for the cost estimate and in the different UCFs applied. Being able to demonstrate that such experience has been applied in generating a cost estimate addresses potential concerns relating to whether care is being taken to prevent repetition of past mistakes, to choose the best decommissioning scenario, and that where possible actual costs and experience have been used in producing the cost estimates.

- Whether there is a possibility to develop a national or programmatic approach to decommissioning across multiple sites: possibilities to develop a national (such as the United Kingdom's Nuclear Decommissioning Authority [NDA], or Spain's Empresa Nacional de Residuos Radiactivos S.A. [Enresa]) or multiple site or fleet-wide approaches to decommissioning (such as that of Électricité de France [EDF], in France) may have significant impacts on cost estimates. Considerations include possibilities to mutualise investments and developing mock-ups of equipment or conducting engineering studies the results of which can be shared among a number of sites to be decommissioned, transferring knowledge and experiences from one project to another. Such considerations may lead to a series effect from synergies and productivity gains which may be incorporated into cost estimates.

- The integration of decommissioning planning with the overall system for management of wastes arising from decommissioning: the availability of the waste management and disposal pathways is a key determinant for establishing a robust decommissioning scenario for the cost estimate, taking into account the extent to which waste management and disposal costs are known, and the degree of confidence in the necessary site and transport logistics essential for maintaining a good dynamic for the overall decommissioning projects and the potential for delays in implementing the planned work.

- Responsibility for undertaking the decommissioning project: the allocation of responsibility for ensuring performance of the decommissioning project also has an impact on the cost estimate: for example where the work is to be performed largely by an external contractor will have a different cost profile to a scenario where the operator intends both to manage and conduct most of the decommissioning of the plant.

- Financial arrangements: the financial responsibility for estimating and managing the fund required for dismantling activities and the extent to which financial provision needs to be made for risk and uncertainty may also impact on the extent of financing that is required from the operator which may be reflected in the cost estimate. Other considerations include the specific tax regime that is applied and other specific financing requirements, for example whether there is an external fund supervisor or a fund is managed internally.

4.2.2 Comparisons to actual field experience

There has been a great deal of decommissioning field experience throughout the world and many lessons learnt have been published. Yet, comparisons of costs amongst actual projects should never be taken at face value.

In general the authors tend to characterise their projects as a success without describing all of the problems encountered that resulted in increased costs or schedule overruns. Often, the real experience is only available through hearsay evidence from sources within the industry that were close to the project. At the same time, contractors performing the work often consider their performance to be proprietary and are reluctant to share either good or poor performance experience.

Another significant issue is the type of contracts used to accomplish the decommissioning work. For example, a contractor working under a fixed-price/lump-sum contract for all or any part of the work scope is not required to reveal its actual cost of work performance. As has happened in many projects, the contractor may have underestimated the cost to perform specific scopes of work. For example, segmenting and removal of reactor vessel internals is probably the most challenging element of the whole project. The difficulty of performing this work remotely and underwater has proven to be a significant challenge to contractors. Once again, hearsay evidence indicates most contractors have underestimated this work by at least a factor of two, but because they bid the job on a fixed-price basis they were required to finish it with no additional cost reimbursement. This valuable cost information is never reported in the literature, making the reliance on actual field data a drawback when trying to benchmark estimate costs against actual costs.

Additionally, specific elements of decommissioning costs are handled differently in different countries in accordance with national policies or precedence. For example, the United States has adopted on-site storage of spent nuclear fuel as a legitimate decommissioning expense because the federal government has not provided a national repository for disposal. In other countries spent nuclear fuel is shipped to a central reprocessing site for recovery of reusable uranium.

Similarly, low- and intermediate-level wastes in some countries are treated under a national policy and the disposition cost may not be charged directly against the decommissioning project. Project management costs in some countries are handled separately from activity-dependent or period-dependent decommissioning costs and are not accounted for in the same manner.

Also, often the only information published on costs for a project is that of the total costs, with perhaps a breakdown of 10 to 15 major cost elements.

Nevertheless, with these caveats in mind, there is value in attempting to compare estimates against actual field data for better understanding the project at hand rather than for justifying projected costs. Reviewers will need specific comparative tables if further value is given to the comparison. Appendix C provides a summary of recent decommissioning projects where some cost information is available. Each case includes a description (*when known*) of the reasons for the actual cost differences.

4.2.3 Role of the ISDC in cost benchmarking

In this context, the role of the ISDC is very important to facilitate the decommissioning cost benchmarking. Based on experience from the NEA and IAEA decommissioning cost benchmarking projects, following items may be identified in the ISDC-based decommissioning cost benchmarking:

- Presentation of the decommissioning project and the facility to be decommissioned.
- Involvement of ISDC Principal Activities in the decommissioning project.
- Assumptions and boundary conditions for a decommissioning project formatted according to the ISDC Principal Activities.
- ISDC cost presenting format, i.e. the ISDC presenting matrix involving the ISDC hierarchical breakdown of typical decommissioning activities in vertical direction and cost categories in horizontal direction. Structure of the ISDC matrix is presented in the ISDC document (NEA, 2012) in Section 3.5. Additional parameters such as the work force, inventory and/or waste quantities may be included into the ISDC matrix.
- Context of decommissioning cost estimation, comparisons of cost data to actual field experience as presented above. These items are not formatted in the ISDC structure, and should be described in a narrative part.

5. Documenting the estimate in a cost estimate study report

The presentation of the results of the cost and schedule estimates is generally accomplished in an Overall/Final Report. From a reader's standpoint, consistency in format facilitates reviews in a timely manner. This is particularly important when estimators from different organisations are submitting overall reports for different reactor sites. Consistent formatting will aid the reviewer in quickly identifying and locating elements of a cost estimate, thereby simplifying the review process. The suggested pyramidal format presented herein is not meant to be mandatory but rather constructive guidance for estimators to follow.

5.1 Pyramidal structure of the study report

There is at present no international standard on the contents of decommissioning estimate study reports, yet a number of international best practices can be identified, and it is suggested that the "ideal" study report could have the structure identified hereafter, namely a pyramidal structure comprising:

- an executive summary, for a broad audience of high-level readers;
- the main body of the report, for an audience of specialists, external reviewers and technical decision makers;
- a set of supporting documents and data, for specialists and internal and external reviewers.

The final report may also contain at its start administrative forms indicating the approval process and subsequent revisions.

The information that would be provided in this structure – or in an equivalent competent study – is detailed hereafter. A sample table of contents for a cost estimate study report is shown in Table 2.

Table 2: Sample table of contents for a cost estimate study report

1. Approvals
2. Revision log
3. Executive summary
4. Introduction
5. Facility description and characterisation data
6. Scope of work/assumptions/exclusions/contracting strategy
7. Work breakdown structure, coding and dictionary
8. Basis of estimate
9. Dismantling methods
10. Cost estimate
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K. Estimate flow diagram

1. *Approvals page*

The approvals page contains the current issue or revision of the cost estimate study report, report originator and his/her name, signature and date, and all appropriate managers' signatures and dates (technical, project, information technology and quality assurance).

2. Revisions log page

Revisions or updates to the report would be recorded on this page with appropriate description of the need for the revision, and project manager's signature and date.

3. Executive summary

The executive summary provides a brief description of the objective of cost and schedule estimate, and any contractual or regulatory requirements mandating the estimate, a brief description of the facility to be decommissioned, a statement of the decommissioning strategy selected, a table of cost estimate results, a statement of the overall schedule for the project (in months or years), a statement of the risk analysis findings (the probability percentage of achieving the estimated cost and schedule) and any significant findings of recommendations or observations relative to the success of the project.

Executive summary should be succinct and at the same time be informative. It will constitute the initial text that any reviewers will read.

4. Introduction

The Introduction states the contractual or regulatory requirement for the estimate, a brief description of the facility to be decommissioned, a statement of the decommissioning strategy selected, a brief resume of the estimating team credentials, and classification of the estimate (Class 1, 2, 3 etc.).

5. Facility description and characterisation data (radiological and hazardous material inventory)

The facility description provides a listing and general description of the facility buildings and structures (the major reactor design and components, the turbine-generator system type and size, and all other specific major pieces of equipment) and the source of characterisation data (radiological and hazardous/toxic materials). It should also include a description of the site and environs involved in decommissioning activities, or excluded in the decommissioning cost estimate. Drawings or sketches of important areas may be included to familiarise the reviewer with the specific areas.

6. Scope of work, assumptions, exclusions, contracting strategy

This section is the core of the input data used in the estimate analysis, and should include the specific scope of work, all assumptions related to the scope of work, scope exclusions, contracting strategy (as discussed earlier, such as self-performance or use of a DOC).

7. Work breakdown structure, coding and dictionary

An overview of the WBS structure at level 2 or 3 should be given to facilitate an understanding of the major elements of the cost and schedule. It should include a WBS dictionary which describes the activities associated with each WBS scope of work. For large projects like a nuclear plant decommissioning, the WBS can be very detailed and confusing if a roadmap overview is not provided.

8. Basis of estimate (BoE)

The basis of estimate provides detailed descriptions of the assumptions and exclusions, boundary conditions, sources of data, and methodology to be employed in the estimate, assets, schedule and risk analysis. It is the backbone of the estimate and sets the groundwork upon which the cost and schedule output rests. The BoE should be broken down into specific areas of common elements as discussed earlier.

9. Dismantling methods

A general description of the major dismantling methods to be employed for the critical elements of the project should be included. The description should be generic to identify the conceptual techniques without being prescriptive, such as thermal cutting of vessel internals (without specifying the particular type of thermal cutting device), or concrete scarification (without specifying the particular tool or process). Often, typical types of equipment may be described, with photos if available, to guide the reviewer as to the intent of the planning. If a new or developmental technique is planned, more description may be required, with sketches or photographs included.

10. Cost estimate

A listing of the cost estimate results at a summary level should be provided. The level of detail from the WBS may be at level 2 or 3, with the detailed analysis or spreadsheet results included in an appendix to the report. The summary level estimate should indicate the costs in thousands (or millions) so as not to include too much clutter on the table. The year of monetary units should be clearly stated. Any contingency amounts should be stated as included in the summary, or listed separately on the table of results.

11. Schedule

Similarly, the schedule results at a summary level (WBS level 2 or 3) should be provided. Often a separate timeline of major milestone events is helpful in understanding when major events occur that drive the project schedule. The detailed schedule results should be included in an appendix to the report.

12. Benchmarks

Benchmarks of cost and schedule, if included should be described as to their source, reference year, applicability for facility size, similarity and relevance. The basis for any adjustments should be included, and the absolute value or percentage differences explained. The complete analysis of the benchmark(s) and adjustments may be included in the Attachments.

13. Risk analysis

The results of the risk analysis findings should be provided, including the Monte Carlo probabilistic estimate of the costs (probabilities at the 50% and 80% confidence levels [P50 and P80], for example), the sensitivity curve and the cumulative probability curve. The detailed risk register, quantitative risk analyses and any other related information may be included in an appendix.

14. Critical path analysis

Another valuable tool is a critical path analysis. It is a review of the major schedule constraints or opportunities that drive the schedule. It identifies potential activities that can lengthen or shorten a schedule if critical events can be shifted on or off the critical path.

15. Recommendations, opportunities and innovations

Like the critical path analysis, this section may identify potential recommendations, opportunities, or innovations through creative approaches in scheduling, project management, or new technologies to reduce costs and schedule. For example, using multiple crews/shifts for critical activities can shorten the schedule and reduce project management period-dependent costs.

16. Quality plan

This section should describe the QAPP applied for the estimate. It may be a summary level description of basic elements, or reference to the complete QAPP in an appendix to the report.

17. References

As in all quality reports, the references relied upon in the report and used in preparation of the estimates should be identified in this section. There are several internationally accepted referencing styles including the numerical referencing (as used herein). The applicant/licensee may choose to adopt a specific system for the cost estimate report.

18. Abbreviations and acronyms

The decommissioning industry is wrought with acronyms specific to the technologies applied in decontamination, removal, packaging, transport and storage/disposal. The applicant/licensee should include a comprehensive list of acronyms used or referred to in the report.

19. Appendices/attachments

Many of the chapters in the body of the report are supported by other sets of documents and data, which are also part of the overall study report. These can be quite voluminous and should be separated by the main body of the report in order to make the latter read easily. These documents should be referenced in the main report and should be provided in formats that are amenable to easy access, e.g. in the form of searchable texts on DVD.

6. Conclusions, observations and recommendations

In general, cost and schedule estimates have come a long way from the days of attempting to estimate nuclear decommissioning costs from the costs of dismantling old fossil-fuelled power plants by ratio of megawatts. The sophistication available in current computer codes affords the ability to handle large quantities of data and perform cost estimates rapidly. It further allows the ability to perform "what if" analyses so as to evaluate whether a better decommissioning strategy should be pursued. From a funding adequacy viewpoint, this is a valuable tool that should be used to protect the financial interests of all stakeholders. From a reviewer's standpoint, cost estimate standardisation and computerisation greatly facilitate the reviewer's ability to quickly and thoroughly determine the quality of the estimate and the reliability of the cost and schedule results.

The guidance provided herein is intended to create a "living" document, modified and updated when new and more detailed information becomes available in the literature and from experience in its use. Decommissioning cost estimation is not a new practice, and in fact has been ongoing since the early 1970s. Only recently have efforts been made to standardise cost estimate formats to facilitate reviews and ensure completeness. The work performed by the NEA, IAEA and EU to update the "Yellow Book" and to transform it into the current *International Structure for Decommissioning Costs (ISDC) of Nuclear installations* (NEA, 2012) will go a long way to establishing a standardised approach for cost estimation. As more consultants and estimators adapt these methodologies into computer codes, the ability to handle large databases is becoming a routine practice. The ISDC may be used for the identification of decommissioning project activities, for the definition of project assumptions and boundary conditions, as the basis for cost calculation structures and for harmonisation of the presentation of decommissioning costs. Use of the ISDC is recommended where possible and where the data exists in the decommissioning project, at least for the presentation of decommissioning project costs.

More importantly, using the cost and schedule estimates as a baseline and incorporating them into such programmes as the earned value management system (EVMS) (NEA, 2013a) provides the basis for tracking actual costs more accurately and controlling cost and schedule overruns. As in every new technology, the EVMS is expected to undergo an evolutionary process. However, the alternative of observing actual costs and schedules overrunning budgets by factors of two or more is clearly not the answer to sound business practice and stakeholder confidence in the nuclear industry.

6.1 Observations on completeness

A basic attribute of any estimate is that it is a complete representation of the work to be performed. Decisions regarding the adequacy of funds to pay for decommissioning can only be based on a sound, comprehensive cost and schedule analysis. While all estimators attempt to deal with absolute values related to the planned activities to be performed and the anticipated schedule to be met, the reality of the situation is that the work involves some uncertainty. Some of the uncertainty within the defined project scope can be accounted for by allowances based on best available information. Other uncertainties within the defined scope can be accounted for by contingency funds that are fully expected to be incurred and spent. Uncertainties dealing with probabilistic events are best handled within a risk analysis based on experienced judgment of the lowest, most likely, and highest cost of each item of the baseline cost. These costs should then be input into a Monte Carlo computer code to determine the probability of the most-likely and not-to-exceed costs and schedule. The risk analysis allows the estimator to visualise the importance of the major drivers through the sensitivity analysis, thereby highlighting those areas where tighter project controls may be needed.

6.2 Observations on accuracy

No estimate can be 100% accurate since the estimator is attempting to anticipate virtually every planned activity, problem area and potential resolution for issues that can change from numerous external causes. Allowances, contingencies and risk analyses are used to account for these potentially changing conditions to ensure sufficient funds will be available to safely perform the work. Every estimate should be subject to changes as site conditions evolve. Most countries accept this fact and allow for periodic updates every three to five years not only to account for inflation, escalation and regulatory changes, but also to incorporate new technologies and techniques to improve the safety and cost effectiveness, and to shorten the schedule.

6.3 Recommendations

This guide is intended as a starting point for the process of preparing cost estimations. Like a project's cost estimation, this guide should also be considered a "living" document, with updated information incorporated as the estimation process matures. It is recommended that the guide be shared with applicants/licensees and estimating consultants to prepare them for what will be expected in terms of quality and confidence in the estimates. It is also recommended that the ISDC be used, at least when presenting the cost for a decommissioning project.

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List of abbreviations and acronyms

AACE International	Formerly: American Association of Cost Engineering (AACE) and Association for the Advancement of Cost Engineering)
ALARA	As low as reasonably achievable
ASME	American Society of Mechanical Engineers
BoE	Basis of estimate
BWR	Boiling water reactor
D&D	Decommissioning and dismantling
DOC	Decommissioning operations contractor
EC	European Commission
EDF	Électricité de France
Enresa	Empresa Nacional de Residuos Radiactivos S.A.
FDP	Funded decommissioning programme
IAEA	International Atomic Energy Agency
ISDC	International Structure for Decommissioning Costing
MWe	Megawatt electric
NDA	Nuclear Decommissioning Authority
NFP	Norsk Forening for Prosjektledelse (Norwegian Project Management Association)
NPP	Nuclear power plant
NEA	Nuclear Energy Agency
PHWR	Pressurised heavy water reactor
PWR	Pressurised water reactor
QAPP	Quality assurance project plan

SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Company)
SSM	Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority)
UCF	Unit cost factor
VVER	Water-water energetic reactor
WBS	Work Breakdown Structure
WDF	Work difficulty factor

Appendix A
Classifications of cost estimates

As noted in Section 2.1 of the main report, various organisations use the concept of classification or class of estimate in order to describe the quality of the underpinning data, the completeness and reliability of the estimate. While a selected classification may be somewhat subjective, it provides guidance to the reader, or reviewer, as to what to expect from the estimate and underlying data. Where a particular classification is used to describe a particular estimate, the reader may need to be able to verify that the content of the estimate and the underlying data are appropriate for that particular classification.

A number of these classification references are described hereafter. Apart from the IAEA and UK NDA scheme, these classification systems have not, however, been developed in the context of nuclear decommissioning. The Canadian classification scheme is more qualitative than the others and is possibly the scheme that is most widely applicable.

The Canadian classification

Table 3 provides the classification system used by the Canadian Treasury Board (Huxley, 2002).

Table 3: Canadian cost classification system

Cost estimate classification summary – estimate attributes					
	Primary attribute	Secondary attributes			
Estimate classification	Project definition	Intended purpose	Methodology	Level of precision	Preparation effort
Class A	High (completed working documents)	Compliance with effective project approval (budget)	Measured, priced, full detail quantities	High	High
Class B (substantive)	Medium (completed design development)	Seeking effective project approval	Mainly measured, priced, detail quantities	Medium	Medium
Class C (indicative)	Low (project plan)	Seeking preliminary project approval	Measured, priced, parameter quantities, where possible	Low	Low
Class D	Lowest (described solutions)	Screening of various alternative solutions	Various	Lowest	Lowest

AACE International classification

AACE International establishes standards for the accuracy of cost estimates that are based on the degree of known information at the time of the estimate. The AACE International Recommended Practice 18R-97 (AACE International, 2005) provides such standards. Based on the criteria shown in Table 4[1], a conceptual estimate would fall into a Class 5 category, and a final detailed "ready to start" project would fall into a Class 1 or 2 estimate. An estimate made prior to permanent facility shutdown might be affected by subsequent operating activities that might change the final conditions of the plant, but generally to a very small degree. A Class 3 estimate according to the table would normally be used for budget authorisation or control, comparable to what would be needed to establish a decommissioning trust fund.

Table 4: AACE international cost classifications

	Primary characteristic	**Secondary characteristic**			
Estimate class	**Level of project definition** (expressed as % of complete definition)	**End usage** Typical purpose of estimate	**Methodology** Typical estimating method	**Expected accuracy range** Typical variation in low and high ranges [a]	**Preparation effort** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study of feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget authorisation, or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -50% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%	5 to 100

[a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

[b] If the range index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools.

1. Reprinted with the permission of AACE International, 1265 Suncrest Towne Centre Dr., Morgantown, WV 25605 United States. Phone 800-858-COST/304-296-8444. Fax: 304-291-5728. Internet: www.aacei.org/ E-mail: info@aacei.org.

ANSI standards and other classifications

The American National Standards Institute (ANSI), the AACE International (the "Association for the Advancement of Cost Engineering International", referred as AACE in Table 5 since 1992), the American Association of Cost Engineers (predecessor of "Association for the Advancement of Cost Engineering International," from 1956 to 1992, referred as AACE pre-1972 in Table 5), the Association of Cost Engineers (ACostE) in the United Kingdom, the Norwegian Project Management Association (NFP) and the American Society of Professional Estimators (ASPE) also have prepared cost estimate classification systems. These classification schemes are compared in Table 5, also reproduced with permission from AACE International.

The UK Nuclear Decommissioning Authority (NDA) also has guidance on cost estimate classification in their Project Control Procedure PCP-09, which is primarily aimed at approving budgets for funding on a very broad scale.

Table 5: Classification comparisons

<table>
<tr><th></th><th>AACE classification standard</th><th>ANSI standard Z94.0</th><th>AACE pre-1972</th><th>Association of Cost Engineers (UK) (ACostE)</th><th>Norwegian Project Management Association (NFP)</th><th>American Society of Professional Estimators (ASPE)</th></tr>
<tr><td rowspan="8">Increasing project definition</td><td rowspan="3">Class 5</td><td rowspan="3">Order of magnitude estimate
-30/+50</td><td rowspan="3">Order of magnitude estimate</td><td rowspan="3">Order of magnitude estimate
Class IV -30/+30</td><td>Concession estimate</td><td rowspan="3">Level 1</td></tr>
<tr><td>Exploration estimate</td></tr>
<tr><td>Feasibility estimate</td></tr>
<tr><td>Class 4</td><td rowspan="2">Budget estimate
-15/+30</td><td>Study estimate</td><td>Study estimate
Class III -20/+20</td><td>Authorisation estimate</td><td>Level 2</td></tr>
<tr><td>Class 3</td><td>Preliminary estimate</td><td>Budget estimate
Class II -10/+10</td><td>Master control estimate</td><td>Level 3</td></tr>
<tr><td>Class 2</td><td rowspan="3">Definitive estimate
-5/+15</td><td>Definitive estimate</td><td rowspan="3">Definitive estimate
Class I -5/+5</td><td rowspan="3">Current control estimate</td><td>Level 4</td></tr>
<tr><td rowspan="2">Class 1</td><td rowspan="2">Detailed estimate</td><td>Level 5</td></tr>
<tr><td>Level 6</td></tr>
</table>

IAEA types of estimate

The IAEA has identified three types of cost estimates which have a different level of accuracy (IAEA, 2005a). These cost estimate types are:

- *Order-of-magnitude estimate*: One without detailed engineering data, where an estimate is prepared using scale-up or -down factors and approximate ratios. It is likely that the overall scope of the project has not been well defined. The IAEA identifies a level of accuracy expected with this type of estimate of being about -30% to +50%.

- *Budgetary estimate*: One based on the use of flow sheets, layouts and equipment details, where the scope has been defined but the detailed engineering has not been performed. The IAEA identifies a level of accuracy expected with this type of estimate of being about -15% to +30%.
- *Definitive estimate*: One where the details of the project have been prepared and its scope and depth are well defined. Engineering data would include plot plans and elevations, piping and instrumentation diagrams, one-line electrical diagrams and structural drawings. The IAEA identifies a level of accuracy expected with this type of estimate of being about -5% to +15%.

The IAEA concludes that it is apparent from these estimate types and levels of accuracy expected that even in the most accurate case, a definitive estimate is only accurate to -5% to +15%. Moreover, it is reiterated that the cost estimator will need to exercise judgement as to the level that the input data will support. As noted earlier, the reader also may need to be able to verify that the content of the estimate and the underlying data are appropriate for that particular classification.

Appendix B
Unit cost factors

Unit cost factors identify the activity task (cutting pipe, removing pumps, etc.), the labour duration and costs for the task, the equipment required and its cost, consumables used and any subcontractor mark-up costs. These elements of the task cost are then related to the unit being worked on such as per metre of pipe, or per kilogramme of pump weight. These unit cost factors are then applied to the entire inventory of systems and structures to determine the activity costs and the duration to perform them in a defined sequence.

Cost estimating formula

Costs for repetitive activities (removal of pipe, valves, pumps, tanks, heat exchangers, ducting, electrical conduit and cable trays, concrete and structural steel) are estimated by the following formula:

Activity cost = inventory quantity X unit cost factor

The inventory of each type of component is developed from the site-specific information for the facility.

Unit cost factor formula

The unit cost factor is developed from a description of the activity to be performed, the estimated time to perform the activity under ideal conditions, the estimated productivity or work difficulty factor (hereinafter WDF), the applicable crew composition and number of workers of each category, and the equipment and consumables required to perform the activity.

UCF = (sum of labour cost + equipment and consumables cost) / unit quantity

Labour cost = (estimated time for activity X WDF X crew cost/hour) / unit quantity

WDF = % increase in time for the activity for the degree of difficulty expected

The application of *work difficulty factors* is intended to account for the productivity losses associated with working in a difficult or hazardous environment. The approach is widely used at operating power plants to account for difficulty in performing maintenance activities during outages. The application of this methodology to decommissioning activities is a natural and reasonable extension of this work adjustment factor.

Respiratory protection factor

Respiratory protection factor is intended to account for the difficulty of a worker performing activities while wearing a full-face respirator or supplied-air mask. The respirator impedes breathing, obscures vision due to the mask window and fogging, and adds stress from the straps around the head. The respiratory protection factor can have a value of 10 to 50%.

As low as reasonably acceptable (ALARA) factor

The ALARA factor is intended to account for the time spent preparing for an entry into a high radiation or high contamination area. This time is used to alert the crew to the potential hazards in the area, the specific activities to be accomplished while in the area, and emergency procedures to be implemented for immediate evacuation. This factor also accounts for the periodic training the crew would receive to maintain their radiation training and certification. The ALARA factor can have a value of 10 to 15%.

Accessibility factor

The accessibility factor is intended to account for difficulty of working on scaffolding, on ladders, in pipe tunnels, or in confined spaces. The limited degree of motion possible under these working conditions reduces the productivity of the worker. The accessibility factor can have a value of 10 to 20%.

Protective clothing factor

The protective clothing factor is intended to account for the time the worker needs to put on protective clothing for each entry and exit from a radiation controlled area. Typically, this represents four clothing changes per day assuming suiting up in the morning, a morning break, a lunch break, an afternoon break and end of the shift. The protective clothing factor can have a value of 10 to 30%.

Work break factor

The work break factor is intended to account for the time a worker needs to take a morning break, a lunch break and an afternoon break. Experience has shown worker productivity under stressful conditions improves when workers are allowed a morning and afternoon break. The work break factor can have a value of 5 to 10% (nominally taken at 8.33%).

Work productivity factor

The work productivity factor is intended to account for site-specific productivity differences in the workforce. These differences may arise through union bargaining agreements, severe weather factors (heat or cold), or other limitations. The work productivity factor adjustment is at the discretion of the estimator.[1]

Crew cost per hour = crew composition X average hourly rate for each craft (including contractor's overhead and profit).

Equipment and consumables:

Equipment = the cost of small tools and equipment needed for the activity/unit quantity.

Consumables = the cost of consumables needed for the activity/unit quantity.

The database for development of UCFs is derived from actual decommissioning experience, other contractor experience and reported results from successful decommissioning projects. Multiple-unit cost factor sets may be developed to account for the different work difficulty factors needed for each activity.

1. WDF for respiratory protection: 10 to 50% inefficiency, WDF for ALARA: 10 to 15% inefficiency, WDF for accessibility: 10 to 20% inefficiency, WDF for protective clothing: 15 to 30% inefficiency, WDF for work breaks: 5 to 10% inefficiency, WDF for productivity: estimator's discretion.

Appendix C

Benchmarks for light water reactors in the United States

Table 6 is a summary of US decommissioning projects for light water reactors (LWRs) and estimated and actual (or estimated to complete) costs.[1] The cost differences are substantial, reflecting the plant and site-specific differences and problems encountered as discussed in the following paragraphs. This is typical of decommissioning projects, complicating the ability to compare estimated to actual costs.

As noted in an NEA document,[2] "Comparability of entire project costs is difficult to achieve and cost **figures should not be taken at face value unless all boundary conditions and assumptions are made clear**. It is advisable to benchmark the costs of specific activities rather than of entire projects." Over-reliance on benchmarked costs can lead to inaccurate conclusions relative to the cost estimate. When benchmarking is used to support an estimate, comparative tables reporting the information available on the various cost elements should also be reported and a rationale given for the quality of the comparison.

The cost per megawatt electric (MWe) is especially misleading if taken at face value, particularly for the two BWRs Millstone Unit 1 and Big Rock Point where the cost for the smaller unit is a factor of ten greater than the larger unit. To a large extent, the cost to decommission a small unit requires essentially the same management staff as that for a larger unit. Since management costs represent in these cases approximately 50 to 60% of the total costs, the cost per megawatt is not a linear relationship with size of the unit.

The costs shown in the table also include actual or an estimated cost to store spent nuclear fuel on site in either wet or dry storage until the US federal government Department of Energy (DOE) accepts the fuel at a national repository. The repository at Yucca Mountain, Nevada was originally scheduled for operation for 1998, then 2005, then 2015, and finally defunded to effectively shut it down.

1. While it would be preferable to have detailed actual and estimated to complete costs for comparison in this table, the fact is the information in the literature is simply not available. For all of the reasons discussed earlier, the cost information reported in this table is incomplete. The values shown in the table are the best available data from the literature and from personal sources of one of the authors (T. LaGuardia).
2. "Estimation of Nuclear Facility Decommissioning Costs: Current Status and Prospects", NEA Working Party on Decommissioning and Dismantling, March 2012, Paris, France.

Table 6: List of recent US reactor decommissioning projects

Nuclear plant	Reactor type	Size (MWe)	Operating life (years)	Reason for closure	Estimated cost, USD millions (M)	Estimated cost USD (M)/MWe
Connecticut Yankee	PWR	582	28	Economic	820	1.41
Yankee Rowe	PWR	167	30	Economic, technical, regulatory	608	3.64
Maine Yankee	PWR	840	25	Economic, technical	592	0.71
San Onofre 1	PWR	410	24	Economic, technical	622	1.52
Rancho Seco	PWR	913	14	Public referendum	466	0.51
Trojan	PWR	1 130	16	Economic, technical	430	0.38
Zion units 1 and 2	PWR	1 040	24	Economic, technical	1 000 (2 units)	0.96
Three Mile Island unit 2	PWR	906	1.5	Accident	893	0.99
Millstone unit 1	BWR	652	25	Technical, regulatory	422 (remaining)	0.65
Big Rock Point	BWR	67	35	Economic, technical	420	6.27

Connecticut Yankee

At Connecticut Yankee, segmentation of the reactor vessel internals using underwater high-pressure abrasive water-jet cutting caused significant contamination of the Service and Fuel pool. It required the contractor to procure a remotely operated vacuum system to clean the abrasive and debris from the pools. The scope of work was further extended to include remediation of contaminated properties off-site, caused by the inadvertent release of contaminated concrete blocks to the local public for personal use. The scope was also extended by an additional USD 329 million to remediate below-grade soil contamination of Strontium-90 and Tritium not previously characterised.

Yankee Rowe

At Yankee Rowe, the utility discovered significant toxic-based paint on the exterior of the containment building, requiring special remediation efforts prior to demolition of the building. In addition, dry cask vendor problems with delivery of casks required a longer period of wet fuel storage. The local stakeholders refused to allow clean concrete rubble to be used on-site for fill of subgrade voids. These additional work scope items increased the schedule and cost of the project.

Maine Yankee

The Maine Yankee project had a number of significant scope changes that account for the difference in the estimate versus the actual costs. These differences include:

- increased costs to address post-September 11 additional security measures;
- increased costs for insurance post-September 11;
- relocation of the control room twice to maintain control of operable systems;
- additional soil removed to meet changed site clearance levels from the US Nuclear Regulatory Commission's 25 mRem/year to the State of Maine's 10 mRem/year criteria (a change that took place after the project started);
- additional costs to remove and bury all containment building interior concrete as radioactive waste instead of demolition and use as on-site fill;
- additional engineering costs to analyse containment building demolition by ram-hoe (hydraulic ram mounted on a backhoe) and blasting;
- additional costs to self-perform spent fuel dry storage after vendor failed to meet contract requirements.

No specific accounting for the magnitude of these individual changes is available at this time. These changes in scope were not anticipated when the original estimate was prepared. As noted earlier, contingency is an allowance for events within the defined project scope, and therefore would not be used for scope changes. The cost listed as USD 592 million is the best available actual cost and an estimate to complete the project.

San Onofre unit 1

At San Onofre, the applicant/licensee could not procure a pre-approved transport route for the reactor vessel disposal. Several routes were considered, but in each case local stakeholder resistance blocked the route. The reactor vessel remains on-site, stored in its transport container, pending an evaluation of alternatives.

Rancho Seco

At Rancho Seco, the applicant/licensee Sacrament Municipal Utility District established a funding limit of USD 19 million (later increased to USD 23 million) per year, charged to consumers in the form of a rate increase to pay for decommissioning. Accordingly, the project schedule was extended to meet this funding limitation. The licence has been terminated but the plant structures were not demolished.

Trojan

The Trojan reactor vessel and internals were transported intact to the disposal site in Washington State, at considerable savings to the project. The nuclear plant's close proximity to the disposal site made this packaging, transport route and disposal option a cost-effective measure. The decontaminated containment building remains intact, along with the administration building (leased for local office space), but the hyperbolic cooling tower was demolished.

Zion units 1 and 2

The two-unit Zion plant site licence was legally transferred from Exelon Nuclear to Energy Solutions, Inc. (Zion Solutions), and the decommissioning trust fund also transferred to Zion Solutions to complete the work on a fixed-price lump-sum basis. The project is ongoing.

Three Mile Island unit 2

Three Mile Island unit 2 is an estimate for the costs to decontaminate the highly contaminated portions of the containment building following the accident. Decommissioning work is expected to be more difficult because of the need for more remote tooling.

Millstone unit 2

Millstone unit 1 reactor vessel internals were removed but the reactor vessel remains within the secured containment building. No published information is available on the cost incurred to date, only the cost of remaining work is available as shown in the table. Final decommissioning will continue when Millstone units 2 and 3 are decommissioned.

Big Rock Point

The Big Rock Point project encountered several scope changes not anticipated at the start of the project and its different years for estimates account for the differences between estimate and actual costs. These differences include:

- Licence termination activities in 2004 reflect the inflationary effect of the cost of money (approximately 3.1% per year).
- Increased spent fuel management costs incurred as the vendor encountered fabrication difficulties and delays in delivery.
- Site restoration activities in 2004 reflect the inflationary effect of the cost of money.

These last two examples highlight the importance of accounting for scope changes for events beyond the original planned scope of work and the impact of inflationary effects on the reported actual data.

Appendix D

Role of the International Structure for Decommissioning Costing (ISDC) in decommissioning cost estimation

The *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations* is the result of the long-term effort for harmonisation in decommissioning cost estimation. The ISDC was developed mainly as a standardised platform for presenting costs of decommissioning projects. Individual items in the ISDC structure are typical decommissioning activities which may be identified in any decommissioning project for nuclear installations of any type, size and operational history.

Generic ISDC definitions of ISDC items facilitate understanding of individual cost items, which is the key issue in comparison of costs for various decommissioning projects. Comparison of decommissioning costs using a common platform may also facilitate defending the costs for decommissioning projects under discussion.

As the ISDC reflects principal phases of decommissioning projects and also the parallel supporting/managing decommissioning activities, sometimes it is considered as the WBS of a decommissioning project. It should be emphasised that the roles of the WBS and of the ISDC are different. The WBS is the project planning and managing tool specific for individual decommissioning projects, while the ISDC is the analytical platform which involves all typical decommissioning activities of any decommissioning project. In principle, the same ISDC activities with the same ISDC number may be repeated many times in various phases of a decommissioning project; the phases are defined by the specific WBS of a decommissioning project. In cost calculation cases for which the WBS is the base of cost calculation structures, the proper linking of WBS elementary items to ISDC items (recommended at the third ISDC level) is the key requirement for ISDC presentation of costs for decommissioning projects.

A proper understanding of ISDC cost categories (labour cost, investment, expenses and contingency) has a key importance in ISDC presentation of decommissioning costs; in organising feedback from ongoing decommissioning projects and in developing the links between the ISDC and costs accounting structures. Cost elements equivalent to ISDC cost categories may be identified in any specific cost calculation structures. Cost estimators may define additional lower levels of these main ISDC cost categories in order to allocate their own cost sub-items as defined in their costing systems. Definitions of ISDC cost categories reflect the different nature of cost items from financial/accounting points of view. Distinguishing between the investment cost items and expenses is normally defined by national accounting definitions and legislation.

Some cost items of specific cost structures are sometimes considered as equivalents of ISDC cost categories. This may cause some problems in converting the cost data from specific cost structure to ISDC. As an example, disposal costs may be considered as one of the cost categories in a specific cost structure. However, disposal is one of the decommissioning activities and not the cost category in ISDC definitions.

The ISDC presenting format is a matrix of ISDC generic definitions of typical decommissioning activities, for which the costs are presented as ISDC cost categories (labour cost, investment, expenses and contingency) per individual typical ISDC decommissioning activity and as total cost, i.e. the sum of ISDC cost categories. In some cases, when the ISDC cost categories are not available in full, the total cost item will represent the costs for individual ISDC decommissioning activities; then the ISDC activities may have indicative meaning. This presenting approach enables presentation of the decommissioning cost in various ways, depending on the structure of data available.

The ISDC third level is the reference level to which the cost items organised in other specific cost structures are normally allocated in order to present the cost for decommissioning projects in the ISDC format. Principles of transformation of costs calculated in specific cost structures into the ISDC are simple – it is important to know the content of individual cost items in a specific cost structure; based on this knowledge, the relevant ISDC typical activity will be identified, to which the cost item of the specific cost structure will be allocated. Total cost of the item in the specific cost structure normally includes a set of cost sub-items which are linked to relevant ISDC cost categories. The most used cost structure of non-ISDC-based cost structures are the WBS's for decommissioning projects; in these cases, the cost calculation items for ISDC conversion are the WBS items at the lowest WBS level. Converting of the cost data from any specific cost structure has two main steps:

1) Allocating the cost for elementary decommissioning activities in specific cost structures to selected items of the ISDC, best at the third ISDC level. As an option, the allocation can be done in principle also at the second and/or first ISDC level, especially in preliminary and/or not detailed costing stages. On the other hand, the allocation to ISDC items can also be done at ISDC levels lower to the ISDC third level.

2) Transformation of cost elements at the level of elementary decommissioning activities in the specific cost structure to ISDC cost categories, keeping in mind the understanding of ISDC cost categories as presented above.

The ISDC presenting matrix may be extended for additional parameters such as workforce, inventory quantities or waste quantities; these data may support the understanding of individual cost items. The workforce in particular may document the extent of workload which may be comparable in decommissioning projects but the labour costs may be very different due to large differences in hourly rates in different countries.

It is recommended to also present, along with the ISDC cost presenting format, the assumptions and boundary conditions for costing cases; these may support understanding of costs for individual ISDC items. It is recommended that the assumptions and boundary conditions for a decommissioning costing case in ISDC structure be elaborated at the second ISDC level at least. Another supporting format for ISDC presentation of cost for decommissioning projects is the "ISDC checklist" which indicates which ISDC decommissioning activities (best at the third ISDC level) were incorporated into the decommissioning costing case.

Appendix E.1

France: EDF methodology for decommissioning cost estimation

From 1996 to 1999, EDF conducted a study known as Dampierre 98 (or DA98), the aim of which was to validate the evaluations used for accounting provisions using actual costed parameters. To do this, it followed a two-step approach: first it evaluated the cost for dismantling a power plant with four 900 MW PWR reactors (in this case Dampierre) which was taken as being representative. Second, it extrapolated the reference cost with the power ratio in order to reconstitute the cost for dismantling the whole EDF PWR 58 reactor fleet.

This evaluation was updated in 2009 and renamed Dampierre 09 (or DA09), firstly to incorporate regulatory, technical and economic changes which had emerged since 1998, as well as experience feedback from dismantling programmes in progress (both on the EDF first generation fleet and the PWR fleets of other operators abroad, in particular in the United States) and secondly to examine the relevance of the "historic" calculation method, based on reference costs, using the evaluation process presented below.

The exercise carried out in 2009 by EDF was based on an update of the 1998 cost parameters (average hourly rates for EDF personnel, costs for using dismantling technology, etc.) using 2009 values and experience feedback from current and past operations. In particular, EDF made use of information drawn from waste management (packing, density, etc.) and the dismantling in progress of Chooz A, the only PWR currently being dismantled in France. EDF has also made use of the experience gained from construction operations for power plants, replacing steam generators and dismantling the first-generation fleet.

In order to evaluate the dismantling cost of the whole PWR Fleet, DA09 study reconducted the two-step approach adopted in 1998:

- First it evaluated the cost of dismantling the four units of a power plant, with the updated data, and based on precise, detailed identification of the operations to be carried out, the costs of each operation are evaluated using parameters relating to the quantities to be processed, unit costs and completion times. These parameters are subjected to sensitivity analysis to take into account identified uncertainties and determine cost brackets based on probabilities of occurrence. Yet, the study did not consist of evaluating the individually, which would have masked the fleet effect. On the contrary, it involved working out an estimate for a site with four 800 MW reactors, incorporated into a series of 58 reactors to be dismantled in order to take into account the size of the fleet and the uniform nature of its design. The objective was to calculate a cost which can be "directly extrapolated" for a power plant, including part of the costs borne by the fleet as a whole, as well as a "prototype" surcharge, which is also spread across all the 58 units. On the basis of these elements, EDF worked out a dismantling estimate for a standard site with four 900 MW units that could be directly extrapolated: this came to EUR 962 million (2008) not including contingencies.

- Second it extrapolated to the other power plants equipped with 900 MW reactors and to the 1 300 MW and 1 450 MW series to take a "size effect" into account. This is done in a series of calculations. Initially, the reference cost is split into fixed costs (i.e. independent from the size of the plant to be dismantled) and variable costs (i.e. dependent from the size of the plant). Then it proposes transposition keys for calculating the variable costs of the different plants of the fleet; and then calculates the impact of the number of plants on a site on the fixed costs. Finally, it reconstitutes the cost for the dismantling of the whole fleet.

Appendix E.2

Italy: Sogin's approach to decommissioning cost estimation

The Italian fleet of shutdown nuclear installations includes by four NPPs: two BWRs, of 840 MWe and 160 MWe respectively; one 270 MWe PWR and one 210 MWe GCR Magnox reactor; plus three other research facilities, i.e. the EUREX facility at Saluggia, OPEC/IPU facilities at the Casaccia Research Centre and the ITREC pilot reprocessing facility at Trisaia.

In 1999-2000, Sogin took charge of the legacy of the ENEL nuclear power plants with the goal to perform the decommissioning. Then, in 2003, it would have the same goal in relation to the other (Italian National Agency for New Technologies, Energy and Sustainable Economic Development – ENEA) research facilities. Consequently, the methodology chosen to calculate the decommissioning cost estimate was established with the following base hypothesis:

- A bottom up technique approach with the help of a decommissioning cost model.
- One cost estimate for each facility considering the analogies and differences between all.
- Consulting of specialists and experts at the early stage of the estimate.

The first cost estimate was made (2000-2002) for the plant hosting the 860 MWe BWR reactor and progressively for the other NPPs without considering the strong analogy between these due to the differences between the plants. Only for vessel dismantling of the two BWRs was it possible to make analogies. The cost estimate for the ENEA research facilities was set at an early stage in 2000-2003 on a preliminary budget base, and in 2009-2010 by turning to specialists and experts consultancy. The approach to the estimate needed to be bottom-up technique, mainly because of the differences between the plants and the shortage of analogous cost items and previous cost data. These estimates were made within the preparation of Overall Decommissioning Plans for these facilities.

The models were then abandoned and for the following years the cost estimate has been updated on the base of actual work progress, design improvements, contract availability and many other conditions that may influence the cost estimate, such as context changes and boundary conditions. Where actual costs may be used for cost factors and items definition, they have been used to finish the estimates.

According to the regulation framework and legislation of the country, the cost base estimate has been periodically reviewed and updated.

This review, based on the concept of a rolling wave planning, is made every four years for the entire cost estimate and yearly updated in detail for budget fine tuning. The actual costs are updated on current currency and quotations (budget year) at fixed currency.

The process used by Sogin to generate and review the cost estimates consists of four main steps.

Preliminary phase: activity cost is determined on the base of physical quantities and productivity standard factors related to work type, its complexity and radiation intensity.

Preliminary design phase: during this phase, main choices, requirements and hypothesis are determined and the estimate refined, taking into account the real operating conditions.

Detailed design phase: in this phase activities are known at a level that permit to sign a contract or to elaborate the working design and thereby further perfect the estimates with figures that come from the bill of quantities or working drawings.

Working (execution) phase: when starting the execution, quotations are replaced by the actual costs of work performed and by the estimates at completion.

Appendix E.3

The Slovak Republic: Approach to decommissioning cost estimation

Decommissioning costing in the Slovak Republic started in the early 1990s in relation to planning Bohunice V1 NPP decommissioning (PWR of VVER-type, 2x440 MWe), and has been performed predominantly by the DECOM company. In general, the costing approach is based on a bottom-up approach. In the beginning cost unit factors were taken over from the civil and machinery industry and adapted and extended for use in decommissioning of nuclear installations. Later these were updated from performed decommissioning tasks in the Slovak Republic (Bohunice A1 NPP) and worldwide. The bases for decommissioning costing are facility inventory databases, unit workforce, energy/consumption and cost factors, work difficulty factors, other related data and work breakdown structures for typical decommissioning scenarios.

An important milestone in decommissioning costing in the Slovak Republic was adapting the international decommissioning cost structure published in the document *A Proposed Standardised List of Items for Costing Purposes*" (so-called "Yellow Book", NEA, IAEA, EC, 1999). More recently, the *International Structure for Decommissioning Costing (ISDC) for Nuclear Installations* (NEA, IAEA, EC, 2012), has been implemented as the base for decommissioning costing calculation and reporting.

In addition, the costing approach includes a simulation of a comprehensive decommissioning and radioactive waste management system. The approach enables evaluation of a wide range of parameters in decommissioning scenarios for nuclear installations, such as cost, manpower, exposure, waste quantities and other project management data for decommissioning planning. Gantt charts for specific decommissioning projects can be generated, using the calculated project management data.

It is considered that the costing approach can be used universally for any type of nuclear installation, with any radiological conditions.

Decommissioning cost estimations are regularly updated for operational NPPs (V2 Bohunice – two VVERs, Mochovce 1 and 2 – two VVERs), for NPPs under construction (Mochovce 3 and 4 – two VVERs), for NPPs under decommissioning (A1 Bohunice – one heavy water gas-cooled reactor (HWGC), V1 Bohunice – two VVERs), and for non-reactor facilities (i.e. radioactive waste treatment facilities and spent nuclear fuel storage) in the Slovak Republic.

Appendix E.4

Spain: Enresa's approach to decommissioning cost estimation

Background

In Spain, the management of radioactive wastes, including spent nuclear fuel and the decommissioning of nuclear facilities is considered as an essential public service corresponding exclusively to the state. This public service is commissioned to the company Empresa Nacional de Residuos Radiactivos (Enresa), in accordance with the General Radioactive Waste Plan (GRWP) approved by the government.

The GRWP is the document that contains the strategies and activities to be implemented and performed in Spain in relation to radioactive waste management, the dismantling of facilities and associated economic-financial studies. It is approved by the cabinet and is periodically updated.

In this respect, Enresa is constituted as a vehicle and technical service of the administration, responsible for carrying out whatever functions might be assigned to it by the government.

The overall costs of management are assessed on the basis of the scenario, strategies and action programmes contemplated in the GRWP as the sum of the costs of the different areas of performance: low- and intermediate-level waste, management of spent fuel and high-level waste, decommissioning of facilities, other activities and R&D, along with Enresa's structural costs. Costs associated with general studies, preparation and execution of dismantling activities represent approximately 20% of total management costs (without consideration to the disposal of wastes generated during decommissioning).

Decommissioning strategy

The key elements of the national decommissioning strategy are considered on the GRWP. Presently, the general strategy established is the total dismantling (IAEA level 3) of light water NPPs, commencing three years after the definitive shutdown and with an expected duration of seven years.

From 2003 to 2006 Enresa carried out studies in relation to the cost estimates for the decommissioning of generic PWR and BWR nuclear facilities. Later, these cost estimates have been developed in detail for several specific sites.

In Spain there are ten nuclear reactors (seven PWRs, two BWRs and a graphite gas reactor) at eight sites.

The Vandellós 1 NPP was a graphite gas reactor which was dismantled until level 2 from 1998 until 2003. Presently, the remaining reactor building is in a dormancy period of 25 years.

Currently, Enresa is executing the total immediate dismantling of the Jose Cabrera NPP.

Jose Cabrera NPP decommissioning project

The decommissioning of José Cabrera NPP (Zorita) is the first total immediate dismantling project to be executed in Spain. It involves performing complex activities, such as the segmentation of all primary circuit components.

The José Cabrera nuclear power plant was the first commercial reactor in Spain. The construction began in 1964 and the plant went into operation in 1969. The nuclear steam supply system was made up of a light PWR reactor with electrical power of 160 MW and the auxiliary systems required for the operation of the facility under safe conditions.

What makes this dismantling project different from others conducted in Spain (Vandellós I) is undoubtedly segmenting the reactor vessel and its internal components, as well as directly conditioning the materials produced in disposal units (containers used up to now only in the El Cabril Disposal centre). To implement this, it has been necessary to first undertake major refurbishment work of the existing installations, especially in the former turbine building and in the containment building.

The decommissioning of Jose Cabrera NPP is ongoing. Presently the project is approximately 60% complete (2014). Initially the cost estimate was determined using a bottom-up technique where costs were estimated according to decommissioning activities taking in account previous experiences and considering contingencies. Nowadays, the estimated cost has been updated considering real costs corresponding to executed work (2006-2013) and the budget until the end of the project (2014-2017).

The main assumptions to establish the cost estimate for the dismantling of Jose Cabrera NPP are:

- cost estimate methodology:
  - real costs of executed work (2006-2013);
  - budget 2014-2017.
- storage of the spent fuel on-site until availability of centralised temporary storage (CTS);
- decommissioning strategy:
  - fully and remotely dismantling reactor internals and vessel;
  - small piece removal, packaging and disposal of components from primary circuit;

  - dismantling of the rest of the components (radiological and conventional);
  - decontamination and demolition of buildings;
  - site restoration.
- waste management:
  - to be disposed of directly in a waste repository;
  - a decommissioning cost estimate does not consider the radioactive waste (high, intermediate and low level) disposal cost.
- costs depending on schedule:
  - engineering, licensing documentation development and works support;
  - project management;
  - supervision of works (execution, quality assurance, radiological protection, industrial safety, etc.);
  - operation and maintenance of systems.
- other costs (taxes, security, insurance, general supplies, etc.).

Four years after the execution of the project started, a significant portion of the components of the Jose Cabrera NPP have been removed and their waste properly managed, including the reactor internals, the cooling pump, the pressuriser and 50% of the steam generator. Presently, the project is on time and on budget.

The analysis and assessment of real costs and lessons learnt associated to Jose Cabrera NPP decommissioning project will contribute with valuable information to obtain accurate cost estimates for future dismantling projects.

APPENDIX E.5

Sweden: Recent decommissioning cost estimation practice

In Sweden, decommissioning cost estimates are core inputs to the process of calculating licensee contributions to the Swedish national fund for radioactive waste management and decommissioning. The calculations of future costs that serve as a basis for the fees to the fund are prepared by the Swedish Nuclear Fuel and Waste Management Company (SKB) on behalf of the licensees and submitted to the Swedish Radiation Safety Authority (SSM), which reviews the estimates and then makes recommendations to the government on the appropriate level of fees required for payment into the national fund.

In recent years, there has been a shift by licensees away from generic decommissioning cost estimates for nuclear power reactors based on reference facilities and inventories, to site specific cost estimates.

Decommissioning of Swedish reactors

There are currently ten nuclear reactors in operation at three power plant sites in Sweden, four reactors at Ringhals and three each at Forsmark and Oskarshamn. Of these, three are PWRs (all at Ringhals) and seven are BWRs. In addition, there are three reactors that are no longer in operation and which are awaiting decommissioning: two BWR reactors at Barsebäck; and the first power-generating nuclear reactor in Sweden, the Ågesta pressurised heavy water reactor (PHWR).[1]

A number of developments in the national waste system form part of the decommissioning scenario. These include the planned repositories for long-lived waste (SFL) which is scheduled to be in normal (routine) operations in 2045. An application for extension of the existing repository for short-lived low- and intermediate-level waste (SFR) so that it also can include decommissioning waste was submitted to SSM in December 2014. One feature of the SFR extension is that it is being designed to facilitate disposal of one-piece reactor pressure vessels (without internals). Also, part of the extension is planned to be used for intermediate storage of long-lived waste (mainly reactor internals) pending completion of the construction of SFL. A special transport package is being developed for reactor internals. According to the industry's current planning

1. This description addresses only decommissioning cost estimation for Swedish reactors. In addition there are a number of other research and industrial facilities for which decommissioning is required, and for which cost estimates are also produced.

scenario, the first decommissioning waste is planned to be received at the expanded SFR facility in 2023.

From generic to site-specific: development of Swedish decommissioning cost estimates

The SKB has been commissioned by the Swedish nuclear power utilities to perform a number of investigations and studies to establish a reference technology for decommissioning and, based on these, estimate the costs to carry out decommissioning of the Swedish nuclear power plant sites. Up until recently these decommissioning cost estimates for nuclear power reactors were largely generic, based on reference facilities and inventories.

The first site specific reactor decommissioning cost estimates for Swedish reactors were presented in 2008 for Barsebäck units 1 and 2, which were shut down in 1999 and 2005 respectively and for which decommissioning is scheduled to commence when SFR is able to receive the decommissioning waste. A further site specific study was submitted in 2012 for the Ågesta PHWR, which operated between 1964 and 1974, and for which decommissioned is envisaged to commence before the end of 2020, according to the present scenario. The decommissioning cost estimates for Barsebäck and for Ågesta were produced by TLG Services, Inc. in the United States.

SSM has encouraged a shift to site specific decommissioning cost estimates in part because of a concern that a generic approach based on extrapolations from reactor type and power could lead to significantly underestimating the cost of decommissioning. This concern was reinforced by SSM's review of site specific decommissioning cost estimates for Barsebäck units 1 and 2 which indicated costs significantly higher than those calculated according to the generic approach. By shifting to site specific decommissioning cost estimates the conditions of the plant are reflected in a more consistent way. Generic approaches based on extrapolations from reactor type and power may contain greater uncertainties which could lead to underestimating the cost of decommissioning.

Decommissioning cost estimates for power reactors currently in operation

According to the industry's current planning scenario, decommissioning of the ten reactors is scheduled to commence between 2025 and 2045 (these dates refer to the commencing of the dismantling and demolition phases). The first of these reactors scheduled to be decommissioned are the two oldest reactors at the Ringhals nuclear power plant, unit 1 (a BWR) and unit 2 (a PWR).

Site specific decommissioning cost estimates for all ten nuclear power reactors currently in operation in Sweden were finalised during 2013. These studies are noteworthy as they are the first occasion that site specific decommissioning cost estimates for all Swedish reactors currently in operation have been produced by the industry and submitted to SSM.

Commissioning and publishing these most recent cost estimates was undertaken jointly by SKB and the licensees. The decommissioning cost estimates for Ringhals were produced by TLG Services, Inc. and those for Oskarshamn and

Forsmark by Westinghouse Electric Sweden AB. For all three studies, the results were presented according to the *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations*. The three studies are published in English and can be freely downloaded from the SKB website.[2]

The cost estimates take into account certain synergy effects when decommissioning a whole site with multiple units in series. These include, for example, that mutual resources within the utility staff organisation are shared, a shorter decommissioning project due to reduced lead time for the various tasks between the units, utilisation of the same decommissioning tools and equipment throughout the projects, possible erection of a combined waste treatment facility for multiple units, etc.

The decommissioning cost estimates themselves do not contain a risk analysis as such. Instead industry has presented certain analyses of risk and uncertainty as part of the overall industry assessment of future costs for radioactive waste and decommissioning.

The Swedish regulatory framework currently requires a review of costs for radioactive waste and decommissioning on a three-year basis. This allows periodical development of the decommissioning cost estimates with its supporting basis of estimates and risk analysis. The next submissions from industry are due in 2016, and SSM has stated that it intends to explore possible further developments to the decommissioning cost estimates and supporting materials with SKB and licensees, with risk analysis being one of the likely focuses of such discussions.

2. See: www.skb.se/Templates/Standard17139.aspx.

Appendix E.6

Switzerland: Decommissioning cost estimation practice

NPPs in Switzerland and the political situation

In Switzerland, five NPPs at four sites are currently in operation: Beznau I and II (365 MWe, PWR), Mühleberg (373 MWe, BWR), Gösgen (985 MWe, PWR) and Leibstadt (1 220 MWe, BWR). There are also four research reactors, of which three are permanently shut down and under decommissioning, and two central disposal facilities for radioactive waste. Disposal facilities for radioactive waste are situated in the surroundings of the NPPs as well. Switzerland's five NPPs have a total capacity of 3.3 GW, and an annual availability rate of approximately 90%.

On 25 May 2011, the Federal Council decided to phase out nuclear power. The Swiss parliament (National Council and Council of States) subsequently confirmed the Federal Council's decision by approving a stepwise phase out of nuclear power. Existing NPPs should be decommissioned at the end of their operational lifespan and not be replaced by new NPPs as originally foreseen. There is no foreseen date for the final shutdown of the NPPs. The Federal Council stated that the existing NPPs can be operated as long as they are safe. Nevertheless, the energy supplier BKW announced in October 2013 the final shutdown of its NPP Mühleberg in 2019.

Legal basis of the funds

In accordance with the polluter-pays principle, producers of radioactive waste in Switzerland are responsible for ensuring its safe disposal at their own cost. The various ongoing costs (e.g. studies carried out by Nagra, construction of interim storage sites, site selection procedure for deep geological repositories) have to be paid as they arise. Decommissioning costs and expenditure associated with the management (including disposal) of radioactive waste after a nuclear power plant has been closed down, are secured through contributions paid into two independent funds by the operator:

- decommissioning fund;
- waste disposal fund.

The Nuclear Energy Act and the Ordinance on the Decommissioning Fund and the Waste Disposal Fund form the legal basis for these two funds. Details of the funding system are regulated in the Ordinance on the Decommissioning Fund and the Waste Disposal Fund for Nuclear Installations (7 December 2007). The ordinance has been revised in 2014. As a modification, the operators now have to pay their contributions to the decommissioning fund until the end of decommissioning and there is new an extra amount of 30% of the overall costs to be paid.

In April 2014, the Swiss Federal Nuclear Safety Inspectorate (ENSI) issued a decommissioning guideline (ENSI-G17) that regulates the decommissioning process in detail and also some aspects of the financing.

Decommissioning fund

The decommissioning fund covers the costs arising from decommissioning, including dismantling and management of the resulting waste. Contributions are paid annually by the owners of the four NPPs and the central storage facility. The contributions are based on the estimated costs of decommissioning of each facility and determined by the Management Commission of the fund. They are reviewed and updated every five years by the Management Commission to ensure that sufficient funds will be available at the time of decommissioning.

Cost estimates

The cost estimates refer to specific decommissioning studies presented by the NPP owners and reviewed by the ENSI. The first decommissioning cost estimates for the NPPs have been done in the 1980s. Since 2001 the cost estimates are updated every five years. If during decommissioning such financial provisions prove insufficient, the owner of the facility concerned has to pay the difference within three years. In the case that the means of the fund are not sufficient to cover the costs of decommissioning of an NPP, the owners of the other NPPs are also liable for the amount in debt.

The costs of decommissioning are determined on basis of the current technical and scientific requirements and on the prices applicable when the calculation is being made (overnight costs). These costs have to be updated every five years based on information from the owner of each nuclear installation. When a nuclear installation begins operations, the initial costs are estimated. They are recalculated when a nuclear installation is shut down or when a substantial change in costs is expected due to unforeseen circumstances.

The cost studies for decommissioning are prepared by NIS Ingenieurgesellschaft mbH (NIS) (Germany) on behalf of the operators' organisation, Swissnuclear. These studies took account of the latest knowledge available regarding the decommissioning of nuclear power plants. NIS uses the calculating programme STILLKO. STILLKO is a programme for planning decommissioning projects and for estimating the technical cost and the staff costs (including radiological exposure). The programme is based on the decommissioning projects in Germany and respects the German experiences in decommissioning. ENSI reviews the cost studies from a technical point of view with the support of external experts (TÜV Nord).

The cost estimates presented in the Cost Study 2011 (CS11) are what is known as "best estimates". "Best estimate" costs are expenses based on a detailed technical and scientific concept, in accordance with the latest knowledge available and a clear time progression of events (based on a WBS). The cost estimates are adequate for the current status of the project; such divergences as were found are insignificant for the purposes of determining the contributions that should be paid into the funds. Hence, the revision of the Ordinance on the Decommissioning and Waste Management Funds for Nuclear Facilities shall take into account a contingency of 30% of the overall costs.

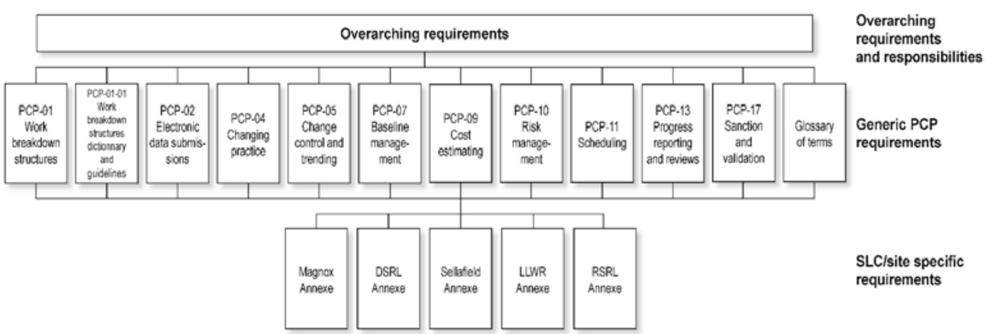
Appendix E.7
United Kingdom: Decommissioning cost estimation practice

Nuclear Decommissioning Authority (NDA) liabilities

The NDA owns and operates (under licence) 17 nuclear licenced sites in the United Kingdom. This includes ten Magnox reactor sites, two other non-Magnox reactor sites, the Dounreay and Sellafield complexes and the low-level waste repository.

The NDA's programme control procedures manual (PCP-M) specifies the requirements for programme and project controls across the NDA portfolio under the site licence company (SLC) management and operations (M&O) contracts. It contains specific requirements to be adopted by all SLCs, for baseline production and management, sanctioning, change control, reporting, risk management and opportunity realisation (see document structure below).

The NDA programme control procedure manual (PCP-M)



It is not intended to define how the SLCs should implement their internal programme controls processes and procedures but specifies the requirements SLCs should adopt to ensure that appropriate processes, systems and procedures are in place to support delivery of the programme.

The NDA is responsible for monitoring, surveillance and audit of the SLCs compliance, in all material respects, with this PCP-M. This includes conducting periodic Assurance reviews and sampling of SLC processes and outputs in line with the NDAs Assurance Working Instruction.

The document relating to cost estimating is PCP-09 which sets out the specific responsibilities and requirements of the NDA contractors for cost estimating and advocates that SLCs estimating process shall feature the following as a minimum:

- statement of the purpose and intent of the estimate;
- definition of discrete activity-based work packages;
- fully bounded scope of work;
- definitive listing of the basis and assumptions;
- use of an approved WBS to facilitate roll-up of cost within the contract work breakdown structure (CWBS) and project summary work breakdown structure (PSWBS);
- selection of appropriate estimating methodologies;
- parallel development of estimate and schedule, including milestones;
- identification of cost elements and resources:
  - labour – man hours;
  - labour costs;
  - subcontract costs;
  - material costs;
  - equipment costs;
  - other costs.
- alignment with the published site charging practice with regard to:
  - direct resources;
  - direct support resources.
- identification and assessment of risk;
- maintenance of an "estimating corporate memory", including a comparison of the actual outturn with the estimated costs in line with good practice;
- capture and dissemination of lessons learnt/demonstration of learning from experience (LFE);
- estimate and basis of estimate version control;
- appropriate estimate review and approval;
- formal sign off by the work scope owner.

The NDA recognises that estimates are prepared at a moment in time and reflect that stage of scope development. It is however expected that as the scope of work evolves through a series of staged development, the estimates are reviewed and updated to reflect the level of scope definition and as such appropriate estimate methodologies are used to generate the estimates.

The NDA requires all estimates to be prepared as deterministic "base estimates" directly relating to the activity scope as described and should not include unspecified contingency on account of either cost/schedule uncertainty or project event risk (other than agreed mitigation strategies).

The "base estimate" shall include the costs of all quantified in-scope work plus normal estimating allowances (i.e. base estimate = base scope costs + estimating allowances) but does not include cost contingency. All "base estimates" are required to be presented in constant money values.

To evolve the "total cost estimate", the NDA requires contingency to be added to the "base estimate". The evaluation of contingency requires the assessment of uncertainty surrounding the "base estimate" and the discrete risks pertinent to the scope of work.

In addition all estimates require a recorded basis of estimate available for review when requested. A fundamental characteristic of consistent and accurate cost estimates is the supporting documentation also known as the BoE. Documentation provides definitive traceability of the information in the estimate to minimise the variability associated with the inherent uncertainty of the estimating process.

The NDA also promotes the practice and utilisation of benchmarking within the industry. As such, it is an expectation that estimates can be validated by comparison and reconciliation to similar work.

Other non-NDA liabilities

In addition, EDF Energy also has requirements to produce decommissioning estimates for the nuclear power reactors currently in operation in the United Kingdom. Although EDF Energy formally does not have to adopt NDA PCP's requirements, their current estimating processes are nonetheless very similar to that described above. Most recently, operators wishing to construct new nuclear reactors in the United Kingdom are required to establish secure financing arrangements to meet the full costs of decommissioning and their full share of waste management and disposal costs of these reactors. Operators of new nuclear power stations are required to have a funded decommissioning programme (FDP) approved by the Secretary of State for Energy and Climate Change (Secretary of State) in place before construction of a new nuclear power station begins. The Secretary of State has published guidance about the preparation, content, modification and implementation of an FDP.[1] This guidance sets out principles

1. Funded Decommissioning Programme Guidance for New Nuclear Power Stations, Department of Energy and Climate Change, London, United Kingdom, December 2011, www.gov.uk/government/uploads/system/uploads/attachment_data/file/70214/guidance-funded-decommissioning-programme-consult.pdf.

that the Secretary of State will expect to see satisfied in the FDP, and information on ways in which an operator might satisfy those principles. The guidance includes a section concerning the decommissioning and waste management plan (DWMP). This is intended to assist operators in setting out and costing the steps involved in decommissioning a new nuclear power station and managing and disposing of hazardous waste and spent fuel in a way which the Secretary of State may approve.

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The Practice of Cost Estimation for Decommissioning of Nuclear Facilities

Decommissioning of both commercial and R&D nuclear facilities is expected to increase significantly in the coming years, and the largest of such industrial decommissioning projects could command considerable budgets. Several approaches are currently being used for decommissioning cost estimations, with an international culture developing in the field. The present cost estimation practice guide was prepared in order to offer international actors specific guidance in preparing quality cost and schedule estimates to support detailed budgeting for the preparation of decommissioning plans, for the securing of funds and for decommissioning implementation. This guide is based on current practices and standards in a number of NEA member countries and aims to help consolidate the practice and process of decommissioning cost estimation so as to make it more widely understood. It offers a useful reference for the practitioner and for training programmes.

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