

Cost Estimation for Decommissioning

An International Overview of Cost Elements, Estimation Practices and Reporting Requirements

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FOREWORD

This report is concerned with exploring current practices on decommissioning cost estimation, having the dual goals of gaining a better understanding of the primary cost elements, including their definition and derivation, and experience of what can go wrong. The underlying study was established on the basis that a better understanding of decommissioning costs should lead to improved cost estimates for existing nuclear power plants and facilities, facilitate funding, and generally enable better control of decommissioning costs. The report also considers the role of national reporting requirements and the implications of these for comparing different estimates.

The report draws from the results of a questionnaire circulated during early 2008 to organisations participating in the NEA Decommissioning Cost Estimation Group (DCEG). The countries participating in the study were Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Slovakia, Spain, Sweden, the United Kingdom and the United States. These issues were discussed at the first and second plenary meetings of the DCEG, in May 2008 and June 2009 respectively, and at the 10th meeting of the NEA Working Party on Decommissioning and Dismantling in November 2009, in which the International Atomic Energy Agency (IAEA) and the European Commission also participated. The present text incorporates the outcomes of those discussions.

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KEY FINDINGS

It is now common practice that decommissioning plans and associated cost estimates are prepared for all nuclear installations. Specific requirements are generally set out in regulations that have their basis in national legislation. These estimates are important for ascertaining that the necessary funds are being collected to cover the actual costs of decommissioning the facility. The long time horizon for both amassing and disbursing these funds is a particular concern for national authorities. It is thus important to maintain a realistic estimate of the liabilities involved and to confirm the adequacy of the provisions to discharge them over time.

Currently, there is considerable variability in the format, content and practice of cost estimates, which makes it very difficult to compare estimates, even for similar types of facility. The reasons are largely due to different legal requirements in different countries and to historical custom and practice, leading to differences in basic assumptions such as the anticipated decommissioning strategy and end state of the site, and to different approaches to dealing with uncertainties. Attaining greater harmonisation in national approaches to cost estimation may therefore be problematic. It is proposed that efforts should be made at least to develop a standard reporting template onto which national cost estimates could be mapped for the purposes of comparison both nationally and internationally. Such comparisons contribute to the transparency of the estimates and build confidence in the estimating basis.

More specific findings of this study are as follows:

- Most countries have established requirements for cost estimation and reporting. Current legal requirements include the preparation of a decommissioning plan and associated cost estimates, with periodic updates – usually every three to five years.
- A cost estimate for decommissioning is necessarily based on an assumed decommissioning strategy and on an assumed end state for the site. Given that the timeframe for active decommissioning may often be several years after the estimate is made (or even decades for plants licensed under early regimes), these aspects represent significant uncertainties, especially at the earlier stages of plant operation.
- The scope of decommissioning generally includes decontamination, removal/dismantling of disused plant and buildings, spent fuel storage or disposition, waste management, transport, and final disposal or long-term storage. However, some countries do not include the disposition of spent fuel, legacy wastes, waste disposal or its long-term storage in cost estimates for decommissioning.
- A wide variety of approaches are applied to the development of cost estimates, depending on the primary objective, i.e. whether it is to provide a basis for funding or as part of preliminary design and cost studies before undertaking the actual work:
 - Most countries, either through regulation or by owner preference, have adopted a formal organisation of the cost estimates; in general detailed estimates are prepared, especially for plants that are already in operation. A work breakdown structure (WBS) format is typically used, based either on the Standardised List “Yellow Book” format or on an equivalent national format.

- Many countries have adopted the breakdown of activity-dependent and period-dependent costs to structure their estimates. Period-dependent cost breakdown may be used to divide financing decommissioning into tranches to reduce overall uncertainties. Several countries apply this notion by having different contingency factors for different phases of the project.
- Calculation methods vary by country. Some countries specify the type of cost estimate expected from operators, while others leave it to the operator to determine. The use of life cycle planning models is prevalent in some countries, with worst case scenarios being used to bound the costs. Some countries specify in detail how costs are to be reported, while others specify the major cost categories, whilst allowing greater discretion on how estimates are structured.
- Risk management, in terms of ensuring robust cost estimates in the context of uncertainties, falls more in the realm of financing rather than of contingency provisioning in cost estimates.

Key cost elements and their ranking

Experience of actual decommissioning projects leads to the following identification of cost elements and their ranking as cost drivers:

- Very significant.
 - Scope definition and changes to the project plan.
 - Regulatory changes and increased requirements for additional information and detail.
 - End-point state and disposition of wastes.
 - Site characterisation of physical, radiological, and hazardous materials inventory.
 - Waste storage and the availability of ultimate disposition facilities.
 - Disposition of spent nuclear fuel and on-site storage prior to a permanent repository.
 - Clean structure disposition and disposal of the site for new developments.
 - Contingency application and use in estimates to account for uncertain events.
 - Availability of experienced personnel with knowledge of the relevant plant.
 - Assumed duration of the dismantling and clean-up activities.
- Moderately significant.
 - Year of the estimate.
 - Inflation.
 - Cost escalation.
 - Discount factor(s).
 - Waste containers.
 - Start point for decommissioning and boundary conditions.
 - Transition from operations to decommissioning.
 - Project management and organisation.

Why cost estimates may be wrong

A sensitivity analysis of the most crucial variables provides a means of improving the adequacy of the estimates for planning and funding purposes. Information from recent decommissioning projects suggests that the aspects most likely to cause estimates to be wrong include:

- Changes in scope of work and/or regulatory standards and associated design changes.
- Changes in scope of work required to address stakeholder concerns.
- Financial considerations and availability of funds.
- Contingency and risk management.

- Methodological differences.
- Knowledge management.
- Change in project boundaries over time (including assumptions about project duration).
- Legacy material and waste.
- Licence delay.

Recently, and especially in the context of new nuclear power plant construction in several countries, it is apparent that existing nuclear sites are gaining increasing strategic value. This may contribute to overall cost reduction by promoting earlier decommissioning of redundant facilities and from increased commercial value of the site.

Overall observation on good practice

Important considerations in ensuring accurate cost estimates include: methodological accuracy and consistency (e.g., recognising that year-to-year funding tends to cause cost over-runs); avoiding changes in project scope (e.g., decommissioning strategy and end point); good characterisation; consistent regulatory requirements; involvement of the plant operator; the approach to setting contingency levels; and risk management. Current good practices also include the use of a standardised list of activities, a strong quality assurance programme, use of a dedicated decommissioning core group, and involvement of regulators and stakeholders in the planning of decommissioning.

1. INTRODUCTION

Estimates of decommissioning costs have been performed and published by many organisations for many different purposes and applications. The results often vary, e.g. because of differences in basic assumptions such as the choice of the decommissioning strategy (immediate vs. deferred), availability of waste management pathways, assumed end states of installations, detailed definition of cost items, technical uncertainties, unforeseen events, evolution of regulation and requirements. Many of these differences may be unavoidable since a reasonable degree of reliability and accuracy can only be achieved by developing decommissioning cost estimates on a case-by-case site-specific basis. Additionally, even if considerable effort is spent in obtaining reliable estimates, unforeseen events may cause estimates to go wrong. The issue of how to deal with uncertainties is therefore an important one, leading in turn to the need for risk management in terms of making adequate funding provisions.

This report examines international practice on cost estimation of decommissioning projects. In many cases this work is carried out by contractors who have the necessary skills and resources to implement the decommissioning work. The use of contractors introduces other factors that will affect the price paid by the owners of the facilities for the decommissioning work. One principal issue will be the commercial strategy chosen. A range of types of contract have been used for decommissioning work, these include: fixed price; target price; cost reimbursable; etc. The optimum commercial strategy will vary from project to project, but will be driven principally by the risks involved and by which party is best able to manage those risks. A detailed discussion of commercial strategy and risk management is outside the scope of this report, but it is important to be aware that this is another major factor that could affect the price (if not the cost) of doing the work.

In March 2008, a questionnaire was circulated among organisations participating in the Decommissioning and Cost Estimation Group (DCEG). The countries participating in the study were Belgium, Canada, France, Germany, Italy, Japan, Netherlands, Slovakia, Spain, Sweden, the United Kingdom and the United States. Information was collected on: legal requirements and the responsibilities of the main parties concerned with the preparing and oversight of cost estimates, the main cost elements and associated boundary conditions; cost estimating methodologies; and experiences gained during the process. This report is informed by the results of this survey, together with subsequent discussions at meetings of the DCEG.

Chapter 2 of the report explores the various national requirements for estimating decommissioning costs, including boundary assumptions that provide basic criteria for cost estimation and circumscribe the extent of the analysis; definition of the costs to be included; cost estimation methods and quality control provisions. These substantive provisions are determined in part by the legal context and the regulatory philosophy expressed in the requirements. Synoptic tables document the various national requirements. Chapter 3 discusses different types of costs and provides an analysis of cost drivers based on the results of the questionnaire survey and on subsequent discussions at meetings of the DCEG. Chapter 4 discusses national cost estimation practices and provides an analysis of implementation problems and lessons learned. Chapter 5 provides the overall findings and conclusions from the study.

Appendix A provides an overview of legal and administrative requirements; Appendix B discusses the different categories of costs that make up the estimate and provides a detailed analysis of cost drivers; Appendix C reviews national experiences in cost estimation and reporting and discusses where estimates may go wrong.

2. LEGAL AND ADMINISTRATIVE REQUIREMENTS

2.1 Legal basis and regulated parties

The general tenor of regulations governing the estimation of decommissioning costs reflects both the laws on which they are based, as well as the general and industry-specific regulatory philosophy of the country. In this regard, national guidelines show a range of regulatory approaches from highly- to non-prescriptive. All regulations dictate to some extent the responsibilities of the parties involved in making decommissioning cost estimates. In most countries a designated competent authority, which is often the nuclear safety regulator, plays a major role in approving the decommissioning strategy selected, reviewing the cost estimates developed, and reviewing (and in some cases prescribing) the funding mechanism used to assure adequate funding for decommissioning. The administrative aspects of various national requirements are reported in Appendix A to this report.

Whereas the role of the regulators is generally defined by law, the roles and duties of other interested parties (licensees/owners, contractors, or stakeholders) are generally defined by the regulator. Owners/licensees are generally responsible for developing cost estimates and funding mechanisms. They are required to submit them to the regulator for review or approval periodically. Stakeholders have grown in importance in recent years. Affected publics have increasingly been encouraged to review and comment on decommissioning plans and proposed site end states, and in some cases cost estimates and funding arrangements. This consultative process may be facilitated through a local information commission or community oversight board, which may comment on technical issues and influence the direction being taken for disposition of the facility. Alongside these civil society representatives, environmental planners and site developers should be considered as stakeholders, as post decommissioning redevelopment of the site can have a significant impact on the decommissioning strategy and costs.

A summary of the administrative and substantive requirements in the countries participating in this study is given in Table 1.a and Table 1.b.

Table 1.a National administrative and substantive requirements for decommissioning cost estimates

Country	Belgium	France	Italy	Japan	Spain	Sweden
	Topics					
Administrative requirements, including the legal basis for regulating decommissioning cost reporting.	Royal Decrees establish the institutional framework for decommissioning, including the national Agency ONDRAF/NIRAS.	Sustainable Radioactive Materials and Waste Management Act 2006, June 28.	Responsibility vested in Government-established independent public company (SOGIN).	Electricity Utilities Industry Law (Art. 36), Ordinance concerning reserve fund for dismantling nuclear power generation facilities.	Responsibility vested in Government-established independent public company (ENRESA).	Legislation provides that operator is responsible for developing and maintaining plans for decommissioning.
	Legal timeframe for review of decommissioning plans:					
	Every 5 years (for initial decommissioning plans).	Every 3 years.	Every 3 years (decommissioning plan and cost estimate). Each year a rolling update of estimated costs over the next 3 years is undertaken.	Every year.	Every 3 years.	Every year.
Roles and responsibilities of regulators.	In most countries (except France and Italy) the nuclear safety regulator plays a major role in approving the decommissioning strategy selected, reviewing the cost estimate developed and reviewing the funding mechanisms used to assure adequate funding for decommissioning. (French and Italian oversight arrangements are described below.)					
Regulations covering the estimation of decommissioning costs.	The national waste management agency (ONDRAF/NIRAS) is required to validate all decommissioning plans, including cost estimates.	These specify the main cost categories, with a competent authority (comprising the economy and energy ministries acting jointly) being responsible for checking adequacy of cost estimations, taking account of advice from the safety authority.	The decommissioning management agency (SOGIN) prepares all decommissioning plan and cost estimates, according to a reporting format set by the government (Authority for Electric Power and Gas), which also approves the estimate and the associated funding arrangements.	The relevant Ordinance (above) specifies the main facilities and activities and associated requirements for cost estimation.	The national waste management agency (ENRESA) prepares all decommissioning plans and cost estimates (no statutory format applies).	Regulations identify basic assumptions; otherwise, the implementer has discretion over the structure of the estimate.

Table 1.a National administrative and substantive requirements for decommissioning cost estimates (Cont'd)

Country	Belgium	France	Italy	Japan	Spain	Sweden
Penalties for non compliance	For disused plants the ultimate penalty for non compliance in most countries is failure to be granted a decommissioning licence. In the case of applications for licences to construct and operate new nuclear power plants, the penalty for not providing an adequate decommissioning plan, financial guarantee or adequate cost estimate would be failure to obtain such a licence.					
Assumptions and Boundary Conditions.	Virtually all national regulations require operators to provide an explanation and justification of the assumptions used in estimating their costs. These assumptions primarily include those used to define the boundary conditions of the decommissioning plan and hence the associated costs.					
	Assumed final end state: ¹					
	Greenfield or free industrial use.	Greenfield.	Brownfield with conditioned waste stored on site; greenfield after the availability of the national repository.	Greenfield or reuse of land for new nuclear power plants.	Greenfield, but final site end state is a matter for discussion between the national authority and the relevant utility..	Free industrial use, preferably for other energy production.
Requirements for costs to be included.	All activities from final facility shutdown to final release, including waste management costs for all waste categories (except spent fuel) on a codified list of radioactive wastes.	Dismantling, management of spent fuel, re-conditioning of old waste, long term management of radioactive waste, monitoring of disposal centres after their closure.	All activities from final facility shutdown to final release, including spent fuel reprocessing, waste management, waste disposal to the national repository; site clearance and monitoring.	Removal of contamination, dismantling, treatment of waste for storage, measurement and characterisation of waste, treatment of waste for disposal, transport and disposal of waste.	No specific information.	No specific information.
	All countries reported that cost estimates are prepared in current monetary units (constant or overnight costs). Net Present Values (NPVs) of these costs are usually estimated taking into account inflation/ escalation – see also Table 2.					
	Management employees and labour costs are generally site specific, based on recent experience at decommissioning reactors or on operating experience. In Japan, national statistics on labour costs (Ministry of Health, Labour and Welfare) are used.					
	Material and Equipment costs are typically taken from previous decommissioning projects or from equipment vendors, rental companies or contractors.					

1. The terms of “greenfield” and “brownfield” do not have a standard international definition.

Table 1.a National administrative and substantive requirements for decommissioning cost estimates (Cont'd)

Country	Belgium	France	Italy	Japan	Spain	Sweden
Requirements for costs to be included.	Scrap and salvage disposition:					
	Scrap cost recovery is not taken into account in the cost estimates.	Scrap cost recovery is taken into account in the cost estimates.	Scrap cost recovery is considered as a separate item in the cost estimate.	Scrap cost recovery is not taken into account in the cost estimates.	No specific information.	Scrap cost recovery is not taken into account in the cost estimates.
	Several countries require specific consideration of cost reduction possibilities:					
	Requires explicit exploration of waste volume reduction.	New regulations recognise the impact of waste volumes on costs but do not address how this should be fully presented.	A reduction of 3.29% for 2009 and 2010 is mandatory for the operation, safety, maintenance and general costs; the rate of reduction is established every 3 years by the Electric Power and Gas Authority.	No specific information.	No specific information.	No specific information.
	Contingency:					
Reference value of 15%.	15% (<i>Électricité de France</i>).	No contingency is included; each year any differences between actual and estimated cost must be justified before release of funds by the Electric Power and Gas Authority.	No specific information.	ENRESA's studies reported without contingency then a global 15% added.	Overall project contingency of 6%.	

Table 1.b National administrative and substantive requirements for decommissioning cost estimates

Country	Canada	Germany	Netherlands	Slovak Republic	United Kingdom	United States
Topics						
Administrative requirements, including the legal basis for regulating decommissioning cost reporting.	Nuclear Safety and Control Act.	Atomic Energy Act (1959) and Ordinance on Cost Regulation Pursuant to the Atomic Energy Act (BGBl.I 2004, Nr. 69).	Nuclear Energy Act.	Ministry of Economy has established laws requiring decommissioning funds.	Energy Act 2008.	Several Laws. Nuclear Regulatory Commission (NRC) regulations.
	Legal timeframe for review of decommissioning plans:					
	Not defined in the regulations, but in practice every 5 years.	No specific information (cost estimates are revised annually)	Every 5 years.	Every 5 years.	Every year.	Every 2 years.
Roles and responsibilities of regulators.	In most countries the nuclear safety regulator plays a major role in approving the decommissioning strategy selected, reviewing the cost estimate developed and reviewing the funding mechanisms used to assure adequate funding for decommissioning.					
Regulations covering estimation of decommissioning costs.	The requirement for cost estimating is associated with a required financial guarantee for the nuclear facility. This is entrenched legally as a licence condition	Law does not prescribe format and content of estimates.	Uses guidelines and criteria of the International Atomic Energy Agency (IAEA).	Law does not prescribe format and content of estimates.	Requires detailed plans addressing waste management, site remediation and for costing purposes.	Specific and prescriptive guidelines for estimating decommissioning. The NRC requires that all guidelines are followed exactly for cost estimates to be acceptable.
Penalties for non compliance	For disused plants the ultimate penalty for non compliance in most countries is failure to be granted a decommissioning licence. In the case of applications for licences to construct and operate new nuclear power plants, the penalty for not providing an adequate decommissioning plan, financial guarantee or adequate cost estimate would be failure to obtain such a licence.					
Assumptions and Boundary Conditions	Virtually all national regulations require operators to provide an explanation and justification of the assumptions used in estimating their costs. These assumptions primarily include those used to define the boundary conditions of the decommissioning plan and hence the associated costs.					

Table 1.b National administrative and substantive requirements for decommissioning cost estimates (Cont'd)

Country	Canada	Germany	Netherlands	Slovak Republic	United Kingdom	United States
Assumptions and Boundary Conditions	Assumed final end state: ²					
	Operator's Discretion.	Greenfield.	Greenfield.	Greenfield, except for Bohunice A1 NPP.	Greenfield wherever possible.	Greenfield.
Requirements of costs to be included.	Planning and preparation, complete decontamination and/or dismantling, site decontamination, restoration and -stabilisation, final radiation survey and long term surveillance for restricted or free release of the nuclear site and also including management or disposal of all wastes, nuclear substances and hazardous materials.	All costs associated with dismantling, decontamination, demolition and release of the site, including waste management, <u>except</u> management of legacy waste and interim storage of spent fuel and high-level waste.	No specific information.	All activities after spent fuel and legacy waste disposition, except for Bohunice A1 NPP which includes all costs.	Dismantling the nuclear power station at the end of its generation life, removing all station buildings and facilities. Returning the site to an approved state and release from nuclear licence control.	Planning and preparation, complete decontamination and/or dismantling, site decontamination, restoration and stabilisation, final radiation survey and long term surveillance for restricted or free release of the nuclear site.
	All countries reported that cost estimates are prepared in current monetary units (constant or overnight costs). Net Present Values (NPVs) of these costs are usually estimated taking into account inflation/ escalation – see also Table 2.					
	Management employees and labour costs are generally site specific, based on recent experience at decommissioning reactors or on operating experience:					
	Typical contractor and consultant hourly rates are used	Contractor labour rates are based on latest costs from ongoing projects. Owner/licensee rates are evaluated annually.	Rates taken from Central Statistics Bureau.	Rates taken from operating owner rates.	Owner/licensee management salary levels are used and labour costs from actual recent contracts for subcontracted labour on site.	Owner/licensee management salary levels are used and labour costs from actual recent contracts for subcontracted labour on site.

2. The terms “greenfield” and “brownfield” do not have a standard international definition.

Table 1.b National administrative and substantive requirements for decommissioning cost estimates (Cont'd)

Country	Canada	Germany	Netherlands	Slovak Republic	United Kingdom	United States
Requirements of costs to be included.	Material and Equipment costs are taken from previous decommissioning projects or from equipment vendors, rental companies or contractors.					
	Scrap and salvage disposition:					
	All material must be considered as wastes. Allowances for scrap cost recovery are not allowed.	Scrap cost recovery is not taken into account in the cost estimates.	No specific information.	Scrap cost recovery is not taken into account in the cost estimates.	Scrap cost recovery is taken into account in the cost estimates.	Scrap cost recovery is not taken into account in the cost estimates.
	Several countries require specific consideration of cost reduction possibilities:					
	Life cycle planning as a means of reducing the complexity/cost of decommissioning.	No specific information.	No specific information.	No specific information.	Waste minimisation must be part of the decommissioning plan.	Life cycle planning as a means of reducing the complexity/cost of decommissioning.
	Contingency:					
Varies with accuracy of estimates Grades A-C (10-30%).	The German commercial code, <i>Handelsgesetzbuch</i> , does not allow the calculation of uncertainty factors.	No specific information.	25% preliminary estimate, 20% detailed estimate.	Modelled to P80 confidence level.	Varies greatly. NRC generally accepts overall contingency of 25%.	

2.2 Requirements for costs to be included

Decommissioning variously encompasses several broad cost categories related to decontamination, dismantling, and demolishing of facilities; the management of spent fuel and several types of waste (including legacy wastes), and has clear interaction with materials and waste transportation, storage, and disposal. Which of the associated costs should be included in a decommissioning cost estimate is governed by the legal and administrative framework that defines the scope of decommissioning under the relevant regulatory scheme – see Appendix A. In some countries, one or more of the fuel/waste activities are not included in the definition of decommissioning as it relates to making cost estimates. Hence, the structure, organisation, and scope of the cost estimates largely depend on what is defined as being within and outside of decommissioning by national regulation.

An example of comprehensive national reporting requirements are those set out in the Belgian regulations, which require a decommissioning cost evaluation to include all activities from final facility shutdown to final release of the site with the exception the cost of removal, transport and disposal/storage of spent fuel disposal and (in certain cases) the costs of site cleanup and landscaping:

- Pre-decommissioning operations.
- Facility shutdown activities.
- Decontamination and dismantling activities.
- Waste processing, storage and disposal.
- Site clean-up and landscaping (if explicitly required).
- Project management, engineering and site support.
- Waste disposal.
- Site restoration if required.

Other countries, e.g. Sweden, exclude the removal, transport and disposal/storage of spent fuel to storage from its definition of decommissioning, as well as the transport, off-site storage and disposal of waste (only treatment and preparation for transport are included). Waste storage and disposal facilities, high-level waste disposal, and management of legacy waste are all similarly defined as being outside the scope of decommissioning in Sweden.

2.3 Boundary assumptions and conditions

The types and extent (level of detail) of assumptions and boundary conditions typically applied in cost estimates have a major affect on the overall costs. Virtually all regulations require operators to provide an explanation and justification of the assumptions used in estimating their costs (see Appendix A). These assumptions primarily include those used to define the boundary conditions of the decommissioning plan and hence the associated costs. As noted above, the legal basis and the administrative structure of decommissioning and waste disposal programmes in each country already establish broad boundary conditions for decommissioning, and hence for estimating decommissioning costs.

Specifying boundary conditions and precise definitions are essential prerequisites for producing any credible analysis. Explaining – however briefly – the reason for a given assumption or requirement, and the consequences of alternatives, is also essential. Regulators can specify boundary assumptions as a way of ensuring completeness in the coverage of the cost estimates, as well as the quality of the analysis. The potential benefits of having common assumptions and boundary conditions for any filings depends largely on the purpose for which the information is being collected. The degree to which the boundary assumptions tally across filings could, for example, affect the ease with which interested parties can perform statistical analyses, including benchmarking, without making statistical adjustments to produce greater consistency or comparability among filings.

2.4 Dealing with cost reduction and uncertainty

There are two additional cost considerations that, for completeness, should be included in any decommissioning cost estimation. These are cost reduction, and the evaluation of and provision for the cost of uncertainties.

2.4.1 Cost reduction

A number of countries require specific consideration of cost reduction possibilities – see box (Cost reduction and characterisation). Countries that have (or propose to have) a comprehensive national decommissioning and waste disposal programme most commonly emphasise the need for waste minimisation, and hence the reduction of ultimate waste disposal costs. Thus, for example, Belgium requires explicit exploration of waste volume reduction options as a cost reduction factor; and proposed UK regulations stipulate that waste minimisation must be part of the decommissioning plan. Canada requires that life cycle planning be considered at the early stages of licensing (i.e. at the phase where a “licence to site” is being requested), in order to ensure that future decommissioning is considered at the facility design stage. Recent French regulations³ also recognise the impact of waste volumes on costs but do not yet fully address how this should be presented. They do require assessment of capital investments needed for functional simplification to reduce surveillance, maintenance and operating costs.

Clearance and release levels also have a major impact on costs, as does the selected end state for the site – greenfield or brownfield. These terms need to be defined in detail in the estimate, as there is currently no universal interpretation. Generally, the use of proven technology also contributes to cost reduction. The redevelopment of the decommissioned sites may be conducive to significant cost savings, due to less pressure on radiological release criteria, or sale or reuse of site infrastructure and land.

Cost reduction and characterisation

The costs of decommissioning vary largely with the radiological inventory and extent of contamination, and the degree of decontamination envisaged. An important aspect of cost containment for both decommissioning and waste disposal is therefore characterisation of the site and of waste to be disposed. Responsibility for site characterisation varies between countries, e.g., in Belgium, characterisation is the responsibility of the operators; in Spain, ENRESA is responsible for site and waste characterisation.

Depending on the level and sophistication of the characterisation, the quality of historical records and whether it is done on a current basis, the cost of characterisation and inventorying can be significant. The cost of inadequate inventorying or characterisation can be even higher, since uncharacterised waste might be treated by default as more active and/or long-lived waste, with associated management and disposal costs. Also important is who will pay this cost and how it is accounted for within the estimate.

2.4.2 Contingencies and uncertainties

For this study *contingencies* are defined as unforeseeable elements of cost *within* the defined project scope, while *uncertainties* may also cover unforeseeable elements *outside* the defined project scope, or changes *in* the scope of the project as defined.

Economic uncertainties include currency and exchange rate fluctuations, inflation beyond the norm of 5% or so assumed for most projects and interest rate fluctuations. While exchange rate fluctuations and inflation may seem to be more a problem of developing countries that import

3. These regulations are subsidiary to the 2006 Act on the sustainable management of radioactive materials and wastes, 28 June 2006.

expertise, labour, or equipment, the possibilities cannot be ignored by OECD countries. The impact of double-digit inflation in many countries during the 1970s, resulting in dramatic cost escalations and cancellations of nuclear power plant construction projects, is one pertinent example. Also, risks that do not necessarily arise in the financial sphere can also have economic consequences, e.g., shortages of labour or bottlenecks in supplies.

There exist as well legal or regulatory, political, technical, and market-related uncertainties that also have potentially significant economic and cost implications. Regulatory and legal risks with far-reaching economic consequences include taxation, changes in approved project scope (generally considered to be the most important factor in estimation error), changes in accepted clearance and release levels (impact on volumes and costs), and changes in waste transport or management regulations. Several regulatory agencies impose taxation on disposed-of waste, providing a strong incentive for minimisation; by contrast, there are no tax incentives to minimise decommissioning waste/costs. Political uncertainty arises when politically acceptable options for decommissioning and disposal are impossible to cost and may not be affordable. Technology risk may include imposition or reinterpretation of “best available technology” requirements in mid project, or greater characterisation needs.

The consequences of any one of these unanticipated changes outside the scope of the project are not limited to any single set of costs. Moreover, uncertainty is not related to the time horizon. Unanticipated changes can happen at any time; longer time horizons merely increase the probability that one or more will occur. However, given the long-time horizon for amassing and disbursing decommissioning funds, and given that the cost estimates are based on today’s techniques, policies, and costs, the estimation of decommissioning costs must also include some mechanism for adjustment to change and for accommodating uncertainties. However, it should also be noted that not all uncertainties are susceptible to solutions that can be incorporated into a decommissioning plan.

3. MAIN COST DRIVERS FOR DECOMMISSIONING

3.1 Types of costs

Activity-dependent costs are those costs associated with performing hands-on decommissioning activities. Examples of such activities include decontamination, removal of equipment, and waste packaging, shipping, and burial. These activities lend themselves to the use of unit cost and work productivity factors (or work difficulty factors) applied to the plant and structure inventories to develop the decommissioning cost and schedule.

Period-dependent costs include those activities associated primarily with the project duration: engineering, project management, dismantling management, licensing, health and safety, security, energy, and quality assurance. These are primarily management staffing level costs, developed by estimating the manpower loading and associated overhead costs based on the scope of work to be accomplished during individual phases within each period of the project.

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

The subdivisions discussed above are widely used to break down the cost elements into groups related to the types of activities for each phase of decommissioning, thus facilitating not only data gathering but also the tracking of changes in costs over time. Such subdivisions also help to convey how the estimate is prepared and how to account for the major elements of cost.

Standardised definitions of cost items are available from a number of international agencies and countries. The NEA publication *A Proposed Standardised List of Items for Costing Purposes* (“the Yellow Book”), issued in conjunction with the IAEA and the European Commission, recognises that important consistency and comparability could be gained – and the transfer of best practices enhanced – if countries used common or comparable definitions of cost elements and cost groups, even if countries do not harmonise their cost estimation methods or the scope and structure of their decommissioning programmes. The “Yellow Book” sets out in great detail the agreed definitions of all cost items relevant to decommissioning and waste disposal, and provides consistent ways to organise, present, and analyse these costs: by activity, by period or phase of the project, and by cost group: (i) labour; (ii) capital, equipment and material costs; (iii) expenses (largely management and administrative costs); and (iv) contingencies. Within this framework, operators can choose the elements that suit their site-specific operations. A detailed discussion of national approaches to cost categorisation is provided in Appendix B to this report.

Developing valid cost estimates requires not only good definitions and specified assumptions, but also good data. The list of costs to be included must not only be complete, but organised into appropriate categories, based on actual plant experience wherever possible and on the experience of

others or reliable estimation techniques where not. Data should be traceable and calculations replicable. Cost data development for each cost element should therefore include the following considerations:

- Sources of data and their validation.
- Implications of poor or non-existent facility records.
- Multi-year baseline data (inventory revisions) and assumptions.

3.2 Categories of cost drivers

The study questionnaire solicited specific information on 20 different boundary conditions related to cost drivers and elements; each is discussed in detail in Appendix C to this report. These cost drivers and elements can be divided into four categories:

- a) Basic assumptions and inclusions in the boundaries of the estimate, comprising:
 - Year of estimate monetary units.
 - Start point for decommissioning and definition of physical boundaries of the project.
 - End-point criteria and conditions for the facility and site.
 - Transition from operation to decommissioning, including characterisation and inventory.
 - Ongoing operations not specific to active decommissioning.
- b) Sources for unit cost for various activities, comprising:
 - Source of employee salary and craft labour rates used in the estimate.
 - Source of material and equipment costs for conventional demolition of clean equipment and structures.
 - Source of material and equipment costs for the monitoring, decontamination and dismantling of contaminated materials and buildings.
- c) Assumptions for waste management, comprising:
 - Disposition of legacy wastes (including melting of contaminated metals and recycling options).
 - Waste canister options (including capacity, design life, and limitations on their use).
 - Waste storage and disposal facilities.
 - Waste transportation options, including weight or radioactivity limits on containers and casks.
 - High-level waste and spent nuclear fuel disposition.
- d) Technical assumptions for decommissioning, comprising:
 - Major component disposition.
 - Scrap and salvage disposition.
 - Construction of new facilities or modification of existing facilities to facilitate decommissioning.
 - Structure disposition.
 - Infrastructure disposition.
 - Strategies for procurement and overall project management.
 - Yield ratios associated with intervention techniques (i.e. choice of technologies for remote handling)

Category (a) cost drivers generally have the greatest influence on the estimated cost, and are important considerations when making comparisons between different cost estimates. It needs to be established at the outset if spent fuel removal and reprocessing, transition from operation to

decommissioning, characterisation and inventory, operations and maintenance, surveillance and security are included or not in the decommissioning cost estimate. Equally important is the final state of the site (greenfield or brownfield). The monetary assumptions (monetary units, inflation and escalation,⁴ the discount rate) also are very important, because they can change the results of the cost estimate without any variation in the technical and other basic assumptions.

Category (b) cost drivers are more technical but are less problematic, because their effect on cost estimates can easily be taken into account.

Category (c) cost drivers may also be very important due to importance of waste management costs as a proportion of the total costs. These costs are closely linked to the category (a) cost drivers, because of the way management of wastes may be included in the first group (boundary assumptions). It is important to establish if waste disposal (to a national repository or interim storage on site) is included in the cost estimate, the unit cost for disposal, the kind of repository (geological or superficial), and the clearance levels to release materials. All these cost drivers can have an important effect on decommissioning cost estimates.

Category (d) cost drivers represent the technical choices made by the owner with respect to decommissioning strategies and activities, and represent the “core” of the cost estimate. In comparing cost estimates, and where the category (a) and category (c) cost drivers are the same, this group represents the essential difference in the cost estimates. A corollary of this is that a prerequisite for a meaningful comparison of different cost estimates is a standardised approach to representing the category (a) and category (c) cost drivers.

3.3 Ranking of key points

The study found that cost elements can typically be grouped as follows in terms of their significance as cost drivers in decommissioning cost estimates:

- Very significant
 - Scope changes and scope growth of the project.
 - Regulatory changes and increased requirements for additional information and detail.
 - Stakeholders impact on end-point state and disposition of wastes.
 - Site characterisation of physical, radiological, and hazardous materials inventory.⁵
 - Waste storage and the availability of ultimate disposition facilities.
 - Disposition of spent nuclear fuel and on-site storage prior to a permanent repository.
 - Clean structure disposition.
 - Contingency application and use in estimates to account for unforeseeable events.
 - Knowledge management of experienced personnel.
 - Standardisation of the cost report format to ensure all cost elements are included.
 - Assumed duration of the dismantling and clean-up activities.⁶
- Moderately significant
 - Year of the estimate.
 - Inflation.
 - Escalation.

4. Escalation beyond normal price inflation (which is based on a consumer price index), and reflects changes in costs associated with enhanced regulatory environmental requirements, unanticipated waste disposal fees, extended on-site waste storage costs etc.

5. The factor includes the extent of contamination and the degree of decontamination required.

6. This factor was not included in the questionnaire, but arose in subsequent discussions of the survey results.

- Discount factor(s).
- Waste containers.
- Start point for decommissioning and boundary conditions.
- Transition from operations to decommissioning.
- Project management and organisation.

Most of the survey responses with respect to the relative importance were subjective, as it is difficult to quantify the magnitude of impact of drivers unless a detailed parametric study is performed using a computer code. One such study performed in the United States⁷ some years ago addressed the work difficulty factors (work productivity factors for tasks involving high radiation exposure, difficult access restraints, respiratory protection, and multiple clothing changes), for ranges of values from the minimum case to the maximum case. The results showed only a 3% difference in overall costs for the low-to-high values for work difficulty factors. From a planning and worker protection perspective, the individual values were important, but the overall impact on costs was negligible. Risk management was typically perceived by respondents as relating to funding and therefore was not judged to be a significant cost driver for costing proposes.

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4. NATIONAL COST ESTIMATION PRACTICES

4.1 Cost methodologies

Most countries permit at least some degree of operator discretion as to choice of cost calculation method, including those countries where cost estimations are the basis for unit fees to be charged for a national programme. In most cases, various methods are suggested as options, but not prescribed; or prescribed methods do permit certain exceptions and adjustments. Specifying an estimation method serves two purposes: it encourages completeness and comparability among filings, and makes it easier for the regulator to compare and readily evaluate the accuracy of the filings. Some laws or regulations also include additional and targeted provisions for quality control.

The study found that a wide variety of approaches is applied to the development of cost estimates, depending on the primary objective, i.e. whether being to provide for funding or being part of a preliminary study prior to undertaking the actual work. The operators in most countries implement their own cost methodology and associated computer software for estimating decommissioning costs. Various approaches are also applied to the assessment of uncertainty, although some do not address this at all in the context of estimating decommissioning costs. As regards the estimated provision for unforeseen events, uncertainties within the defined project scope are generally included as contingencies within the cost estimate. These need to be differentiated from uncertainties outside the defined scope, which are typically addressed within the funding arrangements, e.g. by funding guarantees.

Important considerations in ensuring accurate cost estimates include: methodological accuracy and consistency (e.g., recognising that year-to-year funding tends to cause cost over-runs); changes in project scope (e.g., strategy and end point); good characterisation; consistent regulatory requirements; involvement of the plant operator; the approach to setting contingency levels; and risk management. Current good practices also include the use of a standardised list of activities, a strong quality assurance programme, use of a dedicated decommissioning core group, and involvement of regulators and stakeholders in the planning of decommissioning plans.

National approaches to cost estimation are summarised in Tables 4.a and 4.b at the end of this chapter and are described in detail in Appendix C.

4.2 Quality control provisions

Accurate, verifiable and reproducible cost estimates are deemed essential by most regulators and should be a concern for managers responsible for updating decommissioning cost estimates and for implementing decommissioning plans. Consistency between estimates and actual costs from ongoing decommissioning projects is also crucial. Quality control of estimates is also critical for assuring adequate provisioning of decommissioning activities.

4.2.1 *Quality of data*

The degree of accuracy of a cost estimate depends on the method used and especially on the quality of the data. Actual cost information should be used wherever possible, and contingencies should not be

used to provide a buffer against errors in the estimate. Where possible, unit cost data obtained from previous decommissioning experience should be used. This experience should be recorded using a formal documentation process and labour costs should be reported separately from consumables. Where handbook data is used, a careful verification process is needed to ensure that the data apply to similar relevant technologies. Use of reference facilities as a basis for cost estimates, and use of data from other decommissioning projects are valuable (even where unit costs are not available) for benchmarking estimates. Model computer codes used to process data should be updated frequently to ensure they reflect current decommissioning practice. Besides careful data collection and data preparation, stringent quality control measures should be applied to the development of the cost estimate.

4.2.2 Re-estimates and multi-annual management of costs

One common and essential approach, required by virtually every country, is a periodic revision and review of estimates to reflect inflationary or escalation changes to decommissioning costs. The periodicity varies with each country and each regulator. In France, EdF reported that a reassessment report is required every three years to demonstrate the consistency between costs and funding provisions. A reassessment is also required when a significant change occurs within the ongoing project and/or when significant new data becomes available.

4.2.3 Cost justification

All countries require operators to provide justification of their cost estimates and assumptions. Beyond this requirement, most countries also impose requirements on the regulator for review and validation of the accuracy of the estimated costs. Many of the requirements specifying assumptions and cost calculation methods, and submission of background calculations and worksheets, are measures to facilitate the regulator's review.

4.2.4 Consistency and comparability

In some countries, consistency and comparability among filings are important considerations. Differences in requirements for consistency and comparability are generally due to one of two factors: the purpose for which the information is used by the regulatory agency, and the regulatory philosophy of the government. Different standards of accuracy and scope may apply to cost estimations made at various stages in the decommissioning process, each assessment having a different objective, e.g., assessing the adequacy of funding, planning for new facilities, or project management.

4.3 Why cost estimates may be wrong

An important aim of this study is to identify sensitive factors that may lead to significant discrepancies between estimated costs and actual cost outcomes, noting that estimates made at different times or with different levels of detail can have a major effect. A sensitivity analysis of the most crucial variables provides a means of improving the adequacy of the estimates for planning and funding purposes.

Respondents indicated the following aspects as being most likely to cause estimates to be wrong, each of which is discussed in detail in Appendix C and summarised in the ensuing sub-sections (see also Table 4.a and Table 4.b):

- Changes in scope of work and/or regulatory standards.
- Changes in scope of work required to address stakeholder concerns.
- Financial considerations.

- Contingency and risk management.
- Methodological differences.
- Knowledge management.
- Change in project boundaries over time (including assumptions about project duration).
- Legacy material and waste.
- Design change.
- Licence delay.

Recent experience suggests that post-decommissioning redevelopment of the site can have a significant impact on costs, e.g. for sites that are envisaged potential locations for new nuclear power plants.

4.3.1 Changes in scope of work and/or regulatory standards

Changes to the original strategy and end-point conditions represent one of the most important reasons why estimates go wrong, e.g. safety-related changes reflecting evolving regulatory requirements may increase project cost and the overall time schedule. The countries noting that this was a very significant cost driver included France, Italy, Belgium, Spain and the United States (see Appendix C).

4.3.2 Financial considerations

Estimates are universally prepared in current (overnight) costs. They are reported either in terms of Net Present Value (NPV) or are adjusted for inflation or cost escalation to the year of expenditure – see Table 2. The discount factor used varies over a wide range and, depending on the value used, this may clearly have a significant impact on funding requirements. In Germany and Italy, there is no provision for cost escalation, i.e. all costs and expenditures are assumed to occur on the accounting date.

Table 2. **Financial considerations**

Country	Year cost reported	NPV reported	Adjusted for inflation	Escalation	Discount rate
Belgium	Fixed reference year on 5 year cycle		Yes	Significant impact on estimates	Yes
France	Current year (i.e. year of the estimate)		Yes		Chosen by the operator under regulatory constraints (5% – EdF, AREVA and CEA)
Germany	Current year	No	No	No	No
Italy	Current year	No	No	No	No
Japan	Current year	Yes	Yes	Yes	Yes
Netherlands	Current year	Yes	Yes (2%)		4%
Slovakia	Current year	Yes	Yes	Yes	No (decommissioning funding requirement revised annually)
Spain	Costs in varying years	Yes	Yes	Moderate impact	1.5%
Sweden	Current year	Yes	No	No	Specified by authority
United States	Current year	Yes	Yes	Yes	3-5% (owner specified)

4.3.3 Contingency and risk management

A summary of contingency and risk⁸ management considerations for a range of countries is shown in the Table 3. Contingency is an integral part of the cost estimate and the criteria for its calculation must be defined. Risk assessment is a probabilistic exercise that must be considered apart from the cost estimate. A range of different national approaches are used.

Table 3. Contingency and risk management

Country	Contingency	Risk Management
Belgium	15% of total	Not developed for cost estimates but considered in scope of funding.
Canada	10–30%	Not considered.
France	5 Levels 5-50%	
Germany	None	Not considered.
Japan	None	Not considered.
Netherlands	None	Not considered.
Slovakia	25% for preliminary estimates; 20% for detailed estimates	Not considered.
Spain	15-25%	Not considered.
Sweden	6–20%	Considered in probabilistic analyses of future costs for waste management, disposal and decommissioning.
United States	WBS Level 10-75%	Highly sensitive in United States, 25-50% sometimes added.

4.3.4 Methodological differences

Methodological differences tend to arise from the use of different approaches to cost estimation, including quality assurance standards and different approaches to checking of inventory input to cost calculations. Amongst the countries which noted this as a sensitive, or highly sensitive, factor, were France, Spain and the United States. It is noteworthy that, in 1986, the US Atomic Industrial Forum (see Chapter 6, Bibliography) funded a study to provide *Guidelines for Producing Decommissioning Cost Estimates*. The resulting document organised the estimates into consistent formats, content, and depth of detail.

4.3.5 Knowledge management

Several countries noted the importance of developing knowledge management systems, using information technology, that enable the experience gained from decommissioning projects to be retained for future use, including the maintaining cost databases up to date. Such systems are being developed in particular, in France, Germany, Belgium, Spain, Slovak Republic and the United States.

4.3.6 Change in project boundaries over time

This tends to be an important factor in cases where only limited site characterisation is done prior to project definition. For example, the unanticipated presence of leaking pools or tanks of contaminated liquids can extend the plant decommissioning boundary significantly. In the US case, it was noted that clean up costs have increased by factors of two to five times the original estimate, thus underscoring the importance of a thorough site characterisation before starting decommissioning.

8. The management of uncertainties that are outside the assumed scope of a project.

4.3.7 Legacy material and waste

On commercial reactor sites, legacy material and waste are typically treated as an operational, rather than decommissioning, liabilities. On that basis the decommissioning cost estimate is insensitive to this factor. However, in the particular case of former military and research facilities, legacy wastes are generally regarded as being decommissioning wastes.

4.3.8 Design change

Material quantities from dismantling that are estimated from plant design information may be significantly in error, due to the old age of the plants, rendering design documentation out of date.

4.3.9 Licence delay

Significant delays in obtaining licences from technical, safety and local authorities, are likely to result in increased costs due to inflation, delay of activities, design changes, general services, operations, and maintenance costs that continue even though decommissioning has not commenced.

Table 4.a National cost estimation practices

Country	Belgium	France	Italy	Japan	Spain	Sweden
Topics						
Organisation of costs	Most use a work breakdown structure for their cost estimates but not all follow the Yellow Book List of Cost Items:					
	Based on Yellow Book.	Own WBS.	Own WBS.	Own WBS.	Uses Yellow Book.	Uses Yellow Book.
Cost estimating methodologies and tools, and their impact on the life cycle of the project.	National guidelines in most countries allow some degree of operator discretion as to choice of cost calculation method.					
	ONDRAF/NIRAS can specify general information requirements though not how material is collated or methods used.	Phased approach in developing estimates with increasing accuracy from opportunity study to implementation (CEA).	Cost methodology developed by SOGIN.	Linear approximation related to weight of materials from decommissioning and individual accumulation method (METI)	Cost methodology developed by national waste management organisation (ENRESA).	Cost methodology developed by national waste management organisation (SKB).
Where estimates go wrong – review of experiences.	No broad experience in comparing estimated costs to actual costs.	Changes in original strategy and end-point conditions represent one of the greatest factors.	Unexpected regulatory prescriptions and time for approval of general and specific licences, causing delays and cost increases.	Changes in scope (e.g. changes in the cost of disposing of decommissioning waste because of the introduction of a clearance option.	Changes in scope are a highly sensitive factor, particularly regulatory or other legal requirements cause delay.	No experience in comparing estimated costs to actual costs.

Table 4.b National cost estimation practices

Country	Canada	Germany	Netherlands	Slovak Republic	United Kingdom	United States
Topics						
Organisation of costs	Most use a work breakdown structure for their cost estimates but not all follow the Yellow Book List of Cost Items:					
	Own WBS.	Own WBS.	At operator’s discretion.	Uses Yellow Book	Own WBS.	At operator’s discretion.
Cost estimating methodologies and tools, and their impact on the life cycle of the project.	National guidelines in most countries allow some degree of operator discretion as to choice of cost calculation method:					
	Licenseses have discretion to use their own cost methodology, but requires review and acceptance by regulator	Owners/licenseses have discretion to use their own cost methodology.	No specific information.	OMEGA code based on Yellow Book.	Owners/licenseses have discretion to use their own cost methodology	Requires life cycle planning – suggests use of worst case financial scenarios for uncertainties.
Where estimates go wrong – review of experiences.	Decommissioning experience is extremely limited at this time in Canada.	Annual re-basing to minimise scope changes and regular updating of unit costs.	Changes in the decommissioning plan can have a major impact on costs.	No changes in scope anticipated at this time.	Annual re-basing to minimise scope changes.	Changes in cost are highly sensitive to scope changes.

5. OVERALL CONCLUSIONS AND GENERAL RECOMMENDATIONS

5.1 Overall conclusions

In general, regulations regarding decommissioning plans and related cost estimates have their basis in law. These estimates are important primarily for ascertaining that adequate financial provisions can be or are being made to cover actual costs when the time comes to decommission the relevant facility. The long time horizon for both amassing and disbursing these funds, and the associated need to maintain a realistic estimate of the liabilities involved and to confirm the adequacy of the provisions to discharge them over time, is a particular concern for national authorities.

Overall, it is evident that there is considerable variability in the format, content and practice of cost estimates, and in funding methods. There is a great deal of room for improvement through greater standardisation and consistency of estimates even within countries. Attaining such harmonisation across countries may be problematic because of different legal requirements and historical custom and practice. In this regard, a more appropriate objective would be to develop a standard reporting template onto which national cost estimates could be mapped for the purposes of comparison. A related challenge for the future is to find a mechanism to encourage the sharing of best practices and to provide examples of how this can readily be implemented.

More specific findings of this study are as follows:

- **Most countries have established requirements for cost estimation and reporting. Legal requirements include the preparation of a decommissioning plan and associated cost estimates, with periodic updates – usually every three to five years.**

National requirements include administrative and substantive requirements. Administrative requirements are generally imposed by legal regulatory decrees or associated guidelines. Substantive requirements are generally related to explaining and justifying assumptions and boundary conditions in the cost estimates. These include boundary assumptions and conditions in cost estimates such as the year of the estimate, end-point criteria, site release criteria, legacy waste disposition, spent fuel disposition, transition activities, characterisation, waste canisters, casks, transportation, and disposal options, disposition of high-level and low-level waste, scrap, salvage, remote handling techniques, and project management. Some substantive requirements stipulate the use of overnight costs, and means for handling escalation.

Stakeholders are generally allowed to review and comment on cost estimates, but the owner is usually not bound to revise the estimate as a result of these comments.

- **A cost estimate for decommissioning is necessarily based on an assumed decommissioning strategy and on an assumed end state for the site. Given that the timeframe for active decommissioning may often be several years (or even decades for**

plants licensed under early regimes) after the estimate is made, these aspects represent significant uncertainties.

The nuclear safety regulator plays an important role in the approval of decommissioning strategies, cost estimating formats, and funding. Most regulators do not prescribe a reporting format except in the United States where the NRC has provided reference studies as guidance.

Some countries such as Canada and the United States require a cost-benefit analysis or the equivalent for assessing alternative decommissioning technologies and techniques.

Clearance and release levels have a major impact on costs. Whether the selected strategy is greenfield or brownfield strongly affects the total costs. These terms need to be defined in detail, however, as there is no universal interpretation. Recently, and especially in the context of new nuclear power plant construction in several countries, it is apparent that existing nuclear sites are gaining increasing strategic value. This may contribute to overall cost reduction by promoting earlier decommissioning of redundant facilities and from increased commercial value of the site.

- **The scope of decommissioning generally includes decontamination, removal/dismantling of disused plant and buildings, spent fuel storage or disposition, waste management, transport, and final disposal or long-term storage. However, some countries do not include the disposition of spent fuel, legacy wastes, waste disposal or its long-term storage in cost estimates for decommissioning.**

Characterisation is acknowledged to be an important part of cost estimating accuracy, as it affects system and structure inventory, decontamination, and waste disposal.

Several countries look for cost reduction possibilities through waste minimisation processes.

- **Most countries, either through regulation or by owner preference, have adopted a formal organisation of the cost estimates; in general detailed estimates are prepared, especially for plants that are already in operation. A Work Breakdown Structure (WBS) format is used, based either on the Standardised List “Yellow Book” format or on an equivalent national format.**

Calculation methods vary by country. Some countries specify the type of cost estimate expected from operators, while others leave it to the operator to determine. The use of life cycle planning models is prevalent in Canada and the United Kingdom, with worst case scenarios being used to bound the costs. Some countries such as the United States specify in detail how costs are to be reported, while others (such as France) specify the major cost categories, whilst allowing greater discretion on how estimates are structured.

Quality control is important for validation of cost estimates, e.g. CEA (France) tracks cost estimates twice per year, and benchmarks actual experience against the cost estimate. In the United States, the NRC reviews the accuracy of cost estimates, requiring full documentation of how the cost estimated was developed.

- **Many countries have adopted the breakdown of activity-dependent and period-dependent costs to structure their estimates. Period-dependent cost breakdown could be used to divide financing decommissioning into tranches to reduce overall uncertainties. Several countries apply this notion by having different contingency factors for different phases of the project.**

Contingencies are for unforeseen elements of cost **within** the defined scope. Uncertainties are for unforeseeable elements of cost **outside** of the defined project scope (such as currency exchange rate fluctuations, inflation beyond the norm of say 5% and regulatory changes).

Some countries use a defined contingency; Belgium uses 15%, Canada varies with estimate accuracy – a Grade A estimate 10%, Grade B 15-20%, Grade C 30%. Sweden uses 6-20%, Slovakia uses 20-25%, the United States uses approximately 25%, and Spain 15%.

- **Risk management, in terms of ensuring robust cost estimates in the context of uncertainties, falls more in the realm of financing rather than contingency in cost estimates.**

Risk analyses are being used more frequently in Sweden and the United Kingdom, based, for example, on Monte Carlo calculations – calculating a range of cost estimates and assigning simple distributions to each, and then multiple iterations calculating the distributions in size of the liabilities. Canada requires that cost estimates provide for escalation whereas, in Germany, this is specifically excluded. France follows a procedure for reducing uncertainties over time as the cost estimates improve in accuracy.

5.2 General reflections on good practice

- Important considerations in ensuring accurate cost estimates include: methodological accuracy and consistency (e.g., recognising that year-to-year funding tends to cause cost over-runs); avoiding changes in project scope (e.g., decommissioning strategy and end point); good characterisation; consistent regulatory requirements; involvement of the plant operator; the approach to setting contingency levels; and risk management. Current good practices also include the use of a standardised list of activities, a strong QA programme, use of a dedicated decommissioning core group, and involvement of regulators and stakeholders in the planning of decommissioning plans.
- It is likely that different cost assessment methodologies will need to be used as the project advances. Such methodologies should be continuously updated using cost data from actual decommissioning projects, thus improving the cost assessment, providing better control of uncertainties and contingencies for each major cost category, and facilitating the preparation of an annualised schedule of expenditures for each facility.
- Risk management may benefit from an approach that uses a deterministic calculation (base case) that feeds into a probabilistic assessment of future costs. Such approaches may be used to gain a better of potential cost and programme requirements.
- Regulatory standards should be addressed and fixed in the early stages of planning to avoid delays during the active stages of decommissioning.
- Early attention should also be given to socio-economic factors, including impacts caused by loss of employment, to help in building public support and acceptance of a decommissioning project. Early meetings with stakeholders may be used to gain agreement on project boundary conditions, strategy, release criteria and measurement protocols, and waste containers used.
- Consideration should be given to developing upgraded decommissioning management systems to deal with latest developments, data quality, completeness and safety, while offering flexibility in data processing and cost calculations. Regular interaction between system developers and users is necessary to develop the inventory and maintain user friendliness.
- In view of the very significant impacts that scope changes and scope growth may have on cost estimates, it is important that these be identified and controlled immediately, and incorporated into the estimate so that the estimate might continue as a viable benchmarking resource.

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Appendix A

LEGAL AND ADMINISTRATIVE REQUIREMENTS

The national guidelines reviewed herein show a range of regulatory approaches from highly to non-prescriptive. The general provisions explored cover the legal obligations of regulators and operators and the role assumed by the regulators; practical or administrative requirements (including whether specific guidelines are established, how prescriptive they are, and how they are enforced); assumptions and boundary conditions, and non-cost elements to be considered (such as uncertainties).

A.1 Legal basis

The authority of the regulator can come from a legislative act or a royal decree. In some countries, the law spells out specific requirements; in others, discretion is left entirely to the regulatory authority or to the operator. The requirement to prepare and submit to the regulatory authority an estimate of expected decommissioning costs is usually associated with the requirement to assure adequate financing when the time for decommissioning arises. In several countries (for example, Spain and the United Kingdom), the required cost estimation is tied to a national programme encompassing decommissioning and waste disposal in government-managed repositories, with the government taking title to the waste, and for which operators are assessed a unit fee. Cost estimates in such cases can be used as input for calculating the appropriate fee. In other countries, separate programmes cover spent fuel management or waste disposal apart from decommissioning; some of these programmes include a modicum of government involvement, others are entirely the responsibility of operators.

In each case, the nature and specifics of the cost estimation requirements will be governed by their legal basis, and by the national legal structure and bureaucratic organisation of decommissioning, waste disposal, and spent fuel management programmes. The scope of an operator's decommissioning obligations, for example, will be different where the national decommissioning plan is a seamless decommissioning and waste management programme, and where decommissioning, waste disposal and spent fuel management are all handled under different programmes and a separate set of regulations. Major differences explored below are the level of specificity in the law, and hence the degree of flexibility allowed in the regulations; and the level of specificity in the regulations and hence the degree of flexibility left to operators.

In Belgium, several Royal Decrees establish a programme covering decommissioning, waste disposal, and spent fuel management under which a government authority is ultimately responsible for decommissioning, including decommissioning programmes, cost estimates, and funding, as well as ensuring proper waste management and all decommissioning wastes. A separate government agency was created in 1980: the Belgian Agency for Management of Radioactive Waste and Enriched Fissile Materials, known by the French/Dutch acronym ONDRAF/NIRAS, takes title to the waste for disposal, for which service owners of waste pay it a stipulated fee. The law requires the filing and approval of decommissioning programmes, including decommissioning cost evaluations and provisions for financing. The cost estimates filed are used as input for calculating this fee. The requirement to prepare decommissioning plans and to calculate detailed cost estimates

are defined in the law. ONDRAF/NIRAS is required to validate them; however, the law precludes it from compelling operators to use a specific format, method or approach for estimating and presenting costs – any guidelines issued by the Agency are indicative only. Operators can and do exercise their own discretion for organising and estimating costs and ONDRAF/NIRAS must accommodate any differences. Belgian law requires a rigorous 5-year review of all initial decommissioning plans, cost estimates, and financing provisions. It specifies requirements for traceability and revision of the databases according to the life of a plant and the phasing of a project. Updated cost estimates must reflect any major changes at a nuclear facility that could affect decommissioning (changes specified in a given list). The final decommissioning plan has to be set up at least three years before the final shutdown of a facility.

In Canada, the requirement for filing a cost estimates is associated with the requirement for a financial guarantee for specific facility types. The Nuclear Safety and Control Act (Ref. A.1) allows the Commission authority to include in a licence any condition, including a condition requiring a financial guarantee. Consequently, where a financial guarantee is required, the licence applicant has the obligation to justify its value by submitting a decommissioning cost estimated based on a preliminary decommissioning plan. Preliminary cost estimates required at the beginning of plant operations are based largely on predictions of the type and quantity of contamination expected to accumulate under normal operating conditions. These are monitored during the operations phase and revised every five years or sooner, if required. The final decommissioning plan and related cost estimate reflects this operating history as well as the choice of decommissioning strategy. Updates must include site and operating changes since the previous filing, including operational history, relevant incidents, or accidents.

In France, the law of 28 June 2006 *Sustainable Radioactive Materials and Waste Management Act* (Ref. A.2), similarly requires decommissioning cost assessments as part of a larger filing that includes a decommissioning plan and provisions for financing. The Ministerial Order of 21 March 2007 (Ref. A.3) prescribes in detail the contents and organisation of the filing and the list of operations or liabilities with costs requiring assessment. France requires updates every three years. For commercial power plants, the regulator focuses primarily on the technical aspects of the selected strategy, although regulatory constraints can have a dramatic effect on costs. The owner/licensee is responsible for preparing the cost estimates and for providing the funding. For French government facilities, the *Commissariat à l'Énergie Atomique* (CEA) is responsible for overseeing cost estimates and funding twice a year. In most cases the regulator does not specify the format or content of the cost estimates, but relies on the owner/licensee to use its own judgment or to use the services of a consultant. These estimates serve as a basis for the constitution of discounted financial provisions, which are subject to a full financial coverage (apart from a 5-year transitory period given by the law for the constitution of the assets), through internal segregated dedicated assets.

In the United States, the several laws relating to the peaceful use of nuclear power provide the basis and establish broad guidelines for all NRC (Nuclear Regulatory Commission) regulations. The NRC regulations are codified in Title 10 of the Code of Federal Regulations, Part 50.75 (10 CFR 50.75) (Ref. A.4), and 10 CFR 50.82 (Ref. A.5). These regulations are supplemented by NUREG documents which provide industry practices and define compliance with all relevant laws and regulations, including requirements for filing decommissioning plans with their associated cost estimates, and assurances of financial provisions that are adequate to meet these costs in timely fashion. Updates are required every two years to assure adequacy of funding based on a minimum amount or when amounts or types of material at the facility change. Adjustments are made for inflation, prices of goods and services, and changes in facility conditions or operations. Changes expected in decommissioning procedures, project extensions, and alternative proposals are also entertained. About five years prior to the projected end of operations, the licensee is required to submit to the NRC a preliminary decommissioning cost estimate, which includes an up-to-date assessment of the major factors that could affect the cost to decommission.

The regulations specify the criteria for acceptance of updates as adequacy of the historical data of the site, and adequacy of the characterisation survey since the last report. These cost estimates are ultimately incorporated into a decommissioning licence.

In the Netherlands, under the Nuclear Energy Act (Ref. A.6), decommissioning requires a licence, based on an approved decommissioning plan and decommissioning cost estimates. Regulations implementing the law are issued by decree and generally follow IAEA criteria and guidelines. Updated decommissioning plans and cost estimates are required every five years, using up-to-date techniques and calculating models, and incorporating relevant operating experience.

In Slovakia, decommissioning funding is defined by law established under the Ministry of the Economy. The Nuclear Regulatory Authority (UJD) was established under the Atomic Act of 9 September 2004 (Ref. A.7). Funding sources are from contributions from the V2, EMO 1 and 2, EMO 3 and 4 NPP owners (in two components – one for each MWe of installed power output, and the second from the MW hours of electricity produced), from distributors of electricity (to cover the back end of the nuclear fuel cycle), the European Union and other international organisations (for the V1 NPP at Bohunice – no containment building), contributions from the state budget (for the A1 NPP at Bohunice – for recovery from the accident), and other sources defined in the law (financial operations of the decommissioning fund).

In Italy, in 1999 the government decided the decommissioning strategy, and established the independent public company SOGIN (*Società Gestione Impianti Nucleari*) to prepare and update the decommissioning plans, and prepare cost estimates in accordance with a format agreed upon between SOGIN and the Electric Power and Gas Authority. Funds are collected through electricity bills in the form of a levy. Responsibility for defining the amount of the levy, on the basis of the presented decommissioning programme and of the project advancements, has been given to the Electric Power and Gas Authority. Subsequently, the Authority releases funding to SOGIN for decommissioning work.

In Spain, the Royal Decree 1522/1984 of 4 July (Ref. A.8) set up ENRESA (*Empresa Nacional de Residuos Radioactivos SA*), a national authority to undertake both the dismantling and decommissioning of nuclear power plants, and the management of radioactive wastes generated in Spain. ENRESA not only takes title to the waste to be disposed of, but also takes temporary title to the site to be decommissioned, until the restored site is released. ENRESA responsibilities include spent fuel disposition, but not legacy wastes. For its decommissioning activities, ENRESA files a decommissioning plan and receives a decommissioning permit from the Ministry of Industry and Energy. Financing is provided through a surcharge on electricity (deposited into a state-managed fund), calculated by ENRESA in an annual study that reviews the status of techniques and assesses the associated costs, and submitted for approval as an annual General Radioactive Waste Plan to the Ministry of Economy. It is unclear what the responsibilities are – if any – of individual operators in estimating decommissioning costs.

In Sweden, the law makes operators responsible for developing and maintaining sufficient plans for decommissioning, waste treatment and safe disposal, and calculating the estimated costs of these liabilities (excluding the cost of waste storage facilities and legacy wastes). These plans and costs are included in a plant's operating licence; a fee is levied on nuclear electricity generation to cover these future costs. The cost estimates are reviewed annually by the regulator (Swedish Radiation Safety Authority, SSM), which recommends to the Government the level of the fee. The government ultimately determines the fee; the money is put into a State managed fund for future use by operators as needed. In the 1960s, the Swedish Nuclear Power Inspectorate (SKI) was set up and became responsible for licensing, regulation and supervision under the Nuclear Activities Act. Its three divisions were reactor safety, safeguards, and research. The Swedish Radiation Protection Authority (SSI) operated under the

Radiation Protection Act 1988. In mid 2008, the two organisations were merged to become the independent Swedish Radiation Safety Authority (SSM) encompassing both radiation protection and nuclear safety regulation.

In the United Kingdom, new legislation (Energy Act 2008) (Ref. A.9) proposes creation of a government-managed waste disposal and storage programme similar to that in Belgium. It would require operators to estimate decommissioning, spent fuel, and waste disposal costs as an integral part of the national programme to assure financing of ultimate waste disposal. The proposal requires operators to file decommissioning and waste management plans and related cost estimates that cover both the full cost of decommissioning plus a proportional share in a national waste disposal facility. The government will use these estimates to calculate a fixed unit price for waste disposal. The bill gives the Secretary of State broad powers to compel disclosure and compliance, and includes enforcement provisions.

A.2 Guidelines and operator discretion – A matter of regulatory philosophy

A.2.1 Regulated parties

All regulations dictate to some extent the responsibilities of the parties involved in making decommissioning cost estimates. In most countries responding to the questionnaire, the regulator plays a major role in approving the decommissioning strategy selected, reviewing the cost estimates developed, and reviewing the funding mechanism used to assure adequate funding for decommissioning. Whereas the role of the regulators is generally defined by law, the roles and duties of other affected parties (licensee/owners, contractors, or stakeholders) are generally defined by the regulator. The roles and responsibilities of these regulated parties with respect to cost estimating are summarised generally here, followed by further detail.

Owner/licensees

Owner/licensees are generally responsible for developing cost estimates and funding mechanisms. They are required to submit them to the regulator for approval periodically. Reviews of cost estimates are generally performed every three to five years (in the United States, the NRC reviews every other year, and in Sweden every year).

In Italy, In Italy, SOGIN presents annually to the authority a “status report” which shows any minor changes to the decommissioning plan and cost estimate. Major changes are presented only at the end of a 3-year period, when the overall decommissioning plan is revised.

Spain follows a similar annual review of costs and funding. Except for government-owned facilities, funding is provided by electricity consumers, and funds are held in some form of trust either internally or externally.

In Slovakia, the law (or regulator) does not prescribe the format and content of cost estimates. Cost estimates are reported to the regulator first at the time of the preparation of construction of the NPP, then as part of the preliminary conceptual decommissioning plan, then for the conceptual decommissioning plan (revised every ten years), and finally for the decommissioning plan in preparation for decommissioning (revised every five years).

Individual cost estimates for decommissioning are generated for all German NPPs. These estimates are the basis for the power plant licensee to adjust the provisions required by law to appear in the relevant company balance sheets.

Contractors

Contractors are used for the dismantling activities in most cases. They bring specific expertise in technical decontamination, dismantling, and waste management capabilities. Contractors used for the decommissioning planning are often forbidden to bid on the work to avoid a potential conflict of interest. This leads to the situation where the contractor is not held responsible for the outcome of the planning if problems arise.

In the United States, several utilities have in the past competitively bid out the work to contractors to get the lowest responsive price. The utility then acted as the overseer of the work to ensure public health and safety, security and environmental concerns. In one case, the contractor declared bankruptcy and the utility took over complete responsibility of the project. In another case, the contractor and utility disagreed on the scope of the project included in the fixed price, resulting in litigation between the parties and the utility taking over complete responsibility for the project.

In the United Kingdom, with the exception of the sites owned and operated by British Energy (BE), the existing site operators became "Site Licence Contractors" initially, working under the auspices of the Nuclear Decommissioning Authority (NDA). These sites were later put out to bid to allow and encourage other contractors to be awarded the work.

In Spain, it is common to contract an engineering company to prepare all reports, specifications, and licensing documentation for the project.

In Slovakia, the A1 NPP (damaged reactor) decommissioning contractor (DECOM Slovakia) developed the methodology and computer code (OMEGA) to prepare cost estimates for any type of nuclear facility. All Slovakian NPP cost estimates were prepared by contractors.

In Italy, SOGIN will provide all project management functions and will contract all on-site dismantling and maintenance activities.

In Germany, a large variety of contractor arrangements exist during the planning as well as the implementation period of decommissioning. These include the use of contractors for special planning or dismantling tasks as well as the management of the whole project by a contractor e.g. in case of small research or medical reactors.

Stakeholders

Stakeholders have grown in importance in recent years. They have been permitted to review decommissioning plans and end-point states, and in some cases cost estimates and funding arrangements. Not all countries give stakeholders control status to change or disapprove of plans, but only to review and comment. This is generally done by establishing a local information commission or community oversight board, which is provided copies of all plans, estimates, and funding arrangements. They may comment on technical issues and influence the direction being taken for disposition of the facility. For example, at the decommissioning of the Maine Yankee plant in the United States, the oversight board influenced the final disposition of clean concrete, requiring it to be transported out of the state to an industrial landfill at an additional cost rather than be disposed of onsite as fill. In some countries like Sweden, the stakeholders have no say in the cost estimates or funding, but may interact through the proceedings at the Environmental Court.

In Slovakia, the stakeholders have a role in evaluation of the environmental impact assessment related to the end point of the facility and local vehicular traffic during decommissioning. Socio-economic factors are not currently an issue as the A1 NPP decommissioning is a long-term process extending to 2033, and the employment availability at the operating V1 NPP on the same site.

In Germany, a safety report is published for the benefit of stakeholders. The safety report includes information about planned dismantling activities, waste treatment and waste storage and the related safety assessments as well as a description of the environmental impact from the overall decommissioning activities.

In Italy, as an interim measure, the waste (including spent fuel from the Trisaia plant) is being stored on site (at each plant) until the repository is available.

A.2.2 Flexibility

Regulations covering the estimation of decommissioning costs differ in the degree of prescription they require or the amount of operator flexibility they permit. Some of these differences result directly from specifications of law, or from the institutional history and arrangements of an organisation. But perhaps even more, the differences between prescriptive and discretionary requirements also reflect quite different regulatory philosophies, in much the same way that pollution control regulation can reflect a command and control, or a standards oriented approach. For example, one might expect that where a national authority is established by law to assume responsibility for managing and assuring the financing of a national waste disposal programme, one might see requirements for uniformity in cost estimations but this is not so.

Prescriptive and discretionary approaches to regulation result in the promulgation of different kinds of implementing guidelines, and different levels of detail. A discretionary approach, for example, would tend to result in guidelines that permit operator choice in defining boundary assumptions or choosing a cost estimation method. Use of scenarios might be suggested. Prescriptive regulations would tend to provide worksheets and specify uniform assumptions and estimation procedures. Country requirements reviewed tended to reflect a mixture of these two approaches, reflecting such differences as needs for uniformity, levels of trust, or legal restrictions. The range of differences may be bracketed by the United States on the one hand and the United Kingdom on the other.

The United States has specific and prescriptive guidelines for estimating decommissioning costs, and has provided reference studies to use as examples to follow. As the national regulatory body, the NRC has issued specific guidance on the format and content of the estimates for various types of decommissioning cases, specifying the procedures for administrative filings and record keeping, for review of the estimates, and for evaluation criteria. The regulations also require a standard format for costs and financing estimates. Cost estimates that vary from the prescribed approach in any detail at all will be considered unacceptable. Estimates are to be site specific, with costs tied to specific techniques and methods. The guidelines for estimating costs list nine specific conditions governing the acceptability of cost estimates, relating largely to completeness of scope, level of detail, and reasonableness of estimate; additional requirements are also specified for restricted release sites. The NRC requires that all guidelines must be followed exactly for cost estimates to be acceptable. It also provides a cost estimating benchmark calculation to establish a minimum funding amount for decommissioning. The NRC reviews the fund balance for each filing every two years, and compares it to the Minimum Funding Amount.¹

1. In the United States, for regulated utilities, the state public utility commissions also review decommissioning cost estimates and determine how much the utility may collect from the ratepayer, and how the funds will be managed. For unregulated utilities (merchant plants) the owner/licensee determines the amount to be collected and is responsible for any shortfall. For US government-owned facilities, the funds may be collected from ratepayers or will be paid by the government (using taxpayer funds). In some cases, the government has established a separate organisation to manage the funds and determine the adequacy of funding amounts. The US government is moving to the authorisation of multi-year funding to achieve the desired end-point state as defined by the decommissioning plans. This has greatly improved long-term planning and reduced costs.

UK regulations, by contrast, require a decommissioning plan to be sufficiently detailed to “demonstrate that the operator has a realistic, clearly defined and achievable plan for dealing with all of the waste streams that will be produced by its power station and for remediating the site after use, and to ensure that each element of the work can be costed accurately.” Under the proposed guidelines, the government provides a base case from which operators may prepare variants to make their cost estimates, as well as a parametric cost modelling method that the government will use for making its own estimates of the total and unit costs of waste disposal, and that operators may use for their own estimations if they choose. The proposed regulations provide an 18-page table of specific assumptions for the boundary conditions of its base case for decommissioning, waste and spent fuel disposal, and for the attendant cost estimation. However, these assumptions are deemed to be a framework from which site- and facility-specific estimates will be differentiated; some but not all of these assumptions could be adapted as the proposed regulations give emphasis to operator discretion. “It is recognised that decommissioning and waste management plans for individual power stations will differ in detail, as they will be based on a specific reactor design at a specific site run by a particular operator. If, however, a decommissioning and waste management plan broadly conforms to the base case presented here, the Secretary of State would expect to approve it (or approve it with relatively minor modifications).”

More specific guidelines for making these cost estimates are in preparation, in the context of implementing the new Energy Bill. These will specify life cycle costing of a decommissioning plan that covers spent fuel, waste disposal and management of all waste streams, decommissioning, and site restoration, and specifically provides for waste minimisation (and hence cost reduction). Filings should include provisions for updating and modification to accommodate changes in existing policies, regulations, and technology on which cost estimates are predicated. Cost estimates should be presented according to the phasing of disbursement and should indicate uncertainties. Changes that impact cost estimates and their revision should be reported to the Secretary of State as needed, but at least in a required report to the Secretary of State every five years; changes that have a material effect on the operator’s liabilities would be reported annually (the threshold for this requirement to be established). The proposed regulations would provide a base case produced by the government for its own use, which operators may use as a template and from which they may diverge as needed or appropriate.

Other countries tend to fall between these two extremes. Under Belgian law, ONDRAF/NIRAS is required to validate all decommissioning programmes, including cost estimates, to calculate an appropriate fee for covering the operator share of the costs of the national programme, and to assure over-all adequacy of long-term financing. The guidelines of ONDRAF/NIRAS are the basis for the operators to draw up these decommissioning plans and their five-yearly revisions (at least every five years and three years before the final shutdown of the nuclear installations). The law permits ONDRAF/NIRAS to provide very specific guidelines on the costs to be included, on cost data development for specific cost elements tied to operator-specified decommissioning plans (activity-dependent and period-dependent costs, work breakdown structure, standardised list of cost items), and detailed radiological surveys and inventories. The guidelines also cover assumptions and boundary conditions, the use of scenarios for cost estimation, definitions (of cost elements and of decommissioning activities), and level of decommissioning (usually unconditional clearance). Operators must file cost estimates that can be verified. However, the law precludes ONDRAF/NIRAS from compelling operators to use a specific format, method, or approach for estimating and presenting costs – the guidelines are indicative only. Operators can and do exercise their own discretion for organising and estimating costs, and the agency must accommodate any differences. ONDRAF/NIRAS can provide further guidance more informally or can reach agreement with individual operators.

In Canada, decommissioning cost estimates are associated with the need for a preliminary decommissioning plan, which is a requirement of the *Class I Nuclear Facility Regulations* of the *Nuclear Safety and Control Act*, and the need for a financial guarantee which would be a condition of a Class I

Licence. Licensees are required to provide a cost estimate that provides costs to account for labour, materials, and equipment of decommissioning; to cover contractor wages and overhead, to allow for waste management, to provide for an environmental assessment process, to allow for environmental and facility monitoring activities and to account for general administrative costs, including training, safety, licensing, project management, government relations and public liaison. Operators are required to refer to independent local contract and construction rates for labour, materials, and services (including project management), and to also provide for cost escalation. Regulatory guidance documents require that operators use life cycle decommissioning planning, one main advantage of which, from an economic perspective, is the potential for maximising opportunities for cost reduction. Boundary conditions are defined and sample worksheets are provided as examples, but operators have discretion in preparing the filing. However, if the submission does not meet the expectations of the regulator, and is not of sufficient quality to be independently verifiable, it will be rejected by the regulator. Parties filing estimates grade them in relation to accuracy, detail, and credibility, which sets out the requirements for a contingency allowance. Where precise or verifiable estimates are difficult to define, the regulator requires the operator to assume worst-case scenarios to assure the cost estimate is conservative.

In France, there are new laws and decrees governing decommissioning and waste disposal cost estimates. The Ministerial Order of 21 March 2007 (Ref. 3) prescribes such items as the estimation and reporting of five broad categories of decommissioning-related costs: dismantling, management of spent fuel, re-conditioning of legacy waste, long-term management of radioactive waste, and monitoring of disposal centres after their closure. Definitions, assumptions, and boundary conditions are partly specified by regulation and partly left to operator discretion to define on a site-specific basis. Each filing should include a presentation and justification of the chosen hypothesis and method applied, and a continuous comparison of actual expenditures for the operations in progress with prior estimates, noting any potential impact on costs and lessons learned. In general, the regulatory requirements reflect a commercial accounting framework overlying the initial calculation of engineering cost estimates. All cost estimates, for example, show capital expenditures and cost control, a breakdown between fixed and variable costs, and an annual schedule of expenses. The cost structure now in use (Work Breakdown Structure) differs from the Yellow Book. It allocates cost items for labour, equipment, services, consumables, and capital expenditures to the several functions of (1) preparation, engineering, work management, (2) operation and surveillance, (3) decontamination and dismantling operations, and waste management, and (4) demolition and site reconfiguration operations.

In Slovakia, the OMEGA code developed for decommissioning cost estimates is based on the Standardized List of Cost Items as described in the Yellow Book. The complete Work Breakdown Structure (WBS) of the Yellow Book is fully populated with the detailed activities associated with the decommissioning strategy selected for the facility.

The Netherlands uses the guidelines and criteria of the International Atomic Energy Agency (IAEA) for estimating decommissioning costs. Virtually all decisions as to assumptions, boundary conditions, and specific cost elements or calculation methods are left to operator discretion. The one exception is a requirement to restore the site to a greenfield condition. Cost elements may be taken or estimated parametrically from existing databases, taken from the experience of others, or calculated by outside consultants.

In Spain, since ENRESA prepares its own decommissioning plans and cost estimates, no additional guidelines are needed.

In Sweden, regulations lay out a few basic assumptions (site release for free industrial use, preferably other energy production), boundary conditions and definitions. Operator discretion is assumed for the definition and structure of the cost estimates, as well as the choice of estimation method and data

collection, using commonly acceptable and standard procedures and methods. A certain number of basic assumptions are specified, but no base case is provided, allowing operator discretion for defining and justifying most assumptions and boundary conditions.

A.2.3 Enforcement

The law in some countries, like the United States and the United Kingdom, establish penalties for non-compliance with the appropriate filing requirements. These can be quite stringent, including fines and other penalties. The UK Energy Bill (2008) gives the Secretary of State broad authority and discretion for enforcing both the law and the regulations promulgated to implement it. In France, an Administrative Authority has been created to enforce operator compliance, with authority to impose sanctions, fines, and corrective measures. In Slovakia, there is no specific enforcement action. The Ministry of the Economy reviews the cost estimates and financing plan. The Netherlands and Sweden monitor compliance, but no specific enforcement provisions or penalties are specified. For disused plants the ultimate penalty for non compliance in most countries is failure to be granted a decommissioning licence. In the case of applications for licences to construct and operate new nuclear power plants, the penalty for not providing an adequate decommissioning plan, financial guarantee or adequate cost estimate would be failure to obtain such a licence.

A.3 Requirements for costs to be included

Belgian regulations require a decommissioning cost evaluation to include all activities from final facility shutdown to final release:

- Pre-decommissioning operations.
- Facility shutdown activities.
- Decontamination and dismantling activities.
- Waste processing, storage and disposal.
- Site clean-up and landscaping (not always explicit required).
- Project management, engineering and site support.
- Waste disposal.
- Site restoration, if specific required.

Belgium specifies the inclusion of waste management costs for all waste categories (except for spent fuel) specified on a codified list of radioactive wastes.

Canadian regulations specify that a decommissioning plan should cover management or disposal of all wastes, nuclear substances, and hazardous materials, including:

- Spent fuel.
- Removal of surface buildings and infrastructure.
- Restoration of the site.
- Costs associated with pre- and post-demolition surveys, investigations etc.
- Environmental monitoring and ongoing maintenance of institutional controls.
- All required approval processes (including licensing and environmental assessment and cost recovery fee requirements).
- Administrative and overhead costs through the term of demolition and restoration process.

In France, the start and end of both the dismantling and the decommissioning phases of plant shutdown are defined by the licensing process. Dismantling marks the termination of the initial licensing decree; the decommissioning phase is licensed separately and approved separately.

According to ministerial decree, five different categories of costs must be estimated (and funded):

- Dismantling.
- Management of spent fuel.
- Re-conditioning of old waste.
- Long-term management of radioactive waste (including legacy and non-legacy waste, waste produced by dismantling, spent fuel reprocessing etc.).
- Monitoring of disposal centres after their closure.

In the United States, major decommissioning tasks are defined to include:

- Planning and preparation.
- Complete decontamination and/or dismantling of each site and facility component.
- Site decontamination.
- Restoration and stabilisation.
- Final radiation survey.
- Long-term surveillance for restricted release.

They include waste disposal costs (packing, shipping and disposal of radioactive wastes), but not spent fuel disposal (which is covered by a separate fund).

Proposed UK regulations define decommissioning costs specifically to include:

- Dismantling the nuclear power station at the end of its generating life.
- Removing all station buildings and facilities.
- Returning the site to an approved (most likely greenfield) state and release from nuclear licence control.

The UK requirements for estimating costs distinguish between those costs that cover operator obligations under the national waste disposal programme (i.e., their own full share of waste management costs, plus a proportional share in the costs of constructing and maintaining government-owned and operated high, intermediate and low-level disposal facilities). Based on these filings, a unit price for this will be determined and levied by the government. Operators are additionally responsible for all other activities related to decommissioning and waste management not included in the scope of the national programme, such as preparing and transporting waste for disposal, but these costs are not to be included either in the decommissioning cost estimates or in the calculation of the unit price. The proposed regulations summarise the principal cost streams for decommissioning and waste management and how they will be met, i.e., which will be covered by the unit price and which are direct operator expenses.

In Slovakia, at the A1 NPP, spent fuel is an integral part of the decommissioning process as a result of the accident. At the other NPPs, all spent fuel and legacy wastes and operational liquids are considered to be removed and disposed of prior to decommissioning.

Sweden excludes removal, transport and disposal/storage of spent fuel to storage from its definition of decommissioning, as well as the transport, off-site storage and disposal of waste (only treatment and preparation for transport are included). Waste storage and disposal facilities, high-level waste disposal, and legacy waste are all similarly defined as being outside the scope of decommissioning.

German cost estimates include all costs associated with dismantling, decontamination, demolition and release of the site, including waste management, except management of legacy waste and interim storage of spent fuel and high-level waste.

In Italy, cost estimates include all costs associated with dismantling, decontamination, demolition, waste and fuel management (including reprocessing, interim storage and final disposal)

A.4 Boundary assumptions and conditions

Most countries permit operators to establish their own site-specific boundary assumptions. The United States requires reasonable, justified, and documented assumptions. UK regulations require a decommissioning plan of sufficient detail to “demonstrate that the operator has a realistic, clearly defined and achievable plan for dealing with all of the waste streams that will be produced by its power station and for remediating the site after use, and to ensure that each element of the work can be costed accurately”. The United Kingdom provides the specific boundary assumptions it uses for its own base case, from which site- and facility-specific estimates will be differentiated; some but not all of these assumptions could be adapted at operator discretion, as justified. Sweden also provides a base case from which operators may work and specifies a certain number of basic assumptions, but permits operator discretion for defining and justifying the choice of assumptions and boundary conditions used.

Some of the boundary assumptions designed to ensure consistency or at least comparability among filings include specifying data sources, cost elements, and constant or “overnight” costs – the year of estimate for monetary units. Boundary conditions designed to ensure completeness could include defining the starting point for decommissioning and definition of physical boundaries, end-point criteria and conditions for facility and site release, the specific activities to be included and excluded in the decommissioning plan (e.g., legacy wastes, spent fuel disposition), and transition activities such as characterisation that may sometimes be tacitly considered but not costed. Yet other boundary assumptions specify choices to be made at a more detailed level among options (waste canister, cask, transport and disposal); or available techniques (major components and structures disposition – demolition, modification, infrastructure, and scrap and salvage), or technologies (remote handling, and their respective yield and ratios). Still others define the institutional and commercial umbrella for the project, such as strategies for procurement and overall project management.

One example of a stipulation common to virtually all regulations is the requirement for calculating and expressing all cost estimates as overnight costs. Absent such a requirement, verification and objective evaluation of the cost estimates is not possible; consistency would be elusive, even for updates of the cost estimates for a single decommissioning plan. Moreover, overnight costs will always provide a basis for estimating the impacts of different levels of inflation or cost escalation.

Equally important is a clear understanding and exposition of the consequences of choosing one assumption or another. Two key boundary conditions that have a major impact on costs are clearance and release levels, and the level of decommissioning to be achieved. Except in Sweden, most regulations assume site restoration to unrestricted or greenfield use; Sweden assumes free industrial use, preferably for other energy production. In Spain, the final state to be achieved in decommissioning is a matter of negotiation between ENRESA and the utility. In Italy, plant sites initially have brownfield status whilst being used for waste interim storage until the national repository is available; then they are converted to a greenfield condition. In Slovakia, the A1 NPP will essentially be converted into a waste treatment facility until all the materials of the damaged facility are dispositioned. The other NPPs will follow the greenfield end-point state.

The United States addresses in part the need to expose the consequences of choice by requiring a cost/benefit analysis of the options chosen for achieving ALARA (as low as reasonably achievable), while Canada suggests the use of a simple detriment-benefit analysis for assessing alternative decommissioning techniques. Some countries, like Belgium, require the use of scenarios, analysis of multiple options or a range of assumptions to highlight the different consequences and cost

implications of changing assumptions. Under the proposed UK regulations, this same effect is achieved by specifying variants to be calculated from a base case, by requiring a full report on continued steps taken for waste minimisation, and by requiring a statement of the weight and radiological limits of various waste containers and flasks.

With regard to level of decommissioning, the CEA in France notes that the final state to be achieved has a great impact (up to 20%) on decommissioning costs. Similarly in the case of yield ratios associated with intervention techniques, the CEA acknowledges that it is difficult to identify the most favourable choice of techniques and technologies, but that the yield considered can have a significant impact on costs. The CEA also briefly describes several changes over time in its decommissioning and waste disposal regulations that have had significant cost consequences. These include:

- The creation of a Dedicated Fund in 2001.
- Modifications in the physical and radiological boundaries of a site.
- Changes in the target final state (to unrestricted release).
- Changes in techniques to be used and in technical ratios.
- Extended shutdown dates for facilities.
- The possibility of alternative end states besides greenfield.

Finally, flexibility in defining assumptions and boundary conditions is essential in those cases where the regulations for cost estimation are generic, applicable to all types of nuclear facilities from mines to reprocessing, and including research reactors and medical facilities. While some assumptions and boundary conditions may be common to all, there will be considerable differences among them as to the level of detail required and their ability to provide it.

A.5 Uncertainties and contingencies

There are three aspects of interest in discussing these issues: 1) what is required by the regulations that govern estimating decommissioning costs; 2) what the government does, if anything, to reduce uncertainty, if only regulatory uncertainty (e.g., by grandfathering of technology or regulations once a decommissioning licence has been issued and the process begun); and 3) how a company handles uncertainty in making its cost estimates.

Different regulatory bodies approach the assessment of uncertainty in different ways; some do not address the question at all in the context of estimating decommissioning costs. Three countries address the question of regulatory uncertainty. The Netherlands is the only country to provide simply and directly a degree of regulatory certainty: the operator may assume that the costs of future regulatory changes will be paid by the regulator.

The UK parametric cost assessment model identifies key parameters for cost calculation that could result in cost changes, and assesses the associated uncertainties and their relative significance. Significantly, the government is explicitly taking the risk that ILW and spent fuel repositories will be available for use, the latter case being a major uncertainty in most countries. The government proposes to absorb all costs arising from this eventuality that are not already covered by payments into a fund, although some risk premium for this will be factored into the unit price ultimately charged. It is unclear how the government proposes to deal with the consequences of unfulfilled expectations when calculating unit waste disposal costs.

Spain highlights the costs of regulatory uncertainty, noting that decommissioning costs are highly sensitive to changes in regulatory, licensing, or legal requirements either by causing delays or imposing more onerous standards or additional requirements that result in higher costs of compliance.

However, the only remedy provided is a suggestion for carrying out a thorough risk analysis to identify possible events or situations that could potentially affect the project programme and cost. These events would be assigned a probability and a potential impact in order to permit a range of possible project costs and durations to be determined.

No other responding country addresses regulatory uncertainty, although it is a major element in decommissioning cost changes. All other countries responding require uncertainty assessments and sometimes uncertainty management on the part of those making the decommissioning cost estimates.

Belgium reviews the decommissioning plans and cost estimates every five years for major plant changes, inflation, cost escalation, discount rate, contingency, and risk management. Costs and financing are re-evaluated, taking into account major changes at the nuclear facility or possible accidents/incidents that might affect decommissioning costs. But risk management and uncertainties generally are covered in the rules and regulations for decommissioning funding, and not the regulations for making cost estimates. A large part of the onus for assessing uncertainties and their cost consequences falls to the NIRAS/ONDRAF.

Canada requires flexibility to be built into both the decommissioning plans and associated cost estimates. The preliminary decommissioning plan is an evolutionary document that is periodically reviewed and updated to reflect changes in operations, conditions, technologies, and regulatory requirements. For major uncertainties not resolved by the time of filing the detailed plan, Canada permits building directly into the plan a specific provision for future CNSC approval of a specific work package to be determined as needed in the future. It also permits a worst-case approach to planning a work package to provide some flexibility in both the work plan and the cost estimates. Where cost impacts or effectiveness of specific decommissioning options are “difficult or impossible to estimate with precision, or to substantiate with confidence, it may be cost-effective or necessary to offset these deficiencies by estimating or funding credible worst-case scenarios”. (CNSC Regulatory Guide G 206, Section 4.2) (Ref. A.10). Canada requires that cost estimates provide for escalation.

In France, the law requires operators to establish prudent cost estimations, taking into account technical uncertainties, contingencies, and lessons learned. The CEA recognises that a number of uncertainties are inevitable (“surprises can be encountered at any time”), starting with imperfect definition of the initial state of a site that can skew initial hypotheses. It uses an iterative method for progressively resolving uncertainties over time. The CEA also addresses the cost of regulatory uncertainty, noting that changes in regulations (e.g., for waste transport) can create new constraints and uncertainty as to costs of compliance. The CEA therefore expects uncertainties to be assigned to cost estimates, related to the accuracy (or uncertainty) associated with the type of estimate from an opportunity study (internal, conceptual study) at $\pm 50\%$, to feasibility design study at $\pm 30\%$, to definitive design at $\pm 15\%$, to development at $\pm 7.5\%$, to implementation at $\pm 5\%$. These uncertainties are treated as contingency.

Swedish regulations address the significance of regulatory uncertainty in terms of waste acceptance criteria, noting that different criteria will have an impact on decommissioning costs. In Sweden, a probabilistic analysis of the deterministic costs estimates (based on the “Yellow Book”) is performed by the utility to accommodate uncertainties in estimating future costs and fees. The regulator reviews the results of these calculations.

As for operators, the proposed UK requirements for decommissioning cost estimation incorporate broad flexibility to accommodate adaptation for uncertainties. Moreover, the regulations specifically require not only consideration but analysis of risks and uncertainties, specifying that costs should be distributed according to uncertainties (for example using a Monte Carlo method (calculating a range of

cost estimates and assigning simple distributions to each and through multiple iterations calculating the distribution in the size of the liabilities). Filings should include provisions for updating and modification to accommodate changes in existing policies, regulations, and technology on which cost estimates are predicated. Changes that impact on cost estimates and their revision must be reported to the Secretary of State as needed from time to time, but at least in a required report to Secretary of State every five years; but changes that have a material effect on operator's liabilities must be reported annually (the threshold for this requirement to be established).

The German commercial code, *Handelsgesetzbuch*, does not allow the calculation of uncertainty factors, nor is there provision for cost escalation, i.e. all costs and expenditures are assumed to occur on the accounting date.

In Italy, SOGIN does not consider contingencies *a priori*. The Electric Power and Gas Authority considers whether differences between planned and final costs are justified, based on a submission from SOGIN, before sanctioning the release of the relevant funds.

A.6 References

- A.1 Canadian Nuclear Safety and Control Act, R.S.C. 1997, effective 31 May 2000.
- A.2 Sustainable Radioactive Materials and Waste Management Act, Planning Act No. 2006-739, France, 28 June 2006.
- A.3 French Ministerial Decree of 21 March 2007 *on securing the funding of nuclear liabilities*.
- A.4 *Reporting and Record Keeping for Decommissioning Planning*, US Nuclear Regulatory Commission, 10 CFR 50.75 (b), (c), (e), and (f).
- A.5 *Termination of License*, US Nuclear Regulatory Commission, 10 CFR 50.82.
- A.6 *Nuclear Energy Act of 1963 and Implementing Regulations*, as amended by the Environmental Protection Act of 1979 and its 1992 and 2000 amendments, The Netherlands.
- A.7 Atomic Act of 9 September 2004, Slovakia.
- A.8 Royal Decree 1522/1984 of 4 July 1984, Spain.
- A.9 Energy Act 2008, Her Majesty's Government, United Kingdom, November 2008.
- A.10 *Financial Guarantees for the Decommissioning of Licensed Activities*, Canadian Nuclear Safety Commission Regulatory Guide G 206, June 2000.

Appendix B

DEFINING COST ELEMENTS AND COST DRIVERS ANALYSIS OF SURVEY RESULTS

B.1 Definition of cost types

B.1.1 Activity-dependent costs

France (EdF) and Slovakia appropriately noted that the physical inventory is the basis for this cost driver, and is associated with the radiological (and hazardous material) inventory. The unit cost factor approach depends on an accurate and comprehensive listing of system and structure inventory. The CEA added that the yield ratios for individual activities are required to estimate the costs and working time, meaning that more effective techniques can directly reduce the time to accomplish an activity. In Italy, the early cost estimates for the nuclear plants were calculated using the STILLKO¹ Code, and then validated by more detailed studies by other contractors in preparation for the general licence in 2001/2002. In Spain, the main source of cost data comes from the experience learned from the Vendellos-1 project. Other sources come from generic studies of PWRs, and BWRs, which have been updated to reflect international experience from Sizewell B, Trino, Ringhalls, Maine Yankee, and Connecticut Yankee.

In the United States, cost tracking of actual projects started with Shippingport, where performance measurements were a required deliverable in the form of reports to the DOE as to the amount of piping, valves, major components, and concrete scarification removed, and the recording of associated manpower (crew size and durations). Subsequent projects such as Yankee Rowe, Connecticut Yankee, Maine Yankee, Big Rock Point, Trojan, San Onofre, and Rancho Seco provided valuable data on productivity yields for these activities.

In Germany, activity-dependent costs included in the decommissioning cost estimates are planning, engineering, decontamination, dismantling, measurements as well as waste treatment and packaging. The cost of independent authorised experts for expertises used by the authorities as well as the cost of the approval procedure are also included.

B.1.2 Period-dependent costs

The CEA response noted that these costs concern the contracting authority: project management, surveillance, maintenance, and operating costs of equipment needed to support decommissioning. It depends on the duration of work, number of persons for project management, labour costs, and the diminishing cost of each function as the work progresses.

Slovakia noted that the duration of individual work phases is used to develop the overall project schedule critical path. An activity is on the critical path if start-up or continuation of all other remaining tasks depends on completion of this activity.

1. STILLKO code developed by *NIS Ingenieurgesellschaft MBH*, Germany.

In Italy, the project management costs are calculated as a fixed percentage of the overall decommissioning cost. Other period-dependent costs for operations, safety, security, and maintenance are calculated on the basis of the effective cost from the previous year, and projected to the future with a reduction coefficient (of about 3%) to comply with the efficiency recommendation of the authority, and with a programme of increased efficiency included in the industrial plan of SOGIN.

In Germany, period-dependent costs, including project management, insurance, security, and communication, are reflected in the cost calculation.

The use of period-dependent costs estimates, based on the phasing of decommissioning activities, raises an interesting question about financing possibilities for decommissioning. For nuclear power plant construction, one approach being used to facilitate financing is the use of phased financing, so that the risks (especially the completion risks) and hence the cost of risk of the construction phase, are not carried over into the more risk-free operating phase. Would such a concept be applicable to the funding requirements for decommissioning? Could dividing the financing into tranches reduce the overall uncertainties and hence the costs of the project long term? France, Spain, and Sweden already reflect this notion by applying different contingency factors to different decommissioning phases. Spain similarly has applied different contingencies based on uncertainties for different tasks.

B.1.3 Collateral and special item costs

In Sweden, these costs are treated as activity- or period-dependent costs. In Italy, collateral costs are calculated on the basis of a benchmark performed by the contractors that made the studies for the decommissioning plans. In Spain, the source of this cost data is based on information from ENRESA, and from previous experience in decommissioning.

B.1.4 Contingency costs

Contingency can be defined 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”.² By contrast, uncertainties are changes that occur outside the scope of a project and often beyond the control of project managers. Contingency costs or provisions are not a safety net to cover unexpected events. In fact, the broad set of events covered by contingencies is expected to occur, even though the precise outcomes are not known at the outset. Items to be covered by contingencies include insufficient inventory or characterisation, changes in planned dismantling processes, project delays, and differences between actual and estimated quantities of materials and waste. It should be noted that cost and wage escalation, and inflation and interest rate changes are not contingency issues as the cost estimates are usually stated in current or nominal dollars, and these issues are really factors associated with funding rather than cost estimating. Classic cost estimates are deterministic calculations reflecting a base scenario plus a contingency allowance to cover issues within the defined scope of the project.

For contingencies, Belgium uses a reference value of 15%, with operators free to use (and justify) other figures. In Canada, contingencies vary with the accuracy of the cost estimates. There are three possible grades of accuracy for which operators can qualify (qualifications specified by regulatory guidance): grade A having greater certainty and requiring only 10%, for contingencies; grade B being less certain and requiring 15-20%, and grade C, being least certain, having 30%. Sweden also differentiates contingency factors by cost item in some detail, based on experience, and with an overall project contingency of about 6%.

2. The Association for the Advancement of Cost Engineering International.

In France, EDF reported a contingency value of 15% is systematically taken into account. The CEA reported it uses ETE-EVAL, and assigns an uncertainty value to each main cost item based on a standard percentage weighted by the type of nuclear installation. These values are based on the experience acquired during previous operations. The overall uncertainty is based on a risk analysis, except for smaller projects where a standard contingency cost is used. In Italy, in the cost estimate presented to the Authority in March 2008, there was no contingency cost. The uncertainty of the total amount of the cost is so high, due to the uncertainty of the national repository and regulatory prescriptions, that it was considered not appropriate to include contingency at this time. The next estimate will have to address contingency and a risk assessment.

Spain reported that ENRESA studies are generally presented without any contingency, and a global 15% is estimated in the total costs. In the United States, contingency values are varied for each type of cost element varying from a low of 10% for project management costs, to a high of 75% for vessel internals segmentation. These values relate to a total number of contingency dollars which are summed and compared to the total cost without contingency to give an overall in the range of 18% to 22%. The NRC generally accepts an overall contingency of 25%. German, Italian and Japanese cost estimates do not include contingency costs.

Related to contingency is the issue of risk management, used to estimate the potential cost of contingencies or uncertainties, including, for example, extraordinary increases in waste disposal costs, inordinately high increases in labour and materials costs, or new more stringent regulations for worker safety or environmental protection. A risk analysis typically comprises a qualitative or quantitative assessment of the impact of risks or uncertainties in a decision situation (e.g., long-term budgeting or funding for decommissioning). A standard risk analysis approach involves, first, the definition of risk factors, and then an assessment of which cost items are impacted. One common technique is to develop a Risk Register of all possible risks to a project, and estimate the lowest value, mean or most likely value, and the highest value for each risk. Care has to be taken not to unfairly bias these estimates, as they would influence the outcome. Once these values are entered into Monte Carlo computer analysis programmes the outputs are usually reported, for example, as a P50 probability, that the cost estimate has a 50% probability the total cost can be higher or lower than a calculated value. Or, a P80 probability, that there is an 80% probability the cost estimate will not exceed some higher value of decommissioning cost. By this technique, managers can decide what level of assurance or confidence they want to build into a budget estimate for future expenditures.

A simulation (probabilistic) computation leads to a probability distribution of the project cost and identification of the relative influence of different risk factors in the project costs. Risk analysis may be used to develop contingencies for a determinate estimate, or to develop bounding values and confidence levels associated with an estimate, thereby enabling management to measure the level of risk associated with an estimate.

Risk assessment is also an important tool for managing uncertainty – unanticipated changes outside the scope of the project but that affect project costs. (See Section 2.4.2 of the main report for a more complete discussion of uncertainties.) Uncertainty assessment is variously addressed in different countries, either in the context of decommissioning cost requirements, financing requirements, or in general corporate risk assessment. It is actually applicable in all three cases. Current risk assessment practice, i.e. how established decommissioning cost methodologies deal with risks and uncertainties, include scenario analysis, Monte Carlo simulations and sensitivity analyses. Current risk management techniques include incorporation of flexibility into the project plan, permitting adjustments to meet the consequences of a surprise event, postulation of a range of possible outcomes (use of maximum and minimum costs and “what if” scenarios), with a back-up plan in the event that such cases prove to be correct. Given the inability to consider and predict all factors, adjustment mechanisms are as important as cost identification and estimates. A key element to all such risk analyses is a clear statement of

assumptions and a reality check on their soundness and consistency, along with the sensitivity analysis. There is great value in considering a possible worst economics and financing case, which is different from a worst case scenario for a radioactive accident.

B.1.5 Work breakdown structure and standardised list of cost items

Most respondents use a work breakdown structure (WBS) for their cost estimates, but not all of them follow the standardised list of cost items. Belgium, Spain, and Sweden use the Yellow Book as a basis for their regulations. Belgium specifies that costs should be presented as activity-dependent and period-dependent, using the work breakdown structure and standardised list of cost items from the Yellow Book. Slovakia uses the Yellow Book format in detail, and the OMEGA code was written around the Yellow Book standardised list. Sweden uses the Yellow Book format for reporting purposes and presentation of costs, but uses a bottom-up methodology specific to the facility, and also permits the use of standard definitions. For simplicity, Sweden has organised cost elements into a coded structure; amortisation of capital costs is excluded. Spain does not use the Yellow Book, but rather a WBS it has developed for its projects, which contains essentially the same information. France, the United States and the United Kingdom do not adhere specifically to the format and definitions of the Yellow Book, but they do provide definitions of cost items and organise costs that are roughly similar.

France uses its own WBS to categorise cost elements and work activities into logical groupings tied to the accounting system for decommissioning costs. All estimates should show a breakdown between fixed and variable costs and include a category for capital expenditures. The WBS defines and categorises costs differently from the Yellow Book, but still defines costs as activity- or period-dependent, and arranges them in a hierarchy from more general to more detailed. Costs must cover the detailed activities in each of the five major areas of dismantling, spent fuel liabilities, liabilities for reconditioning legacy waste, long-term waste management liabilities, and monitoring of disposal facilities.

The United States also uses a bottom-up methodology specific to the facility, and specifies its own definitions of decommissioning and waste disposal cost elements, and its own system for organising cost items. However, the standardised US work sheets for calculating decommissioning costs includes a category for direct and indirect costs, and uses an activity-based approach for some elements: the output of these worksheets can thus be converted into the Yellow Book format when needed.

The United Kingdom provides its own definitions and organisational structure for making cost estimates for “designated technical matters” that cover: decommissioning an installation, site clean-up and “such aspects of waste management and disposal activities undertaken during the generating life time of the station as the Secretary of State may specify by Order”. It requires costs for all waste streams (including non-radioactive hazardous wastes), requires costs to be phased according to time scale, and requires costs to be distributed according to uncertainties (calculating a range of estimates and assigning a distribution to each, e.g., by using a Monte Carlo method).

Canada provides regulatory guidance in regulatory document G-219 “Decommissioning Planning for Licensed Activities” but allows for operator discretion within the submission. However, the submission is reviewed to assure it meets regulatory expectations as set out in G-219.

The Netherlands also leaves these choices to operator discretion. It is assumed that most Dutch operators will contract out their decommissioning cost estimates to NIS, which has its own scheme for selection, definition, and estimation of cost elements.

In Germany, the decommissioning study of the reference plant follows a bottom-up technique based on a work breakdown structure suitable for the particular facility. New knowledge that may influence the cost calculation and the necessary provisions for decommissioning is reflected in the annual review of cost estimates.

Italy does not use the Yellow Book but a bottom-up WBS to define costs elements and work activities. The WBS defines plant, building/room, and equipment/activity. For each activity costs are divided into four main categories that are design, licensing, purchasing, and realisation.

B.1.6 Facility characterisation for traceability and revision of the databases

The importance of a good radiological inventory and careful characterisation of facilities, materials, and waste cannot be overstated. In France, EdF reported that the historical data base of operations is the basis for classification of rooms and components. The data is collected during the operations phase of the facility and used for preparing the decommissioning plans which rely on the radiological and hazardous physical inventory. The CEA reported that the inventory and characterisation is one of the first steps in a decommissioning project. The characterisation inventory provides the basic data necessary to perform the detailed planning for the facility.

In Slovakia, the databases have a room oriented structure (building objects, floor, room and equipment). The database is reviewed and approved by the owner prior to cost calculation. In Italy, SOGIN has no plants being decommissioned for use in obtaining a data base; this is planned for the future, but inventory and characterisation activities are in progress. Spain reported that it performs an historical site assessment (HSA) as part of the radiological characterisation before decommissioning begins. At the same time, ENRESA conducts site interviews with operating personnel to determine the facility history. The United States also uses an HSA prior to the start of any major work. It is the primary input for planning the project.

In Germany, a detailed cost analyses is made for a reference plant with all assumptions and input data documented. The computer based calculation system STILLKO is used to evaluate decommissioning costs for the reference model for light water reactors. Revisions are made each year and the update covers also inflation. Based on the reference model each plant has its own individual decommissioning cost estimation taking into consideration plant specific differences compared with the reference plant as well as decommissioning related aspects from the operation history, e.g. failures of spent fuel elements.

B.2 Main cost drivers – Analysis of survey results

B.2.1 Objectives of survey

A questionnaire was developed and distributed to a number of countries to gather information on the important cost drivers in decommissioning cost estimates. The cost drivers vary in importance from one country to another, and are prepared for different purposes at different times. The objectives of the survey were to collect different national perspectives, to provide the basis for a report giving an international perspective on the variables that may influence cost and on their relative importance.

Although the survey questionnaire was structured to gather specific information believed to affect cost estimates in many areas, respondents were encouraged to include other specific information important in their respective countries to the development of cost estimates and funding issues. Respondents were also requested to identify and explain which variables were (a) very important; (b) moderately important; and (c) insignificant.

The major topics identified in the questionnaire included:

1. Roles and responsibilities of regulators, implementers, and stakeholders.
2. Assumptions and boundary conditions.
3. Cost data development for cost elements.
4. Cost estimating methodologies and tools, and their impact on the life cycle of the project.
5. Where estimates go wrong – review of experience.
6. Conclusions and experience.

The questionnaire further identified subordinate issues within these major topics to assist in understanding the level of detail desired in the responses.

B.2.2 Responses to the questionnaire

There were 12 responses in total received from the contributing countries. France contributed two responses, one from the commercial reactor segment and one from the government research segment. The commercial reactor segment was represented by EDF, representing 58 reactors located on 20 sites. The government research segment (CEA) is responsible for nine research centres with numerous nuclear fuel cycle facilities. Belgium contributed a response representing the views of ONDRAF/ NIRAS, the agency responsible for the safe management of all radioactive waste, including decommissioning waste. One response (and revision) was contributed for Sweden from SKB, representing ten commercial reactors and associated nuclear fuel cycle facilities. Canada did not directly respond to the questionnaire, but provided copies of two regulatory guides dealing with decommissioning planning and costs and funding. Information was extracted from these guides to respond to the questionnaire. The US response was provided as additional guidance to the respondents as to the level of detail and focus requested. Responses were also contributed from the Netherlands, Italy, Japan, Spain, Slovakia and Germany. Additional comments were added for specific topics as appropriate.

The following summary and analysis of these responses provides some insight as to how boundary conditions are defined, how cost drivers are handled, and what cost elements and factors are considered most important in each of these responding countries. The 20 cost drivers and elements can be divided into four categories:

1. Basic assumptions and inclusions in the boundaries of the estimate.
2. Sources for unit cost for various activities.
3. Assumptions for waste management.
4. Technical assumptions for decommissioning.

B.2.2.1 Assumptions and boundary conditions

1. Year of estimate monetary units

All respondents reported the cost estimates are prepared in current (or constant, or overnight costs) monetary units of the country currency. Net present values (NPVs) of these costs are estimated taking into account inflation, escalation,³ and the discount rates. In Spain, the discount rate is specified to be the same 2.5% used in the General Radioactive Waste Plan calculations. In Sweden, the discount rate to be used for future cost NPV calculations are provided to SKB annually. In the United States, cost estimates are based on current estimates, and are updated periodically to assure adequacy of funding. The United States generally does not use NPV calculations as they tend to under-estimate the fund if the inflation/escalation discount rates change significantly. A one-half percent change in either inflation/escalation or discount rate has a far greater effect on long-term costs than any single cost driver.

2. Start point for decommissioning and definition of physical boundaries of project

In most cases, the starting point is the physical final shutdown of the plant. In some countries like Italy, spent fuel removal and reprocessing is a decommissioning cost. In the United States, the spent fuel onsite storage is included as a cost item for collection of funds, although the NRC does not consider onsite storage or final disposition a decommissioning cost. The costs for pre-decommissioning engineering are

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3. Escalation beyond normal price inflation (which is based on a consumer price index), and reflects changes in costs associated with enhanced regulatory environmental requirements, unanticipated waste disposal fees, extended on-site waste storage costs etc.

generally allowed as a decommissioning expense by the regulators. In the United States, up to 3% of the decommissioning fund may be spent on engineering and planning for decommissioning (with certain limitations).

In Slovakia, at the A1 NPP because of the accident spent fuel is an integral part of decommissioning, but at the other NPPs, spent fuel is not included in the decommissioning costs. In Sweden, spent fuel transport to a storage facility is not included as a decommissioning cost. In Spain, once the decision is made to shut down the site, including public consultation, the site is transferred to ENRESA to decommission. In Germany, the start of decommissioning is taken to coincide with the last planned shutdown of the power plant. Decommissioning cost estimates include costs associated with the planning of decommissioning activities including those associated with licensing of decommissioning.

3. End-point criteria and conditions for the facility and site

All respondents indicated immediate dismantling is the preferred strategy. Some multi-unit sites incorporate delays while waiting until the second (or more) units are ready to shut down. The final release from regulatory control is the objective, with the site meeting the country's release criteria. Dismantling includes demolition of structures to one meter below grade, unless there is a specified re-use of a building(s) in another application. The final condition is either greenfield or brownfield, the latter considered appropriate when the site is to be reused for another power plant or industrial facility. Brownfield may permit some low levels of radioactivity to remain if the site is to be put to some radiological use.

4. Transition from operation to decommissioning, including characterisation and inventory

All respondents reported that the transition phase is needed to prepare the site (and personnel) for decommissioning. Facility and site characterisations are performed starting from historic data bases, and expanded by radiological (and hazardous material) measurements. In Italy, the nuclear facilities have been shut down since 1987, and the research and fuel cycle facilities shut down some years before that. Accordingly, the transition phase is long past. Nevertheless, the current activities are to update the characterisation data and use it for detailed decommissioning planning.

5. Ongoing operations not specific to active dismantling

All respondents considered these activities related to continued operations for maintenance, surveillance, and security. Sweden responded by relating this period to defueling and shutting down the plant. In the United States and Slovakia for example, all activities related to shutting down the facility (draining systems, de-energizing systems, etc.) are considered performed by the operating staff and not specifically charged to decommissioning. In Germany, costs associated with defueling, shutdown, disposition of operational waste, ongoing maintenance, inspection and repair of nuclear and non-nuclear systems, and regulatory requirements not related to decommissioning are not included in decommissioning cost estimates.

B.2.2.2 Sources of unit costs for activities

1. Source of employee salary and craft labour rates used in the estimate

Generally the respondents indicated the source of management employees and labour costs were site-specific, and were based on either recent experience at decommissioned reactors or on operating experience. The labour costs are usually taken from outside contractors work on these sites. In Slovakia, the classifications are grouped into the categories of basic worker, skilled worker, technician, clerk, engineer, senior engineer, and manager. Labour rates established for these categories are agreed with the owner prior to performing cost calculations. In the Netherlands, the rates are taken from the *Central*

Bureau voor de Statistiek rather from prior decommissioning experience. Italy reported it uses the average cost of SOGIN personnel in the year of the estimate used. In the United States, owner/licensee management staffing salary levels are used, and labour costs are taken from actual recent contracts for subcontracted labour on site. In Germany, contractor rates are based on best estimates provided by consultants; management rates are based on relevant average salary costs.

2. Source of material and equipment costs for conventional demolition of clean equipment and structures

The respondents reported the source of material and equipment costs were taken from previous decommissioning projects, or from equipment vendors, rental companies, or contractors. The Netherlands indicated the estimate for Dodeward conventional demolition was made by a power plant engineering group experienced in demolition, but subsequently, the German company NIS was used. Italy responded that unit prices are taken from the commercial associations that perform these tasks in Italy. In the United States, handbooks and estimating guides such as R.S. Means, *Building Construction Cost Data*,⁴ for the year of the estimate are used.

3. Source of material and equipment costs for monitoring, decontamination, and dismantling of contaminated materials and buildings

The respondents reported that the sources for material and equipment for monitoring, decontamination, and dismantling are taken from prior experience and from handbooks. In Germany, a structured process is used to collect relevant data from ongoing decommissioning projects, with the aim of providing a source of up-to-date material and equipment costs for decommissioning costing.

B.2.2.3 Assumptions for waste management

1. Disposition of legacy wastes (including melting of contaminated metals and recycling options)

There were mixed responses regarding whether legacy wastes are considered operational wastes or decommissioning wastes. In France, EdF indicated legacy wastes were an operational expense and not included in decommissioning. However, major components removed and stored during operations (steam generators, reactor vessel heads, etc.) may be treated as decommissioning wastes if the cost estimate model includes the disposition in the estimate. The CEA noted that melting is not well developed in France, except for lead and steel. Sweden also considers legacy wastes as operational wastes even if processed during the decommissioning period.

In Spain, no legacy wastes can be transferred to ENRESA to be dealt with as part of the decommissioning project,⁵ and must be sent directly to the disposal facilities before ENRESA takes over the site. Spent fuel must also be out of the pool and transported off site.

In Slovakia at the A1 NPP, all legacy and decommissioning wastes will be treated on site because of the presence of alpha-containing materials from the accident. The other NPPs will disposition legacy wastes and spent fuel as an operating cost before decommissioning begins.

Italy reported that, for conventional hazardous waste like asbestos, it uses the costs of skilled contractors for removal, packaging, and transport to an authorised disposal facility. Currently, no recycling of contaminated metal is considered in Italy, except for the Latina Boilers that are being considered for melting and recycling abroad. Studies are also underway to consider the general transport of contaminated metals abroad.

4. *Building Construction Cost Data*, R.S. Means Company, Inc., Kingston, MA.

5. i.e. the operator is responsible for the disposition of such wastes, including their ultimate transfer to the national waste disposal repositories, which are also managed by ENRESA.

The Netherlands indicated that legacy wastes would be recycled.

In the United States, legacy wastes are treated during the decommissioning period by the operating staff at no cost to the project. The final disposition of reactor vessel water, fuel pool water, etc. are costed as decommissioning costs since they are needed during decommissioning.

In Germany, waste from the operational phase of the plant is considered as operational waste; wastes occurring during the decommissioning period are included in the decommissioning costs. Major components removed/stored during operation (steam generator, reactor vessel, heads, etc.) may be treated as core scrap and as decommissioning waste after shut down. Slag and ashes from melting and burning processing of radioactive materials will be accounted as decommissioning or operational waste and estimated in the decommissioning cost calculation depending on the date of production.

2. Waste canister options (including capacity, design life, and limitations on their use)

It is difficult to provide detailed specifications regarding capacity, design life, and limitations for the variety of waste canisters in use in each country. All transport containers must meet the IAEA transport conditions for normal and accident scenarios. The United States adopted virtually similar requirements for their containers a few years ago to be consistent with the rest of the industry. The respondents attempted to describe in general terms the types of canisters in use in their respective countries, and they are summarised herein.

In France, EdF noted that waste canisters are used for storage and transportation, but there are a limited number of approved containers for these purposes. CEA reported they use an average “cost per waste disposition route” during the feasibility phase of an estimate, independent of the specific type of cask to be used. When the estimate and feasibility assessment is sufficiently advanced, detailed estimates are prepared using specific types of packages and casks.

Belgium relies on past experience of ongoing decommissioning projects for canister costs, or on experience during operation of facilities.

In Slovakia, all wastes from the A1 NPP (damaged reactor) are being packaged in 200 litre drums. Transporting of liquid radioactive wastes is performed in special IAEA approved specification containers. All other NPP wastes are packaged in 1.5 cubic meter containers which are then loaded in 3.1 cubic meter containers and grouted with concrete for disposal at the surface repository.

In Italy, a contract is in progress to design, qualify, and construct cylindrical and rectangular containers. In Sweden, cost estimates are based on the use of standard 20 foot (15 cu m) containers, as well as smaller boxes and drums.

Spain uses four types of containers for decommissioning wastes. A Metallic Transport Cask (MTC) for dismantling of systems and structures in active zones (that are grouted for transport to El Cabril); a Measurement and Declassification Container (MDC) for movement of wastes on site; a Vandellos Dismantling Container (VD) for secondary radioactive wastes such as clothing, gloves, masks, and filters (until the waste is classified and then become VD drums that are sent to El Cabril); and a Big Bag containing non-radioactive but toxic insulation materials (glass fiber, asbestos).

The United States uses a variety of containers, including Sea Vans for bulk shipments of dismantled equipment, concrete, and soils sent to off-site waste processors for further characterisation and disposition. Low-specific activity (LSA) containers such as B-25 steel boxes (exterior dimensions of 1.85m l, 1.19m w, 1.32m h – interior volume 2.55 m³) for wastes sent directly for burial, 55-gallon (200 litre) drums for contaminated clothing, etc., and canvas bags for contaminated soil for direct burial. Large components are usually transported as their own containers, with additional shielding

added to meet transportation requirements. Reactor vessels are transported in specially designed containers with shielding and are buried directly in the containers. Reactor vessel internals are transported in liners loaded in heavily shielded casks which are returned for reuse. The liners are buried with the internals in place. There are a limited number of these casks available for these purposes, and it becomes a logistics scheduling issue to maintain programme schedule.

In Germany, waste packaging for low and intermediate level waste is defined according to the regulations for the German repository “Konrad”. The cost estimates for waste packaging depends on the radiological level and kind of waste. A wide range of packages, e.g. drums and containers, are in use for buffer and interim storage of radioactive wastes.

3. Waste storage and disposal facilities

Waste storage and disposal facilities vary for each country depending on whether they have a national repository available. In France, EdF reported waste storage is centralised for every radioactive waste producer. The state agency National Agency for Radioactive Waste Management (ANDRA), places contracts with producers with a fixed part and a variable part. It establishes specific Waste Acceptance Criteria (WAC) and addresses physical form of the wastes (solids only, no liquids or less than 1% liquids, no exposed rebar in concrete, and special container reinforcement to prevent subsidence of the overburden soil). ANDRA also specifies the radiological and hazardous materials permitted, including concentrations, total quantity, and hazardous material limitations. CEA reported waste treatment cost is calculated for each site, including logistics. The disposal cost is based on a surveillance period of 300 years from the time the disposal facility is sealed. There are three disposal sites; La Manche (CSM) now closed, Aube Surface Disposal Site currently operating, and a very low-level disposal site (CSTFA) in operation. A 1991 radioactive waste management act called for a 15-year research programme for intermediate- and high-level wastes. At the end of this period (in 2006) the French parliament passed legislation for a geological repository by 2025 and a disposal centre for graphite and radium-bearing waste in 2013.

In Slovakia, low and intermediate level wastes are disposed of in the near surface repository in Mochovce. Radioactive wastes not meeting surface disposal acceptance criteria will be placed in Interim Storage at the JAVYS site in Jaslovske Bohunice for ultimate disposal in a deep underground geological disposal facility.

Italy uses interim storage on individual plant sites (e.g. existing facilities such as turbine buildings) until a national repository is available; it is currently planning a new repository. There are recurring difficulties in obtaining licences, especially from local authorities.

Belgium is studying a geological disposal facility; a surface disposal facility for low-and intermediate-level short-lived wastes is foreseen for the years 2015-2016. ONDRAF/NIRAS sets the costs for storage and disposal.

Sweden reported waste storage and disposal are not included in decommissioning costs estimates. Spain reported existing facilities at El Cabril are used for decommissioning.

The Netherlands reported wastes are stored at COVRA, the national waste management organisation.

In the United States, wastes were buried at Barnwell, SC until June 2008, when it was closed to out-of-compact waste generators. Only South Carolina, Connecticut, and New Jersey will now be permitted access to Barnwell. Other sites include the Ecology site in Richland, WA, and the Envirocare (Energy Solutions, Inc.) site in Clive, UT for Class A (low-level) wastes.

In Germany, the costs for evaluation, exploration, commission and operating an interim storage partly on site and off site are part of the reference decommissioning cost evaluation related to the chosen waste management strategy. Costs for final disposal related to decommissioning wastes are included in the cost estimate.

4. Waste transportation options, including weight or radioactivity limits on containers and casks

Respondents reported truck transport is used for most shipments because of the availability of roads. Heavier loads are transported by rail and the heaviest loads by barge. The limitations of rail shipments include narrow bridges or tunnels, steep hills, etc., requiring rerouting over longer distances at additional cost. In some cases facilities have to be upgraded to accommodate these shipments. In Italy, because of the difficulty of not having a national repository, they have calculated an average unit cost for waste disposal to the national repository (including transportation) of 10 000/mc for low-activity waste, and 40 000/mc for high-activity waste. In Germany, transportation costs are estimated assuming that existing transport systems and scenarios with existing limitations are used; transportation of decommissioning wastes to a final repository are included in the estimate.

5. High-level waste and spent nuclear fuel disposition

In France, EdF reported the costs for high-level wastes are included in decommissioning, but the cost for reprocessing is an operational cost. Financial provisions are set up to handle this cost. The CEA reported that future expenditures for geological disposal are estimated from the projected operating cost of the repository, and estimates of the Class B and C wastes volumes are made every three years to predict the impact on the repository capacity. Spain reported that high-level waste and spent nuclear fuel are not included in decommissioning. Spain does not have a repository at the present time for these wastes, and it is considering using El Cabril for temporary storage until a repository is available.

In Slovakia, all operating NPPs use the open fuel cycle (no reprocessing). At present, the closed cycle with reprocessing is not possible as the VVER-440 reactors are not licensed for the use of mixed oxide (MOX) fuel. Therefore, all fuel is placed in long-term storage (40 to 50 years) awaiting disposal in a deep geological repository.

Italy has not considered the cost for geological disposal, but considers temporary storage in the national repository for low-level waste. The waste produced from reprocessing spent fuel will return to Italy by 2020. The Netherlands transfers all fuel to a foreign reprocessor and reprocessing wastes are to be returned to COVRA. All uranium and plutonium is or will be sold.

In the United States, spent fuel is stored on site in wet pools or in dry storage casks until a federal repository is available (probably at Yucca Mountain, NV). However, there is ongoing litigation between the Department of Energy (DOE) and Nevada about the suitability of Yucca Mountain for such disposal. Other independent off-site storage facilities in Utah are being developed as an interim measure, but again there is resistance against licensing such facilities. The United States recently announced a programme between the DOE and Tennessee Valley Authority to investigate reprocessing again (formerly performed at the West Valley, NY Reprocessing Center – now decommissioned).

In 2005 the German federal environmental ministry decided to stop reprocessing of spent fuel elements and to store spent fuel elements on each site in an interim store until a final repository is available. The costs for interim storage and all related costs for establishing a final repository for high-level wastes and spent fuel elements are calculated separately from the calculation of decommissioning costs.

B.2.2.4 Technical assumptions for decommissioning

1. Major component disposition

The decision to remove large components as either one-piece or segmented differs significantly with each country responding. In France, EDF responded that the one-piece removal of steam generators of PWRs and GGRs is preferred to save costs. Turbine-generators are generally non-contaminated or can be decontaminated for resale as conventional metallic waste. Other secondary side components would be dispositioned similarly depending on the levels of contamination. The CEA reported it has less experience than EDF dealing with large components, but noted ANDRA has a limited capacity for handling large components.

Slovakia reported that one-piece disposition is not used at this time but is being considered for specific components (steam generators, pressurisers), which will subsequently be fragmented (segmented) on site for disposal in cubical containers.

Italy anticipates that major components will be segmented and packaged in containers as waste and stored on site until the national repository is available. Belgium reported that, based on experience at the BR-3 reactor, major components would be segmented to fit 400 L drums or larger containers. Sweden indicated it could remove them in one piece or segmented.

Spain reported that depending on their radiological condition, they could be disposed of in Authorised Waste Storage Areas, or in conventional areas prepared for them.

The Netherlands reported no decision has been made yet. The United States has had great success removing large components in one piece, saving millions of dollars in packaging, transportation, and disposal.

In Germany, the dismantling of major contaminated or activated components of the controlled area is part of the technical specification of the reference decommissioning cost estimation. The calculation is based on the assumption that the components will be cut into pieces according to the acceptance criteria from the final repository for intermediate level wastes.

2. Scrap and salvage disposition

Generally, the respondents consider clean scrap and salvage as scrap materials. The cost to decontaminate them for free release is prohibitive, and the issue of liability for secondary use is important. In France, scrap cost recovery is taken into account in the cost estimates, but not in Slovakia, Italy, Belgium, Sweden, or in the United States. In Germany, metals suitable for decontamination and free release metal are regarded as scrap. Scrap is assumed to be collected without charge at the site. Sales revenues from equipment and components are included in cost calculations.

3. Construction of new facilities or modification of existing facilities to facilitate decommissioning

For the most part, existing facilities are modified with respect to security requirements, electrical service, ventilation, and communications; workshops and warehouses may be dismantled. Construction is envisioned for new facilities for storage of special wastes (graphite or large components), and for spent nuclear fuel (as in the case of the United States), until a federal repository is available. The costs are included in the decommissioning estimate; Spain includes the amortisation of these investment costs, but not Sweden or the United States.

In Slovakia, at the A1 NPP damaged reactor, a complete system for waste treatment was established in the machine (turbine) building to handle all legacy and decommissioning wastes. The other NPPs will use the turbine building as a staging area for sorting and segmentation of materials in preparation for disposal. The costs for modifying these buildings are considered a decommissioning expense.

Italy anticipates new facilities such as the Waste Management Facility, the Monitor Release Facility and some special waste treatment and conditioning such as cementation of high-activity waste in Saluggia (Eurex), and cementation of the liquid uranium-thorium solution in Trisaia (Itrec). As these facilities cannot be re-used in Italy, the relevant costs are considered as an expense cost and not an investment cost. Cost estimates include the cost for dismantling these facilities.

The Netherlands foresees new dedicated plant infrastructure being provided to support decommissioning.

In Germany, it is anticipated that modifications to ventilation, electric systems, control units, etc. will be necessary and these activities are regarded as being part of the preparation of the facility for the decommissioning activities. Buildings are provided for long-term interim storage of operational and decommissioning wastes on site or in external interim stores until a final repository is available.

4. Structure disposition

For the Immediate Dismantling strategy, most respondents indicated the non-radioactive structures would be demolished as part of the decommissioning as they are not generally suitable for re-use. However, the cost of demolition is not always treated as a decommissioning expense. In France, the CEA indicated the costs are not included in the dedicated fund, and EDF indicated the structures are removed but did not address whether the costs are included in the estimate.

Sweden noted that most of the demolished material is planned to be used on site for filling below-grade cavities. In Slovakia and Italy, all structures will be demolished up to one meter below grade. No decision has been made regarding reuse of the sites, but the subject is being studied by SOGIN. The Netherlands indicated all structures have to be removed from the site to a landfill.

In the United States, clean demolished materials generally are used on site for fill except at the Maine Yankee decommissioning, where local stakeholders insisted the clean concrete be transported and disposed of out of state. The NRC does not recognise demolition of structures as a decommissioning expense (to ensure funds will not be expended that should be spent on removal of radioactivity). The public service commissions (which regulate ratepayer collections for the fund) require demolition funds to be collected to properly remove all vestiges of the structures safely.

5. Infrastructure disposition

Respondents varied on what infrastructure would be removed in the Immediate Dismantling strategy. In France, EDF reported that roads, rail sidings, barge facilities, screen houses, electrical substation and transmission lines, and subgrade piping and conduit would be removed. CEA reported the disposition would depend on the future projects planned for the site. Sweden reported infrastructure outside the site boundary is assumed to be left untouched.

The Netherlands and Slovakia reported that, under the greenfield strategy, all infrastructures will be removed. In the United States, roads, rail sidings, barge facilities, and screen houses would be removed, but the electrical substations and transmission lines would remain in service to convey power through the site and on to local communities. Subgrade piping greater than one meter below

grade would be abandoned in place. Large diameter subgrade piping would be either excavated or filled with sand/soil to prevent subsidence. In Germany, all infrastructure (e.g. roads, rail sidings, electrical sub-stations, transmission lines and water intakes) are included.

6. Strategies for procurement and overall project management

In general, respondents reported that the overall project management was performed by the owner/licensee, and subcontractors were procured to perform the actual dismantling work.

In France, EdF uses a dedicated engineering office (CIDEN), which includes the administrative and preliminary design work. On site management focuses on maintenance and operation of the remaining operational systems, and waste management. Dismantling work is done by contractors. CEA reported it is following a new European Directive 2004/18/CE dated 31 March 2004, which requires contractors be selected from a pool of companies approved and inspected by an internal CEA commission. Before approval, a company must demonstrate its technical skills in the relevant fields and prove that its quality organisation accounts for all inherent risks.

In Slovakia, at the A1 NPP damaged reactor, the first phase of decommissioning through 2008 is managed by the contractor (VUJE, a.s.) with a long-term nuclear background. The core group of owner personnel created during the first phase will develop and manage the detailed plans for the second phase. The V1 NPP is currently managed by the Project Management Unit (PMU) which involves members of the owners, and international consultants, as it is funded by EBRD. The activities for preparation of decommissioning and licensing are contracted by the PMU to subcontractors.

In Italy, project management will be performed by SOGIN, and it is discussing going to a main contractor for the primary systems, major equipment in the power plants and highly contaminated components in the research facilities.

Spain reported that it concentrates the main and specific work within a few main contractors, and distributes smaller scope works to a large number of local companies. This requires detailed task specifications and administrative control. Fixed price contracts are commonly established and used to drive overall progress. Contingency is used to cover out of scope contract work.

In the United States, the owner/licensees initially took responsibility for oversight of the project and used contractors to perform all project management and dismantling activities. However, in two major projects, problems arose with the contractors, and the utility took back all the work and self-managed the project successfully.

In Germany, a large variety of contractor arrangements exists during the planning as well as the implementation period of decommissioning. This includes the use of contractors for special planning or dismantling tasks as well as the management of the whole project by a contractor e.g. in case of small research or medical reactors.

7. Yield ratios associated with intervention techniques (i.e. choice of technologies for remote handling)

In almost all cases, the respondents indicated that the selection of manual versus remote technologies is based on a case-by-case basis. Sweden reported existing technologies are used for the estimate, and then individual owner/licensees determine the best technique for the job.

In Slovakia at the A1 NPP, remote handling activities are used because of the high activity and dose rates following the accident. Similar remote/semi-remote technologies will be used for the other NPPs.

In Italy, SOGIN has started studies for technologies for the dismantling of nuclear islands and highly contaminated components. Remote segmentation is being considered for under water cutting of reactor vessels and in-air cutting for other components.

Spain indicated it has had limited success with remote technologies, especially abrasive blasting techniques, because of the large amounts of secondary wastes generated.

In the United States, manual techniques are generally used for equipment dismantling, and Brokks (mobile articulated arms mounted with hydraulic hammers) or the equivalent are used for interior and some exterior concrete demolition. Segmentation of reactor vessel internals (and vessels) is performed with remote operated tooling, either plasma arc torches or high pressure abrasive water jet cutting. Demolition of the reactor containment buildings is now being done using controlled blasting techniques. Maine Yankee and Big Rock Point used blasting techniques for containment buildings.

In Germany, the use of existing techniques is assumed for cost estimates.

Appendix C

REVIEW OF NATIONAL APPROACHES TO COST ESTIMATION

C.1 Methodology

C.1.1 General requirements

In France, the CEA uses a phased approach in developing estimates with increasing accuracy, from an opportunity study (internal, conceptual study) at $\pm 50\%$, to feasibility design study at $\pm 30\%$, to definitive design at $\pm 15\%$, to development at $\pm 7.5\%$, to implementation at $\pm 5\%$. At each stage the estimate is refined as more detailed information becomes available. The CEA permits a choice of cost calculation methods for overall costs as well as for specific cost items (like waste canister options and for investment costs). The agency takes note of three possible estimation methods: estimate by analogy (based on experience), parametric assessments, and preliminary design studies (detailed analyses of technical decommissioning programmes). Several levels of cost assessment are permitted based on the amount of information available to the operator; costs can be successively refined. In this context, EdF chooses its own method for making cost estimates based on OECD and EU guidelines. The company acknowledges a choice of five possible approaches: bottom up, specific analogy, parametric, cost review and update, and expert opinion techniques. EdF uses a bottom up approach. EdF notes that methodological differences affect the accuracy of the estimates, which also depends on the quality of available data and rigorous quality assurance (including checks on the reasonableness of results). Cost calculations are designed to track actual decommissioning activity performance against the estimate.

Under Belgian law, ONDRAF/NIRAS can specify the information it requires from operators for the evaluation of decommissioning and waste management and disposal costs, and the adequacy of funding for these efforts. But it cannot legally specify how this material is collected, or what method individual companies must use to make their cost estimates. Given that operators may submit estimates using a range of approaches, the ONDRAF/NIRAS model has been fine-tuned to accommodate and integrate input from a range of company submissions. The model has modules to cover inventories, techniques, waste and scenarios (best estimate as well as alternatives). In Belgium, the OECD/NEA and IAEA guidelines are followed through the decommissioning management system of ONDRAF/NIRAS.

Sweden generally follows the Yellow Book Standardized List for presentation, although the actual cost calculation may be developed from a different format. Sweden provides one reference plant from which all actual plants are calculated as variants, but does not mandate any specific method for operators to calculate their estimated costs. The model used for the base case, developed over 15 years of experience, proceeds in transparent fashion from a deterministic calculation of costs to a probabilistic analysis of uncertainties and their impact on costs. In Spain, ENRESA developed reference studies for BWRs and PWRs using the “Yellow Book”, but it also uses a more specific WBS approach for estimating. Slovakia uses the “Yellow Book” incorporated into the OMEGA code. The Netherlands uses the STILLKO programme to calculate costs.

In the United States, most estimates are prepared using the AIF Guidelines (AIF/NESP-036),¹ based on a bottom-up costing analysis employing unit cost factors against a detailed inventory of equipment and structures. US regulations specify in detail how costs are to be derived for various nuclear installations and cases, and provide standardised and required worksheets for doing so. Cost estimates that vary from the prescribed approach are considered unacceptable. Estimates are to be site-specific, with costs tied to specific techniques and methods. The United States also requires a cost-benefit analysis of the decommissioning plan that results in residual radioactivity reduced to ALARA. Government facilities (former weapons facilities under DOE control) use a variety of estimating methods, essentially based on a level-of-effort approach wherein a management staff and crew are assigned to a task for a specified time.

Canada requires life-cycle planning and requires that if a work activity is difficult to cost or anticipate, that worst case scenarios be considered to assure that the cost estimate remains conservative. In the decommissioning planning phase, Canada requires licensees to consider appropriate alternative decommissioning strategies and techniques.

In the United Kingdom, estimates generally follow a level-of-effort estimating approach. The United Kingdom, like Canada, requires life cycle analysis of decommissioning and waste management costs. Regulations do not specify how operators should calculate their estimates, but the government does provide, as a sample, its own parametric cost estimation model based largely on estimates of waste inventories that would be produced by different generic reactor types. This would serve as a model of how operators might make their required cost estimates, but the regulations clearly state that alternative approaches are acceptable. The model identifies key parameters for cost calculation that could result in cost changes, and assesses their relative significance and the associated uncertainties. The regulations require that costs be distributed according to uncertainties, using, for example, a Monte Carlo method. This method uses expertise and judgment to estimate possible ranges for the model parameters and assign simple distributions to them through a series of iterations.

C.1.2 Developing the cost estimate

In France, the CEA uses three methods to assess the costs of its very diverse types of facilities, depending on whether the objective is to provide for funding or to proceed with preliminary studies before undertaking the work. The first is an Overall Estimate by Analogy, using ratios developed from experience with already completed projects and applied to the parameters (surface areas, building volumes, number of work stations, and total weight of equipment) of the facility being decommissioned. This approach is to obtain a preliminary assessment of cost and selection of the end state of the facility. It is not widely used because of the diversity of the facilities and the small number of completed projects. Parameter Assessments are performed using the ETE EVAL software developed by the CEA and AREVA NC, following a physical inventory of the facility. The code uses about twenty standard scenarios for which lists of operations have been defined. The ratios (labour hours, dose, waste produced) assigned to these operations are then applied to the parameters of the facility. Virtually all existing CEA facilities have been assessed this way for budgetary purposes. Preliminary Design Studies are used prior to initiating a decommissioning project, as they are based on the intended strategy, site-specific facility information, and organisational requirements. The costs are broken down into categories of work, subcontractor supervision (with and without the prime contractor), waste, contracting authority, and operation of the facility.

1. *Guidelines for Producing Nuclear Power Plant Decommissioning Cost Estimates*, Atomic Industrial Forum (now Nuclear Energy Institute), (AIF/NESP-036), 1986.

In Sweden, a detailed work breakdown structure (WBS) is developed and experience from other studies as well as from operations and facility modifications are applied to estimate costs. They use a probabilistic approach for estimating future costs and funding.

In Slovakia, cost estimating follows the sequence of preparation of the inventory database (in three parts – technology inventory, building inventory, and radiological parameters), preparation of the database of technical and economic parameters (unit cost factors), creating the calculation options with the OMEGA code (based on the selected strategy), optimisation of the calculations (critical path re-scheduling and resource loading), and final review and presentation of selected options.

C.1.3 Tools for estimating costs for different types of facilities

Belgium, France, the Netherlands, and Sweden all specify particular computer programmes that are used and acceptable for estimating decommissioning costs. In France, EdF reported that it uses two computer codes; one specifically developed for decommissioning using a bottom-up approach; and the second, a commercial code based on a parametric approach. Both codes are used to crosscheck the results. The CEA relies on its ETE EVAL software for internal estimates. Each room in the facility is matched to one of the standard cells built into the code, and is developed from a structured physical inventory. This methodology has its limitations in that the total cost is uncertain, it is not user-friendly (it uses a rigid Excel worksheet), some cost items are missing, and the costs are not in the standardised list format. In Belgium, the ONDRAF/NIRAS gained valuable experience from ongoing decommissioning projects on decontamination rates and on waste processing techniques, and incorporated this experience in their estimating tools.

Slovakia uses the Omega code as discussed earlier. It is a bottom-up costing approach, evaluating the costs at the level of elementary decommissioning activities in the Yellow Book standardised structure. It incorporates the management of material flow, scheduling through Microsoft Project, sensitivity analyses and management of uncertainties.

In the United States, utilities have relied on consultants' computer codes written specifically for decommissioning cost estimating, such as the code DECCER. This code is a bottom-up code using unit cost factors for estimating decontamination, removal, packaging, shipping and disposal. It also calculates management costs, undistributed costs, scrap, salvage, and contingency.

The cost estimates for dismantling, decontamination and demolition are usually estimated by the NIS-STILLKO software system. The operators/licensees of the plants collect data from decommissioning projects continuously which is used to maintain the cost data base up to date.

C.2 Quality control provisions

Accurate, verifiable and reproducible cost estimates are deemed essential by most regulators and should be a concern for managers responsible for updating decommissioning cost estimates and for implementing decommissioning plans. Consistency between estimates and actual costs is also crucial. Consistency between estimates from different companies, or from different countries may be less urgent. Quality control of estimates is also critical for assuring adequate provisioning of decommissioning activities.

C.2.1 Quality of data

The degree of accuracy of a cost estimate depends on the method used and especially on the quality of the data. Although not specifically addressed in the survey questionnaire, quality of data bears discussion here. Actual cost information should be used wherever possible, and contingencies should not be used to cover errors in the estimate. Where possible, unit cost data obtained from

previous decommissioning experience should be used. This experience should be recorded using a formal documentation process and labour costs should be reported separately from consumables. Where handbook data from handbooks is used, a careful verification process is needed to ensure that the data apply to similar relevant technologies. Use of reference facilities as a basis for cost estimates, and use of data from other decommissioning projects are valuable (even where unit costs are not available) for benchmarking estimates. Model computer codes used to process data should be updated frequently to ensure they reflect current decommissioning practice. Besides careful data collection and data preparation, there are several quality control measures available for cost estimation.

C.2.2 Best practices

Important considerations in ensuring accurate cost estimates include: methodological accuracy and consistency (e.g., recognising that year-to-year funding tends to cause cost over-runs); changes in project scope (e.g., strategy and end point); good characterisation; consistent regulatory requirements; involvement of the plant operator; the approach to setting contingency levels; and risk management. Current good practices also include the use of a standardised list of activities, a strong QA programme, use of a dedicated decommissioning core group, and involvement of regulators and stakeholders in the planning of decommissioning plans.

C.2.3 Re-estimates and multi-annual management of costs

One common and essential approach, required by virtually every country, is a periodic revision and review of estimates to reflect inflationary or escalation changes to decommissioning costs. The periodicity varies with each country and each regulator. In France, a reassessment report is required every three years from the operators to the economy and energy ministers to demonstrate the consistency between costs and funding provisions. An updating note of this report is also required every year (and an inventory of coverage assets every three months). Internal control procedures are also required for the operators, on both the cost assessment and on the financial coverage. Internally within EdF, a reassessment is initiated every time a significant change occurs within the ongoing project. In addition, data bases are updated at every new contract and parametric estimating set points are checked. This allows extrapolating increases or decreases of costs to all the ongoing projects. The CEA reported a comprehensive reassessment programme, looking at all 24 facilities in the programme. Costs are re-estimated whenever there are new data available and validated for each project.

In Belgium, re-estimates are performed every five years, taking into account changes in the facility, possible incidents, and inflation. In the case of an accident a re-estimate has to be performed before this period of five years. In Slovakia, cost estimates are reported to the regulator first at the time of the preparation of construction of the NPP, then as part of the preliminary conceptual decommissioning plan, then for the conceptual decommissioning plan (revised every ten years), and finally for the Decommissioning Plan in preparation for decommissioning (revised every five years).

In Italy, SOGIN must present an update of the cost estimate for all decommissioning plans annually, and an estimate for the next three years. The update must report what was spent in previous years and justify the expense against the old estimate. In Spain, estimates are reviewed annually with the preparation of the annual budget, and include checking of data, and feedback from other projects.

In the United States, the NRC requires the owner/licensee to estimate the minimum funding amount based on specific guidelines established for inflation of labour and energy costs, and escalation of burial costs. State public service commissions regulating regulated utilities require updates every three to five years. Unregulated merchant plant owners evaluate estimates approximately every three years to ensure they are funding decommissioning adequately.

C.2.4 Cost justification

All countries require operators to provide justification of their cost estimates and assumptions. Beyond this requirement, most countries also impose requirements on the regulator for review and validation of the accuracy of the estimated costs. Many of the requirements specifying assumptions and cost calculation methods, and submission of background calculations and

In Belgium, ONDRAF/NIRAS is required by law to review and verify the reasonableness of all cost estimates submitted. Since the government also does its own decommissioning of national sites, ONDRAF/NIRAS develops cost estimates for its own work; it uses its own models, experience, and data bases to verify the reasonableness of the cost estimates submitted. It has fine-tuned its DMS model (costs evaluation tool “*Decommissioning Management System*”) to accommodate and integrate input from a range of company submissions, and to check their credibility. Some of these are common sense checks (e.g., the contaminated weight of a material cannot exceed the weight of the material).

Canada requires licensees to consider local construction rates for labour and materials, sufficiently detailed as to demonstrate accuracy and to facilitate independent verification, and to assume that decommissioning activities would be completed by independent contractors and consultants. All cost estimates must be graded as to quality and accuracy, from Grades A to C, with A having the highest level of confidence. Criteria for grading are established by regulatory guidance with operators grading their own submissions. However, the regulator conducts a review of the submission to assure it is acceptable. Contingency requirements vary with the credibility of the estimates, with Grade A being assigned the lowest contingency at 10%.

In France, the CEA reviews operations and costs relating to decommissioning funding twice each year: once to review the method and internal control, and once to validate the exhaustiveness and genuineness of the accounts, which are also subject to external audits. The agency does not approve or disapprove the operator estimates but it can comment and prescribe corrective measures or audits. Cost calculations are designed to track actual decommissioning activity performance against the estimate, an important validation measure. The regulator reviews the decommissioning and waste disposal plans and the cost estimates to determine if all of the licensed site and activities are included, if any shared liabilities/responsibilities are properly shared, and whether all costs required by law are covered. It reviews the scope and coherence of methods applied and the viability of the funding proposal. Operators are required by regulation to devise a specific internal control process and regularly report on this process to the administrative authority. This authority can also ask for any further information, prescribe audits, or prescribe corrective measures if needed. But it does not formally approve the situation of the operators, who remain responsible for their dismantling strategies, their cost assessment and funding. Besides this administrative authority, a national financial evaluation commission (including members of Parliament) supervises the system for controlling the adequacy of the financial coverage provided by the operators for decommissioning liabilities.

In the United States, the NRC reviews the accuracy of all cost estimates and adjustment mechanisms, requiring a full explanation of how the costs were derived. The NRC is the sole arbiter of whether administrative compliance, the decommissioning plan, and the cost estimates are acceptable. Moreover, it will only validate costs after a verification that the contamination assumptions on which they are based are also reasonable, based on knowledge of the specific site.

C.2.5 Consistency and comparability

In some countries, consistency and comparability among filings is an important consideration. Differences in requirements for consistency and comparability are generally due to one of two factors: the purpose for which the information is used by the regulatory agency, and the regulatory philosophy

of the government. Different standards of accuracy and scope may apply to cost estimations made at various stages in the decommissioning process, each assessment having a different objective (e.g., assessing the adequacy of funding, planning for new facilities, or project management).

The CEA in France specifically highlights this point. It notes that it has used three different methods to assess decommissioning cost estimates, each with a different objective and degree of precision, depending, for example, on whether the objective of the cost estimates is to demonstrate adequacy of reserves for funding decommissioning, or whether it is to assess the readiness to proceed with preliminary pre-decommissioning studies.

Virtually all countries permit at least some measure of operator discretion in complying with cost estimation requirements. But most do not say whether consistency is important, nor do they describe how the regulator regularises the filings, if at all. Belgium is the only country to describe its efforts at regularising disparate data. The government uses its own DMS model to assure a measure of consistency among the cost estimates submitted. The model accommodates and integrates input from a range input data from company submissions.

The United States assures consistency by prescribing a single approach for cost estimation. The NRC requires that all guidelines must be followed exactly for cost estimates to be acceptable, stipulating nine specific conditions for acceptability (NUREG-1757, Vol. 2, Appendix A).² The US requirements are results based, as indicated by the requirement for a cost/benefit analysis of achieving ALARA, but nonetheless allow virtually no operator discretion in estimating the relevant costs.

C.3 Where estimates go wrong – Review of experience

Respondents indicated the following aspects as being most likely to cause estimates to be wrong, each of which is discussed in the ensuing sub-sections:

- Changes in scope of work and/or regulatory standards.
- Financial considerations.
- Contingency and risk management.
- Methodological differences.
- Knowledge management.
- Change in project boundaries over time.
- Legacy material and waste.
- Design change.
- Licence delay.

C.3.1 Changes in scope of work and/or regulatory standards

Reflections from a number of countries on how this issue is addressed are provided in table C.1.

2. *Consolidated Decommissioning Guidance*, US Nuclear Regulatory Commission, (NUREG-1757, Volume 2, Appendix A)

Table C.1 **Changes in scope or regulations**

Country	Experience
Belgium	A Royal Decree in 2001 ³ requires a licence for decommissioning be granted by the Federal Agency for Nuclear Control. This additional licence has affected the schedule by about two years. It has however not affected the ongoing decommissioning projects.
France	<p>EDF noted that changes in original strategy and end-point conditions represent one of the greatest factors explaining where estimates go wrong. Estimates should be living documents and changed as the scope of work changes. Project schedules are updated monthly, and changes and new contracts reviewed so that the cost estimate can be updated. Innovative changes to reduce costs are also taken into account. Safety related changes reflecting regulatory requirements could increase cost and schedule.</p> <p>The CEA set up a new organisation to provide: 1) accurate and exhaustive data and training on the methodology; 2) guidelines for physical, radiological, and waste inventories; 3) documented inventory of equipment for easy updating; 4) development of a computer programme (IDEA) to manage inventories; 5) a contractor to validate inventories; 6) plant operator involvement for validation of deliverables; and 7) traceability through meeting minutes, photos, and technical notes. New French regulations have extended project durations. Improved characterisation of inventories has shifted waste to lower-activity categories, but overall quantities have increased from the improved accuracy.</p>
Germany	The scope of work in the overall planning of the decommissioning is fixed at the outset and will be described within the licensing procedure. A change in the overall strategy during the project (whether caused by external or internal reasons) leads to increased effort in the project and the supervision process by the federal regulators. Nevertheless the roadmap and the key issues have to be fixed and calculated initially as part of the licensing process.
Italy	Italy reported that unexpected regulatory prescriptive requirements after the regulator has approved the detailed design have been the major causes of cost escalation.
Japan	<p>The funding reserve system for decommissioning of nuclear power units in Japan encompasses dismantling costs and the disposal cost of decommissioning waste. A condition for the funding reserve is to be able to estimate these costs reasonably accurately. The amount of the reserve for decommissioning of nuclear power units is reviewed each year.</p> <p>The reserve system was established in 1989, when only funds to cover decommissioning costs were accumulated. Decommissioning costs were reviewed in 1996, at which time, because cost for disposal of decommissioning waste could be reasonably estimated, these costs were added to the reserve. Revised costs, taking account of the changes in the expected quantities of waste and the cost of clearance measurement, were reflected in the reserve following the introduction of clearance as a material management option in 2008.</p>
Netherlands	The Netherlands noted that the regulations state that a facility operator may assume that future regulatory changes will be paid by the regulator.
Slovak Republic	The Slovak Republic does not anticipate extensive changes in scope to the decommissioning plans for the WWER reactors, nor for interim spent fuel storage or LLW and ILW waste disposition. The plans for the deep geological repository are in accordance with international experience. The regulatory standards for decommissioning are well defined currently, and not expected to change soon or to affect decommissioning. The A1 NPP decommissioning scope is completely different, and subject to change as new information is identified.
Spain	Spain reported that changes in scope are a highly sensitive factor, particularly regulatory or other legal requirements that cause delays.

3. *Arrêté royal du 20 juillet 2001 portant règlement général de la protection de la population, des travailleurs et de l'environnement contre le danger des rayonnements ionisants.*

Table C.1 **Changes in scope or regulations** (Cont'd)

Country	Experience
Sweden	Sweden reported they have no experience in comparing estimated costs to actual costs. They have learned that estimates should be made for an entire facility, not just for parts of it as it is easy to overlook an item or to double count.
United States	Changes in cost are highly sensitive to scope changes. Often, estimates are prepared for a baseline cost estimate and not reviewed when the project scope changes due to regulatory, stakeholder, or management changes. The estimate is viewed as being at fault, when in fact it is management's failure to update the estimate accordingly.

C.3.2 Financial considerations

Year of reported costs and NPV

In France, EdF indicated costs are reported in current (overnight) costs and adjusted for inflation or escalation to the year of expenditure. In Belgium, estimates are linked to a reference year of the decommissioning plan review (every five years). The estimates are prepared in current costs. Spain reported that this is a moderately sensitive factor. Current year costs are adjusted for inflation and a discount rate of 1.5% is applied, as is used in the General Radioactive Waste Plan calculations. The Netherlands uses net present value calculations, so data is given in current costs. Slovakia reports the estimates in current costs. In the United States, estimates are prepared in current dollars and adjusted for inflation/escalation for future expenditures and for discounted NPVs. In Germany, cost estimates are revised annually, providing a best estimate of costs based on the assumption of overnight costs.

Inflation

In France, the CEA reported that inflation and discount rate are tied together. The discount rate is based on the BT02 index adopted for cost revaluation in current Euros. The maximum discount rate is determined as the financial discount rate minus the inflation rate. To avoid revising the discount rate with fluctuations in the maximum discount rate, the actual discount rate used is 0.5% below the maximum discount rate.

In Belgium, inflation is adjusted during the five-year review of the estimates. Spain reported that inflation is a moderately sensitive factor. Since they rely on the NPV of costs and income in their funding plans, inflation plays a significant role. The Netherlands uses an average of 2% inflation rate in their calculations. Slovakia accounts for inflation in decommissioning funding operations.

In the United States, inflation is accounted for in the preparation of funding plans for presentation to the public service commissions. Inflation is also accounted for in determining the Minimum Funding Amount calculation to be submitted to the NRC every two years. Inflation for labour and energy factors are taken from the Department of Labor, and the Producer and Prices Index published monthly. Burial cost inflation (or escalation) is taken from an annual report published by the NRC on waste disposal costs at Barnwell, SC, Richland, WA and Clive, Utah. This is a moderately sensitive factor in the United States.

Escalation

Belgium reported that escalation in costs for waste processing, storage, and disposal resulted in a doubling of the tariffs for some waste categories, which can have a significant impact on the global decommissioning cost, this depending on the specifications and characteristics of the nuclear facilities.

Recent estimates by ONDRAF/NIRAS for some nuclear facilities suggest that the additional costs resulting from these new tariffs varied from 0% to 26%.

Discount rate

Belgium noted the discount rate is not a cost estimate consideration, but rather one of funding. Spain reported that the discount factor is a moderately sensitive factor, and uses the same 1.5% as is used in the General Radioactive Waste Plan calculations. The Netherlands uses a 4% discount rate. Slovakia accounts for the discount rate as part of the decommissioning funding operations. In the United States, each owner/licensee determines its own discount rate based on its experience with banking institutions and investment instruments. It can range from three to five percent.

C.3.3 Contingency and risk management

Contingency is an integral part of the cost estimate and the criteria for its calculation must be defined. Risk assessment is a probabilistic exercise that must be considered apart from the cost estimate.

Contingency

The CEA reported that France uses five levels of contingency ranging from 50% to 5%, as a function of the type of estimate. For each accounting period, the risk level is adjusted jointly with DEN/DPA with respect to the revised cost estimates for each project. In Belgium, the contingency costs are based on a reference value of 15% of the total decommissioning cost, with operators free to use (and justify) other values. Spain characterised contingency as a highly sensitive factor, using values between 15 to 25%. The Netherlands uses no contingency factors. Slovakia uses 25% for preliminary decommissioning estimates, and lowered to 20% for detailed estimates.

The United States considers contingency a highly sensitive factor. At the outset, it must be clear what the definition of contingency is relative to the adequacy of funding. One definition used in the United States clarifies that contingency is only for events that occur in the field during decommissioning, such as tool or equipment breakdown, packaging or shipping problems, multiple passes required to achieve decontamination factors, multiple cuts required to segment reactor vessel internals underwater etc. If there is a well-defined physical and radiological inventory, and a reliable unit cost factor data base, no contingency is needed for estimating error. Contingency does not include inflation influences, as all cost estimates are in nominal dollars. Other estimators include inflationary factors, etc., without properly clarifying what portion is inflation and what portion is for true contingency events. This issue has caused great confusion among regulators in the past, although more regulators have recognised the above approach in recent years. Values of individual activity contingency range from a high of 75% (cutting reactor vessel internals) to a low of 10% (project management issues), with an overall average of about 18 to 22%.

Risk management

Risk management is used to account for increases in cost beyond the defined project scope, such as extraordinary increases in waste disposal costs, inordinately high increases in labour and materials costs, new more stringent regulations for worker safety or environmental protection, or for potential accidents relating to project shutdowns for extended periods. Risk analysis provides a technique whereby managers can decide what level of assurance or confidence they want to build into a budget estimate for future expenditures. Belgium responded that risk management is not yet developed by ONDRAF/NIRAS for cost estimates, but is rather to be considered in the scope of funding. Spain reported risk management is not formally considered. The Netherlands and Slovakia reported that no

risk management is considered in decommissioning. In the United States, risk management is a highly sensitive factor, sometimes adding 25 to 50% to an estimate to ensure adequacy of funds.

C.3.4 Methodological differences

A summary of methodological differences for each of the responding countries is shown in the following table, and explained in detail in the subsequent paragraphs.

Table C.2 Methodological differences

Country	Experience
France	The CEA reported methodological differences were highly significant. Subsequently, the CEA established an organisational system founded on agreed objectives, and a single methodological framework of project management, consistent regulatory provisions, quality assurance standards, and procurement strategy. Recent experience has demonstrated very beneficial effects from this programme.
Japan	Decommissioning cost is calculated as a linear function of the weight of materials from decommissioning.
Spain	Spain responded that this is a moderately sensitive factor. Some attempts have been made to unify the Spanish cost methodology to the IAEA WBS.
United States	In the United States, this is a highly sensitive factor. In 1986, the AIF/NESP (Ref. 9) funded a study to provide guidelines for producing decommissioning cost estimates. The study report received wide peer review. The resulting product organised the estimates into consistent formats, content, and depth of detail.

In France, the CEA reported methodological differences as highly significant. Early programmes aimed at decommissioning had no consistent management direction, and projects were carried out according to the volume of available funding. Each facility performed its own estimates in whatever format and content deemed appropriate to that facility. There were no formal design reviews or clear specification requirements, which led to major changes in scenarios schedules and cost overruns. Subsequently, the CEA established an organisational system founded on agreed objectives, and a single methodological framework of project management, consistent regulatory provisions, quality assurance standards, and procurement strategy. Recent experience has demonstrated very beneficial effects from this programme.

Efforts to compare estimates to actual costs have proven very difficult in Belgium, as conservative approaches are assumed in the estimates, whereas unexpected costs can occur in the field.

Spain responded that this is a moderately sensitive factor. Some attempts have been made to unify the Spanish Cost Methodology to the IAEA WBS.

This is a highly sensitive factor in the United States. In the 1970s, there was no cost estimating guidelines available. Estimates were prepared by several different consultants and utilities, with no direction or consistency. Regulators were frustrated at trying to reconcile one estimate to another prepared by a different company. In 1986, the AIF/NESP funded a study to provide guidelines for producing decommissioning cost estimates. The study report⁴ received wide peer review. The resulting product organised the estimates into consistent formats, content, and depth of detail. It was based on a bottom-up estimating methodology using unit cost factors derived from direct industry experience. A rigorous quality assurance programme for applying the methodology is facilitated through use of the

4. Undertaken by TLG Services, Inc.

computer code DECCER to calculate costs. State and federal regulators widely embraced the methodology, and the NRC incorporated much of the methodology into its regulations.

C.3.5 Knowledge management

In France, EDF responded that knowledge management is a key issue and it has created a dedicated engineering centre to address it. It ensures maintaining the core capability to deal with all the technical issues and negotiations with the safety authorities. The large size of the EDF fleet justifies this organisation. The CEA reported that Marcoule has become the centre of expertise for decommissioning and evaluating lessons learned from experience in support of its major decommissioning operations. Its missions include reviewing and synthesising the methodological and organisational experience acquired, implementing tools for cost assessment, maintaining technical expertise of methods for tele-operation, tooling, and maintenance, and proposing development of suitable tools for decommissioning projects. An important lesson learned from the previous generation of CEA activities was the importance of determining what information should be conserved.

Belgium concurred that the staff assigned to a decommissioning project be thoroughly familiar with the facility, and the major projects in Belgium are performed by the operators themselves. Concerning future decommissioning projects, it is likely that contractors will be more involved in future work.

Spain reported this as a moderate sensitivity factor. Data generated from a variety of sources is collected and transferred for use in future projects. Decommissioning record keeping has been computerised in Spain and will be used in the José Cabrera nuclear plant project. ENRESA will integrate the developed tools into a unique system to cover the complete scope of the decommissioning project.

In Slovakia, in the case of the V1 NPP where decommissioning is funded by the EBRD and others, the change in management personnel from the original owners to subcontracted subprojects can have a significant effect.

In the United States, this is a high sensitivity issue. The recent six major decommissioning projects provided a wealth of experienced personnel for the industry. No new commercial decommissioning projects are envisioned in the near future, so many have gone on to work with the DOE on cleaning up former weapons facilities, or have travelled overseas to work in the United Kingdom on the Magnox and Sellafield decommissioning projects.

From the perspective of Germany, knowledge management offers the possibility of influencing strategically the management of future decommissioning projects and may facilitate the further development of regulatory requirements with associated reductions in supervision needs.

C.3.6 Change in project boundaries over time

Spain reported this issue is not technically considered but reviewed under a strategic point every year with the revision of the General Radioactive Waste Plan.

In Slovakia, at the V1 NPP, the change in project boundaries from the original concept of structure disposition to one metre below grade, to complete removal of all underground structures is having a significant effect on costs.

In the United States, this can be a significant issue where at certain sites, when a proper characterisation was not performed initially, leaking pools or tanks have leached into surrounding areas and extended the plant decommissioning boundary significantly. Cleanup costs have been known to

increase by factors of two to five times the original estimate. This underscores the importance of a thorough site characterisation before starting decommissioning.

In Germany, operators/licensees have to establish and operate on site interim stores or demonstrate the availability for external interim store capacities for decommissioning wastes pending the availability of appropriate waste repositories.

C.3.7 Legacy material and waste

Spain reported this is a non-sensitive factor, as in Spanish regulations the operator is obliged to manage all the operational waste (fuel included) before the transfer of ownership to ENRESA.

The Netherlands reported similar treatment of legacy wastes as transferred to COVRA upon facility shutdown. In Slovakia except for the A1 NPP damaged reactor, no legacy wastes are taken into account in decommissioning costs.

In the United States, commercial reactors treat legacy wastes in the same manner – the operator has the responsibility to dispose of them. However, at the former weapons facilities under the DOE stewardship, all legacy wastes become decommissioning wastes and must be dispositioned under the DOE cost structure.

In Germany, legacy wastes are not included in cost estimations for decommissioning of NPPs.

C.3.8 Design change

Italy reported that material quantities to be dismantled are very different from design quantities, due to the old age of the plants, rendering design documentation out of date.

C.3.9 Licence delay

Italy reported that the delay in obtaining licences from technical, safety, and local authorities had the effect of increasing costs due to inflation, delay of activities, design changes, general services, operations, and maintenance costs that continue even though no dismantling work is being undertaken.