International Developments on Uncertainties in NPP Decommissioning costs and planned work on Benchmarking at the OECD-NEA – 17074

Simon Carroll, Swedish Radiation Safety Authority (SSM)[1]

ABSTRACT

The ability to decommission NPPs shut down after normal operation has been proven technically. Issues of current concern include the ability to accurately calculate and demonstrate the validity of decommissioning cost estimates, and to control costs during decommissioning. This paper describes recent international developments concerning addressing uncertainties in NPP decommissioning cost estimation, and work currently being planned relating to decommissioning cost benchmarking at the OECD Nuclear Energy Agency. The process of decommissioning cost estimation is evolving, with a general trend towards showing greater levels of detail in the estimate. The International Structure for Decommissioning Costing was published in 2012 and presents a common reporting format for decommissioning costing undertaken on a deterministic basis. However, this does not address probabilistic methods or associated presentation formats for the inclusion of uncertainties in decommissioning estimates. A consistent and comparable treatment of uncertainties in decommissioning cost estimation would further facilitate comparison between different cost estimates and enhance understanding of and confidence in the estimates themselves. There is growing interest in benchmarking decommissioning costs, reflecting a need to better understand the relationships between estimates and actual costs, to give greater confidence that funding will be sufficient, and as a useful tool in project management and enhancing project delivery.

INTRODUCTION

The process of decommissioning cost estimation is constantly evolving, in line with national requirements and practice, and taking account of experience from other sectors. There is a general trend towards showing greater levels of detail in the estimate and more explicit representation of the uncertainties that bear on the final cost.

There are a wide variety of approaches for presenting the various elements of a cost estimate, and the details may differ considerably between countries, organizations and estimators. Nonetheless, all these approaches necessarily have some core elements in common. These common elements are illustrated in Figure 1. This shows the cumulative impacts as cost components are added or subtracted. Such a presentation is useful for understanding how an initial value (for example, the reference base cost) is affected by a series of positive and negative cost elements.

[1] The author has prepared this paper in his role as Chair of the Decommissioning Cost Estimation Group (DCEG) of the OECD Nuclear Energy Agency.

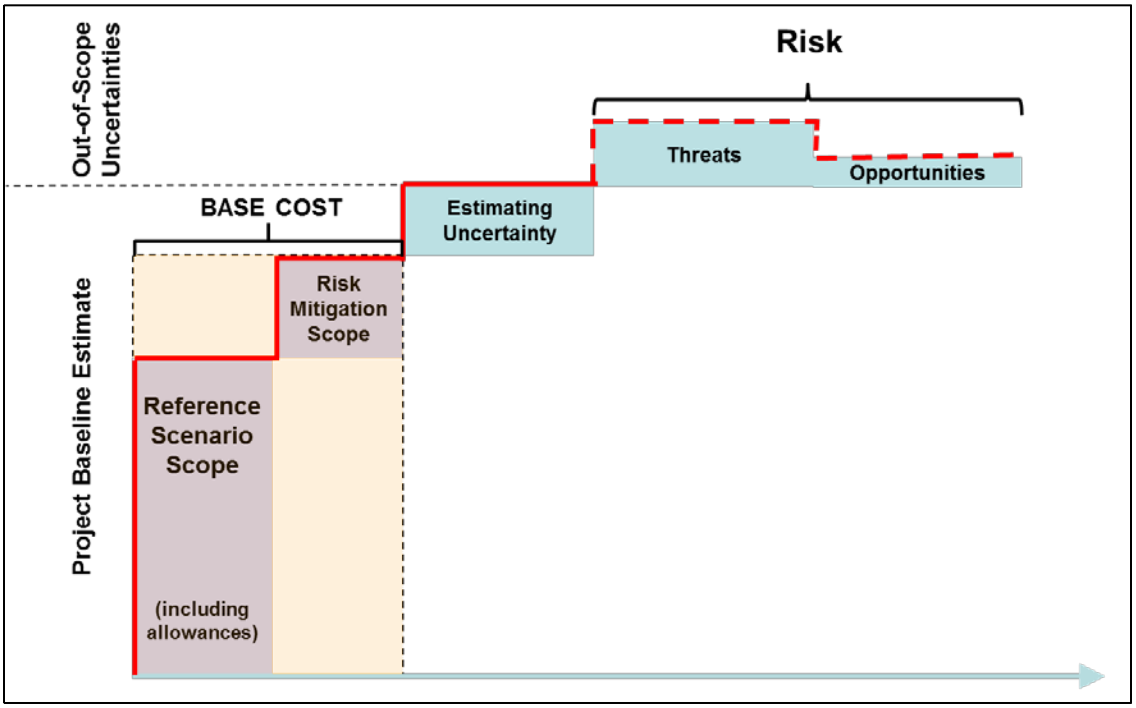

Fig. 1. Elements of a Cost Estimate (from reference [2])

The OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) have long been concerned about the need to promote greater transparency in decommissioning costing and have collaborated in a number of initiatives in pursuit of this objective. Together with the European Commission, they published "*The International Structure for Decommissioning Costing* (ISDC)" in 2012 [1]. The ISDC presents a common reporting format for decommissioning costing undertaken on a deterministic basis. However, the ISDC itself also does not address probabilistic methods or associated presentation formats for the inclusion of risk in decommissioning estimates. The ISDC and its exclusion of treatment of risk is illustrated in Figure 2. It is generally recognized that developing a consistent and comparable treatment of uncertainties in decommissioning cost estimation would further facilitate comparison between different cost estimates and enhance understanding of and confidence in the estimates themselves.

Benchmarking is increasingly referred to in the context of cost estimation for nuclear decommissioning. This reflects growing focus on understanding variations between decommissioning cost estimates and apparent escalation of decommissioning costs; and assuring the adequacy of decommissioning financing arrangements. A related interest is in improving the performance and ensuring value-for-money in the delivery of decommissioning projects and services.

This paper describes recent international developments concerning addressing uncertainties in NPP decommissioning cost estimation, and work currently being planned relating to decommissioning cost benchmarking at the OECD Nuclear Energy Agency.

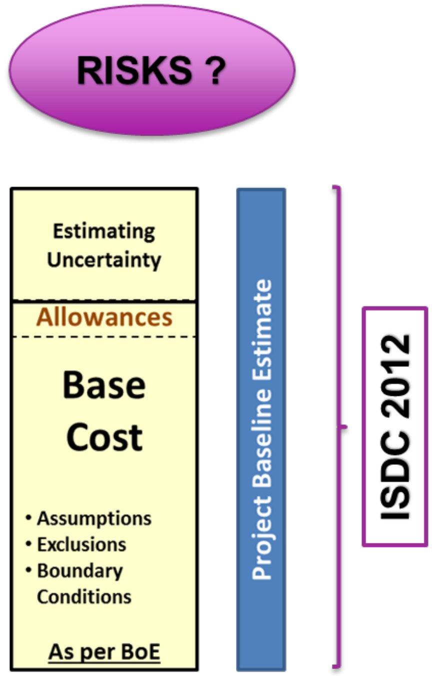

Fig. 2. The ISDC does not include treatment of risk

ADDRESSING UNCERTAINTIES

In 2014 the NEA and IAEA initiated a joint activity to facilitate preparation and presentation of nuclear decommissioning cost estimates which include explicit consideration of uncertainties in an integrated manner, and as a complement to the existing ISDC cost presentation format. This outcome of this activity is to be published by NEA in 2017 [2]. It aims to inform cost estimators and reviewers about practical approaches to address aspects of cost estimation, including uncertainties, for NPP decommissioning projects. Specifically, it describes how uncertainties in decommissioning cost estimation can be addressed using uncertainty and risk analysis methods. Its recommendations aim at enabling more consistent and systematic application of the treatment of risk and uncertainty in the preparation of decommissioning cost estimates.

Building on the ISDC

The ISDC presents a common reporting format for decommissioning costing undertaken on a deterministic basis. As illustrated in Figure 2, the Basis of Estimate (BoE) is the foundation upon which the cost estimate is developed, and provides a detailed description of the project. A well-documented BoE should fully reflect the current applicable decommissioning plan for the nuclear installation, and highlight any relevant variation between the plan and reference scenario used for calculating the decommissioning cost estimate. As described in the BoE, all scope is defined by a set of scope statements and bounded by use of assumptions, exclusions etc. At the working level in the Work Breakdown Structure (WBS), scope statements and assumptions are used to clearly define the work to be executed. The sum of all WBS scope statements represents the project scope as set out in the BoE. The use of the ISDC list of activities is a way to facilitate understanding the project scope, establish a WBS, and ensure that all relevant activities within the project scope are reflected in the cost estimate.

Including Risk-Mitigation Scope

The ISDC addressed the development of an estimate for a given, defined scope and did not fully consider issues relating to poorly defined or immature scope, and how these should be addressed in an estimate. Whilst very repeatable projects and sub-projects may simply adopt a lump sum cost estimate based on a parametric approach, this approach rarely works for complex decommissioning projects. Instead, attention needs to be given to an iterative process of scope refinement or optimizing of the initial project scenario. It may take several iterations of scenario development to optimize the base scenario for the project, with an understanding of the potential impacts of alternative decommissioning strategies. This iterative development of the base scope is part of the scope maturity process and can be undertaken progressively at any time in the cost assessment process.

Figure 3 illustrates how an initial Base Scope can be adjusted by adding additional scope in order to mitigate potential risks. This additional risk mitigation scope is associated with expert judgment being applied to the original reference scenario for the project. Where an initial assessment reveals potential events and outcomes that may be seen as intolerable or undesirable, these may be better dealt with by adding appropriate risk mitigation scope to the original Base Scope, rather than by being addressed separately as potential out-of-scope risks. Accordingly, potential risks to be mitigated are treated as in-scope issues and therefore included in the BoE, for example by including insurances, permits, new technologies, etc. The additional cost for the risk mitigation scope should then be estimated as part of a revised Base Cost for the project.

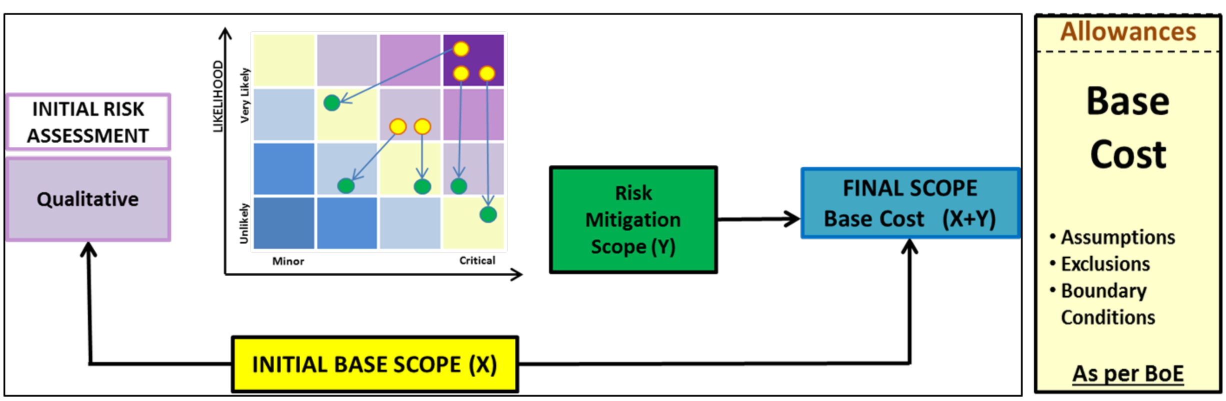

Fig. 3. Adding Risk-Mitigation Scope, as part of the Base Cost (adapted from reference [2])

The Project Baseline Estimate includes Estimating Uncertainty

The Project Baseline Estimate is the estimated cost of the base scope of the project as defined by the BoE, including provision for the Estimating Uncertainty. It excludes provision for any risks considered beyond the defined project scope, but includes any added risk-mitigation scope. As shown in Figure 4, Estimating Uncertainty can be specifically evaluated and should be provisioned for in the estimate as part of the Project Baseline Estimate.

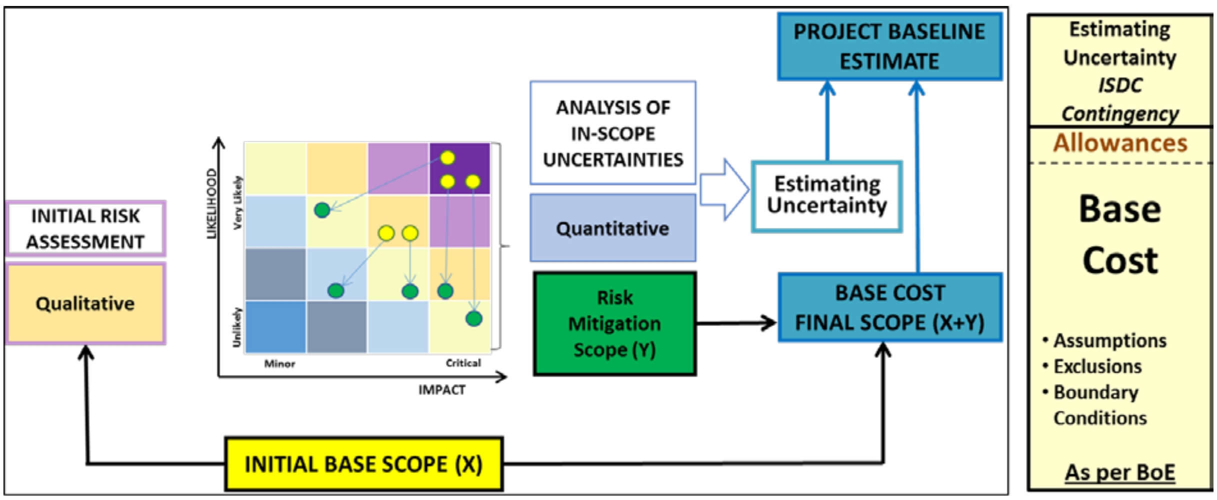

Fig. 4. Project Baseline Estimate, including risk mitigation scope and Estimating Uncertainty, and its relation to the ISDC (adapted from reference [2])

The term “Estimating Uncertainty” is used here for a provision for uncertainties associated with conduct of work under other than the ideal (theoretical) conditions used to derive the project base cost. Within ISDC this is referred to as the “contingency” and it is assumed to be fully spent during execution of the project. These uncertainties arise from events that are likely to occur, and include events which occur during the execution of a project such as equipment breakdown, inclement weather, logistical delays, etc. Consistent with the ISDC approach, it is assumed that the Estimating Uncertainty would be expected to be fully spent during project execution.

In the context of this paper, uncertainty related to input parameters is generally treated as Allowances, and these are included within the Base Cost. However, it should be noted that currently there exist a range of approaches to addressing Allowances and whether these are considered as part of the Base Cost or calculated as Estimating Uncertainty. This makes it essential that the definitions used and approach taken be fully explained and documented in the estimate.

Uncertainties vary in whether and to what extent they may be reduced over time in the light of additional information or more in-depth analysis. Some may be addressed by additional effort (research, measurements, planning, elaboration of the regulatory requirements, etc.). How this is done may vary but narrative and supporting analyses should be used to make transparent how uncertainties have been addressed in a particular cost estimate. The choice of analysis methods, or whether such methods are used at all, depends on the specific context for a given estimate.

Adding Risk Elements Beyond the ISDC

The ISDC does not address uncertainties which lie above the Project Baseline Estimate as they are considered beyond the defined project scope ("Out-of-Scope"). Out-of-scope uncertainties are referred to as "Risks" in the context of this paper. Addressing such Risks in an estimate is determined by the nature of the decommissioning project, the uncertainties being considered, the impact of proposed risk events, and last but not least, the perspective of those analysing this data. The consequence is to address the need for an additional cost provision for risk above the project baseline estimate.

As we are dealing with a potential range of outcomes, it is logical to consider both deterministic and probabilistic means to derive a further funding provision to tackle the issue of funding shortfall against out-of-scope risks. A step-wise approach to the analysis of out-of-scope risk and how this can be used to derive a cost provision in the final cost estimate is set out in [2]. This describes a process which involves risk identification, assessment and analysis to generate a set of outcomes for several different scenarios (and hence a range of additional cost provisions) that are directly tied to a probability of occurrence. Taking the Risk Appetite[2] into consideration allows a determination to be made of which of these Risks are to be funded or not, as Funded Risk and Unfunded Risk elements respectively, as illustrated in Figure 5. The additional cost provision for Funded Risk above the Project Baseline Estimate can now be included in the estimate to yield a Final Funded Cost.

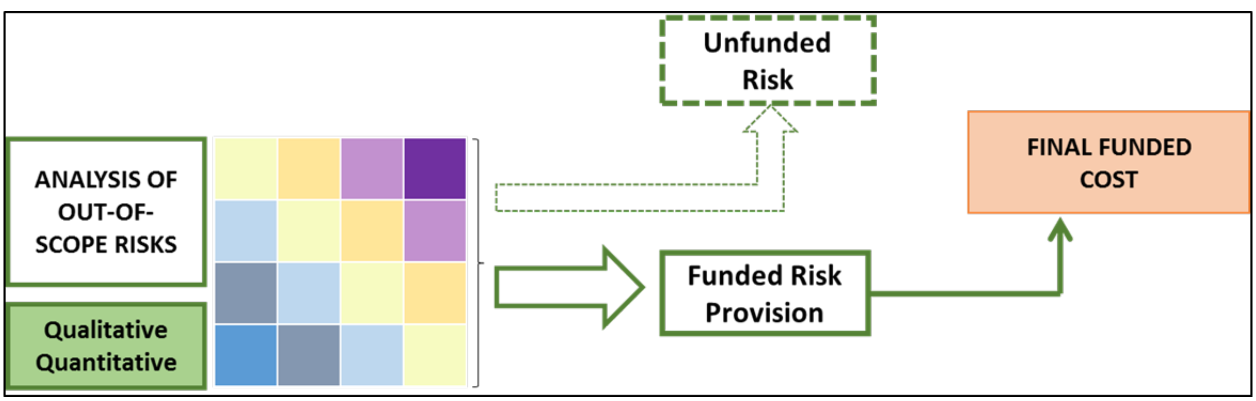

Fig. 5. Addressing Risk in the Cost Estimating Process (from reference [2])

[2] "Risk Appetite" can be defined as the amount of risk above the Project Baseline Estimate that an individual, group or organisation is prepared or required to fund in order to complete the project objectives. The logic and basis for the Risk Appetite used should be clearly set out in the BoE.

An Estimate Which Integrates Risk-Mitigation Scope and Risk Elements

Putting all elements mentioned in the preceding sections together allows the production and presentation of a cost estimate that is able to integrate treatment of issues of scope maturity, uncertainty within the defined project scope, and out-of-scope risk. This integrated approach, and its relation to the ISDC, is illustrated in Figure 6.

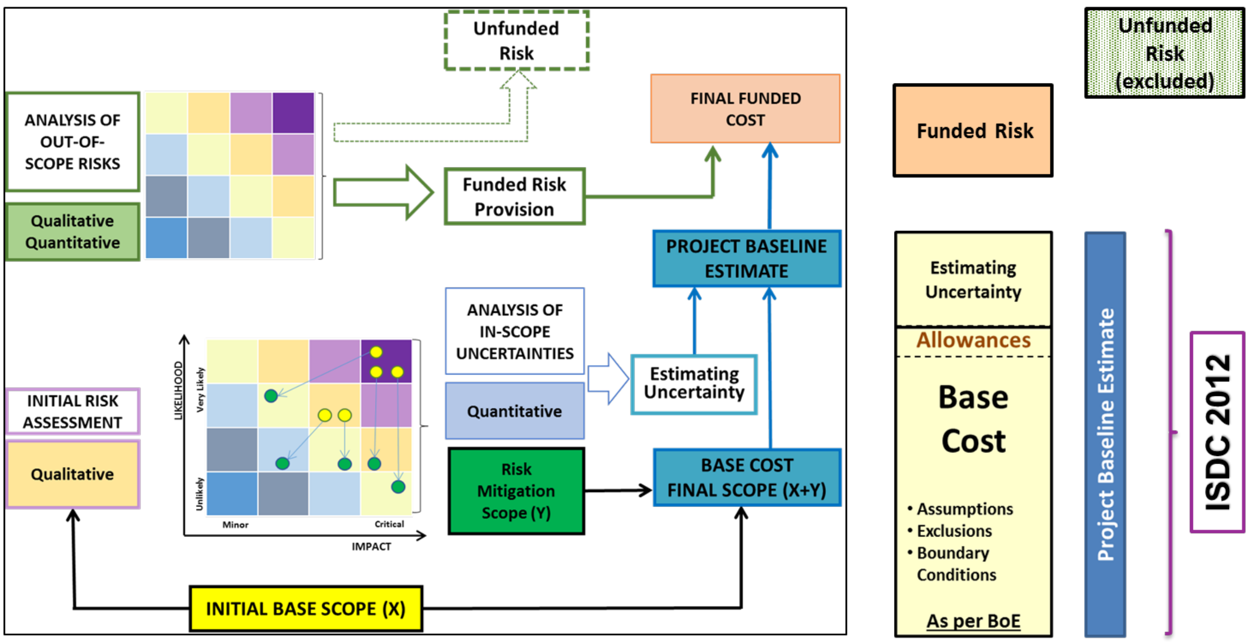

Fig. 6. Calculating a Final Funded Cost, including addition of a Funded Risk Provision to the Project Baseline Estimate, excluding Unfunded Risk, and the relationship to the ISDC (adapted from reference [2])

It should be noted that a prerequisite of addressing risk beyond the defined project scope, requires understanding of the BoE, assumptions and exclusions; and how estimating uncertainties within the defined project scope have been treated. For example, here we have set out how risk mitigation scope is included in the base scope, and such activities are therefore not included when considering risks beyond the defined project scope. If the Base Scope has not been optimised by the process of addressing risk-mitigation scope, then these risks would need to be taken into consideration within the analysis of risks beyond the defined project scope, and a larger risk provision would need to be incorporated in order to balance the outcome.

The completeness and maturity of the scope definition also needs to be taken into account in the risk analysis process. Risk associated with incomplete or poorly defined scope should be considered in the risk analysis.

Implications for an Estimate

Decommissioning cost estimates are produced for a number of different purposes at different points of time, spanning the period from conceptual design prior to construction of the power plant, through to the execution of decommissioning. They are updated periodically throughout the facility's operation, following plant shutdown and during the period in which decommissioning activities are undertaken. Estimates will evolve as knowledge is accumulated and planning for the decommissioning project develops. Changes may occur for example as a result of modifications made to the defined project scope, increasing maturity of project scope, and developments in the definition and analysis of risks at different points in time.

Figure 7 illustrates how relationships between different components of an estimate may be expected to evolve over time. In this figure, a mid-point of Risk Appetite is assumed to be the objective and hence the actual costs should converge to this mid-point over time - through the project execution phase. However, it is important to recognize that this is by no means a given, and no simple pattern of progression applies to all projects. Thus the development of cost estimates over time will vary from project to project.

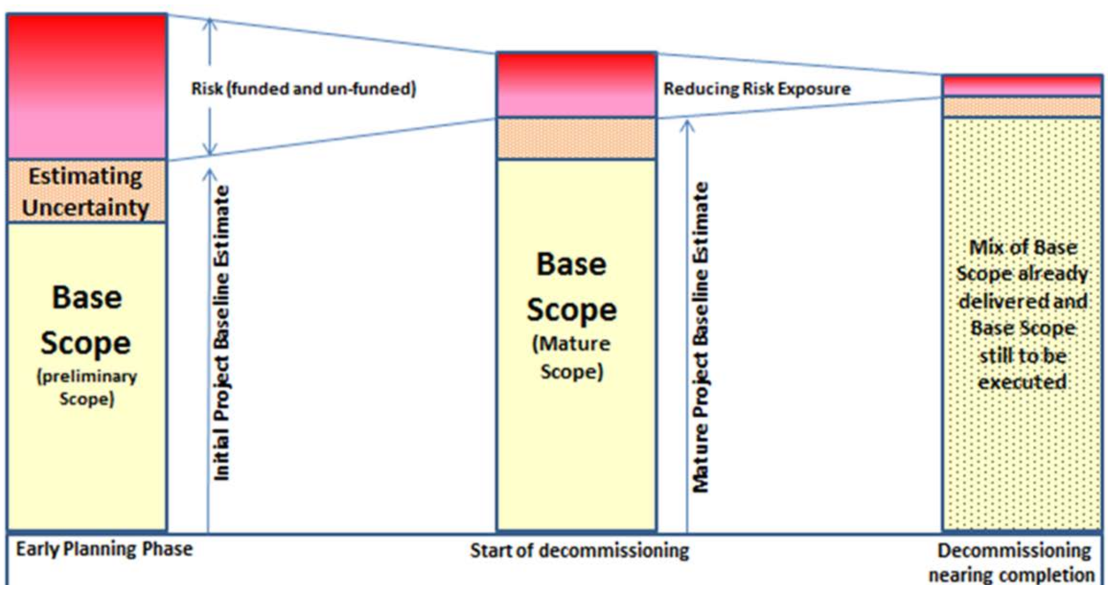

Fig. 7. Change in scope maturity and relationships between elements of a cost estimate over time (adapted from reference [2])

The first column in Figure 7 illustrates a cost estimate produced during the very early stages of decommissioning planning and is typically for most of the operational period of the nuclear installation. It is based around a reference scenario and involves Boundary Conditions deemed to be true at that point in time and considered in the BoE. However, as these can change with time they are a major source of uncertainty. Moreover, scope definition can be low at this stage. These issues are reflected in the relative size of the Estimating Uncertainty and Funded Risk provisions.

The middle column in Figure 7 reflects the situation at a point in time much closer to where decommissioning activities start. This column is representative of more mature scope definition and an associated detailed uncertainty and risk analysis. Whilst Boundary Conditions are less likely to change through the project execution phase, some scope assumptions may have changed and uncertainties will be re-determined as part of the project base-lining for the execution phase. A detailed risk register is usually also developed at this stage which enables risk mitigation strategies to be fully documented. At this stage, project execution strategies need to be fully developed. A better understanding of contamination and radiation levels and other characterization aspects of the nuclear facility undergoing decommissioning is also needed. Previous assumptions are sometimes shown to be wrong during project execution, and if this results in a change of approach it may mean a step change in the project Base Cost and a change to the provisions for project uncertainty. During this stage, allowances may be refined upwards or downwards as more complete process and technological definition is available.

The third column in Figure 7 reflects the point in time where the decommissioning project is nearing completion. At project completion it is assumed that the Estimating Uncertainty provision will have been fully spent. In this column it has been assumed that the Boundary Conditions and Scope assumptions as per the middle column were broadly correct. A proportion of the Funded Risk provision will have been used to accommodate out-of-scope uncertainties that materialized during the decommissioning project execution.

Figure 7 also clearly illustrates an increase in project Base Scope over time. There are many project dependent issues that can manifestly change scope over time, and therefore the implications of scope change, and the associated need for progressive evolution of a cost estimate over time are important considerations. This scope evolution process is an important factor that may drive costs beyond agreed budgets unless financial provision is made for the impact of all related uncertainties. Experience suggests that many early decommissioning project forecasts did not address adequately the maturity of the definition of scope when considering provision for both in-scope and out-of-scope uncertainties. To address this, the completeness and maturity of the scope definition needs to be explicitly considered in the estimate. As the Project Baseline Estimate is specific to the scope as defined in the BoE at that point in time, the relative maturity and completeness of the scope definition needs to be taken into consideration in the assessment of Risk beyond the defined scope of the project.

Whilst some projects will adhere to the theoretical relationship illustrated in Figure 7, many will not. It is therefore necessary to ensure a systematic approach to addressing the impact of uncertainty and Risk in financing of decommissioning projects. From a decommissioning funding perspective, a range of potential cost outcome scenarios is not unreasonable for projects with low scope definition (low project maturity). Multiple cost estimate scenarios may need to be prepared to explore the cost impacts of modifying single or multiple variables to fully assess their relative significance. Ultimately funds will need to cover the Project Baseline Estimate, and include sufficient provisions for the uncertainties and Risks assessed.

Enhancing Understanding of and Confidence in an Estimate

Estimates are more than just numbers, and understanding of an estimate also requires consideration of a range of factors beyond the process by which cost estimates are calculated, such as when it was prepared, for whom, and in what context.

The circumstances or “context” in which a project takes place are important considerations for understanding an estimate, as facts and data do not exist in a void, unconnected from other information. These perspectives can generate very diverse outcomes for the estimate, in particular where provision for uncertainties outside of the defined project scope is being considered. Project context will vary from project to project and country to country. It may also change over time as a function of national strategies and organizational accountabilities. Some countries have adopted standards (and created associated project control procedures) to enable better transparency and consistency in cost estimating, and to generate the need for cost and schedule integrated decommissioning baselines. Some countries mandate production of “owner’s estimates” and third party (independent) assurance whilst others rely more on the supply chain to provide budget prices and use these to create reference cases and extrapolate from these on a site by site basis. It is important that a cost estimate BoE clearly provides the specific conditions and perspectives which apply.

Sensitivity analysis can also be used to give greater insight into an estimate and the underlying calculation processes. Sensitivity analysis is the study of how the output of a mathematical model or system (numerical or otherwise) can be related to variances in its input variables. By means of this analysis, insight is provided into how and to what extent changes in particular variables may influence the model outputs. The BoE is designed around a set of boundary conditions that defines what work packages are to be produced. This is based on a single reference scenario and results in a Project Baseline Estimate cost covering the in-scope elements. Cost modelling can therefore be used to conduct sensitivity of the Project Baseline Estimate to particular input parameters such as labor rates or waste package disposition costs. By changing key parameters one at a time this will inform what the key cost drivers are and enable more analysis of options, opportunities and risk mitigation. As noted earlier, scenario analysis may also be used to explore the possible cost outcomes of alternative scenarios and options.

To be able to understand an estimate and the implications of the numbers presented therein, also requires consideration of the quality of the underpinning data and calculation processes. It is vital for all decision makers to understand that the quality of the Estimating Uncertainty and risk analyses are tied to the quality of the input data and the analysis of specific risks and impacts. In order to enhance understanding of the estimate and confidence in the results, the analyses and calculations underpinning these provisions need to be traceable, the processes understandable, and the estimate output needs to be able to be referenced to the input data. It is therefore important to consider aspects of quality assurance and how these are addressed in an estimate.

The NEA has published a guide which sets out a detailed process to describe quality decommissioning cost estimates in relation to the maturity of scope definition; the basis of estimates; the structure of estimates; risk analyses of costs and schedules and estimating uncertainty; and quality assurance requirements followed by the licensee to ensure the estimate conforms to the requirements of its quality assurance (QA) program [3].

More generally, the U.S. General Accountability Office (GAO) has produced a cost estimating guide which provides an assessment of the processes, procedures, and practices needed for ensuring development of high-quality - that is, reliable - cost estimates [4]. In this context, a high-quality cost estimate helps ensure that readers are given the information they need to make informed decisions and conclusions concerning the cost estimate.

The UK National Audit Office (NAO) has published a report [5] on performing audits of models, which is applicable to cost estimation models. It lays out a seven stage plan which can be used for auditing estimates and the foundation on which the cost estimate is built, starting with the model concept and design, and ending with making use of model outputs and all overseen by a governance and assurance structure. The steps involved in performing the NAO's approach to a model audit are shown in Figure 8.

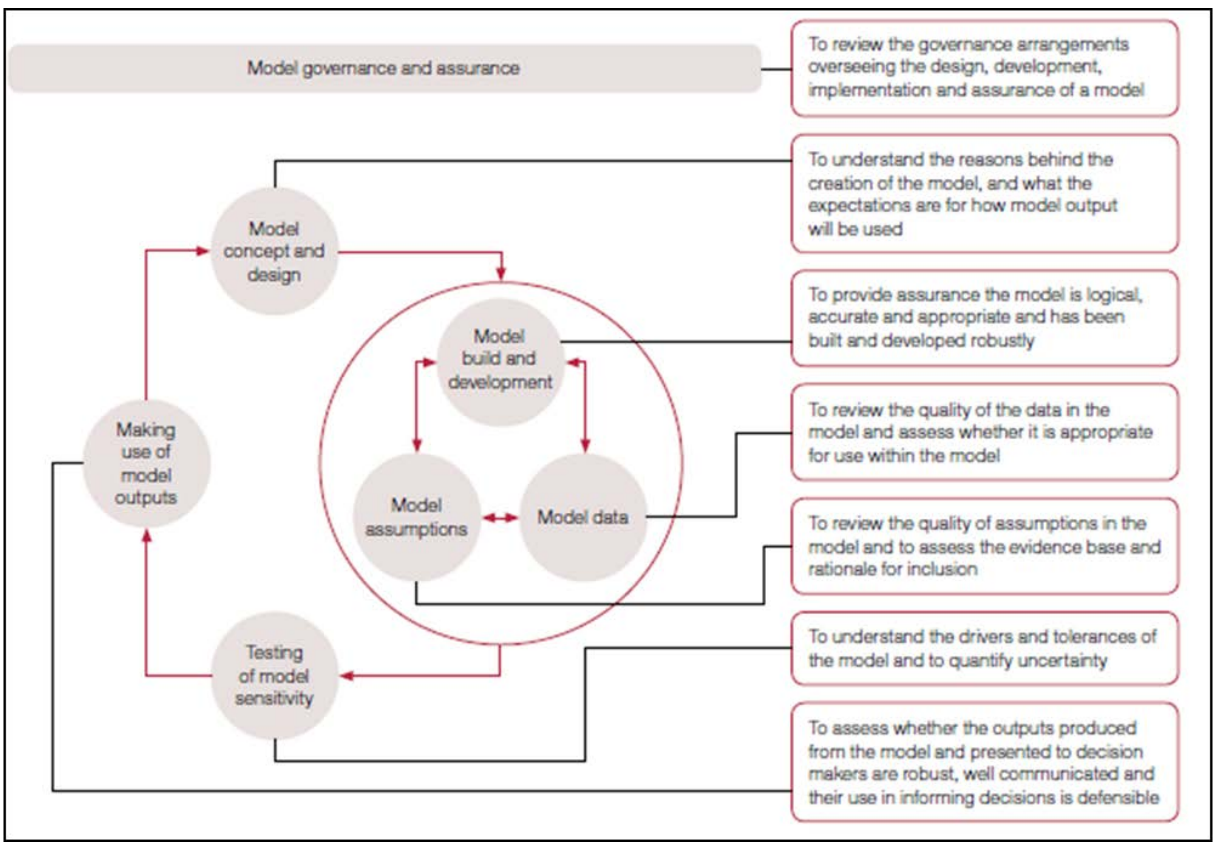

Fig. 8. NAO framework for a model audit. © NA0 2016

BENCHMARKING

Benchmarking is increasingly referred to in the context of cost estimation for nuclear decommissioning. At present, the term is not well-understood: it may mean different things to different people in different contexts; and there is currently little experience with specific benchmarking approaches. Nonetheless, the growing interest in "benchmarking" in decommissioning costing reflects increasing attention on understanding variations between cost estimates and apparent escalation of decommissioning costs; and assuring the adequacy of financing arrangements for future decommissioning projects. A related interest, is in improving the performance and ensuring value-for-money in the delivery of decommissioning projects and services.

Systematic approaches to benchmarking costs and enabling comparison with other estimates and assumption sets may be invaluable in understanding risks and possible cost outcomes. It requires the collection and analysis of data relating to cost estimates and/or actual (incurred) costs. A major challenge for benchmarking in the context of NPP decommissioning costing at present is that key project and cost data typically is not readily available [6].

Even on the basis of such limited data as is currently available, careful comparisons of estimates and outcomes may be valuable and give useful insights. These include comparisons with costs from other decommissioning projects, as well as other projects that offer relevant useful data. Comparing estimates with actual costs from completed or on-going projects can be used to support or challenge the results of a cost estimate in light of actual experience. Such comparisons should ensure the differences between the estimate scope and the actual decommissioning project have been taken into account, and include information about relevant specific contexts or conditions and other factors that may impact on costs. Systematic approaches to benchmarking and enabling comparison with other estimates and assumption sets is valuable.

A number of challenges need to be addressed before benchmarking approaches for NPP decommissioning costing can be practically implemented. These challenges arise in part because the key relevant project and cost data typically required for such benchmarking exercises is not readily available. In the context of nuclear power plant decommissioning, the problem here is two-fold:

- Firstly, there is a heavy dependence on cost estimates rather than actual cost data because of the relatively limited experience in actual NPP decommissioning; and
- Secondly, where there is actual experience, the access to actual decommissioning project cost data is limited, not least of all because of strong sensitivity around sharing of such data.

The NEA's Decommissioning Cost Estimation Group (DECG) will be turning its attention to benchmarking issues following completion of the uncertainties activity. The first phase of this work is planned to continue until the end of 2018.

It is envisaged that this work on benchmarking in decommissioning costing will focus on a number of inter-related components:

- Identifying possible benchmarking approaches and discussing their specific application to decommissioning costing, including the 'added value' in developing decommissioning cost benchmarking approaches;
- Discussing prevailing barriers to the sharing of information and data required for decommissioning cost benchmarking, and exploring what is needed to facilitate implementation of benchmarking approaches in nuclear decommissioning costing (a possible "road map"); and
- Possible benchmarking exercises or case studies in order to develop and illustrate decommissioning costing benchmarking concepts and methodologies, if suitable cost estimate and actual cost data is made available.

CONCLUSIONS

Issues of current concern include the ability to accurately calculate and demonstrate the validity of decommissioning cost estimates, and to control costs during decommissioning. This paper describes recent international developments concerning addressing uncertainties in NPP decommissioning cost estimation, and work currently being planned relating to decommissioning cost benchmarking at the OECD Nuclear Energy Agency.

The process of decommissioning cost estimation is constantly evolving, in line with national requirements and practice, and taking account of experience from other sectors. It is essential to have a good understanding of the costs, including associated uncertainties, so that it can be demonstrated that the full range of relevant potential cost outcomes has been considered in the decommissioning cost estimate. There is a general trend towards showing greater levels of detail in the estimate and more explicit representation of the uncertainties that bear on the final cost. In order to enhance understanding of the estimate and confidence in the results, the analyses and calculations underpinning these provisions need to be traceable, the processes understandable, and the estimate output needs to be able to be referenced to the input data. It is therefore important to consider aspects of quality assurance and how these are addressed in an estimate.

Systematic approaches to benchmarking costs and enabling comparison with other estimates and assumption sets may be invaluable in understanding project uncertainties and risks and the range of possible cost outcomes. It requires the collection and analysis of data relating to decommissioning cost estimates and actual costs. The industry will need to address the challenge of making relevant project and cost data available for analysis if it is to be able to avail itself of the insights such benchmarking initiatives can offer for the analysis and management of decommissioning project costs, demonstrating the adequacy of decommissioning funding, and ensuring value-for-money in the execution of decommissioning projects.

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