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Cost Estimating for Decommissioning Nuclear Reactors in Sweden

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SSM perspektiv

I Sverige är avvecklingskostnader en viktig komponent i processen för beräkning av den kärnavfallsavgift som tillståndshavarna ska betala till kärnavfallsfonden.

I det nuvarande systemet ansvarar tillståndshavarna för beräkning avvecklingskostnaderna. Beräkningarna genomförs vart tredje år och lämnas in till Strålsäkerhetsmyndigheten (SSM) som granskar dessa. SSM lämnar sedan förslag till regeringen på en lämplig avgiftsnivå.

Under senare år har tillståndshavarna gjort ett skifte från generiska kostnadsberäkningar baserade på underlag från referensanläggningar med antagande om inventarieuppgifter, till anläggningsspecifika kostnadsberäkningar. Anläggningsspecifika kostnadsberäkningar för alla tio kärnkraftsreaktorer som idag är i drift i Sverige presenterades för SSM för vid halvårsskiftet 2013. SSM arbetar nu med att granska dessa kostnadsberäkningar. I granskningen kommer SSM bl.a att bedöma om kostnadsberäkningarna är väl förankrade, transparenta och stabila samt tar hänsyn till större risker och osäkerheter som är relaterade till avvecklingsprojekt. Ytterligare en viktig aspekt som SSM tar hänsyn till är om kostnadsberäkningarna reflekterar det planerade avvecklingsarbetet som redovisas i avvecklingsplanerna för anläggningarna.

SSM tog initiativet till studien som redovisas i den här rapporten, delvis som underlag för diskussion med tillståndshavare om förbättringar i kostnadsberäkningarna för att underlätta SSM:s granskning av dessa, men också för att ge stöd för utvecklingen av granskningsmetoderna. Studien har genomförts av Thomas S. LaGuardia och LaGuardia & Associates, LLC i Sanibel, Florida, USA. Thomas LaGuardia har lång erfarenhet av arbete med avveckling av kärnkraftverk. Han har mer än 40 års erfarenhet av planering, styrning och beräkningar av kostnader för stora avvecklingsprojekt samt att ta fram kontrollprogram. Utöver detta har han även erfarenhet av att granska planer och kostnader för anläggningar med lågaktivt avfall samt utveckling, genomförande och revision av kvalitetssäkringsprogram. Thomas LaGuardia har skrivit två avvecklingshandböcker i USA och bidragit till andra handböcker/handledningar internationellt.

SSM välkomnas kommentarer och förslag om studien. Dessa kan skickas per e-post till registrator@ssm.se eller simon.carroll@ssm.se, eller med vanlig post till Strålsäkerhetsmyndigheten, 171 16 Stockholm.

SSM Perspective

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.

Under the present system, the decommissioning cost estimates are produced by licensees every three years and formally 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.

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. Site specific decommissioning cost estimates for all ten nuclear power reactors currently in operation in Sweden were presented to SSM for the first time during 2013. Presently SSM is evaluating these latest studies in detail. In its review, SSM will be making judgments on whether the decommissioning cost estimates are well founded, transparent and robust, and take due account of major project risks and uncertainties. A further important consideration for SSM is that the cost estimates actually reflect the planned decommissioning work to be undertaken as set out in the decommissioning plans for the facilities.

SSM initiated the study presented in this report partly in order to facilitate the discussion with licensees on further improving the quality of the cost estimates prepared for submission to SSM; and partly to support the development of its methodologies for reviewing these decommissioning cost estimates.

The study has been conducted by Thomas S. LaGuardia, LaGuardia & Associates, LLC, Sanibel, Florida, USA. Thomas LaGuardia has long experience in the field of nuclear decommissioning with more than 40 years of experience planning and managing decontamination and decommissioning programmes; preparing and reviewing cost estimates for major domestic and international government decommissioning projects; preparing cost estimates and cost control programs for decommissioning; reviewing plans and costs of low-level waste facilities; and developing, implementing, and auditing quality assurance programmes. Mr. LaGuardia has written two Decommissioning Handbooks in the United States, and contributed to other handbooks internationally.

SSM welcomes comments and suggestions on the present study. These may be send by e-mail to registrator@ssm.se or simon.carroll@ssm.se, or by post to SSM, 171 16 Stockholm, Sweden.

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PART 2 – REVIEWING DECOMMISSIONING COST ESTIMATES

Foreword by the Author

This guide was prepared at the request of the Swedish Radiation Safety Authority (SSM) for the purpose of assisting the Authority in developing its approaches for reviewing decommissioning cost estimates for nuclear power reactors. Swedish reactor licensees are required to periodically submit to SSM cost estimates for decommissioning. Reactor licensees are preparing detailed site-specific decommissioning cost estimates, and accordingly SSM is developing its approaches for reviewing these estimates with the aim of ensuring a comprehensive and transparent review process can be applied.

Following the Introduction the core of this guide is organized in two principal sections:

- Part 1- the content of cost estimates, their completeness, and the quality of cost estimates; and
- Part 2 - the review of the estimates.

The first of these describes the expected content of an estimate to ensure completeness and, where useful, conformance with internationally accepted principles and practices. It describes the attributes contributing to a quality cost and schedule estimate, as a means for establishing a measure of confidence in the reliability of the estimates to establish a funding basis for decommissioning. Estimates involve some uncertainty; otherwise they would not be estimates. This section includes a discussion of uncertainty in estimates and how risk analysis can be used to address both contingency and uncertainty.

The second part of this guide describes a review process and provides checklists for the reviewer to use as part of the documentation for the review.
There have been many successful decommissioning projects reported in international literature, from which many lessons have been learned. However, there is a dearth of reliable actual cost data reported from these projects to use in benchmarking estimates against actual costs. In some cases the cost data is not accurately recorded, in other cases the information is deemed proprietary to the decommissioning contractors and the owner-licensees. This guide provides a discussion of these issues and caveats for over-reliance on comparisons to international experience. At best, such comparisons can provide an order-of-magnitude basis of an estimated cost versus actual experience. Nevertheless, benchmarking has value if the appropriate precautions identified in this guide are observed.

This guide is intended as a starting point for the process of reviews of nuclear reactor decommissioning cost estimates. It should be considered a ‘living’ document, with updated information incorporated as the review process matures and experience also accrues to the reactor licensees in the preparation of decommissioning cost estimates and decommissioning planning. It is recommended that the guide be shared with the licensees to give them guidance as to what is expected in terms of quality and confidence in the estimates. This approach has been applied successfully in other countries such as the U.S. and the UK.

1. INTRODUCTION

1.1 Objective

The objective of this guide for the Swedish Radiation Safety Authority (SSM) is threefold:

- to provide a detailed program to describe the content of cost estimates and their completeness with reference to quality estimates in terms of estimate cost classifications, basis of estimate, structure, risk analysis on cost and schedule and contingency, and quality assurance requirements as followed by the licensee to ensure the estimate conforms to the requirements of its Quality Assurance (QA) program;
- to provide a process to assess the quality of cost estimates and review the estimates with respect to data presented and underpinning explanations to support the estimate results. This will be supplemented with information (and analysis) concerning risk and uncertainty, as well as typical bench-marking information, and a checklist to ensure all elements of the estimate are included.
- to provide the applicant/licensee or estimator with guidance as to what will be expected in preparing a quality cost and schedule estimate.

1.2 Scope

The scope of the guide includes two elements: the content and quality of cost estimates and a review process. Where appropriate, comparison sources from other countries will be included to provide a basis for what is considered a quality estimate.

The main focus of this guide is nuclear power plants currently in operation in Sweden-- both the Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR). The general approach described in this guidance is also applicable to research or demonstration reactors, with appropriate adjustments for the physical and radiological differences.

1.3 Background

The SSM is responsible for the review of cost estimates to decommission nuclear facilities throughout Sweden as part of the overall regulatory process relating to the national system of financing of decommissioning and radioactive waste management. To prepare for the review of site-specific nuclear reactor decommissioning cost estimates for all Swedish power reactors, SSM commissioned this study to support the development of a review process that could be used by its staff in reviewing these cost estimates in a robust and consistent manner. As the Swedish reactor decommissioning cost estimates are updated and re-calculated periodically, it is anticipated that this guide will assist in ensuring that modifications to the estimates and underpinning data and reasoning are visible and any variations introduced can be fully assessed with reference to the original estimates.

Decommissioning cost estimates have been prepared by virtually every country to provide adequate funding for ultimate dismantling and license termination of the units. While several organizations have provided guidance within their respective countries there is no internationally accepted guide as to what constitutes a quality estimate. Organizations such as the Association for the Advancement of Cost Engineering International (AACEI) and US General Accounting Office (US GAO) have issued cost estimating classifications based on the degree of information at the time the cost estimates were developed. Each country has its own specific considerations that it must include to address issues related to the decommissioning of nuclear facilities.

The review of decommissioning cost estimates involves a multi-phase effort to establish confidence in the adequacy and quality of the estimate. Standards need to be established that represent an objective regulatory review process so that the licensee estimators know what will be required to include in the estimate. SSM plans on using this document to support the development of its review process for decommissioning cost estimates and for furthering a dialogue with licencees concerning the quality of cost estimates submitted as part of the regulatory process.

1.4 Decommissioning strategy and planning

The International Atomic Energy Agency (IAEA) addressed the issue of selection of decommissioning strategies in its TECDOC Report, "Selection of Decommissioning Strategies - Issues and Factors" (Ref. 1). The preferred strategy for nuclear reactor decommissioning in Sweden corresponds most closely to the IAEA (Ref. 2) category of Immediate Dismantling which it has defined as follows:

Immediate dismantling is the strategy in which the equipment, structures, components and parts of a facility containing radioactive material are removed or decontaminated to a level that permits the facility to be released for unrestricted use as soon as possible after permanent shutdown. In some cases, where unrestricted release is not feasible, the facility may be released from regulatory control with restrictions imposed by the regulatory body. The implementation of the decommissioning strategy begins shortly after permanent termination of operational activities for which the facility was intended, normally within two years. Immediate dismantling involves the prompt removal and processing of all radioactive material from the facility for either long term storage or disposal. Non-radioactive structures may remain on-site. Immediate dismantling is the preferred decommissioning strategy.

According to the Swedish Regulations concerning Safety in Nuclear Facilities (SSMFS 2008:1), preliminary decommissioning plans are required to be prepared and submitted to SSM for evaluation as part of the licensing process. Thereafter the decommissioning plans are to be kept updated by the licensee and communicated periodically to SSM. These plans are finalized prior to the actual start of decommissioning activities, and supplemented where necessary by more detailed plans for specific decommissioning projects within the overall decommissioning plan.

1.5 The international structure for decommissioning costing (ISDC) in Sweden

Cost estimation for the decommissioning of nuclear facilities has tended to vary considerably in format and content reflecting a variety of approaches both within and between countries. These differences do not facilitate the process of reviewing estimates and make comparisons between different estimates more complicated. A joint initiative of the OECD Nuclear Energy Agency (NEA), the International Atomic Energy Agency (IAEA) and the European Commission (EC) was undertaken to propose a standard itemisation of decommissioning costs either directly for the production of cost estimates or for mapping estimates onto a standard, common structure for purposes of comparison. The International Structure for Decommissioning Costing report (Ref. 3) was published in 2012. It updates an earlier itemisation published in 1999 and takes into account more recently accumulated experience. The ISDC aims to ensure that all costs within the planned scope of a decommissioning project may be reflected in the cost estimate. The report also provides general guidance on developing a decommissioning cost estimate, including detailed advice on using the structure. Swedish licensees have indicated that their upcoming reactor decommissioning cost estimates will be prepared in line with the ISDC.

1.6 The Swedish context for decommissioning cost estimates

The legal requirement for decommissioning cost estimates in Sweden is to provide a basis for SSM to estimate and recommend to the Government the required contributions to the waste fund and associated financing arrangements for decommissioning and waste management. It is important to note that cost estimates submitted to SSM should be fit for this particular purpose. SSM needs to be satisfied that it has received robust cost estimates with major project risks identified and due account taken of uncertainties and risk. This leads to particular expectations on the part of SSM for clarity (as to the actual results and how these are presented), transparency (assumptions, sources of data), and traceability (how data has been processed to yield the results). Thus the specific purpose for which such estimates are prepared for SSM should guide the determination of both the nature and content of a cost estimate presented to SSM (so that it is fit for that particular purpose) and its evaluation by SSM (what conclusions can SSM draw on costs, uncertainties and risks). SSM fully expects that decommissioning cost estimates will be based on the currently applicable decommissioning plans. SSM recognizes that the preliminary decommissioning plans will increase in the level of detail and specificity as actual decommissioning approaches, and thus would expect that any such uncertainties related to the decommissioning plan would be reflected also in the cost estimate. Moreover, it will be important that any significant variations between what is envisaged in the decommissioning plan and the basis for the decommissioning cost estimate are identified and the implications for the cost estimate explored. The goal of such checking is to assure consistency between the decommissioning plan and the cost estimate. In general, it is expected that the decommissioning plans contain realistic, clearly defined and achievable plans for decommissioning and waste management with any technology or gaps identified. Coherence with the decommissioning plan should be reiterated as an explicit check-list criterion.

1.7 Organization of this document

This guide is organized into two parts: Part 1 covers Cost Estimation for Decommissioning; Part 2 covers Reviewing Decommissioning Cost Estimates. Part 1 provides the basis for what a quality cost estimate should include, and Part 2 provides guidance on reviewing cost estimates with suggested detailed checklists. Both parts should be viewed in concert when performing a review to have all the necessary underpinning for the review.

Part 1 of this document includes the following chapters:
Chapter 1 – Introduction
Chapter 2 – Cost Estimation – This chapter covers the accuracy classifications adopted by international agencies and organizations, the approaches to cost estimation, the structure of a cost estimate and the concepts of risks and contingencies.
Chapter 3 – Estimated Schedule – This chapter covers the development of the integrated schedule of the activity-dependent work scope, and the determination of the project critical path.
Chapter 4 – Quality Assurance Programme Applied – This chapter 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 – Documenting the Estimate in a Cost Estimate Study Report – This chapter describes the pyramidal structure of the report, and scope and content that should be included in the cost study report, to ensure consistency and transparency in the estimate underpinnings.
Chapter 6 – Conclusions, Observations and Recommendations – This chapter provides some observations on completeness, accuracy and recommendations on its use as a guide.
Chapter 7 – References – Provides references used in this part of the guide.
Chapter 8 – Acronyms – Provides acronyms used in this part of the guide.

Part 2 of this document includes the following chapters:
Chapter 1 – Introduction
Chapter 2 – Reviewing the Contents of a Cost Study Report – provides a detailed checklist approach for the review of the cost study report.
Chapter 3 – Comparison to Other Estimates - Benchmarking – provides checklists to assist in reviewing benchmarked information.
Chapter 4 – Conclusions – provides comments on the approach and recommendations on the use of this guide.
Chapters 5 and 6 – References and Additional Reading Material - provide the background material used in developing this guide.
Chapter 7 – Acronyms - provides the acronyms used in this guide.

Part 1: COST ESTIMATION FOR DECOMMISSIONING

2. Cost estimation

As with all projects that evolve from their infancy (conception) through maturity (detailed definition), the degree of accuracy of the cost estimate improves as more definitive information becomes available with each progressive phase. The ascension of accuracy is identified by the classification level of the estimate from lowest to highest as it changes with the stage in the decommissioning sequence. Cost estimates tend to increase over time, influenced by the effects of inflation. Advances in technology may increase costs (for example, if more expensive robotic technologies are employed), or decrease costs (if the activity is accelerated and the duration reduced). Regulatory changes may increase costs if more rigorous requirements are imposed. Project management costs may be reduced if more effective cost control techniques are applied. It is difficult to predict with accuracy what overall effect these changes may have on the estimate, but in general historically the costs have increased over time.

Nuclear facility licensee's cost estimates should identify the appropriate classification of the estimates based the on knowledge of the level of reliability of the information and the resources used to prepare the cost estimate. The licensees should support their cost classification selection with sufficient information to defend the selection.

From the standpoint of the reviewer, the classification is an indicator of the degree of completeness and quality as related to the inherent uncertainties at the decommissioning stage of the nuclear power plant. As actual decommissioning approaches, a clearer understanding of nuclear plant conditions and characterization is available to reduce some of the uncertainties (radiological inventory, for example) and therefore improve the estimate accuracy.

The ultimate objective of the estimate is to assure adequate funding for decommissioning, starting at the earliest possible time to allow for adequate collections from the ratepayer (electricity consumer). As actual decommissioning approaches, adjustments to the funding collections can be made based on updated estimates incorporating clearer objectives and greater accuracy of work to be performed, and addressing any underlying uncertainties in the assumptions thereby improving the accuracy of the estimates.

This Chapter covers the accuracy classifications adopted by international agencies and organizations, the approaches to cost estimation, the structure of a cost estimate and the concepts of risks and contingencies.

2.1 Classifications of cost estimates

Various internationally recognized organizations use the concept of Class of Estimate in order to describe and assess the quality of the underpinning data, the completeness, and reliability of the estimate. While a selected class may be somewhat subjective, it provides guidance to the reader, or reviewer, as to what to expect. There are several international classification references available, but none of them have been specifically developed in the context for decommissioning. The Canadian scheme is more qualitative than the others and will be included for purposes of illustration. The Association for the Advancement of Cost Engineering International (AACEI) classifications have been peer-reviewed internationally, and is more definitive as to the degree of completeness and accuracy of the estimate but perhaps more difficult to apply. Appendix A provides the AACEI and other classifications in current use.

1. Responsibility of the applicant or licensee

It is important to note that cost estimates should be fit for their purpose. At the conceptual stage of a project a lower cost classification of estimate is sufficient to identify major cost drivers and the areas of principal concern. At a more advanced stage of the project one would expect a higher classification to be provided by the licensee.

The applicant/licensee has the responsibility to select the level of classification for the stage of the project. The applicant/licensee should include sufficient documentation in support of a classification selection based on the uncertainties inherent in the estimate at the stage of decommissioning (planning versus actual decommissioning). As will be discussed later, the uncertainties include allowances, contingency, risks and risk mitigation accounted for in the estimate.

2. The Canadian Classification

Table 1 provides the classification system used by the Canadian Treasury Board (Ref. 4).

Table 1: Canadian Cost Classification System

Table 1 – 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

2.2. Approaches to cost estimation

There are five recognized 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 (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 unit cost factors.

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. 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.

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 meters, per cubic meters, per kilogram, etc. The analysis produces cost equations or cost estimating relationships that may be used individually or grouped into more complex models.

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.

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 2: 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 labor, material and equipment costs for the UCFs
Specific Analogy	Accurate if prior estimates are appropriately adjusted for size differences, inflation and regional differences in labor 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 Order of Magnitude Estimates	There is no way to track actual inventory. 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 Work Breakdown Structure (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 unit cost factors (described later) for repetitive decommissioning activities. This estimating approach was originally developed and presented in the AIF/NESP Guidelines (Ref. 5), and was followed in the ISDC guidance as well (Ref. 3). From a funding regulatory standpoint, the Bottom-Up method provides the most accurate estimate and assurance of credibility and transparency. It is the recommended method for applicant/licensees to use for SSM review.

2.3 Elements of a cost estimate

There are four basic elements to a cost estimate: Basis of Estimate (BoE), Structure of Estimate, Work Breakdown Structure and Schedule, and Risk Analysis. These four elements are described in detail the following sections.

2.3.1 Basis of Estimate

The basis of estimate is the foundation upon which the cost estimate is developed. It is based on the currently applicable decommissioning plan 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 & 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 characterization (radiological/hazardous material inventory)
7. Waste management (packaging, storage, transportation, and disposal)
8. Sources of data used (actual field data vs. estimating judgment)
9. Cost estimating methodology used e.g. Bottom-Up, Specific Analogy
10. Contingency basis
11. Discussion of techniques and technology to be used
12. Description of computer codes or calculation methodology employed
13. Schedule analysis
14. Uncertainty, Contingency and Management of Risk

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, the use of interim waste storage disposal facilities, and the extent to which site restoration will be performed. Exclusions may include 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. Other limitations such as free-release criteria, employee exposure limits, or other land restrictive criteria, or generic criteria from another country which may be used in the estimate should be identified and the implications for the estimate discussed.

3. Decommissioning Strategy Description
The preferred strategy in Sweden is prompt dismantling from both SSM's viewpoint and the nuclear plant operators. In Sweden, strategy refers to the "site" as a whole, where there is more than one facility on the site and an individual facility's decommissioning is coordinated with the decommissioning of other facilities as well as any ongoing operations.
The major elements of the prompt dismantling strategy should be described sufficiently to capture the basic principles to be incorporated in the work. The description should be fully consistent with the decommissioning plan.

4. End Point State
The intended end point state should be described in sufficient detail consistent with the decommissioning plan to clearly establish the facility and site conditions upon completion of decommissioning and termination of the license. Any deviations such as generic criteria or if criteria from another country are used, they should be identified and the implications for the estimate discussed.

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 Characterization
The facilities being decommissioned should be described sufficiently and should be fully consistent with the decommissioning plan to understand the scope of the estimate, and the extent to which the facility is dismantled and demolished. Any deviations such as generic criteria or if criteria from another country are used, they should be identified and the implications for the estimate discussed.
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 characterization programme, included by reference to the Characterization Report. The characterization 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. The methods proposed should be fully consistent with the waste management plan (also a regulatory requirement) and the decommissioning plan. Any deviations such as generic criteria or if criteria from another country are used, they should be identified and the implications for the estimate discussed.

8. 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 judgment. If field data were used, specific references as to the source of data should be included. Similarly, if estimating judgment was used the experience of estimators should be identified either through copies of their resumes or through a summary listing. Where generic data or data from other facilities or countries are used, their relevance and any limits to applicability in this instance should be addressed.

9. Cost Estimating Methodology Used

The estimating methodology used should be identified as Bottom-Up, Specific Analogy, or any other recognized method. If Specific Analogy was used, references should be provided as to the source of scaling information. As noted in Section 2.2, the most accurate method is the Bottom-up methodology, particularly as the date of actual decommissioning draws near. The other methods listed may be used for early planning, allowing for funding collections to be initiated with sufficient time for a more detailed estimate to “true up” the fund balance.

10. Contingency Basis

There is inconsistent use of terms in the literature concerning “contingency” and “uncertainty” (see also Item 14 and Appendix B). In this guide we address the term contingency 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," (Ref. 6). When increases occur these are mainly due to the novelty of some of the tasks.

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 (Item14 and Appendix B).

11. Discussion of Techniques and Technology to be Used

A brief discussion of D&D techniques and specific technologies upon which the estimate was based should be included. This should be fully consistent with the current facility decommissioning plan. Any deviations between what is in the decommissioning plan and the basis for the cost estimate must be identified, and the implications for the estimate addressed. It is a formal regulatory requirement that a decommissioning plan is developed and maintained current at all times of a facility’s life.

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, or high-pressure abrasive water-jet cutting.

12. 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.

13. Schedule Analysis

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

14.Uncertainty, Contingency and Management of Risk

In this guide, "uncertainty" is the word used to refer to a broad range of cost variations from causes within and outside the control of the project. Uncertainty includes contingency and risk. Contingency, as described earlier, covers cost variations within the defined project scope such as delays, interruptions, inclement weather, tool or equipment breakdown, craft labor strikes, waste shipment problems, or disposal facility waste acceptance criteria changes, or changes in the anticipated plant shutdown conditions, etc. Risk includes cost variations outside of the project scope such as currency exchange fluctuations, unexpected inflation rates, regulatory changes, availability of new technologies or disposal routes, etc. Appendix B provides a further discussion of Uncertainty, Contingency and Risk.

The definition of contingency as used in a cost and schedule estimate should be clearly stated, as well as the method used to develop a percentage or lump sum amount included in the estimate. Similarly, 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.

Additional detail on Risk Analysis is provided in Section 2.3.4.

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 has been 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 unit cost factors (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 the AACEI (Ref. 6) 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. In general, line item contingency is preferred over bottom-line lump sum contingency, as it provides greater insight as to the degree of uncertainty.

As noted earlier in Section 2.3.1(14), some estimators use Risk Analyses to determine Contingency. This fact highlights the importance of describing how contingency was developed. Unless the estimator has specific experience in applying contingency percentages on a line item basis, the Risk Analysis approach provides a definitive basis to evaluate the uncertainties and contingency.

5.Scrap and Salvage

The cost estimate should not consider the asset value, e.g., from scrap and/or salvage, from materials that might be recovered from decommissioning because in Sweden the value of scrap is not included as a credit to the decommissioning cost.

Unit Cost Factors:

As noted in Section 2.2 the Bottom-up cost estimating method lends itself to the use of unit cost factors modified by experience to account for work productivity (or work difficulty) factors. These unit cost factors are described in this section.

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 (UCF) 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.

1. 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 percent.

2. 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 percent.

3. 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 percent.

4. 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 percent.

5. 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 percent (nominally taken at 8.33%).

6. 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.

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

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 data base 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.

7. Non-Repetitive Activity Cost Estimates
Non-repetitive or unique activities, such as reactor vessel and internals segmentation, steam generator and pressurizer removal (for large nuclear power plants), hot cell decontamination and demolition, and glove box decontamination and removal, are typically estimated using a crew man-hour and schedule duration methodology. Wherever possible, licensees should make use of their own experience, ideally that from decommissioning activities or alternatively derived from relevant major maintenance or renovation projects. Data may also be available from other relevant projects in Sweden. Lastly, data may be available from other countries. In all cases, where estimates include data drawn from other projects or experience elsewhere, the applicability and implications for the specific decommissioning cost estimate should be discussed.
Some guidance on the duration of these specialized activities may be extracted from reports of actual reactor vessel and internals segmentation activities at large and small power reactors. In Belgium, the BR-3 reactor decommissioning may provide some data. In Japan, the JPDR decommissioning was well documented. In Germany the Gundremmingen Unit A reactor vessel segmentation was also well documented, and some of the more recent German NPPs decommissioned. In the U.S. the decommissioning projects of Yankee Rowe, Connecticut Yankee, Maine Yankee, and Big Rock Point were well documented. Similarly, activity durations for removal of steam generators and pressurizers may be extracted

from actual records of the successful removal and disposition of the Gundremmingen Unit A, and US Trojan and Rancho Seco units Unfortunately, specific data on crew-hours may not be generally 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. 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 Work Breakdown Structure (WBS) is used to categorize 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 European Commission (EC), Organization for Economic Cooperative Development – Nuclear Energy Agency (OECD/NEA) prepared a Standardized List of Definitions for Cost Items for Decommissioning Projects. This document was recently revised and replaced with the International Structure for Decommissioning Costing (Ref. 3). This document may be used to establish this chart of accounts.

2.3.3.1 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, Decommissioning and Dismantling Activities, and Facility and Site Restoration. The International Structure for Decommissioning Costing (Ref. 3) provides a breakdown of decommissioning into phases that have been paraphrased and/or modified herein. It is expected that this structure will be used by Swedish licensees for presenting their cost estimates. 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-state.
Facility decommissioning follows deactivation; that is, after 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 characterization 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. Decommissioning and Dismantling 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, pressurizer, reactor coolant pumps, reactor vessel and internals, all safety related systems and structures, the turbine-generator, condensate system, feedwater 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 license termination criteria. Note that timing of this may be a sequential activity in Sweden: one might declassify equipment, rooms, and buildings at different stages of the decommissioning project, with a final site survey coming at the end of all other operations involving radioactivity.

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 re-use of facilities following decommissioning to conserve natural resources and to take advantage of the site infrastructure of equipment and structures may be included if it is specified in the decommissioning plan. It should be so noted in the list of assumptions as to whether re-use of specific facilities was to be included or excluded. 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.

2.3.3.2 Project Management Approach

The management organization is the applicant/licensee staffing assigned to the administrative and technical oversight of the project. In general, it may include the project-specific management organization and the licensee-support organization.

The project-specific organization would cover the functions of project manager (and typically assistant project manager), and technical managers (engineering and planning, cost and schedule control, and waste management). The licensee-support may include the routine functions of health physics and radiological protection, quality assurance, operations and maintenance, and others as appropriate. The licensee-support may also include administrative managers (security, personnel/human resources, financial/accounting, public relations, janitorial, 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. One example of how this has been done in cost estimating in Sweden is where the industry (SKB and the licensees) have developed a Reference Organization for NPP Decommissioning (Ref. 7) to address the project management organization. This reference model has been developed to separate project functions from licensee support functions with the purpose of isolating the project-specific costs from those normally covered by a project sponsor. This reference model, was included in the 2013 nuclear reactor decommissioning cost estimate studies, and defines a project management organization that, on average consists of 27 man-years/year. In addition to this, a licensee support organization of 41 man-years/year is assumed.

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 organization above. If the applicant/licensee elects to subcontract the field work to an external Decommissioning Operations Contractor (DOC), the DOC will establish its own management staff from its project manager on down through superintendents and foremen to direct the field work.

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

2.3.4 Risk Analysis – Cost and Schedule, Contingency

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. Contingency costs are expected to be fully spent. The basis for any contingency needs to be fully explained.

Where an estimator has evidence of prior contingency experience through field activities, a contingency estimate may suffice for cost and schedule. If an estimator lacks such field experience, a risk analysis is a suitable substitute for estimating contingency and risks. The estimator needs to defend its approach for selecting one method over the other.

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.
It should be noted that risk issues often extend well into the future to anticipate potential problems (risks) or improvements (opportunities) that may be incurred. This issue raises the concern for 'intergenerational inequities,' where current consumers (ratepayers) are expected to pay for potential future expenses. The purpose of risk analyses in this case is to attempt to anticipate the future expense and equalize the ratepayer payments over the operating life of the plant. Otherwise, future ratepayers will have to bear the burden of making up for a shortfall in funding as the facility nears shutdown and current ratepayers won't share the full burden of the cost of electricity or of the ultimate costs of decommissioning. Typically, periodic (every three to five years) cost estimates are reviewed and re-estimated to account for inflation as it occurs and any changes to regulations or stakeholder concerns for example. 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 fully both the basis and applicability of 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). This can be used to prepare a Quantitative Risk analysis.

Quantitative Risk Analysis

1. Using the Baseline (best estimate) of the costs to perform the work, load that Baseline Cost Estimate into a Monte Carlo analysis computer code (such as PERTMASTER, Crystal Ball, @Risk, ModelRisk, or other commercially available software programmes). The same approach would be applied for the estimated schedule for the project.
2. From the Risk Register, identify the positive and negative percentage changes that could occur and cause the individual line items of the Baseline Cost Estimate to be higher or lower in cost, resulting in a three-point estimate. It is important that the Risk Register address the same activities considered in the Baseline Cost Estimate. On very large projects, the selection of the ranges should be accompanied by a separate calculation to determine those high and low range values. Generally, experienced personnel are assigned this task to ensure the ranges are selected meaningfully.
3. Using the Monte Carlo code (such as @Risk or PERTMASTER for example), select the probability ranges desired, typically 10% and 90%, which in-

dicates there is a 10% probability the cost will not be less than some low value and a 90% probability the cost will not exceed some high value. This calculation is commonly called a P80 analysis since it includes the cost in excess of 10% and less than 90%. Another analysis is at a 50% probability, interpreted to mean there is a 50% probability the costs will be no higher or no lower than a calculated value. This is commonly referred to a P50 analysis.

4. The computer code will perform a Monte Carlo Analysis of the high and low ranges of cost for each line item in the Baseline Cost Estimate and calculate the P80 (90/10 % probability), and the P50 (most likely cost).

The value of the Monte Carlo approach is that it considers all risks in the context of the financial impact on a probabilistic basis. In particular, when calculations are performed to estimate the high-and low-ranges of a cost item risk the individual magnitude of each risk is accounted for in the overall programme. That is not meant to say there can't be errors or under-estimates of ranges for each line item of Baseline Cost, but when supported by calculations to select each range the calculations highlight the importance of the risk. The Monte Carlo analysis promotes consistency in risk analysis, and provides another valuable tool to identify and control costs or anticipate a potential future problem.

Sensitivity Analysis of Major Cost Drivers

One of the outputs of the quantitative risk analysis is a Sensitivity Analysis of the major cost drivers. The code prints out a listing from highest to lowest cost in a graphical representation, often called a Tornado Analysis since its shape is similar to a cyclonic plume. The Sensitivity Analysis highlights the areas requiring specific management attention to prevent project overruns.

Cumulative Probability Curve

The code also provides a Cumulative Probability Curve versus estimated costs to guide the reviewer of the potential levels of risk involved in the estimate.

Contingency

Some estimators use this Risk Analysis methodology to select the appropriate contingency to include in an estimate. The estimator's judgment is thereby reinforced by a quantitative evaluation of potential cost impacts. Either method for estimating contingency, using a line item percentage directly or using a Risk Analysis to estimate overall contingency may be acceptable as long as the basis and applicability is clearly stated and explained.

3. Estimated schedule

The duration of a decommissioning project affects its cost importantly (Ref. 8) through the period-dependent costs (project management – the largest component of 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. The estimated schedule should be fully consistent with the current decommissioning plan or any deviations between what is in the decommissioning plan and the basis for the cost estimate must be identified, and the implications for the estimate addressed.

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 Bottom-Up UCFs (or Parametric Estimating methodology) 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

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 and data sources
- 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 2.3.3.1 describes these phases in detail and will not be repeated here.

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 sequences 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 optimize 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 judgmental 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 Optimization 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 as it directly affects the Period-Dependent costs of Project Management which in itself is a major cost driver.

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 organization 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 applied

Quality Assurance 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 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 ASME (NQA-1 certified) programmes

The American Society of Mechanical Engineers (ASME) established a nuclear QA programme NQA-1 (Ref. 9) 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 organization (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 overemphasized. 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. The source data for development of Unit Cost Factors (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. All sources of data should be fully documented in the estimate. Productivity rates used in UCFs, such as the number of meters of piping removed in a defined sequence (meters of pipe per hour) or cubic meters 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" (Ref. 10). There is no internationally accepted decommissioning cost standard. The NEA (Ref. 11) 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 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.

From an applicant/licensee's estimator point of view comparing cost estimates by benchmarking, not all of the foregoing criteria may be available for comparison. Estimators from other organizations or countries may use differing formats for presentation of the assumptions and cost data, and may reflect site-specific or country-specific regulations, stakeholder interests, and end point criteria. This was one of the driving reasons why the OECD/NEA International Structure for Decommissioning Costing (ISDC) (Ref. 3) was developed. From a Swedish regulator's point of view, the same limitations apply with respect to obtaining representative costs for the same or similar 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 solely on comparisons with other projects. Reviewers will require compelling evidence for the quality of the comparison.
These site-specific differences in comparative cost analyses for benchmarking make exact or absolute cost values virtually unobtainable. At best, the estimator or reviewer may be able to establish a range of cost values for similar facilities undergoing decommissioning to a similar end point objective. Sometimes, only the bottom line cost estimate can be compared, while in other cases individual tasks such as reactor vessel removal or steam generator removal may provide useful comparisons. In the Swedish context, the starting point of a comparison and benchmarking is the decommissioning and waste plans, as they set the framework for the cost estimate. The facility physical and radiological inventories similarly establish the size and complexity parameters for any benchmark comparison.
The reviewer must balance the commitment of time and resources to create a benchmark comparison against the ultimate value of the benchmark results. If evaluating the benchmark data for applicability takes as long as it took to create the baseline cost estimate under review, the benchmark is not worth pursuing any further. Nevertheless it can be a valuable exercise to compare cost and schedule against actual field decommissioning experience. There is a hierarchy of preference for data, e.g., licensees own field experience, Swedish experience, and experience of relevant projects in other countries. In applying such data, the relevance and applicability to the particular cost estimate needs to be documented. Benchmarking may be accomplished by two methods:

• comparisons with other studies
• comparisons to actual field experiences

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, both methods should be used to bound the range of estimate results.

4.2.1 Comparisons with Other Studies

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 identified in the decommissioning and waste management plans as in the estimate under review. The Basis of Estimate for both studies must be compared in detail and any differences noted for the comparison.

Differences in the size of a plant or facility, such as megawatt rating of the units, will affect the overall costs for decommissioning.

4.2.2 Comparisons to Actual Field Experience

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

In general the authors tend to characterize 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.

There are three basic requirements to evaluate benchmarks: 1) a standardized cost structure; 2) the Basis of Estimate; and 3) lessons-learned from actual field experience. These are described in the following paragraphs.

Standardized Cost Structure

Benchmarks are most effective for comparison when the estimate format is presented on a consistent basis. This was one of the principal objectives of the ISDC. The cost breakdowns and supporting documentation must be transparent so that meaningful comparisons can be made. A summary level estimate does little to build confidence in the estimate basis. Reformatting cost estimates into the ISDC structure will facilitate the benchmarking process.

Basis of Estimate

The Basis of Estimate (BoE) as described in Section 2.3.1 earlier is the backbone of an estimate. It identifies the assumptions, limitations, decommissioning strategy, end point objective, facility physical and radiological characterization, technologies to be employed, and schedule for completion. The quest for transparency depends primarily on the BoE. From a cost estimator's viewpoint, the BoE elements should be specifically addressed in the report of findings, and documented clearly. From a regulatory reviewer's viewpoint, the key elements can be summarized in a table for comparison to other estimates as part of the benchmarking process.

Lessons Learned

The Lessons Learned from international experience add valuable insights as to the relevance and applicability of an estimate under review. Unrealistic assumptions related to the speed of proposed technologies for example, can lead to a gross underestimate of achievable performance, costs and schedules. The Lessons Learned themselves must be taken with a grain of salt so as not to put too much reliance on reported successes unless they are documented adequately.

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 an estimator's own 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.

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 organizations are submitting Overall Reports for different reactor sites. Therefore, 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.

5.2 Study report content

In all aspects of the cost and schedule estimate and study report, the basis should be fully consistent with the decommissioning and waste management plans.
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 3.

Table 3: Sample Table of Contents for a Cost Estimate Study Report

1.	APPROVALS
2.	REVISION LOG
3.	EXECUTIVE SUMMARY
4.	INTRODUCTION
5.	FACILITY DESCRIPTION AND CHARACTERIZATION 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
11.	SCHEDULE
12.	BENCHMARKS
13.	RISK ANALYSIS
14.	CRITICAL PATH ANALYSIS
15.	RECOMMENDATIONS, OPPORTUNITIES AND INNOVATIONS
16.	QUALITY PLAN
17.	REFERENCES
18.	ACRONYMS
19.	ATTACHMENTS/APPENDICES:
	A. WASTE CLASSIFICATION
	B. INVENTORY LIST OF EQUIPMENT AND STRUCTURES
	C. REQUEST FOR INFORMATION
	D. DETAILED COST ESTIMATE
	E. P6 (OR MICROSOFT PROJECT) SCHEDULE
	F. BENCHMARKS
	G. RISK REGISTER
	H. RISK ANALYSIS
	I. CRITICAL PATH SCHEDULE
	J. QUALITY ASSURANCE PROJECT PLAN
	K. ESTIMATE FLOW DIAGRAM

1. Approvals Page
The approvals page contains the current issue or revision of the cost estimate 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 an appropriate description of the need for any subsequent revision.

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.
The 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 A, B, C, etc.) for the purpose of identifying the limitations on accuracy.

5. Facility Description and Characterization 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 characterization 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 familiarize 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
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, 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. Refer to the discussion in Section 4.2 on Benchmarks.

13. Risk Analysis
The results of the Risk Analysis findings should be provided, including the Monte Carlo probabilistic estimate of the costs (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. The Recommendations will most likely be site-specific, and should only be included if considered by the licensee in further development of the decommissioning plan.

16. Quality Plan
This section should describe the Quality Assurance Project Plan (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. 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. Attachments/Appendices
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 & 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 to dismantle old fossil-fueled power plants by ratio of megawatts. The sophistication available in current computer codes affords the ability to handle large quantities of data and cost estimating norms rapidly. It further allows the ability to perform 'what if' analyses quickly 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, the cost estimate standardization and computerization greatly facilitates 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 literature and from experience in its use. Decommissioning cost estimating is not a new practice, and in fact has been on-going since the early 1970s. Only recently have efforts been made to standardize cost estimate formats to facilitate reviews and ensure completeness. The work performed by the OECD/NEA, IAEA, and EU to update the 'Yellow Book' into the current International Structure for Decommissioning Costs (ISDC) (Ref. 3) will go a long way to establishing a standardized approach for cost estimating. As more consultants and estimators adapt these methodologies into computer codes, the ability to handle large data bases is becoming a routine practice.

More importantly, using the cost and schedule estimates as a baseline and incorporating them into such programmes as the Earned Value Management System (EVMS) (Ref. 3) 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 be an evolutionary process. But the alternative of helplessly watching actual costs and schedules overrunning budgets by factors of two or more is clearly not the answer to sound business practices 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 every estimator attempts 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 uncertainty 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 and then input into a Monte Carlo computer code to determine the probability of most-likely and not-to-exceed costs and schedule. The risk analysis allows the estimator to visualize the importance of the major drivers through the sensitivity analysis, thereby highlighting those areas for tighter project controls.

6.2 Observations on accuracy

No estimate can be 100 percent accurate since the estimator is attempting to anticipate virtually every planned activity, problem area, and resolution of issues that can change from numerous external causes. Allowances, contingencies, and risk analyses are used to account for these potential 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 to not only account for inflation, escalation, and regulatory changes, but also to incorporate new technologies and techniques to improve the safety, cost effectiveness and schedule reduction.

6.3 Recommendations

This guide is intended as a starting point for the process of preparing cost estimates. Just like a project's cost estimate, any guide should also be considered a 'living' document, with updated information incorporated as the estimating process matures. It is recommended that the guide be shared with applicant/licensees and estimating consultants to prepare them for what will be expected in terms of quality and confidence in the estimates.

7. References

1. “Selection of Decommissioning Strategies – Issues and Factors,” IAEA – TECDOC – 1478, November 2005, Vienna

2. “Decommissioning Strategies for Facilities Using Radioactive Material,” IAEA Safety Report Series No. 50, Vienna, 2007

3. “International Structure for Decommissioning Costing (ISDC) of Nuclear Installations,” OECD 2012, NEA No. 7088, Paris, France 2012

4. “Estimate Classes: An Explanation,” Anthony L. Huxley, Construction Economist, Vol. 12, Number 2, June 2002

5. “Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates,” T.S. LaGuardia, et al, AIF/NESP-036, May 1986

6. “Project and Cost Engineers Handbook,” Second Edition, (p 239), American Association of Cost Engineers (now AACEI), Marcel Dekker, Inc., New York, NY 1984

7. Avveckling och rivning av kärnkraftblock (Decommissioning and dismantling of nuclear power stations – in Swedish only), SKB Document 1359832, November 2012.

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9. “Quality Assurance Requirements for Nuclear Facility Applications,” ASME NQA-1, New York, NY 2008

10. Cambridge Dictionaries, On-Line at: [http://dictionary.cambridge.org/dictionary/british/benchmark_2?q=benchmarking]

11. “Estimation of Nuclear Facility Decommissioning Costs – Current Status and Prospects,” Leaflet. OECD/NEA, March 2013.

8. Acronyms

AACEI	Association for the Advancement of Cost Engineering International
ASME	American Society of Mechanical Engineers
BoE	Basis of Estimate
BWR	Boiling Water Reactor
DOC	Decommissioning Operations Contractor
EC	European Commission
ESC	Escalation Factor
EVMS	Earned Value Management System
IAEA	International Atomic Energy Agency
ISDC	International Structure for Decommissioning Costing
MFA	Minimum Funding Amount
MWe	Megawatt electric
MWt	Megawatt thermal
NPP	Nuclear Power Plant
NQA-1	Nuclear Quality Assurance -1 (ASME Quality Assurance programme)
NRC	(U.S.) Nuclear Regulatory Commission
OECD/NEA	Organization for Economic Cooperation and Development/Nuclear Energy Agency
PDM	Precedence Diagramming Method
PERT	Programme Evaluation and Review Technique
PWR	Pressurized Water Reactor
P50/P80	Probabilities at the 50% and 80% Confidence Levels
QAPP	Quality Assurance Project Plan
SBoE	Schedule Basis of Estimate
UCF	Unit Cost Factor
US GAO	U.S. General Accounting Office
WDF	Work Difficulty Factor

Part 2: REVIEWING DECOMMISSIONING COST ESTIMATES

1. Introduction

1.1 Objective

The objective of this Part 2 of the guide is:

- To provide orientation of Peer Reviewers in preparation of performing a peer review.
- To provide a process to review the cost estimate study with respect to its content and the underpinning support to the estimate results.
- To provide any applicants/owners/licensees and estimating consultants and future reviewee with guidance as to what may be expected in terms of quality and confidence in the estimates and relevant peer review questions.

1.2 Scope

The scope of the guide is directed at the process of reviews of decommissioning cost studies by providing checklists for each attribute of a quality cost estimate. The checklists are intended to be supplemented with additional questions and requests for clarification as needed by the reviewer to complete the review. As the peer review process matures, additions to the checklists can be implemented for future guidance. Part 2 of this guide is intended to be used in concert with Part 1, as much of the background and basis of an estimate is covered in Part 1 for reference.

1.3 Organisation of this document

The remainder of this guide provides the following information:

Chapter 2: Reviewing the Contents of a Cost Study Report – provides a detailed checklist approach for the review of the cost study report.

Chapter 3: Comparison to Other Estimates - Benchmarking – provides checklists to assist in reviewing benchmarked information.

Chapter 4: Conclusions – provides comments on the approach and recommendations on the use of this guide.

Chapter 5: References - provide the references used in developing this guide.

Chapter 6: Additional Reading Material – provides the background material used in developing this guide

Chapter 7: Acronyms - provides the acronyms used in this guide.

2. Reviewing the contents of a cost study report

This Chapter of the guide addresses the review of the quality of the estimate for completeness and accuracy, while the comparisons to international benchmarks for validation of the results are addressed in Chapter 4. Both sections provide sample checklists of issues as to the adequacy of the estimate report's presentation of the information. These individual checklists are combined into an overall, master in Appendix A for the sake of convenience.

2.1 Items of a cost study report

For convenience, this study uses a sample structure and typical items of a Cost Study report. This is reported in Figure 1. A brief description of each item in the table of contents is provided as well.

1. Approvals Page
The approvals page contains the current issue or revision of the cost estimate 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 estimate would be recorded on this page with appropriate description of the need for any subsequent revision.

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.

Figure 1: Sample Structure and Typical Items of Cost Study Report

1. APPROVALS
2. REVISION LOG
3. EXECUTIVE SUMMARY
4. INTRODUCTION
5. FACILITY DESCRIPTION AND CHARACTERIZATION DATA
6. SCOPE OF WORK/ASSUMPTIONS/EXCLUSIONS/CONTRACTING STRATEGY/DATA GAP ANALYSIS
7. WORK BREAKDOWN STRUCTURE, CODING AND DICTIONARY
8. BASIS OF ESTIMATE
9. DECONTAMINATION AND DISMANTLING METHODS
10. COST ESTIMATE
11. SCHEDULE
12. BENCHMARKS
13. RISK ANALYSIS
14. CRITICAL PATH ANALYSIS
15. RECOMMENDATIONS, OPPORTUNITIES AND INNOVATIONS
16. QUALITY PLAN
17. REFERENCES
18. ACRONYMS
19. ATTACHMENTS/APPENDICES:
    - A. WASTE CLASSIFICATION
    - B. INVENTORY LIST OF EQUIPMENT AND STRUCTURES
    - C. REQUEST FOR INFORMATION
    - D. DETAILED COST ESTIMATE
    - E. PRIMAVERA P6 (OR MICROSOFT PROJECT) SCHEDULE
    - F. BENCHMARKS
    - G. RISK REGISTER
    - H. RISK ANALYSIS
    - I. CRITICAL PATH SCHEDULE
    - J. QUALITY ASSURANCE PROJECT PLAN
    - K. ESTIMATE FLOW DIAGRAM

The 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 A, B, C, etc. – see Part 1, Section 2.1 for more detail).

5. Facility Description and Characterization 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 characterization 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. The facility description and characterization data should be consistent with the decommissioning plan. Drawings or sketches of important areas may be included to familiarize the reviewer with the specific areas.

6. Scope of Work, Assumptions, Exclusions, Contracting Strategy, Data Gap Analysis
This section is the core of the input data used in the estimate analysis, and as described in Part 1, Section 2.3.1 "Basis of Estimate," should include the specific scope of work, all assumptions related to the scope of work, scope exclusions, contracting strategy such as self-performance or use of a DOC), and data gap analysis. This section should be consistent with the decommissioning plan.

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

8. Basis of Estimate
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, 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 (see Part 1).

9. Decontamination and Dismantling Methods
A general description should be included of the major decontamination and dismantling methods to be employed for the critical elements of the project. 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). 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 schedule should be consistent with the decommissioning plan which would provide and integrated strategy with decommissioning all facilities at the site. 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 an appendix. For further guidance and limitations of benchmarks, refer to Part 1, Section 4.2.
In case of benchmarks of whole project costs, the caveats and elements that were considered for comparison (see
Part 1 should be clearly stated and the analysis reported in an appendix.

13. Risk Analysis
Uncertainty and contingency contribute to risk in the cost estimate and they may be subject to further 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.
The results of the risk analysis findings should be provided in the main text, including the Monte Carlo probabilistic estimate of the costs (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.
A more detailed description of risk analyses and application to funding requirements is shown in Part 1, Sections 2.3.1 and 2.3.4, and Appendix B.

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. Any recommendations proposed should be those actually considered by the licensee in further development of the decommissioning plan.

16. Quality Plan
This section should describe the Quality Assurance Project Plan (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.

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

19. Attachments/Appendices
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 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.
A common practice shows that the information described above may also be found in decommissioning plans. The structure of a decommissioning plan is often stipulated in country's regulatory framework or in the regulator's guidance.

2.2 Detailed review of the cost study report items

The approach selected for conducting the peer reviews is to develop a series of checklists to guide the IRT in evaluating the quality and content of cost estimates. It is important to note that these suggested checklists are intended as a starting point for the review, and additional questions are expected to be generated as the IRT gets in to the detail of the review.

2.3 Screening of the overall estimate report

The reviewer should perform a preliminary screening of the content of the report to ensure all major elements are included. If there are significant deficiencies, the reviewer should notify the estimate originator (applicant/owner/licensee and/or estimating consultant) in writing as soon as possible. If the deficiencies cannot be corrected quickly, the reviewer must assess whether to postpone the review and wait for the revised version, or continue reviewing without all the information needed for a fair assessment and evaluation. Table 1 provides a checklist of the major report elements.

Table 1: Report Screening Checklist

	Yes	No	n/a
Title Page			
Approvals			
Revisions Log			
Executive Summary			
Introduction			
Facility Description and Characterization Data			
Scope of Work, Assumptions, Exclusions, Contract Strategy/Data Gap Analysis			
Work Breakdown Structure and Coding			
Basis of Estimate			
Dismantling Methods			
Cost Estimate			
Schedule			
Risk Analysis			
Critical Path Analysis			
Recommendations, Opportunities and Innovations			
Quality Plan			
References			
Acronyms			
Attachments			

2.4 Statement of the class of the estimate

The report should state the classification of the estimate accuracy and the basis used for establishing that classification and its limitations. For additional guidance, refer to Part 1, Section 2.1 and Appendix A. For instance, the estimator could categorize the estimate in accordance with the Canadian Classifications Shown in Table 2 as suggested by SSM for purposes of illustration for this Review Guide, or other national or international guidance shown in Tables A1 and A2 of Appendix A. Depending on the status of the facility or maturity of the estimate (e.g. conceptual, feasibility, budgetary, control or check estimate/bid-tender), the classification indicates the estimator's confidence in the accuracy of the results.

Table 2: Canadian Estimate Classifications Checklist

Classification	Project Definition	Yes	No	N/A
Class A	High			
Class B	Medium			
Class C	Low			
Class D	Lowest			

2.5 Purpose and scope identified

The reviewer should insure there is a clear statement of the purpose of the study and the scope of work in the report. The purpose of the cost study is to provide an estimate of the resources needed for future decommissioning, in accordance with the regulatory requirements. Table 3 provides a checklist of the significant points that should be addressed in the report.

Table 3: Purpose and Scope Checklist

	Yes	No	n/a
Purpose and scope is clearly defined			
Prerequisites to decommissioning (shutdown, system draindown, site prep., per assumptions) are identified			
Estimate exclusions and boundary conditions are identified as per the decommissioning plan			
The end-point criteria and end-state is stated and as per the decommissioning plan			

2.6 Regulatory criteria for decommissioning

The reviewer should be informed that the appropriate government regulatory requirements are referenced in the report. The reviewer should be informed about basic responsibilities of the Government – Relevant Ministry(ies) – Regulators (nuclear, public health, industrial safety, others) – License Owner – Decommissioning Operator in the industrial segment of decommissioning. The reviewer should also be informed about the most important parliamentary acts, departmental and regulator's decrees and guidance related to decommissioning to check appropriateness of references in the report.

Table 4: Government Regulatory Requirements Checklist

	Yes	No	n/a
Tier 1: Parliamentary acts dealing with:			
1. Decommissioning licensing, operation, site release			
2. Radiation protection, public health, Health & Safety			
3. Material clearance, reusable material and waste management			
4. Environmental protection, environmental impact assessment			
5. Industrial safety & fire protection			
6. Civil construction			
7. Area and landscape development, nature and heritage protection			
Tier 2: The most important departmental and regulator's decrees and guidance relevant to decommissioning:			
1. Decommissioning licensing, operation, site release			
2. Radiation protection, public health, Health & Safety			
3. Material clearance, reusable material and waste management			
4. Environmental protection, environmental impact assessment			
5. Industrial safety & fire protection			
6. Civil construction			
7. Area and landscape development, nature and heritage protection			

2.7 Decommissioning strategy by phase

The reviewer should be informed of the decommissioning plan considered in the study. Table 5 lists key elements constituting their implementation within the immediate dismantling strategy.

Table 5: Decommissioning Strategy by Phase Checklist

	Yes	No	n/a
Phase 1 – Preparations			
Engineering and Planning - Feasibility studies, licensing, permits, and procedure preparation			
Site Preparations - Facility shutdown activities, legacy waste disposal, draining/deactivating systems			
Phase 2 - Decommissioning Operations			
Construction of temporary facilities to support decommissioning			
Reconfiguration/modification of site structures and facilities to support decommissioning			
Design and fabrication of shielding and special tooling			
Procurement of transport canisters, cask liners, industrial packages			
Decontamination of piping, components and contaminated concrete surfaces			
Removal of piping and components not required to support decommissioning			
Steam generators, pressurizers, and reactor coolant/recirculation pump removal and disposition			
Reactor vessel internals segmentation and disposition			
Reactor vessel segmentation/one-piece removal and disposition			
Demolition of the biological shield, fuel storage and service pools			
Removal of contaminated turbine-generator, condenser and feedwater system components			
Final site radiological survey for license termination			
Submittal of all licensing documentation for license termination			
Phase 3 - Conventional Demolition and Site Restoration			
Demolition and removal of all remaining site buildings and structures			
Restoration of the site			

2.8 Project management approach

The reviewer should verify that the report identifies whether the decommissioning will be managed as an applicant/owner/licensee self-directed project, or managed by a Decommissioning Operations Contractor (DOC) under applicant/owner/licensee oversight. For the applicant/owner/licensee scenario, the full responsibility of costs and risks lies with the applicant/owner/licensee, whereas in the DOC scenario the DOC assumes all responsibility for the costs and risks under fixed-price/lump sum, or cost plus incentive fee contracts. Refer to Part 1, Section 2.3.3.2 for additional discussion of project management considerations. Table 6 provides guidance as to the functional responsibilities/positions of the management staff for each scenario.

Table 6: Project Management Approach Checklist

	Yes	No	n/a
Applicant/Owner/Licensee Self-Directed Management			
Mobilization and preparations			
Project Management			
Project planning and on-going implementation			
Cost and schedule controls			
Safety and environmental controls			
Quality Assurance and quality control			
Administration and accounting			
Public relations and stakeholder involvement			
Support Services			
Engineering - mechanical, civil, electrical, environmental, instrumentation, structural			
Information systems and computer support			
Waste management			
Decontamination, chemistry support			
Decommissioning operations			
Personnel management and training			
Document control and records retention			
Procurement, warehousing, materials handling			
Housing, office equipment and support services			
Overhead expenses for central (home) office support			
Collateral costs for procurement of heavy equipment, special tooling, laundry service			
Health Physics and Safety			
Health physics services, radiation control			
Industrial safety			
Mobilization/Demobilization			
Mobilization of temporary facilities, telephone, internet, trailers, laundry			
Demobilization of all temporary facilities at project completion			
Specialty Contractors			
Decontamination - chemical, mechanical concrete scabbling			
Vessel and internals segmentation			
Steam generator, pressurizer, reactor coolant/recirculation pump removal			
Demolition - concrete and steel structures			
Site restoration - backfill, earthmoving, grading, landscaping			
Health physics, radiation control, laboratory services			

DOC Management			
Applicant/Owner/Licensee Oversight Services			
Project management oversight			
Project cost and schedule control			
Procurement and contracting (of DOC)			
Quality Assurance			
Health physics and industrial safety			
Administration, accounting and financial			
Licensing			
Environmental			
Public relations and stakeholder involvement			
Overhead expenses for central (home) office support			
DOC Management Services			
Mobilization and preparations			
Project Management			
Project planning and on-going implementation			
Cost and schedule controls			
Safety and environmental controls			
Quality Assurance and quality control			
Administration and accounting			
Support Services			
Engineering - mechanical, civil, electrical, environmental, instrumentation, structural			
Information systems and computer support			
Waste management			
Decontamination, chemistry support			
Decommissioning operations			
Personnel management and training			
Document control and records retention			
Procurement, warehousing, materials handling			
Housing, office equipment and support services			
Overhead expenses for central (home) office support			
Collateral costs for procurement of heavy equipment, special tooling, laundry service			
Health Physics and Safety			
Health physics services, radiation control			
Industrial safety			
Mobilization/Demobilization			
Mobilization of temporary facilities, telephone, internet, trailers, laundry			
Demobilization of all temporary facilities at project completion			
Specialty Contractors			
Decontamination - chemical, mechanical concrete scabbling			
Vessel and internals segmentation			
Steam generator, pressurizer, reactor coolant/recirculation pump removal			
Demolition - concrete and steel structures			
Site restoration - backfill, earthmoving, grading, landscaping			
Health physics, radiation control, laboratory services			

2.9 Assumptions

The reviewer should check that the key assumptions for the estimate are clearly listed in the report, and are fully consistent with the current decommissioning plan. Since site-specific cost estimates deal with the actual conditions existing or predicted to exist at the facility, any assumptions used must also be site-specific. Table 7 provides a list of typical assumptions for the Immediate Dismantling Strategy as an indication of the level of detail that should be addressed. The scenario presented is for an applicant/owner/licensee oversight of a DOC. It is not intended to be prescriptive or limiting.

Table 7: Assumptions Checklist

	Yes	No	n/a
Licensing, Permits, Insurance			
All licensing documentation will be prepared by applicant/owner/licensee and submitted to regulatory agencies			
Regulatory agencies will not impose unforeseen delays to the start of the work			
Applicant/owner/licensee to provide all facility licenses, permits, and insurance (decreasing with phase)			
Site Preparations			
DOC will prepare all work plans for the implementation of decommissioning			
Applicant/owner/licensee will provide electrical power, water, and legacy waste disposition as needed			
Electric power costs for decommissioning (lighting, tooling, ventilation, etc.) is included in estimate			
Applicant/owner/licensee will drain all contaminated liquids from piping/components and dispose of the liquids.			
DOC will remove and dispose of all asbestos in accordance with applicable procedures			
Applicant/owner/licensee states there are no known areas of soil or groundwater contamination			
Applicant/owner/licensee will provide approved location for delivery/storage of diesel fuel for heavy equipment			
Applicant/owner/licensee will provide radiological dosimetry and health/safety oversight for all on-site personnel			
Applicant/owner/licensee will provide an industrial safety specialist for oversight of the project			
DOC will provide crew with all protective clothing, respiratory equipment and laundry services			
Applicant/owner/licensee will erect physical barriers and/or secure access to radioactive/contaminated areas			
DOC will provide all health physics/radiation control technicians for the hands-on work			
DOC will provide industrial safety specialists for the hands-on work			
DOC will provide workers compensation insurance for crew, and general liability insurance for project			
Continued…			

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Facility Dismantling			
DOC will be the principal contractor for this work. Selected subcontractors will be retained as needed			
Unit Cost Factors (UCFs) based on applicant/owner/licensee provided labour rates for all classes of labour/staff			
UCFs include overhead and profit on materials and supplies			
UCFs incorporate Work Difficulty Factors (WDFs)			
UCFs are based on Protective Clothing (PPE) changes four times per day			
UCFs are based on packaging factor void percentage of 10% to 30% for all transport containers			
UCFs are based on a transport time to the disposal facility			
UCFs are based on non-contaminated waste being placed in roll-off containers for landfill disposal			
UCFs are based on LLW and ILW placed in half-height/full-height ISO containers for disposal			
Materials suitable for scrap or salvage have been accounted for			
No credit for sale of scrap/salvage has been assumed			
All LLW and ILW will be transported by ship to for final disposal			
DOC will provide the final site survey and all necessary documentation to regulatory agencies			
Applicant/owner/licensee will provide oversight of the final site survey and documentation			
Conventional Demolition and Site Restoration			
Non-contaminated or decontaminated buildings/structures will be demolished to 1m below grade			
All below-grade voids (building basements) will be backfilled with clean fill and compacted			
Clean concrete rubble will be used as fill			
All excavations will be re-graded to a final contour consistent with adjacent surroundings			
Any affected areas from building demolition and backfill will be covered with loam and seeded			
Furniture, tools, mobile equipment (forklifts, trucks, bulldozers) will be removed at no cost or credit			

2.10 Cost estimating methodology

The report should state the cost estimating methodology applied for the estimate. Part 1, Section 2.2 identifies the most common types of cost estimating methods and cases where they may be applied.
A common methodology is the unit cost factor approach, which is the methodology developed by the Atomic Industrial Forum (now the Nuclear Energy Institute) in its document, “Guidelines for Producing Nuclear Power Plant Decommissioning Cost Estimates,” for use by US nuclear power plant licensees (Ref. 1). Table 8 provides a list of methodologies and key information that should be included with the methodology.

Table 8: Cost Estimating Methodology Checklist

	Yes	No	n/a
Bottom Up Technique			
Is a work statement provided?			
Are drawings/specifications used to extract material quantities requiring dismantling/removal?			
Are UCFs (costs per unit of productivity) applied to these quantities to determine the cost for removal?			
Are direct labour, equipment, consumables, and overhead are incorporated into the unit cost factors?			
Are costs reported in local currency for the current (or last previous) years?			
Specific Analogy			
Are the known costs of an item in prior estimates used the cost of a similar item in a new estimate?			
Are adjustments made to known costs to account for differences in size, weight, and configuration?			
Are costs reported in local currency for the current (or last previous) years?			
Parametric			
Are costs based on historical databases of similar systems or subsystems and structures?			
Are statistical analysis performed on data for correlations between cost drivers and other parameters?			
Are parameters based on units of inventory per item, or per square/cubic meters, per kilogram?			
Have analyses produced cost equations/relationships used individually or grouped in complex models?			
Cost Review and Update			
Was the estimate constructed by examining previous estimates of the same or similar projects?			
Was the estimate checked for internal logic, complete scope, assumptions, estimating methodology?			
Expert Opinion			
Were several specialists consulted iteratively until a consensus cost estimate was established?			
Are the credentials of the specialists identified in their respective areas of expertise?			
Are curriculum vitae provided for each specialist?			

2.11 Facility physical description and characterization data

The facility physical description (and its radiological and hazardous/toxic material inventory) is the heart of the bottom-up estimating methodology, and must be fully consistent with the currently applicable facility decommissioning and waste management plans, including inventories. In practical terms it is the most time-consuming part of developing a site-specific estimate. The credibility of the estimate hinges on the completeness of the data that represents the facility to be decommissioned. The physical inventory of piping, valves, pumps, tanks, heat exchangers, ducting, electrical cable and conduit, electrical switchgear, and building structures must be accounted for in a rigorous fashion to ensure the facility is properly represented. To this end, current drawings, equipment specifications, operating manuals should be used to extract the data on lengths, numbers of units, weights, volumes, configuration, and size limitations (for removal through existing doorways or hatches). Similarly, the radiological and hazardous/toxic material inventory must be identified to accurately represent the conditions that precede and drive decommissioning decisions. For a permanently shut down facility, the Site Characterization Report should be consulted to determine the levels of radiological contamination, activation of the reactor vessel, and high radiation areas requiring restricted access and decontamination. Similarly, a listing of hazardous/toxic materials is necessary to address asbestos, legacy chemicals, and spills that may not have been fully cleaned. For a facility still in operation, current operating radiological records may be used to determine the foregoing information, supplemented by calculated levels of vessel activation assuming operation through the full license life of the facility.

The cost estimate may follow the ISDC format with respect to its WBS listing. At sub-level WBS elements, the details of the inventory should be listed by system and structure. Alternatively, any format that addresses all the equipment and structures in a logical, complete manner may be used. The reviewer should be cognizant of the format applied to ensure the inventory is properly included.

Table 9 provides a sample listing of the systems and structures that should be accounted for in the estimate. As this information is site-specific, the reviewer needs to become familiar with the facility systems and structures. A site visit can provide significant insight as to the arrangement, degree of difficulty and special considerations associated with decontamination, removal and disposition of the materials.

Table 9: Facility Physical Description and Characterization Data Checklist

	Yes	No	n/a
Facility Physical Description			
Are the following systems and structures addressed in the estimate?			
Ion exchangers and resins			
Spent fuel racks			
Boron injection system and boron waste			
Chemical and volume control			
Safety injection system			
Residual heat removal system			
Spent fuel pool cooling system			
Reactor pressure vessel (RPV) internals			
Contaminated cranes			
Radiological decontamination, removal, and packaging of spent fuel pool liner			
Removal of reactor coolant system (RCS) piping and equipment			
Removal of pressurizer and relief tank			
Removal of steam generators and blowdown system			
Removal of control rod drive system			
Segmentation and packaging of reactor pressure vessel			
Bio-shield shield			
Post-accident sampling system			
Main steam piping, valves and controls			
Turbine generator(s)			
Turbine gas (hydrogen) system			
Turbine generator hydrogen seal oil system			
Turbine generator stator cooling			
Turbine lube oil storage, filtration and cooling			
Turbine condenser(s)			
Turbine plant sampling system			
Moisture separator reheaters			
Feedwater heaters, drains and vents			
Auxiliary feedwater system			
Feedwater condensate system and chemical injection			
Feedwater pumps/turbine drives			
Condensate filter demineralizer			
Condensate air injection			
Extraction steam system			
Auxiliary gas system			
Auxiliary steam system			
Circulating water system and chemical injection			
Engineered safety system room coolers			
Plant makeup water treatment, storage and degas system			
Component cooling water			
Auxiliary component cooling water			
Chilled water system			
Containment spray system			
Containment air purification and clean-up system			
Floor drains - all buildings			
Diesel generator			
Electrical switchgear and control equipment			
Fire protection system			
Continued…			

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Service air system			
Instrument air system			
Plant demineralized water system			
Potable water system			
Radioactive waste solidification and volume reduction equipment			
Waste processing – gas			
Waste processing – liquid			
Sewage treatment system			
Contaminated concrete			
Heating, ventilation, and air conditioning (HVAC) ducts and equipment - all buildings			
Demolition of Remaining Site Buildings and Structures			
Are the following systems and structures addressed in the estimate?			
Reactor containment			
Auxiliary			
Circulating water intake canal			
Control			
Cooling tower - hyperbolic/mechanical			
Diesel generator			
Miscellaneous buildings and tanks			
Station tunnels			
Turbine building and pedestal			
Fuel handling			
Surface and groundwater			
Contaminated soils			
Radiological and Hazardous Materials			
Are systems/structures categorized in accordance with respect to levels of contamination/activation?			
Was the categorization used as a basis for disposition of the equipment and structures?			
Was the categorization of the reactor vessel and internals activation used as a basis for disposition?			
Were the levels of contamination used as a basis for applying work difficulty factors (WDFs)?			

2.12 Quality of the data

The quality of the data refers to not only that listed in Table 9 for the source of the information, but also to the source of information used to develop unit cost factors, packaging information, transportation, and storage/disposal costs. If other than a bottom-up estimating method is used, the source of reference plant information is important to validate the accuracy of the estimate. Table 10 provides the reviewer with guidance as to the assessment of the quality of data.

Table 10: Quality of Data Checklist

	Yes	No	n/a
Facility Physical Source Data			
Are all physical data references listed as to the source of the data?			
Are the physical data references based on site-specific drawings, specifications or operating manuals?			
Was a site visit/tour performed by the estimating team to familiarize themselves with the facility?			
Is there a clear statement as to the source of cost data for waste packaging, transport and storage/disposal?			
Is there a clear statement as to the source of cost data for radiological/hazardous equipment/structure removal?			
Is there a clear statement as to the source of cost data for non-radiological equipment and conventional demolition?			
Does the estimator's quality assurance program require checking of the input data to cost estimate codes?			
Radiological and Hazardous Source Data			
Was a Facility Characterization Report used to identify sources, concentrations, radiation levels in the facility?			
Was a Facility Characterization Report used to identify sources, concentrations of hazardous/toxic materials?			
If no Characterization Report, does the estimate state how radiological/hazardous conditions were estimated?			
If references were used, are they clearly stated/provided in the estimate?			
Do the references represent current state-of the-knowledge data?			
Bottom Up UCF Based Estimates			
Are the UCFs based on local labour, equipment, and materials costs?			
If non-local labour, equipment, material costs were used, were appropriate cost indices/exchange rates applied?			
Do the UCFs provide the basis for productivity rates (cost/kg, etc.) from actual field data from projects or vendors?			
Do the UCFs describe the task activities to perform a given removal/decontamination sequence?			
Do the UCFs allow for parallel task activities without a serial increase in task duration (i.e., critical path work)?			
Are the UCFs adjusted for Work Difficulty Factors (WDF) to account for site-specific conditions in the facility?			
Is there a clear statement of which WDFs were applied and under what conditions			
Is the UCF task crew clearly identified by worker category and labour rate?			
Continued….			

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Are the appropriate labour rates applied to the WDF adjusted durations to develop the task labour cost?			
Are equipment and consumables identified and costed, with an appropriate mark-up for overhead and profit?			
Is total cost of labour and equipment/consumables for the sequence divided by the productivity parameter (kg, m)?			
Is a summary listing of UCFs used in the estimate provided (there may be more than one set for different WDFs)?			
Is there a general description of how the estimator's computer code combines the inventory with the UCFs?			

2.13 Dismantling sequence and approach

The dismantling sequence and approach is key to a logical progression of activities, taking into account predecessor/successor events and potential delays related to securing regulatory approvals or other time-dependent events. The sequence drives the duration of the hands-on work, which sets the overall schedule for the project. The period-dependent project management costs are then related to the overall schedule. Table 11 provides the reviewer with guidance for evaluating the reasonableness of the sequence.

Table 11: Dismantling Sequence and Approach Checklist

	Yes	No	n/a
Does the estimate provide a written sequence of activities for the selected decommissioning strategy?			
Is sequence in the form of written text, a PERT (Program Evaluation & Review) Chart, or a Gantt Chart?			
Is the sequence presented in chronological order consistent with the Baseline Cost Estimate?			
Are multiple paths identified to show parallel work activities to minimize overall schedule?			

2.14 Baseline schedule estimate

The Baseline Schedule Estimate should follow the same level of underpinnings as the cost estimate as far as assumptions, WBS format, and logic. Most scheduling programs offer a predecessor-successor network sequencing of activities in either a Program Evaluation and Review Technique (PERT) format, or a Gantt chart format. The typical scheduling programs are Oracle's Primavera P6 and Microsoft Project. Other programs may also be used. The estimator plans the activities to minimize the Critical Path of the program to reduce the overall duration, and should perform a Critical Path Analysis to ensure the shortest schedule. The estimator should also evaluate whether the individual and total float can be minimized. Table 12 provides the reviewer with a checklist for evaluating the Baseline Schedule Estimate.

Table 12: Baseline Schedule Estimate Checklist

	Yes	No	n/a
Does the estimate include a schedule with WBS elements linked to the cost estimate?			
Is the Critical Path of the schedule included on the PERT or Gantt chart?			
Is the dismantling sequence consistent with that of the "Dismantling Sequence and Approach" Table?			
Was the schedule estimate developed using approved software (P6, Microsoft Project, etc.)?			
Is program "float" identified (time a task in a network can be delayed without delaying other tasks or completion)?			
Is there discussion as to how float may be minimized?			
Has a Critical Path Analysis been performed to shorten the overall schedule?			

2.15 Risk analysis

The project Risk Analysis provides a level of confidence that the estimate will adequately bound the costs and schedule, taking into account potential events that could increase costs and delay the schedule. The Risk Analysis should also identify potential opportunities that could reduce costs and accelerate schedule. The process as described earlier in Part 1, Section 2.3.4 includes conducting a risk workshop to identify risks and opportunities, categorizing the level of risk, and preparing a Risk Register (a list of all potential risks and opportunities). The Risk Register should include an evaluation of methods to reduce risk or to enhance opportunities. If a quantitative Risk analysis was prepared, generally accepted computer codes should be used. Table 13 provides the reviewer with a checklist to evaluate the Risk Analysis.

Table 13: Risk Analysis

	Yes	No	n/a
Does the estimate include a Risk Analysis?			
Was a Risk Workshop convened by estimator to identify all potential risks and opportunities in a Risk Register?			
Is there evidence that a risk mitigation evaluation was made?			
Was a quantitative Risk Analysis performed using a Monte Carlo based computer program?			
Was Monte Carlo analysis performed using approved software (PertMaster, Crystal Ball, @Risk, ModelRisk, etc.)?			
Was a triangular distribution assumed?			
If a triangular distribution was used, are the low, most likely (Baseline estimate), and high values explained?			
Is a different distribution used (double triangular, Bernoulli, etc.)?			
Were opportunities included in the quantitative risk calculation?			
Does the Risk Analysis identify the P50 and P80 probabilities of costs?			
Does the Risk Analysis include a Sensitivity Analysis (tornado chart) of major cost drivers?			
Does the Risk Analysis include a Cumulative Probability curve?			

2.16 Contingency

Contingency is a recognized cost, fully expected to be spent. The concept of contingency is to allow for unexpected events within the defined project scope as described in Part 1, Section 2.3.1(14) and Appendix B.

Contingency is defined by the AACEI (Ref. 2) 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." Indeed, as with any major project, events occur that are not accounted for in the base estimate. Therefore, a contingency factor needs to be applied.

The methods for accounting for contingency vary from estimator to estimator. The method for application of contingency should be clearly stated and explained. It may be a single-valued percentage based on the total cost of the project, or a multi-valued percentage applied to each line item of the estimate. Some estimators use the Risk Analysis to determine the contingency. Table 14 provides the reviewer with a checklist to evaluate how the contingency was applied.

Table 14: Contingency

	Yes	No	n/a
Does the estimate include Contingency?			
Is the definition of Contingency included in the report?			
Is the contingency stated as an overall single-valued percentage?			
Is the single value basis justified by reference?			
Is contingency calculated on a line-item basis (individual contingency % for each element of cost)?			
Are the percentages for contingency elements explained?			
Are the contingency percentage bases identified (reference source or by committee judgment)?			
Was Contingency developed using the Risk Analysis?			
Does the report identify how Contingency was developed from the Risk Analysis?			

2.17 Decommissioning techniques and technologies employed

The decommissioning techniques and technologies employed for the purpose of an estimate can have a major influence on the success of the project, the overall schedule, and costs. The techniques and technologies should be fully consistent with the current decommissioning plan. For example, selecting a slow cutting technology for the reactor vessel internals can result in greater direct costs (if contracted on a cost plus incentive fee basis) and extend the project duration, thereby increasing the project management costs for the contractor, the DOC and the applicant/owner/licensee. In general, for routine cutting of piping/components and the demolition of concrete/steel structures, the estimate should be based on proven technologies and techniques where representative cost data is available from vendors if possible or reasonable representations can be made based on published information.

A different approach may be used for more difficult tasks. For example, segmenting the reactor vessel internals is one of the most difficult tasks yet does not lend itself to unit cost factor approaches. The technologies used in the past include plasma arc cutting, high-pressure abrasive water jet cutting, and mechanical cutting. Contractors using these techniques have all encountered numerous, costly problems resulting in project delays. Estimators typically will use the field experience of the longest duration of any of the technologies used, and a fixed field crew for all cutting. This type of estimating is called Level-of-Effort since the crew cost per hour (day, week) is set and the duration determines the labour cost. An allowance is included for equipment and consumables as appropriate. No specific technology is specified, as individual contractors will use their creativity to select one. Table 15 provides the reviewer with guidance as to how to evaluate the technologies considered in the estimate.

Table 15: Decommissioning Techniques and Technologies Employed Checklist

	Yes	No	n/a
Does the estimate describe the techniques/technologies expected to be used in decommissioning?			
For decontamination of piping and components, are specific decontamination technologies identified?			
Does the estimate identify productivity rates (Decontamination Factors - DFs) for these technologies?			
Are these DFs based on actual field data or vendor estimates/quotes?			
For cutting piping, components, ducting, electrical cable etc., are specific proven technologies identified?			
Are these technologies identified in the UCFs as part of the task description for aforementioned work?			
Are technologies identified for reactor vessel and internals segmentation/removal?			
Is the estimate for reactor vessel and internals done on a UCF or Level-of Effort basis?			
If a UCF basis, does estimate identify the source of productivity rates assumed for the current estimate?			
If a Level-of-Effort basis, does estimate identify source of crew size/composition and duration assumed?			
For demolition of concrete and steel structures, are proven techniques identified?			
Are productivity rates for these techniques based on actual field data, vendor quotes or handbook data?			
For the final site survey, does estimate identify the basis (MARSSIM, other) used for survey time/cost?			

2.18 Baseline cost estimate

This section of the guide provides the reviewer with a checklist to ensure the Baseline Estimate is complete. Table 16 lists the major elements of the Baseline Cost Estimate.

Table 16: Baseline Cost Estimate Checklist

	Yes	No	n/a
Does the estimate use a Work Breakdown Structure (WBS) based on ISDC or other reasonable basis?			
Does the WBS include a Dictionary describing each activity?			
Does the WBS include a list of acronyms used in the estimate report?			
Does the estimate include a table of costs by phase for each decommissioning strategy?			
Does the estimate list all of the systems and structures shown in checklist Table 9?			
Does the estimate list costs down to WBS Level 3 as a minimum?			
Are project management costs identified in the estimate by phase?			
Are all overhead costs for project management and contractor labour costs included?			
Are licensing and regulatory issues described in the report, and appropriate costs included?			
Are stakeholder concerns identified in the report?			
Are allowances included for the costs of conducting stakeholder information meetings?			
Are waste management considerations for LLW, ILW and spent nuclear fuel included in the report?			
Are the costs for disposal of LLW and ILW identified in the report and costs broken down appropriately?			
Are Site Restoration considerations included in the report?			
Are regulatory end state and site clearance and exemption considerations included in the report?			
Is facility re-use considerations included in the report?			
If site re-use is included, is a credit included in the cost estimate?			
If an EVMS is assumed to be applied in decommissioning, are costs included?			
Are all references used to develop the estimate included in the report?			

3. Comparisons to other estimates – benchmarking

The comments regarding benchmarking are provided as a caution on over- reliance on the accuracy or comparability of cost data from international sources. Part 1, Section 4.2 and Appendix C provide additional discussion of benchmarking considerations and limitations.

As noted earlier, obtaining accurate representative cost data from completed projects is most difficult. Contractors consider this experience to be proprietary, and applicants/owners/licensees are not willing to share such information if in fact they tracked the costs to any level of detail or accuracy. With these caveats, it may still be reassuring to compare cost estimates to actual decommissioning experience to provide a level of validation not otherwise possible.

3.1 Similar facilities – size and complexity

The first and obvious consideration is to ensure the benchmarked facility is similar in design, size and complexity to the estimate under review. The differences posed by projects at single unit sites versus multi-unit sites can raise significant problems in attempting to compare costs. Table 17 provides the reviewer a checklist of considerations to examine in establishing the similarity in comparative plants, in part (a) for PWRs and in part (b) for BWRs.

Table 17(a): Similar Facility – Size and Complexity Checklist (PWRs)

	Yes	No	n/a
Pressurized Water Reactors - PWRs			
Is the benchmark reactor a single unit site or multi-unit site?			
Assuming a single unit site, what is the megawatt rating?			
Is the difference in megawatts of the benchmark to existing reactor more than a factor of 10?			
Are the number of steam generators the same?			
Are the number of reactor coolant pumps the same?			
Do the benchmark actual costs include the costs for handling and storage of spent nuclear fuel?			
Is there sufficient detail to delete spent fuel handling/storage costs?			
Do the benchmark actual costs include costs for packaging, transporting and disposal of LLW and ILW?			
Is there sufficient detail to separate the costs for packaging, transporting and disposal of LLW and ILW?			
Is the Containment Building of the benchmark plant similar in design to the plant in review?			
Are there separate buildings for fuel, auxiliary, control, turbine-generator, diesel, security, administration, etc.?			
Did the benchmark plant have a single or multiple turbine-generator?			
Was there soil contamination at the benchmark plant?			
Was there groundwater contamination at the benchmark plant?			
Are the end point states similar - greenfield vs. brownfield?			
Were any buildings retained for re-use at the benchmark plant?			
Was the switchyard equipment retained for continued use at the benchmark plant?			

Table 17(b): Similar Facility – Size and Complexity Checklist (BWRs)

Boiling Water Reactor - BWR			
Is the benchmark reactor a single unit site or multi-unit site?			
Assuming a single unit site, what is the megawatt rating?			
Is the difference in megawatts of the benchmark to existing reactor more than a factor of 10?			
Does the benchmark reactor have recirculation pumps with or without jet pumps in the reactor vessel?			
Do the benchmark actual costs include the costs for handling and storage of spent nuclear fuel?			
Is there sufficient detail to delete spent fuel handling/storage costs?			
Do the benchmark actual costs include the costs for packaging, transport and disposal of LLW and ILW?			
Is there sufficient detail to separate the costs for packaging, transport and disposal of LLW and ILW?			
Is the benchmark containment building a Mark I (torus), Mark II (over/under), Mark III (concrete circular pool)?			
Are there separate buildings for fuel, auxiliary, control, turbine-generator, diesel, security, administration, etc.?			
Did the benchmark plant have a single or multiple turbine-generator?			
Was there soil contamination at the benchmark plant?			
Was there groundwater contamination at the benchmark plant?			
Are the end point states similar - greenfield vs. brownfield?			
Were any buildings retained for re-use at the benchmark plant?			
Was the switchyard equipment retained for continued use at the benchmark plant?			

3.2 Adjustments for year expenditure

Since ‘recent’ decommissioning experience dates back as far as the early 1990s, adjustments for the year of expenditure are a necessary element of any comparison. Accounting for inflation during the period of completion of the benchmark plant basis and the estimate under review should take into account the cost elements of labour, materials, energy, and transport/disposal of wastes. The US NRC’s guidance for inflation adjustments provides an approach for a detailed comparison (Ref. 3). If the data is available, the benchmark breakdown into labour, materials, energy, and transport/disposal of wastes can be individually escalated (inflated)[1]. If detailed data is not available, the only recourse is to use an overall inflation rate for the difference in years in the comparison. A finer-tuned escalation would attempt to correct for inflation over the years of performance of the decommissioning project, as some projects have extended into decades of work. Generally, there is insufficient data available to perform these calculations. Table 18 provides the reviewer with a checklist of considerations in adjusting for inflation between comparative benchmarked costs.

Table 18: Adjustments for Year of Expenditure

	Yes	No	n/a
Is the year of the actual cost for decommissioning of the benchmark plant clearly stated?			
Is there a detailed breakdown of costs of the benchmark into labour, materials, energy and disposal?			
Can such a breakdown be assembled from the benchmark data provided?			
If source data is based on international resources for equipment and consumables, is the source identified?			
If source data is based on international currency, can costs be converted to local currency by exchange rate?			

[1] **Cost escalation** is defined as changes in the cost or price of specific goods or services in a given economy over a period. While escalation includes general inflation related to the money supply, it is also driven by changes in technology, practices, and particularly supply-demand imbalances that are specific to a good or service in a given economy.

3.3 Ten external factors for benchmarking

The OECD/NEA (Ref. 4) indicates that, when comparing costs, “Cost figures should not be taken at face value unless these (10) elements and their history are specified in comparative tables”. The ten elements are:

1. Scope of work through to the end-point of the site;
2. Regulatory requirements, including details of reporting and clearance levels;
3. Stakeholders’ demands;
4. Characterisation of physical, radiological, and hazardous material inventory;
5. Waste processing, storage and the availability of ultimate disposition facilities;
6. Disposition of spent fuel and on-site storage prior to emplacement in a deep repository;
7. Clean structure disposition and disposal of the site for new developments;
8. Contingency application and use in the estimates;
9. Availability of experienced personnel with knowledge of the plant;
10. Assumed duration of the dismantling and clean-up activities.

The benchmark analysis should make reference also to the above criteria.

4. Conclusions

The approach described in this Part 2 of the guide provides a reference roadmap for conducting the peer reviews that is consistent. Consistency is accomplished through the use of checklists. It is intended that the findings and observations will provide constructive direction to achieving a quality cost estimate. Consistency of approach may also permit establishing trend analyses, to help guide in cost planning future decommissioning projects.

The checklists are not static, however, and will be reviewed and modified as necessary to improve upon them. Such input provides a valuable updating function not readily anticipated until the results of a review are available. This guidance document itself should be considered a living document, and updated and revised as needed.

5. References

1. “Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates,” T.S. LaGuardia, et al, AIF/NESP-036, May 1986

2. Cost Engineers Notebook: American Association of Cost Engineers, AA-4.000, p. 3 of 22, Rev. 2, January 1978, (updated periodically)

3. “Report on Waste Burial Charges: Changes in Waste Disposal Costs at Low Level Waste Burial Facilities,” NUREG 1307, Revision 14, November 2010

4. “Estimation of Nuclear Facility Decommissioning Costs – Current Status and Prospects,” Leaflet. OECD/NEA, March 2013.

6. Additional reading

1. Standard Review Plan for Decommissioning Cost Estimates for Nuclear power Reactors," US Nuclear Regulatory Commission, NUREG-1713, Washington, DC, December 2004

2. "Common Summary Format for Decommissioning Cost Estimates," 2012 Nuclear Decommissioning Cost Triennial proceeding, California Corporation Commission, Exhibit A, 2012

3. "Selection of Decommissioning Strategies – Issues and Factors," IAEA – TECDOC – 1478, November 2005, Vienna

4. Lough, W.T., Johnson, W.R., White, K.P., "A Multi-Criteria Decision Aid for Evaluating Nuclear Power Plant Decommissioning," Proceedings of an International Decommissioning Symposium, Pittsburgh, PA, 1987 (pp. 314-323)

5. Rahman, A., "Multi-Attribute Utility Analysis – A Major Decision Aid Technique," Nuclear Energy, 42, No. 2, April 2003

6. "Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries," AACE International, Recommended Practice No. 18R-97, AACEI, 2005

7. Anthony L. Huxley, "Estimate Classes: An Explanation," Construction Economist, Vol. 12, Number 2, June 2002

8. "Project and Cost Engineers Handbook," Second Edition, (p 239), American Association of Cost Engineers (now AACEI), Marcel Dekker, Inc., New York, NY 1984

9. "Quality Assurance Requirements for Nuclear Facility Applications," ASME NQA-1, New York, NY 2008

10. "Process Equipment Cost Estimating by Ratio and Proportion," Randall W. Whitesides, PE, 2012

11. "Report on Waste Burial Charges: Changes in Waste Disposal Costs at Low Level Waste Burial Facilities," NUREG 1307, Revision 14, November 2010

12. R.I Smith, et. al., "Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station," Battelle Pacific Northwest Laboratory, NUREG/CR-0130, June 1978

13. H. Oak, et, al., "Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station," Battelle Pacific Northwest Laboratory, NUREG/CR-0672, June 1980

14. Title 10, Code of Federal Regulations, Part 50, Washington, DC

15. "Common Summary Format for Decommissioning Cost Estimates," 2012 Nuclear Decommissioning Cost Triennial proceeding, California Corporation Commission, Exhibit A, 2012

7. Acronyms

AACEI	Association for the Advancement of Cost Engineering International
ASME	American Society of Mechanical Engineers
BoE	Basis of Estimate
BWR	Boiling Water Reactor
DOC	Decommissioning Operations Contractor
EC	European Commission
ESC	Escalation Factor
EVMS	Earned Value Management System
IAEA	International Atomic Energy Agency
ISDC	International Structure for Decommissioning Costing
MFA	Minimum Funding Amount
MWe	Megawatt electric
MWt	Megawatt thermal
NPP	Nuclear Power Plant
NQA-1	Nuclear Quality Assurance -1 (ASME Quality Assurance programme)
NRC	(U.S.) Nuclear Regulatory Commission
OECD/NEA	Organization for Economic Cooperation and Development/Nuclear Energy Agency
PDM	Precedence Diagramming Method
PERT	Programme Evaluation and Review Technique
PWR	Pressurized Water Reactor
P50/P80	Probabilities at the 50% and 80% Confidence Levels
QAPP	Quality Assurance Project Plan
SBoE	Schedule Basis of Estimate
UCF	Unit Cost Factor
US GAO	U.S. General Accounting Office
WDF	Work Difficulty Factor

APPENDICES

Appendix A – Cost estimate classification systems

Cost estimate classification systems have been developed by several countries for their own cost estimate needs. The basic principles are the same as discussed in Section 2.1. It is a rating system based on the degree of completeness of the estimate and level of uncertainty of conditions upon which the estimate is based. The Canadian classification system was selected for illustrative use in the text of Section 2.1 This Appendix presents several other classification systems available for consideration in preparing and reviewing cost estimates.

1. AACEI Classification

The Association for the Advancement of Cost Engineering International (AACEI) establishes standards for the accuracy of cost estimates that are based on the degree of known information at the time of the estimate. The AACEI Recommended Practice 18R-97[2] provides such standards. Based on the criteria shown in Table A.1 (reproduced from the AACEI document with permission), 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 authorization or control, comparable to what would be needed to establish a decommissioning trust fund.

2. ANSI Standards and Other Classifications

The American National Standards Institute (ANSI), the American Association of Civil Engineers (AACE), Association of Cost Engineers (ACE) in the UK, the Norwegian Project Management Association (NPMA), and the American Society of Professional Estimators (ASPE) also have prepared cost estimate classification systems. These classification schemes are compared in Table A.2 (also reproduced from AACEI with permission)[3].

3. UK Nuclear Decommissioning Authority PCP-09

The United Kingdom Nuclear Decommissioning Authority (NDA) also has guidance on cost estimate classifications in their Project Control Procedure PCP-09, which is primarily aimed at approving budgets for funding on a very broad scale. Figure A.1 is a graphical representation of the UK NDA classification system.

[2] "Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries", AACE International, Recommended Practice No. 18R-97, AACEI, 2005

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

Table A1: AACEI Classification System

ESTIMATE CLASS	*Primary Characteristic*	*Secondary Characteristic*			
	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 or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, 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: -5% 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

Notes: [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.

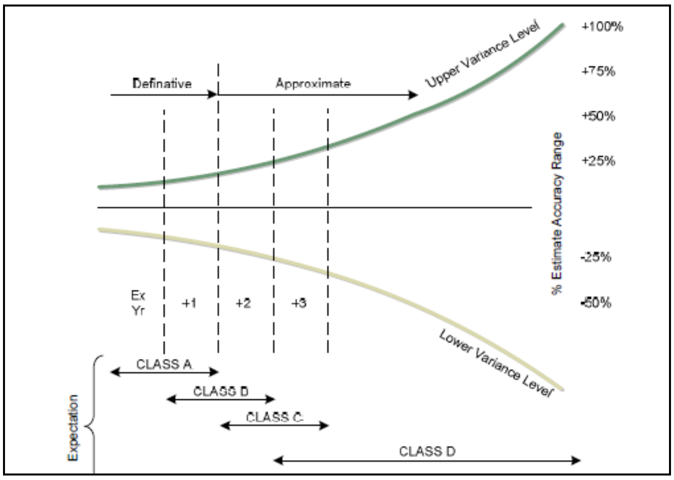
[b] If the range index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools.

Table A.2: Comparison of Cost Classification Systems

AACE Classification Standard	ANSI Standard Z94.0	AACE Pre-1972	Association of Cost Engineers (UK) ACostE	Norwegian Project Management Association (NFP)	American Society of Professional Estimators (ASPE)
Class 5	Order of Magnitude Estimate -30/+50	Order of Magnitude Estimate	Order of Magnitude Estimate Class IV -30/+30	Concession Estimate Exploration Estimate Feasibility Estimate	Level 1
Class 4	Budget Estimate -15/+30	Study Estimate	Study Estimate Class III -20/+20	Authorization Estimate	Level 2
Class 3		Preliminary Estimate	Budget Estimate Class II -10/+10	Master Control Estimate	Level 3
Class 2	Definitive Estimate -5/+15	Definitive Estimate	Definitive Estimate Class I -5/+5	Current Control Estimate	Level 4
Class 1		Detailed Estimate			Level 5 Level 6

INCREASING PROJECT DEFINITION

Figure A.1: UK NDA Classification System



Appendix B – Uncertainty, contingency and risk

Uncertainty has a negative connotation with respect to cost estimation. In fact, all cost estimates have some uncertainty or otherwise the estimate would be exact and not an estimate. There are several elements contained in the term uncertainty which will be discussed in this section. Unfortunately, there is no international standard definition or concurrence on what uncertainty is or how it is to be addressed in a cost estimate.

Uncertainty covers a broad range of terms and interpretations that are often confusing and lead to mistrust of the estimate's credibility. In fact, the inclusion of uncertainty analyses refines and builds confidence in the credibility and recognition of risks of achieving the estimates' purpose – to provide for adequate budgeting and funding for a specific future project.

> *"There are known knowns; there are things we know that we know. There are known unknowns; that is to say, there are things that we now know we don't know. But there are also unknown unknowns – there are things we do not know we don't know."*
>
> — United States Secretary of Defense, Donald Rumsfeld

The known knowns form the basis of decommissioning cost estimates, also called Point Estimates. Uncertainty in its broadest interpretation includes known unknowns often referred to as contingency, and unknown unknowns often referred to as risks.

1 Elements of Uncertainty

The following list identifies the elements of uncertainty which will be further described in the text.

- Estimating Uncertainty
- Estimating Allowances
- Contingency
- Risks

1.1. Estimating uncertainty

Estimating Uncertainty can best be described as that associated with insufficient or inadequate data quality such as the physical and radiological inventory, cost basis for labor, materials or equipment, productivity rates for the performance of work activities applied in Bottom-Up unit cost factors (UCFs), actual contractor markups included in fixed price bids, (and circumstance differences when employing Specific Analogy, or Parametric estimating techniques. Estimating uncertainty can include the cost basis year of data (current year, current quarter, etc.), and whether proper accounting for inflation has been included. It may also be influenced by national or regional variations in labor, material and equipment costs.

In a broader sense, Estimating Uncertainty can include Estimating Allowances, Contingency and Risks which will be described in the following section.

1.2. Estimating allowances

Estimating Allowances are used by cost estimators to account for costs that are certain to occur, but current cost information is not available. For example, the cost of a special tool for segmenting the reactor vessel internals generally requires sophisticated remote technology, mockups and in-factory testing prior to being transported to the reactor site, and final on-site testing of the equipment. The actual equipment would likely be procured on a competitive basis, where several bidders would propose a design and services. This process can take many months to accomplish, well beyond the timeframe of developing a budgetary estimate. The cost estimator therefore must include an allowance based on experience from other projects or from informal discussions with potential vendors to include a cost for this equipment. This is the purpose of an allowance, and is commonly used in cost estimation.

1.3. Contingency

Contingency is probably the least well understood cost internationally. Several cost estimating organizations have offered definitions of some merit with respect to the overall estimate, but each must be clearly explained with respect to its application and limitations. This Appendix of the Guide will identify some of the more common definitions by the leading cost estimating organizations.

1.4. Risks

Risks are the unknown unknowns in developing a cost estimate to account for those elements of cost beyond the project scope. In some cases, estimators combine contingency (within the project scope) with risks (outside the project scope). In either case, the definitions applied must be clearly stated.

2. The point estimate

The Point Estimate is the term given to the sum of all costs derived from the WBS developed for the project. It is prepared for a single point in time without attempting to include cost escalation due to other factors to be discussed later.

3. Contingency

Early estimates, including decommissioning cost estimates addressed uncertainty through the use of contingency, a fixed or percentage amount of the Point Estimate to account for the uncertainties associated with accomplishing a project. Contingency amounts were selected based on industry standard guidelines or estimator’s experience, and were applied as a single value to the bottom-line cost or multi-valued percentages applied on individual line items of the Point Estimate and then summed along with the total cost.

The practice of including contingency in estimates was to ensure adequate funding would be available to decommission the facility at the end of its useful life. From experience and now practice, all contingency moneys are expected to be fully spent on the project.

In this guide, contingency is the amount included in an estimate to account for unforeseeable elements of cost within the defined project scope and will be fully spent.

This is fully consistent with the AACEI Cost Estimator's Notebook[4] as noted in the following subsection. It may be determined by industry standard guidelines, an estimator's experience and judgment, or calculated by a quantitative risk analysis using Monte Carlo techniques. Contingency may be included as part of the broader risk analysis to include out of scope elements of cost, but must be clearly stated in the definition of contingency.

Contingency is probably the least well understood cost internationally. Several cost estimating organizations have offered definitions of some merit with respect to the overall estimate, but each must be clearly explained with respect to its application and limitations. This section will discuss some of the more common definitions by the leading cost estimating organizations.

3.1. AACEI Cost Estimator's Notebook

The Association for the Advancement of Cost Engineering International (AACEI) Cost Estimators Handbook has defined contingency as follows:

"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."

This definition provided a clear and concise description of the scope and impact of contingency application. The important phrase "within the defined project scope," restricted the uncertainty to known unknowns so as not to confuse the definition to include escalation or other potential cost increases.

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 labor 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 is applied.

3.2. AACEI Recommended Practice 10S-90

The AACEI further modified its definition of contingency in its Recommended Practice document 10S-90[5] as follows:

Contingency – An amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs. Typically estimated using statistical analysis or judgment based on past asset or project experience. Contingency usually excludes:

1) Major scope changes such as changes in end product specification, capacities, building sizes, and location of the asset or project;
2) Extraordinary events such as major strikes and natural disasters;
3) Management reserves; and
4) Escalation and currency effects.

[4] "Project and Cost Engineers Handbook," Second Edition, (p 239), American Association of Cost Engineers (now AACEI), Marcel Dekker, Inc., New York, NY 1984

[5] AACEI Recommended Practice Document 10S-90, "Cost Engineering Terminology, TCM Framework: General Reference," October 10, 2013

Some of the items, conditions, or events for which the state, occurrence, and/or effect is uncertain include, but are not limited to, planning and estimating errors and omissions, minor price fluctuations (other than general escalation), design developments and changes within the scope, and variations in market and environmental conditions. Contingency is generally included in most estimates, and is expected to be expended. The basic concepts included in this latter definition are the same as the earlier definition, but with some clarifications.

3.3. OECD/NEA/IAEA ISDC

The OECD/NEA/IAEA International Structure for Decommissioning Costing (ISDC) also adopted the earlier AACEI definition for its guidance to estimators.

4. Risks

As noted earlier, unknown unknowns are generally identified as project risks. They include all of the uncertainties excluded from the known unknowns or contingency as previously defined, and refer to such events as inflation/escalation, changes in regulatory actions, unexpected increases in costs for materials, equipment or services, or accidents. In general, risks include downside uncertainties called "threats" as just noted, and upside uncertainties such as reductions in costs called "opportunities." Several organizations have provided definitions of risks, some of which are shown in the following paragraphs.

4.1. AACEI Recommended Practice

This AACEI document, "Risk Analysis and Contingency Determination using Range Estimating[6]" defines risk as follows:
Risk means "an undesirable potential outcome and/or its probability of occurrence, i.e. downside uncertainty (a.k.a. threats). Opportunity, on the other hand is a desirable potential outcome and/or its probability of occurrence, i.e., upside uncertainty."

4.2. HM Treasury - The Orange Book

This UK document, "Management of Risk - Principles and Concepts[7] " defines risk as follows:
Risk is defined as this uncertainty of outcome, whether positive opportunity or negative threat, of actions and events. The risk has to be assessed in respect of the combination of the likelihood of something happening, and the impact which arises if it does actually happen. Risk management includes identifying and assessing risks (the "inherent risks") and then responding to them.
Risks are addressed by both qualitative and quantitative methods to arrive at a confidence level of the estimated cost of a project. Some estimators use quantitative risk analyses on the base estimate (without contingency) to estimate contingency, while others use quantitative risk analyses on the base estimate including contingency, as this contingency cost is fully expected to be incurred.

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[6] AACEI Recommended Practice RP 41R-08, "Risk Analysis and Contingency Determination using Range Estimating" October 27, 2008
[7] HM Treasury - The Orange Book, "Management of Risk - Principles and Concepts," October 2004

4.3. Intergenerational Inequity

As noted earlier in this guide, issues often extend well into the future to anticipate potential problems (risks) or improvements (opportunities) that may be incurred. This issue raises the concern for 'intergenerational inequities,' where current consumers (ratepayers) are expected to pay for potential future expenses. The purpose of risk analyses in this case is to attempt to anticipate the future expense and equalize the ratepayer payments over the operating life of the plant. Otherwise future ratepayers will have to bear the burden of making up for a shortfall in funding as the facility nears shutdown, and current ratepayers won't share the full burden of the ultimate costs of electricity produced or of decommissioning. Typically, periodic (every three to five years) cost estimates are reviewed and re-estimated to account for inflation as it occurs and any changes to regulations or stakeholder concerns for example.

Appendix C – Some benchmarks for light water reactors

Table C1 is a summary of U.S. decommissioning projects for Light Water Reactors (LWRs) and estimated and actual (or estimated to complete) costs . 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 OECD/NEA document[8], "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 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 percent 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 Federal Government (US 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 de-funded to effectively shut it down.

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.

[88]"Estimation of Nuclear Facility Decommissioning Costs: Current Status and Prospects," OECD/NEA Working Party on Decommissioning and Dismantling, March 2012, Paris, France

While it would be desirable 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 the author (T. LaGuardia).

Table C1: List of Recent U.S. Reactor Decommissioning Projects

Nuclear Plant	React or Type	Size (MWe)	Operating Life (years)	Reason for Closure	Estimated Cost, $ millions (M)	Estimated Cost $(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

<u>Connecticut Yankee</u>

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 $329 million to remediate below-grade soil contamination of Strontium-90 and Tritium not previously characterized.

<u>Yankee Rowe</u>

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.

<u>Maine Yankee</u>

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 NRC’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 $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 $19 million (later increased to $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 license 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 license 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 on-going.

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:

- License 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.

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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