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DEVELOPING COST ESTIMATES FOR ENVIRONMENTAL REMEDIATION PROJECTS

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA NUCLEAR ENERGY SERIES No. NW-T-3.8

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
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FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

Cost estimates in environmental remediation are developed to evaluate remedy selection decisions and waste site cleanup options or to assess environmental liabilities. The quality and, ultimately, the accuracy of the cost estimate will depend on the quality of the information available at the time it is prepared, and on the application of the appropriate cost estimation methodology.

The present publication addresses preparing and documenting cost estimates associated with key phases of the environmental remediation project life cycle. Its goal is to help the reader make informed decisions on ways to develop and document cost estimates for environmental remediation projects. To help achieve this goal, the publication presents clear procedures and includes a checklist of cost elements, examples of work breakdown structures, cost estimating plans and approaches, and an overview of potentially suitable remediation technologies.

The information included in this publication is designed to help those with varying levels of cost estimating expertise, including cost estimators, design engineers, technical support contractors, remedial project managers and programme managers.

The IAEA is grateful to all contributors to the drafting and review of this report, in particular L. Martino (United States of America). The IAEA officer responsible for this publication was H. Monken-Fernandes of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The activities addressed in this publication include the following: mining and processing ores and the close-out of associated facilities; sources of ionizing radiation/production, use, import and export; the transport of radioactive materials; site remediation; and waste management. The facilities discussed in this publication include fuel manufacturing plants; power plants and other reactors; spent fuel processing plants; radioactive waste management facilities; and nuclear and irradiation facilities for medical/industrial research. The IAEA advises that Member States establish a statutory and regulatory framework that emphasizes responsibilities for both activities and facilities mentioned above.

In some cases, past practices and accidents at even the best managed and designed current era facilities may require site remediation. Depending on the nature of the facility, remediation may involve addressing both radioactive waste and non-radioactive waste (which is often referred to as 'mixed waste' when combined). Uranium exploration, mining and processing are going on worldwide in over 30 countries; this includes both current and former suppliers as well as new prospects with established resources [1]. Currently, there are millions of tons of mixed waste produced by these activities. In the case of some Cold War era nuclear complexes, highly toxic wastes resulting from weapons production were disposed of in design deficient tanks, unlined trenches, pits, ponds and lagoons, resulting in the contamination of plant infrastructure, soil, groundwater and surface water features. The presence of mixed waste in the environment has led to concerns regarding potential negative impacts on the environment and the health, social and economic well-being of people, especially in communities located near these activities.

Environmental remediation is ongoing or planned in many international and national settings but guiding, overseeing and monitoring the remediation process is often the responsibility of local authorities.

Remediation measures not only have to ensure the safety of humans and the environment with respect to radiological and mixed waste risks, but their benefits (for individual sites and for national programmes as a whole) have to be maximized with the limited funds available. In some cases, a paradigm change is needed, which convinces the involved parties that remediation does not mean just expenditure or even loss of money but represents a strategic investment for ensuring a healthy environment for humans and ecosystems; repurposing formerly contaminated land and infrastructure; and gaining long term benefits. These benefits may or may not be easily quantifiable. However, the cost of remediation alternatives can at least be estimated so that stakeholders can easily compare and contrast the costs from among a selection of alternatives.

Remediation may or may not mean returning a site to the pristine conditions that existed before that site was developed (for example: as fuel manufacturing plants; power plants and other reactors; spent fuel processing plants; radioactive waste management facilities; and nuclear and irradiation facilities for medical/industrial research). According to section 5 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [2], "The implementation of remedial actions (remediation) does not imply the elimination of all radioactivity or all traces of radioactive substances. The optimization process may lead to extensive remediation but not necessarily to the restoration of previous conditions."

In the decision making process, the authorities responsible for managing remediation often develop several site investigation strategies and multiple remediation alternatives so that stakeholders have a choice. In general, each of the remediation alternatives has a unique cost. Cost is typically one criterion used to compare the various remediation alternatives that have been developed. As a result, the estimation of costs is a central element when developing and identifying a preferred remediation solution from among a range of feasible options. Furthermore, the cost of implementing an alternative can end up having an outsized influence on the planning process since a remediation approach used for a single site can become the exemplar approach used for other sites in a national programme. Further on in the remediation project life cycle, cost estimates tend to become more realistic as uncertainties are reduced as the project matures. This publication is dedicated to the cost estimation methodology in the various stages of environmental remediation projects.

1.2. OBJECTIVE

The present publication provides information on approaches that can be used to estimate remediation costs for all parties involved in environmental remediation, including the following:

— Implementers of environmental remediation projects;
— Regulators and permitting authorities;
— Financing sources and investors;
— Other stakeholders (e.g. the public, non-governmental organizations (NGOs)).

It addresses costs arising during the individual phases of a project, how they can be calculated, and how they can be structured. These cover not only apparent technical expenditures, but also include non-technical costs and (economic) values for associated aspects as well as achieved benefits. By combining the life cycle of remediation with its effect within an economic framework, it is possible to efficiently allocate limited funds and prioritize sites. The advantages and disadvantages of different remediation approaches, such as control versus removal, can be assessed in a more holistic way when future land use is integrated into the methodology.

Remedial action planning and operation usually span a long time frame during which site characteristics are investigated and boundary conditions for the decision making process and even the scope of the project itself may change. This puts substantial uncertainties into the economic evaluation, which is often a challenge to estimating remediation costs. However, by being able to identify and (ideally) quantify uncertainties, appropriate economic and statistical methods can be applied to integrate uncertainty into the evaluation procedure. This will ultimately facilitate both cost-optimal and reliable application of remediation. Therefore, a special goal of this publication is elucidating the different sources of uncertainty and describing how to treat them effectively in an economic context.

Remediation ideally achieves a balance between objectives such as risk reduction and the constraints set by a fixed or limited budget. A flexible and structured procedure, which can be adapted to the unique site specific conditions, is desirable for transparent reflection of different cost components and their sensitivities. This is fundamental for communication between regulators, liability owners, financing/funding sources and stakeholders. This also allows an objective comparison of a set of different remediation alternatives that would all achieve the remediation goals. Such a scenario analysis is ideally complemented by a cost based sensitivity analysis in order to identify and manage the economically sensitive factors.

The objective of this publication is then to present the steps for outlining the remediation process and effectively estimating the costs. Only if the entire process of environmental remediation is understood can meaningful cost estimates be developed and/or refined in each successive phase.

1.3. SCOPE

This publication is intended to provide information on ways to estimate and document costs. It summarizes the remediation process life cycle only to the degree that is required to understand the cost estimation process and provide a background for the general methodology used to estimate remediation costs. However, it is not a set of cost estimating tools, as the detailed mechanics of cost estimation would be country and site specific.

A fundamental background on the justification of a remedial action and its criteria for completion is laid down in GSR Part 3 [2]. IAEA Safety Standards Series No. WS-G-3.1, Remediation Process for Areas Affected by Past Activities and Accidents [3], is dedicated to the entire remediation procedure, as well as to specific aspects of planning, technology, regulation, stewardship and the post-remediation phase. The IAEA publication on non-technical factors that impact the decision making processes in environmental remediation [4] is dedicated to revealing those economic aspects of a remediation project which are not directly associated with the technology. These include employment, education, infrastructure, environmental impact, occupational hazards and public participation. In this context, methods that would aid in decision making, such as multiple criteria analysis and economic valuation, are discussed; these are demonstrated in detail in the Common Approach for Restoration of contaminated sites (CARE) project report to the European Commission on radiation protection [5]. More detailed descriptions of the remediation process are given in Ref. [3], technological options are described in Ref. [6], and insight into the practice of releasing sites from regulatory control after remediation is provided by Ref. [7].

The present publication describes the calculation of environmental remediation costs in general, but with a focus on the specifics of radioactive contamination. In fact, whereas the general approach to environmental remediation is the same for conventional and radioactive contamination, radioactive contamination has some peculiarities in the following respects:

— Site investigation and remediation technologies may be more demanding, in that radioactivity must be considered in addition to conventional contaminants. This is reflected both in time and in cost estimates. Uncertainties of timing and cost estimates are usually also higher.
— Permitting is a more complex process for the remediation of radioactively contaminated sites. It requires a broader skill set of all parties involved, it generally leads to longer time frames and it ties up more resources than conventional environmental remediation projects.
— Expectations by society and authorities are higher, and there are concerns related to radiation issues which may lead to longer time frames and costs. As concerns are often partly emotionally driven, uncertainties related to time and cost are usually higher.

1.4. STRUCTURE

This publication is structured into four sections. Section 1 provides an introduction and the background of the guide. Section 2 summarizes the remediation process and the setting of remediation objectives as a precondition to remediation planning and cost estimation. It also briefly describes the principles for policy and strategy and the interaction with regulators. Section 3 describes the steps to develop the basic cost estimate for a remedial action alternative, including alternative description, identification of cost element structure, estimation of cost elements, application of contingency, present value analysis, sensitivity analysis and review of estimates. Section 4 provides an overview of financing sources and mechanisms, including funding of long term stewardship costs, and briefly discusses specific requirements such as control and oversight of funding sources.

This publication also includes four appendices and two annexes. Appendix I concerns potential remediation options. Appendix II gives an example of a cost estimate in the planning of uranium sequestration testing. Appendix III provides an alternative in situ treatment. Appendix IV outlines a work breakdown structure (WBS) representing the sequence of activities and their implementation. Appendix V offers an overview of the costs of some remediation technologies. Annex I contains a list of terms used in a WBS, while Annex II provides a checklist of all the estimated costs associated with a remediation project.

2. THE REMEDIATION PROCESS

2.1. INTRODUCTION

Paragraph 3.1 of WS-G-3.1 [3] states:

> “The overall remediation process … involves four main activities: (a) initial site characterization and selection of remediation criteria; (b) identification of remediation options and their optimization, followed by subsequent development and approval of the remediation plan; (c) implementation of the remediation plan; and (d) post-remediation management.”

Figure 1 shows an overview of the IAEA remediation process [3]. As a corollary to the IAEA remediation process depicted in Fig. 1, the remedial investigation and feasibility study (RI/FS) process is followed for uncontrolled hazardous waste sites in the United States of America. The RI/FS process is used for sites covered under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA, also known as ‘superfund’) in the United States of America, as amended. The RI/FS process is depicted in Figs 2 and 3 [8].

2.2. REMEDIATION PROCESS STEPS

In this subsection, the elements of the flow chart in Fig. 1 are briefly described. The elements 'remediation end state' and 'options study', which are most relevant in the context of cost estimation, are elaborated in more detail in Sections 2.3 and 2.4, respectively.

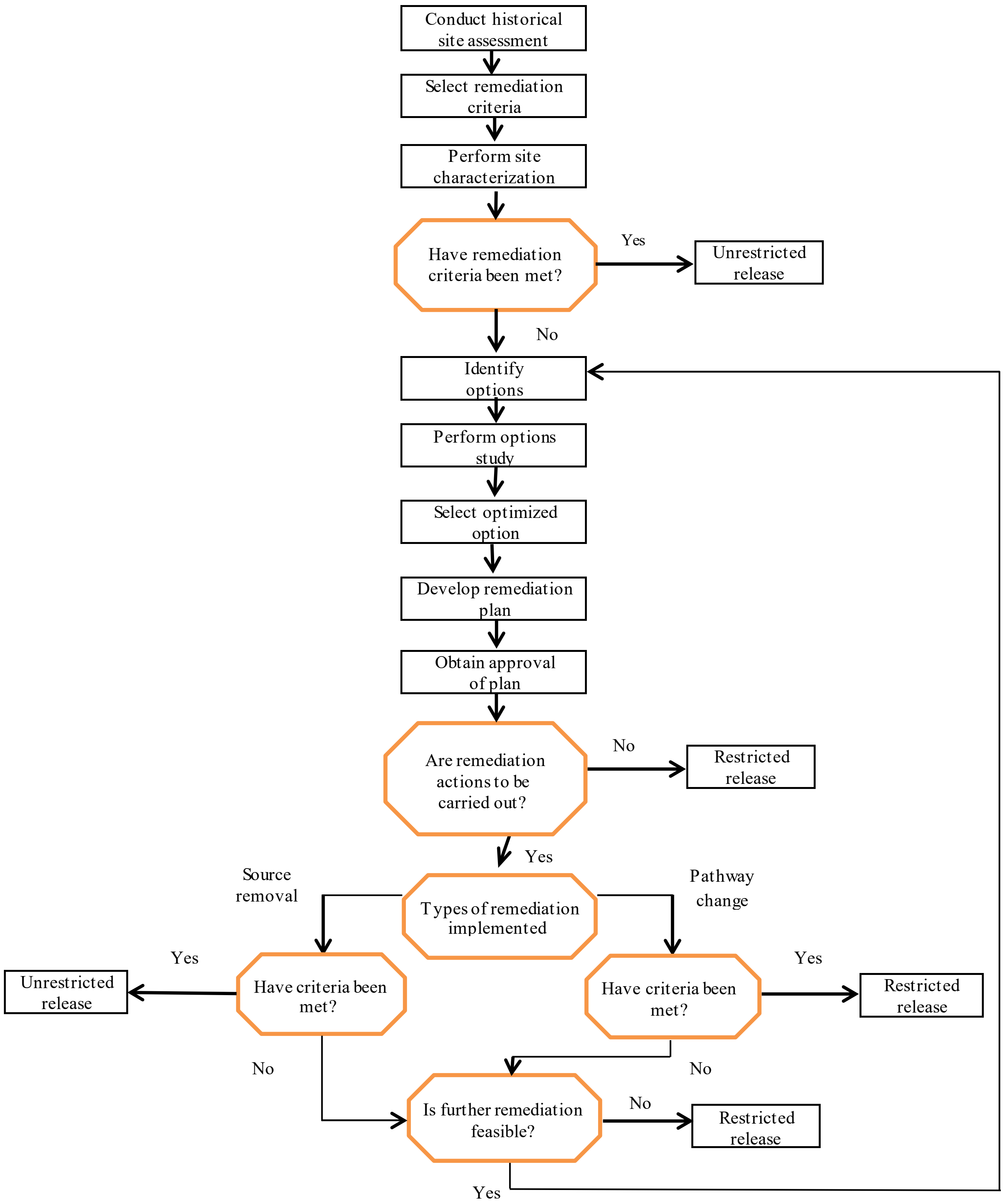

FIG. 1. *The IAEA remediation process.*

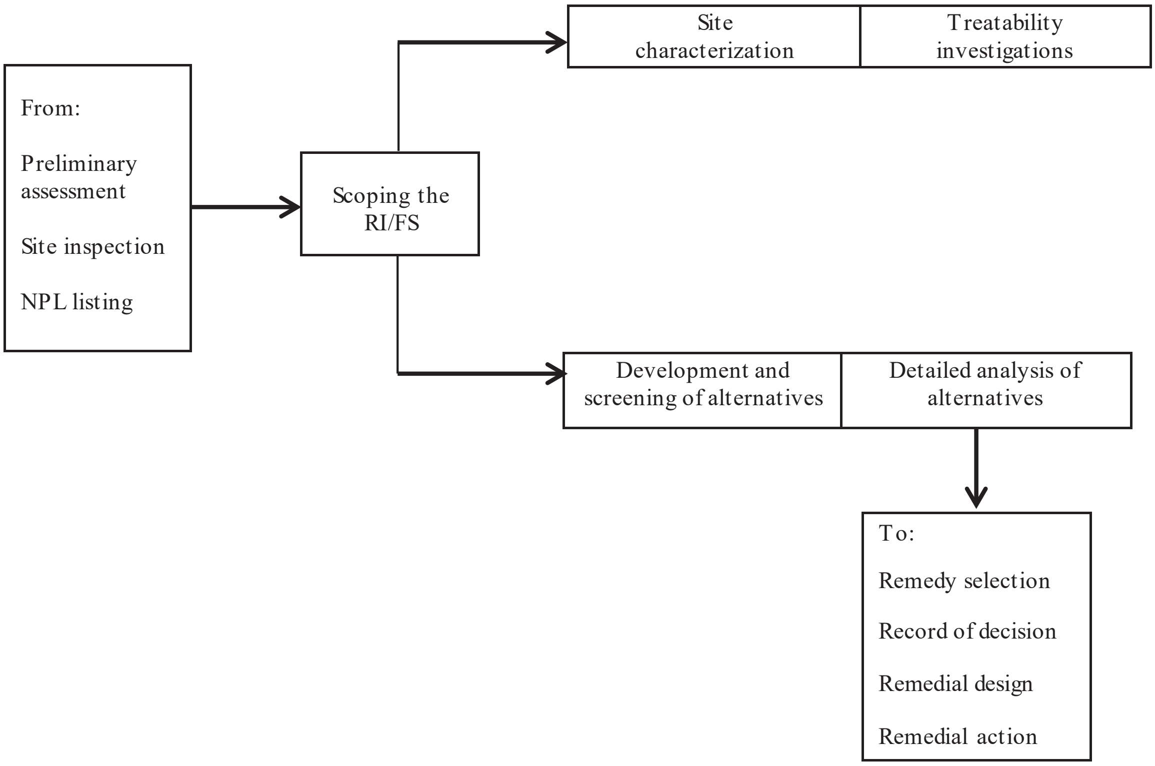

FIG. 2. General summary of the RI/FS process [8].

2.2.1. Historical site assessment

The first step of the IAEA remediation process is an assessment of the site's history. The main objectives of the historical site assessment are to identify possible sources of radiological and non-radiological contamination, to document related past activities or accidents that occurred in the area, and to provide a qualitative assessment of the potential for contaminants to be present at the site or to be migrating off-site at concentrations of concern from the human health or environmental standpoints. The preliminary assessment, a site inspection step in the RI/FS process (Figs 2 and 3), is similar to the historical site assessment step (Fig. 1).

2.2.2. Remediation criteria

Remediation criteria define the radiological and non-radiological aspects of the intended end state. Reference information on radiological contaminants can be found in GSR Part 3 [2] and other country specific regulations and guidance principles. References for non-radiological contaminants are also available in country specific regulations.

The development of remediation criteria is closely linked with the stakeholders' vision of the end state for the site, site history, contaminants present at the site and the iteration between stakeholder vision and site characterization results. Site characterization is discussed in Section 2.2.3. The development of remediation criteria is discussed in more detail in Section 2.3. The selection of remediation criteria occurs early in the IAEA cleanup process. Similarly, in the RI/FS process, remedial action objectives and applicable remediation criteria (known as applicable or relevant and appropriate requirements, or ARARs) are identified during the RI/FS scoping and site characterization steps.

2.2.3. Site characterization

In addition to the historical site assessment, a site characterization survey should be performed to collect current information and to validate the information provided in the historical site assessment. A corollary for the site characterization step in the IAEA process is the remedial investigation step in the RI/FS process. Site characterization can be a protracted and costly process involving the collection and analysis of numerous

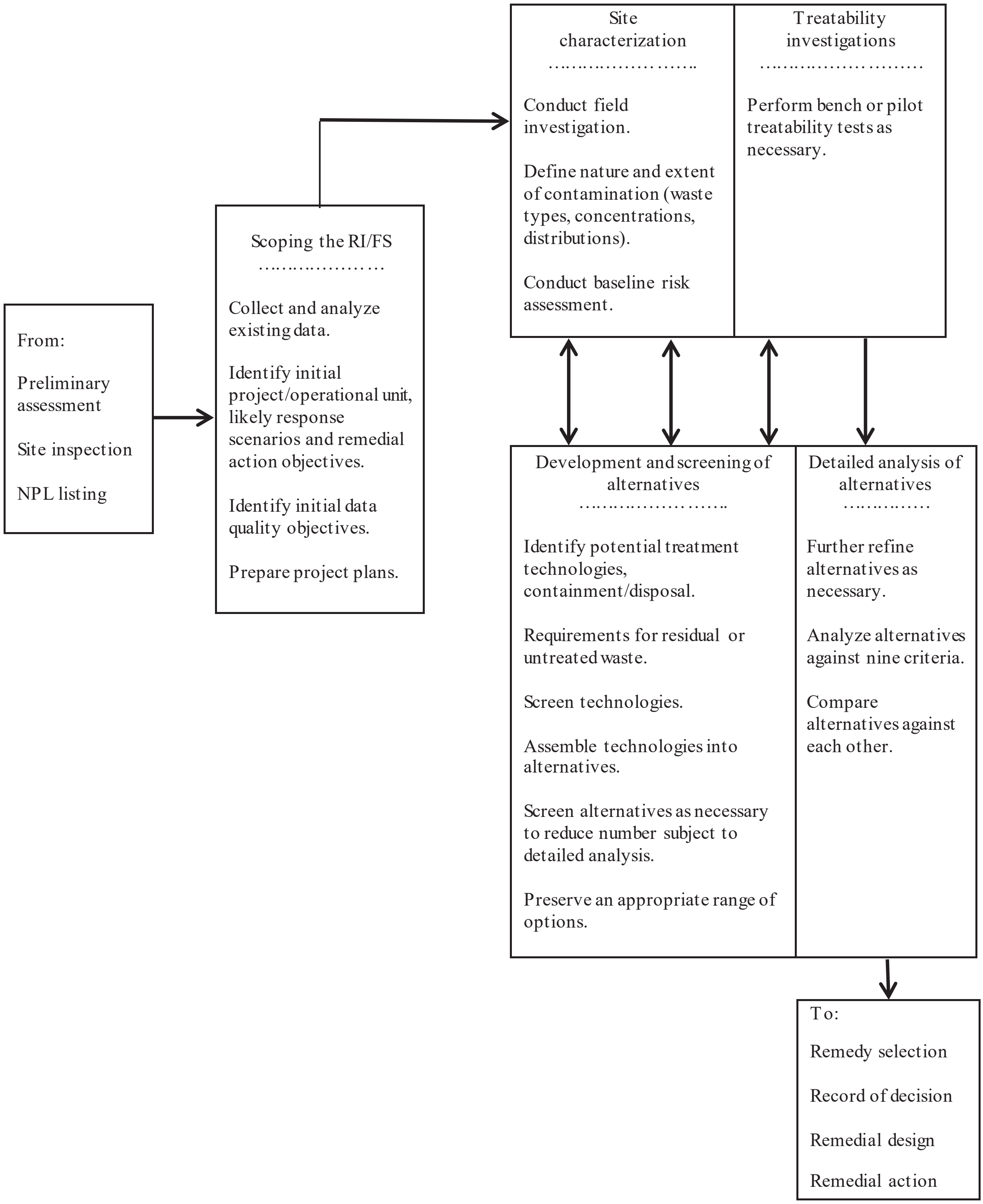

FIG. 3. Detailed summary of the RI/FS process [8].

environmental media such as soil, surface water, sediment, air and groundwater samples. Site characterization may require the preparation of detailed sampling and analysis plans linked to quality assurance plans that address every aspect of the assessment from sampling to analysis at analytical laboratories and data reduction and reporting. Site characterization can involve geophysical and geotechnical investigations as well as the sampling and analysis of all environmental media: air, soil, sediment and surface water. Site characterization may also require the installation of groundwater monitoring wells to collect information about the hydrogeology of a site. The results of the site characterization effort support the preparation of human health and ecological risk assessments and the development of possible remediation options, and inform stakeholders about what end states may be possible for the site. As a result, the site characterization results are typically reported to the regulatory body and stakeholders; they constitute a key step in the decision making process. Although the focus of this publication is on estimating costs for the remediation phase, readers need to be aware that the site characterization phase can be protracted and costly. For example, Aerojet-General Corporation incurred US $30 million in site investigation costs for a site located in Rancho Cordova, California [9].

2.2.4. Planning remediation

Under the IAEA approach, when a decision has been made to remediate a contaminated area, a remediation plan should be prepared. The first step in the development of this plan should be to determine and evaluate remediation options. These options can range from complete remediation and unrestricted release of the site to more limited remediation, with some subsequent uses of the site being restricted. Remediation should be planned with the end goal in mind. Typically, for the sake of comparison, the 'no-action' option should also be considered in the decision making process. Under the RI/FS process, possible remediation options are evaluated and screened as part of the feasibility study step depicted in Fig. 3. Remedial alternatives are developed and screened in that step. If necessary, treatability studies can be performed as part of the screening process. Typically, alternatives are screened so that a detailed analysis of alternatives need only be performed on a subset of the options originally identified. See also Section 2.4.

2.2.5. Implementation of remedial action; operations and maintenance; and the post-remediation monitoring and maintenance phases

Once the preferred option has been selected and the planning for remediation has been completed and approved, implementation of the remediation should begin within an appropriate time frame. Under the IAEA process, these steps are referred to as 'develop remediation plan", and 'type of remediation implemented'. Under the RI/FS process, these remediation planning and implementation steps are referred to as the 'record of decision', 'remedial design' and 'remedial action' phases depicted in Fig. 3. Once a decision has been made regarding which remedy should be implemented, from both a planning and cost estimating standpoint, the remediation project can be broken down into three phases: remedial action construction, operations and maintenance (O&M) and long term monitoring (LTM).

Costs associated with the remedial action construction phase are also typically referred to as 'capital costs' or 'category 1' costs, as described in Section 3.4.4.1. The following list identifies examples of the issues and cost drivers to be addressed in the remedial action phase:

— Remedial action plans, permits, licences, approvals, design documents, etc.;
— Equipment and staffing mobilization and demobilization (e.g. transporting equipment to the job site);
— Site improvements requiring pre-remedial action construction (e.g. physical security structures and staffing, sediment and erosion control, power, water and wastewater utility improvements);
— Remedial action construction (e.g. constructing a groundwater extraction system or land use restriction ordinances);
— Residual waste handling (e.g. the off-site transport of excavated wastes and investigation-derived waste);
— Site worker health and safety monitoring and oversight (e.g. worker training, radiation/chemical hazard protection monitoring);
— Construction oversight and quality control (e.g. supervision by specialized professionals, also known as professional labour management);
— Remedial action construction performance testing (e.g. testing the permeability of clay liners);
— Project management;
— Procurement and contracting fees;
— Contingency estimates (for unanticipated conditions).

2.2.6. Operations and maintenance

Once a remedial action has been implemented, it must be operated and maintained. The actions and issues associated with O&M can and should be considered a phase separate and distinct from the remedial action phase. Typically, the remedial action construction phase involves a brief expenditure of funds — for example, costs incurred over the term of the construction phase of a remedial technology. In contrast, the O&M phase typically involves issues and actions that can occur over a protracted period involving years, decades and perhaps centuries. As a result, the time value of money — that is, the way the value of money changes over time — becomes a key concept, especially when comparing remedial actions that have differing timescales. The O&M phase is often broken down into what are referred to as annually recurring costs and periodic costs (costs that occur at an interval greater than annual). These costs are also referred to as 'category 2' and 'category 3' costs as noted in Section 3.4.4.1.

The following list identifies some of the issues and cost drivers that should be addressed in the O&M phase [10]:

- Remedial technology performance monitoring (e.g. contaminant removal efficiency);
- Remedial technology discharges (e.g. to surface water or air);
- Monitoring of a subset of existing groundwater monitoring well systems;
- O&M labour (e.g. soil vapour extraction (SVE) systems);
- Parts and materials for planned equipment repair;
- Consumable materials (bulk chemicals);
- Utility requirements (e.g. power charges, discharge fees for sanitary sewers);
- Off-site transportation and disposal of treatment residuals;
- Periodic costs (those costs that typically recur at intervals more than annually, e.g. replacement and updating of remedy components);
- Maintenance of land use controls (e.g. fences, signage, institutional controls).

2.2.7. Post-remediation monitoring and management

There are several possible end points for the remediation process:

- Monitoring of environmental media (i.e. sampling of groundwater and surface water may be required to substantiate the efficacy of the remedial action);
- Unrestricted use of the area;
- Restricted and possibly controlled use of some or all parts of the area, for example, through a system of planning consents;
- Restricted access to the area with measures to enforce this.

In each case, further surveillance and monitoring may be required to confirm the long term effectiveness of the programme of remediation, and additional controls may need to be imposed on the basis of the monitoring results (see also Section 4.2). The degree, extent and duration of control, if any (ranging from monitoring and surveillance to restriction of access), should be reviewed and formalized with due consideration of the residual risk. The duration of the control must be understood to estimate future costs associated with this phase.

Like the O&M phase, the post-remediation phase can involve issues and actions over a protracted period. The following are some of the issues and cost drivers that should be addressed in the post-remediation monitoring and management phase [10]:

- Maintenance of land use controls (e.g. fencing, signage, institutional controls);
- Monitoring (i.e. sampling air, surface water and groundwater to verify the functioning of the remedy);
- Periodic reviews in the event that contaminants remain post-remediation (e.g. reviews of containment systems and monitoring systems, and of risk assessment assumptions to ensure the remedy remains protective).

2.3. REMEDIATION END STATE (REMEDIATION CRITERIA)

The end state in the context of this publication is defined as a predetermined criterion defining the point at which a specific task or process is considered completed. However, some form of long term stewardship will be required in many instances of site remediation. This definition of an end state involves residual risks that are deemed acceptable and can therefore be left in place.

2.3.1. General considerations

A clear definition of the required end state after remediation is essential, as otherwise the technical options cannot be defined to achieve this end state and hence the associated costs cannot be estimated. An ultimate goal of remediation might be the unrestricted release of an area. However, factors such as technological limitation or budgetary constraints may not allow this goal to be achieved. Judgements about permissible residual contamination levels are often driven by society's perspectives on bringing a site back into use. Evaluating residual contamination levels should be done using risk assessment methodology. Aspects of risk assessment are dealt with in Section 2.3.2.

Permissible residual contaminations will differ depending on legislation, the envisioned land use and foreseeable exposure pathways. For example, land to be sealed and earmarked for industrial use might be left with a higher residual contamination than land for residential, recreational or agricultural uses. The criteria should encompass the establishment of residual contaminant levels which give rise to radiation doses that are below regulatory guidelines for humans and are therefore considered acceptable for specified human activities.

A discussion of possible end states is provided in section 6.1 of WS-G-3.1 [3]. The definition of a desired end state of a remediated site and the optimization procedure may require several revisions. For example, if an initially defined end state is found to have significant technological challenges or requires unacceptably high costs to achieve, the end state may need to be modified to reduce the costs to acceptable amounts. Therefore, not only are remediation costs determined by the definition of the end state but, conversely, the achievable end state may depend on how the estimated cost relates to the available budget.

2.3.2. Risk assessment

Human health risk assessments should be performed to evaluate past, current and potential radiological and chemical exposures in air, soil and water. Quantitative or qualitative risk assessments are designed to protect public health, typically performed in a manner that is unlikely to underestimate the actual risk.

Risk assessments rely on scientific understanding of pollutant fate (i.e. the toxicity and life cycle of the pollutant upon release into the environment) and transport, exposure, dose and toxicity. In general terms, risk depends on the following factors:

— The amount present in an environmental medium (e.g. soil, water, air);
— The amount of exposure a person has to the pollutant in the medium;
— The toxicity of the pollutant.

Data regarding the amount of a pollutant present are obtained during the site characterization stage of the project. Using the amount (i.e. mass or activity) present along with physiochemical, fate and transport characteristics and toxicity of the substance, the potential exposure can be estimated. As these data are not always available, many risk assessments require that estimates or judgements be made regarding some data inputs or characterizations. Consequently, risk assessment results have associated uncertainties, which should be described as much as possible.

Despite these uncertainties, human health risk assessments can help to answer basic questions about potential dangers from exposure to chemicals, such as:

— What exposures pose the greatest risks?
— What are the risks of drinking water or ingesting soil contaminated with these substances?
— What are the appropriate emergency response measures?
— Should remediation of the contaminated soil or groundwater be performed?

— What limits of exposure (remediation objectives) should be established to limit human exposure to these chemical and radiological contaminants?

The first quantitative step in the risk assessment process is to perform an exposure assessment to determine the degree to which people are in contact with potentially hazardous contaminants, by which route (swallowed, inhaled or by skin contact), through which media (air, water or soil) and for how long. From the assessment, the exposure concentration is determined: the concentration of a contaminant in a medium with which a person is in contact. Ideally, exposure concentrations will be obtained for all media, locations and durations that are representative of potential human contact with a contaminant of concern.

The risk characterization step of a human health risk assessment is typically a quantitative estimate of the exposure relative to the most appropriate health based guidance value or media specific guideline value, or by calculating the excess lifetime cancer risk associated with the estimated exposure.

From this risk characterization step, the extent of remediation for both soil and groundwater can be determined. Typically, the (mass) amount of soil required to be treated, removed or stabilized is determined from this step, as well the volume of groundwater requiring remediation.

2.3.3. Stakeholder involvement in defining the end state

It is important to define the end state of a site in consultation with the affected community. Not involving the community in this process would risk using the remediated site for something which the remediation solution was not designed for, which could make it ineffective or even useless.

There are several aspects which need to be considered when defining the end state of a site. These aspects can differ significantly between remediation projects and must be considered on a site specific basis. These include the following:

— Local and regional planning aspects which may reflect a scarcity of land resources;
— Proximity to residential, agricultural or industrial areas;
— Local population's lifestyle and traditional and/or future use of similar areas;
— Socioeconomic considerations, potentially including the realization of the enhanced value of the site due to remediation;
— Time over which institutional control is expected (or can even be guaranteed) to exist;
— Societal values and preferences.

The detail involved in defining the end state may vary considerably, depending on the views of the regulators, available budget and stakeholder opinion. There are numerous tools and guidelines on how community consultation and stakeholder involvement need to take place. For example, a comprehensive toolbox is available from the International Council on Mining and Metals [11].

2.3.4. Long term stability of the end state

Another aspect to consider in the determination of the remediation end state is its long term stability. There is no authoritative information on the design period over which the end state must be guaranteed. Clearly, the timescale for which the end state is relevant will depend on the physical half-life of the radionuclides present at the site. Some national information is available, such as the US Environmental Protection Agency regulation [12]. It requires that the performance criteria be met over a minimum of 200 years, whereas the typical design life should be 1000 years. This requirement has also been adopted in the WISMUT remediation programme of radioactive mining and milling sites in Germany [13]. Another example is Romania, where a design life of at least 300 years is required for some components of closed uranium mill tailing ponds [14].

It is very important to note that cost estimates must cover the entire life cycle of a remediation project, including long term O&M and LTM costs. Long term measures may have to be carried out; this requires sufficient funds and includes:

— Operation of the selected remediation technology, such as water treatment plants;

— Monitoring of environmental media such as surface water, groundwater or air and site surveillance;
— Maintenance of the re-vegetation on covered areas;
— Corrective action, should any of the technical controls fail.

Reference [15] contains a section on surveillance of closed and remediated mining and milling sites. It lists a broad range of issues which may be relevant and can easily be adapted to other remediated sites as well.

It must be clear throughout the decision making and design process that funding for any and all long term requirements must also be secured along with the requirements for short term capital expenditures. It is important to develop an understanding of the probable time frame over which O&M costs, periodic costs and LTM and management costs will be incurred. Predictive models can be used to forecast these time periods. However, the set-up, calibration and operation of predictive models requires specialized and highly skilled staff, and an adequate database. In practice, the ownership of a site often changes after the short term remediation measures are complete. The transfer of ownership and possible responsibility for long term measures must be carefully planned. An important part of the stakeholder involvement discussed in Section 2.3.3 is to identify future owners of the remediated site and endow them with sufficient means to carry out long term measures. Appropriate funding sources for the post-remediation phase must be identified and secured, preferably with a binding commitment to make the monies available when and where they are needed. Higher administration costs may arise if a site is managed by a separate entity, and this fact needs to be taken into account in the cost planning.

In evaluating alternative options with different needs for long term funding, the preferred option should be the more robust solution with respect to a possible lack of funding.

2.4. OPTIONS STUDY

Following completion of the site wide characterization and determination of remediation objectives, the identification of potential remedial alternatives and evaluation of these alternatives begins. If, based on site characterization, the area requires remedial action, suitable remedial measures need to be identified and an options study performed to compare the benefits and detriments of these measures (Fig. 4). These options should cover a broad range of situations and be based on a set of credible exposure scenarios consistent with dose limits. Other (non-radiological) biophysical and social impacts need to be taken into consideration as well. For all the options identified, a study needs to be performed to determine the option that is best for the area. The study should factor in both justification and optimization [3].

An options study consists of two main phases which are discussed in more detail below: Section 2.4.1 on development and screening of remedial options; and Section 2.4.2 on comparison of each option that passes screening in a detailed analysis. A list of potential remedial options is provided in Appendix I.

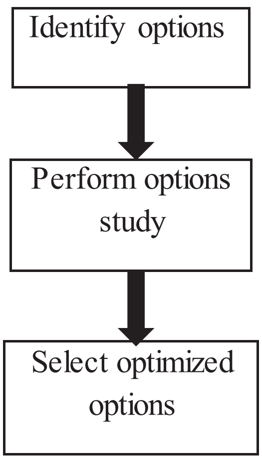

FIG. 4. Portion of the IAEA remediation process [3].

2.4.1. Options study: Remedy screening

Under the IAEA process delineated in Figs 1 and 4 for the set of options under consideration, optimization of radiological and non-radiological protection needs to be performed for the justified options, to determine the option that has the highest net benefit. On the basis of this optimization, a preferred option should be selected that also takes into account non-quantitative considerations such as social, economic and political aspects. Site specific criteria are developed which the remedial options can be compared against to reduce the number of alternatives that are carried forward into a more rigorous, detailed options analysis. A rough cost estimate may be performed at this stage in order to exclude options whose cost would clearly exceed the available budget.

During a related step in the RI/FS process, alternatives are developed and screened and for those alternatives that pass the screen, a detailed analysis of alternatives is performed, as shown in Fig. 3. As is the case with the IAEA options study, rough cost estimates are developed especially during the screening of alternatives. In the RI/FS process, alternatives are screened based upon effectiveness, implementability and cost.

2.4.2. Options study: Remedy selection (optimization)

During the remedy selection stage of the options study, a more comprehensive analysis of the remedial options is performed. The purpose of the detailed analysis of alternatives is to provide decision makers with adequate information to permit selection of an appropriate remedy for the site.

This detailed analysis enables evaluation of the options, considering the features of justification and optimization. Justification of the risk means the remedial options will be driven by estimation of the level of risk linked to the potential radiation exposure. The second feature or element is optimization, which is also known as the practice of ALARA (as low as reasonably achievable). This means that the residual radiation exposures must be reduced to the lowest possible level considering the social and economic factors.

As part of the remedy selection step, a comprehensive cost estimate for the reduced number of alternatives needs to be implemented. For the options analysis concerning cost and performance of the technological alternatives, laboratory scale treatability studies and field pilot studies can help to reduce the uncertainties.

The RI/FS process includes a similar optimization step. The subset of alternatives that pass the effectiveness, implementability and cost screen are evaluated in greater detail. Criteria used for the detailed analyses include these nine criteria:

— Protection of human health and the environment;
— Compliance with regulations;
— Long term effectiveness and permanence;
— Reduction of toxicity, mobility or volume;
— Short term effectiveness;
— Implementability;
— Cost;
— State acceptance;
— Community acceptance.

Typically, the alternatives are analysed individually against each criterion and then the alternatives are compared with each other [8].

3. THE COST ESTIMATION PROCESS

3.1. PLANNING CONSIDERATIONS

The planning process is important to the successful implementation of any project. The process of decision making, setting goals, strategies and priorities, and outlining tasks and schedules to accomplish these goals is the focus of many sources of information. Many formal decision making processes focus on strategic planning as the cornerstone of the success of a remediation programme.

Life cycle management or planning requires the consideration of broader costing concepts, including the costs required to establish and launch a project, from the initial planning phase through to the remediation and long term stewardship phases. This life cycle costing concept is key to considering all elements of required planning and associated costs.

Part of the early planning considerations is to allow for the identification of funding sources. The provision of funds for not only immediate remediation measures but long term liabilities needs to be planned at an early stage. These initial planning costs, together with the remediation cost implementation and long term stewardship costs, are estimated by calculating their present value. This cost is equivalent to the present value of the cost to be incurred until the end of the life of the remediation project (including the stewardship phase) under a life cycle costing perspective. Among the major issues facing regulators is how institutional control can be maintained over times exceeding a few decades (i.e. the question of how the 'rules' can be enforced and funding for long term measures can be ensured).

3.2. PROBLEM IDENTIFICATION AND CONCEPTUALIZATION

Each environmental restoration project starts by identifying its own unique problem followed by conceptualizing the target problem. Problems could result from many sources, including data that show increased regulatory standards; higher concentrations of waste products than normal in the environment; negative health and biological effects associated with certain emissions from the operations; and current knowledge of the inadvertent emissions and disposal practices that have the potential to contaminate the environment. All available data need to be utilized in this problem recognition phase and, if necessary, additional preliminary data may be needed to supplement the existing information.

Conceptualization follows problem identification and consists of a simple but clear picture or model of the specific problem with contamination magnitude, the required end state, consideration of remediation options, and a rough order of magnitude (ROM) cost range for the remediation. The ROM range should be based upon all available data, including applicable data and existing knowledge from similar projects. The bounding cost range needs to include consideration of the worst case scenario and project contingency.

Stakeholders need to be involved in the development of the conceptualization phase and, ideally, arrive at a consensus. This conceptualization is then used as the basis for developing the funding proposal to the appropriate funding agency. It is therefore critically important to persuade the funding agency that its investment will result in a successful execution of the project. The cost of developing the conceptualization of the project is not included in the total project cost, since it occurs prior to the approval of the project. This cost is instead included in the organization's programme cost and is most likely funded by the owner of the project or another source.

The proposal needs to focus on convincing the funding agency that: the contamination problem exists; it warrants remediation and remediation is affordable; adequate project management and controls are in place to control cost; and assurances are in place for post-remediation management of activities, as necessary.

The ability to credibly defend the conceptualization is critical to obtaining funding and a 'go' decision for the project. It is therefore imperative that maximally affordable efforts be expended in developing this phase. These efforts should not only include the study of case histories with applications to the particular project, but also the investment in obtaining additional data through further, but limited, characterization, as necessary.

However, in nations that strictly follow 'the polluter pays' principle, the polluter may have an obligation to pay for the cleanup. In this case, the polluter is the source of the funding for the project. For example, under the RI/FS process, typically the polluter performs the investigation, develops and evaluates the remedial alternatives in concert with stakeholders, and then implements the remedy. Regardless of the funding source for a remediation project, developing a robust cost estimate is essential.

3.3. OBJECTIVES AND APPROACHES FOR THE DEVELOPMENT OF COST ESTIMATES

Cost estimates need to be developed for remediation projects for three primary reasons:

(1) For budget forecasting from the standpoint of planning for the best use of finite financial resources for the remediation of a single site and for the remediation of all sites in a national cleanup portfolio;
(2) As one typical criterion of many used when evaluating and comparing remedial options;
(3) For use in evaluating vendor proposals for constructing the selected remedy once a remedial option has been selected.

These areas are considered in the following subsections.

3.3.1. Budget forecasting

The allocation of funds for specific environmental projects is based on estimates of the costs of those projects. These costs include capital, annual O&M, periodic and LTM and management labour costs, materials and other related expenses. The project budget is often broken down into specific tasks, with task budgets assigned to each. A cost estimate is used to establish a project budget. For remediation projects, there are several approaches that can be used to forecast costs, including:

- Work breakdown structure (WBS) — discussed further in Section 3.3.1.1 and in Appendix IV.
- Analogous estimating — estimating cost based on past performance or experience.
- Parametric estimating — based on cost per unit (e.g. cost per square metre, cubic metre, hectare, litre). Depending on the project, this method, which works quite well in the construction industry, can work well in an environmental remediation scenario.
- Three point estimating — also known as programme evaluation and review technique — involves developing estimates based upon most likely, likely and least likely options.
- Ranged estimates (or an optimistic, likely and pessimistic estimate).
- Expert judgement estimating — made by experts using their judgement.
- Hybrid method — a combination of the above techniques.

Some of these approaches are described below.

3.3.1.1. Work breakdown structure

A WBS can be created using a combination of bottom up and top down budgeting. Bottom up budgeting involves identifying all the constituent tasks that are involved in implementing a project and working out the resources and funding required for each task. In the case of bottom up estimating, usually, the smaller the task, the easier it is to understand and approximate costs. However, since bottom up budgeting can sometimes involve separate work groups performing specific tasks, bottom up estimating may not address issues like the critical path of a project and redundant actions. Top down budgeting may need to be combined with bottom up budgeting in order to smoothly merge the estimate from separate work groups into a coherent project estimate. A detailed discussion of the WBS approach is found in Appendix IV.

3.3.1.2. Analogous estimating

If a remediation programme is mature, there may be a history of remediation projects to draw from to inform stakeholders and decision makers about potential end states, optimal cleanup levels, remediation technologies and costs. As a result, it may be possible to draw lessons from costs that have been incurred for projects that are similar (analogous) to the project of concern. If the project of concern is similar to a completed project in the remediation portfolio of a country, analogous estimating can result in a relatively accurate estimate.

3.3.1.3. Parametric cost estimating

Parametric cost estimating can involve manually calculating costs based upon an understanding of costs involved in performing unit operations (i.e. extrapolating the costs to remove 1000 cubic metres of soil when it is known that excavation costs about US $300/m^3) or by using cost estimating models. One example of a parametric cost estimating tool is the Remedial Action Cost Engineering and Requirements (RACER) model [16]. RACER is a Windows-based, verified, validated, accredited cost estimating tool designed to provide a total cost to investigate and clean up a site. RACER has been accredited by Price-Waterhouse Coopers [17] and by the US Air Force Civil Engineer Center [18].

The RACER model is a parametric cost estimating system with two components that work in tandem: a detailed database of unit prices and an expert system that can estimate the amount and nature of work to be performed to address environmental liabilities. The user can enter site specific information that customizes generic engineering solutions and calculates the quantities of labour, equipment and materials necessary to complete the project. The work quantities and the database of unit prices are then used to calculate costs. Users can select from among 130 cost estimating modules for feasibility studies, site work, waste removal, containment, treatment and disposal. The RACER system currently can model costs for the technologies listed in Figs 5 and 6.

The technologies listed under ‘Studies’ in Fig. 6 refer to studies associated with US national cleanup programmes. They include RI/FR phases referenced in Figs 2 and 3. However, the US based studies have corollaries in the IAEA remediation process as well as in international settings. In general, the technologies fall into the following broad categories: site investigations, expedited removal actions, remedial action construction, long term operations and monitoring, and site closure.

3.3.1.4. Three point estimating

Three point estimating can be a particularly useful cost estimating approach when there is some uncertainty about an environmental remediation project (for example, uncertainty about the extent of contamination at a site and/or where stakeholders’ end state goal is uncertain). Cost engineers can develop estimates to bound the uncertainty by using criteria such as most likely, likely and least likely or pessimistic, likely and optimistic. Some examples are provided in Table 1.

3.3.2. Evaluating and comparing options

Cost estimates need to be developed for any remediation project for two reasons:

(1) In some circumstances, a budget is not estimated based on a project’s needs. Instead, the project is designed to match the available funding. Cost estimating of various project elements will allow the project manager to adjust the number of samples, type of chemical species or volume of contaminated material, with the aim of identifying the optimal acquisition of data or scope of remedial actions according to the available funding.

(2) Risk management decisions will demand the development of different remediation options and evaluation of the scenarios based on factors that include technical implementability, short and long term effectiveness, public acceptability and cost.

Options are usually compared using the above noted factors. The present value of the life cycle cost allows for the comparison of different remedial alternatives that might have different timescales on the basis of a single cost figure for each alternative. This number, called the net present value (NPV), can be seen as the amount of funding that must be set aside at the beginning of a remediation project to ensure that funds will be available for the entire duration of the project, with certain economic conditions taken into consideration. The concept of the NPV is discussed in more detail in Section 3.4.4.3.

Containment
Capping
In situ biodegradation
Permeable barriers
Slurry walls
Storage tank installation

Demolition
Demolition of buildings
Demolition of catch
Demolition of basins/manholes
Demolition of fences
Demolition of underground pipes
Demolition of sidewalks

Discharge
Discharge to POTW
Infiltration gallery
Injection wells

Disposal
Off-site transportation and waste
Residual waste management

Documentation
Administrative record
Five year review
Restoration advisory board
Site close-out documentation

Ordnance
MEC archives search report
MEC institutional controls
MEC monitoring
MEC removal action
MEC site characterization and removal assessment
MEC siting

Radioactive
D&D conduit, pipe and duct work
D&D contaminated building materials
D&D final status survey
D&D rad contaminated building
D&D removal attached hazardous materials
D&D sampling and analysis
D&D size reduction
D&D specialty process equipment
D&D surface decontamination

Remediation support
Administrative land use controls
Bulk material storage
D&D sampling and analysis
Decontamination facilities
Ground water monitoring wells
MEC institutional controls
MEC monitoring
Miscellaneous field installation
Monitoring natural attenuation
Operation and maintenance
Professional labour management
Remedial design
Remedial waste management
Treatment system building
Trenching/piping
User defined estimate

Removal
Asbestos removal
Buried drum recovery
D&D contaminated building materials
D&D surface contamination
Drum staging
Excavation
Free product removal
French drain
Ground water extraction wells
MEC siting
Residual waste management
Special well drilling and installation
Transportation
UST closure/removal

FIG. 5. RACER technologies—1 (courtesy AECOM [16]). D&D — demolition and dismantling; MEC — munitions of explosive concern; POTW — publicly owned treatment works; UST — underground storage tank.

3.3.3. Evaluating cost proposals for contract awards

Cost is one of the main elements used to evaluate proposals for a remediation project. However, one cannot rely on a cost proposal alone since there may be differences in project approach, understanding of the scope of work, the remediation project owner's exposure to liability and the contractor's work quality.

3.4. STEPS IN THE COST ESTIMATION PROCESS

3.4.1. Introduction

Before developing a comprehensive cost estimate for a project, an options study can be used to characterize the nature and extent of the risks posed by radioactive and other hazardous substances in the environment and to evaluate potential remedial options. An options study or feasibility study is based on the problem recognition and conceptualization phase discussed above and should be seen as a starting point in the development of a more elaborate cost estimate of a remediation project.

Site work and utilization Access roads Cleanup and landscaping Clear and grub Earthwork Fencing Load and haul Overhead electrical Distribution Parking lots Resurfacing roadways/parking lots Sanitary sewer Sprinkler system Storm sewer Water shortage tanks Well abandonment **Studies** Corrective measure study D&D final status survey D&D site characterization survey Feasibility study Ground water monitoring well MEC archives search report MEC site characterization and removal Assessment Monitoring Petroleum UST site assessment Preliminary assessment Professional labour management RCRA facility investigation Remedial investigation Site inspection Special well drilling and installation Disposal waste management User defined estimate	**Treatment** Advanced oxidation process Air sparging Air stripping Bioventing Carbon adsorption (gas) Carbon adsorption (liquid) Coagulation/flocculation Composting Dewatering (sludge) Ex situ bioreactors Ex situ land farming Ex situ solidification/stabilization Ex situ vapour extraction Heat enhanced vapour extraction In situ biodegradation In situ land farming In situ solidification Low level rad soil treatment Media filtration Metal precipitation Neutralization Off-site transportation and thermal treatment Oil/water separation On-site incineration On-site low temperature desorption Passive water treatment Phytoremediation Soil flushing Soil vapour extraction Soil washing Thermal and catalytic oxidation

FIG. 6. RACER technologies—2 (courtesy AECOM [16]). D&D — demolition and dismantling; MEC — munitions of explosive concern; RCRA — Resource Conservation and Recovery Act; UST — underground storage tank.

As discussed in Section 2.4, an options study and a feasibility study consist of two main phases: development and screening of remedial action alternatives and comparison of each alternative that passes screening in a detailed analysis. Different remedial action alternatives are developed during the options study and feasibility study as data are made available from the site characterization, with pilot studies assisting in reducing uncertainties related to the cost and performance of technological alternatives. In some cases, the best remedial option is immediately apparent, and a presumptive remedy can be pursued with a focus on cost optimization.

A cost estimate can be regarded as an evaluation of all the cost elements of a project as defined by an agreed upon scope. The total estimated cost of a project depends primarily on how well, or to what extent, the project is defined (i.e. ‘scope’ or completeness of design). It is clear that a change in project definition will imply a change in the project cost estimate.

As a project moves from the planning stage into the design and implementation stage, the degree of project definition increases. That allows for a more accurate cost estimate. An initial estimate of the project’s life cycle costs is made during the options study/feasibility study to select the remedial approach.

At the options study/feasibility study, the design for the remedial action project is still conceptual (i.e. the level of detail is not yet high); therefore, the cost estimate is seen as being within an ‘order of magnitude’. The cost engineer will make some assumptions about the detailed design to prepare the cost estimate. As the project is

TABLE 1. UNCERTAINTY IN COST ESTIMATES

Parameter	Impact of the site on environmental media		
	Minimal impact — An optimistic assessment	Moderate impact — A likely assessment	Significant impact — A pessimistic assessment
No. of soil samples required	x	$2x$	$10x$
No. of monitoring wells required	x	$2x$	$10x$
Depth of contaminated soil (m)	x	$2x$	$4x$
Extent of contaminated groundwater (m^3)	x	$2x$	$4x$

implemented (e.g. in the RI/FS remedial design phase), the design becomes more complete and the cost estimate becomes more definitive, and an increase in the accuracy is expected.

During the options study, cost estimates are developed for each remedial action alternative for comparison purposes. The accuracy of these estimates is connected to the quality of the site characterization data, which is a very important step in defining the scope of each individual alternative. Because the site investigation and options study cannot remove all uncertainty, no matter how good the data may be, the expected accuracy of cost estimates during the options study is smaller than that of estimates developed during later stages.

Cost estimates are developed both at the early screening and more detailed stages of RI/FS, with expected accuracy ranges of –50 to +100 per cent and –30 to +50 per cent, respectively, as shown in Fig. 7. Cost estimates developed during these two stages are further described in the following sections. Figure 7 also demonstrates that the accuracy of the cost estimate increases as the project proceeds.

After the RI/FS, a detailed cost estimate has to be produced. It generally takes the form of the following steps, which are described in more detail in Section 3.4.4:

(1) Establish planning parameters.
(2) Estimate quantities and unit costs — point estimates.
(3) Analyse life cycle.
(4) Analyse risk factors.
(5) Review and verify (performed by independent body).

3.4.2. Screening alternatives

Screening level cost estimates are used to rule out disproportionately expensive alternatives so that more appropriate ones can be retained for further consideration. Screening level cost estimates should focus on relative accuracy in order to make comparative estimates. The procedures used for this purpose are similar to those used for the detailed analysis, with the exception that alternatives are not well refined and cost components are not well developed. The screening level accuracy range is typically –50 to +100 per cent.

The basis for a screening level cost estimate can include different sources, such as cost curves, generic unit costs, vendor information, standard cost estimating guides and models, historical cost data and estimates for similar projects, as modified for the specific site. Both capital and O&M costs should be considered wherever appropriate at the screening level. As O&M costs can dominate the overall cost, especially for long time periods, an estimate of the time frame over which O&M costs are necessary should be developed.

The capital and O&M costs for many remediation technologies can be determined using a screening matrix available on a web site for the US Federal Remediation Technology Roundtable [19]. The screening matrix provides information for technologies that can be used to remediate both groundwater and soil. These technologies are

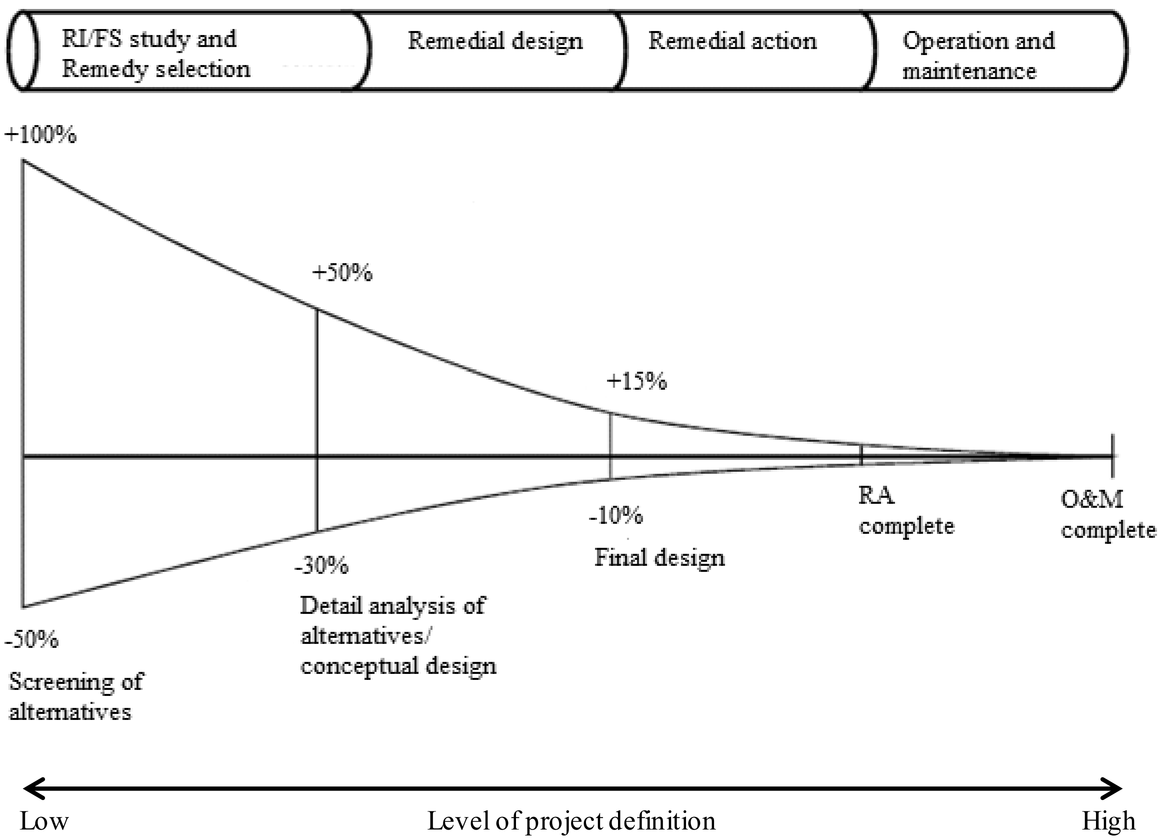

FIG. 7. Improving accuracy in cost estimate as project progress [8].

further categorized for in situ and ex situ configurations. Costs are provided for construction and operation of the technologies of ‘easy’ and ‘difficult’ sites (distinguished by differences in hydrogeologic settings). Costs are also provided for the construction and operation of the technologies for ‘small’ and ‘large’ sites (distinguished by the amount of contaminated media being remediated). Researchers need to be cautioned that this approach simplifies cost drivers that can vary significantly from site to site. As a result, a cost estimate that draws solely from the costs included in the matrix should be considered to vary by an order of magnitude. For illustrative purposes, a summary of the construction and operation costs for a number of technologies in the matrix is provided in Table 2. It should be noted that the costs in Table 2 are 2007 values.

The same source from the US Federal Remediation Technologies Roundtable [19] also reports costs (in 2007 cost values) for other technologies that might be applicable for the treatment of radionuclides or mixed waste in water. Such water treatment costs depend on flow rates, contaminant concentrations and the desired effluent target concentrations. Costs for ion exchange are reported to be US $0.08 to US $0.21/1000 L. Costs for separation/filtration are reported to be US $0.36 to US $1.20/1000 L. Costs for the treatment of water using granulated activated carbon at flow rates of 0.4 million litres per day are reported to range from US $1.70 to US $32.0/1000 L. Using this information and the information in Table 2, a project manager could research and predict costs for the construction, design and operation of many environmental remediation technologies. Costs for each of the technologies in the table are dependent upon the contamination extent; costs per unit of contaminated media are therefore provided (i.e. US $/m^3 of soil or US $/L of groundwater).

Text cont. on p. 28.

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
GW technology: Air sparging				
Contaminated volume (m^3)	841	3 899	16 821	77 989
Air sparging marked up construction cost (US $)	30 648	79 300	174 047	1 178 583
O&M cost (US $)	30 169	53 869	206 194	797 662
O&M duration (years)	2	2	5	5
Remedial design cost (US $)	10 000	10 000	19 145	94 287
Total marked up cost (US $)	70 817	143 169	399 386	2 070 532
Unit cost (US $/$m^3$)	84.20	36.72	23.74	26.55
GW technology: Chemical oxidation				
Influent flow rate (L/min)	76	76	379	379
O&M duration (years)	2	2	5	5
Chemical oxidation marked up construction cost (US $)	181 842	180 030	335 248	330 597
O&M cost (US $)	127 638	170 520	446 198	668 839
Remedial design cost (10% or US $10 000)	18 184	18 003	33 525	33 060
Total marked up construction cost (US $)	327 664	368 553	814 971	1 032 496
Amount processed (L)	79 575 840	79 575 840	994 698 000	994 698 000
Unit cost (US $/10 000 L)	41.18	46.31	8.19	10.38

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES (cont.)

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
GW technology: Ex situ air stripping — low profile tray stack				
Influent flow rate (L/min)	189	189	1 892	1 892
O&M duration (years)	2	2	5	5
Ex situ air stripping marked up construction cost (US $)	42 109	49 610	165 160	209 031
O&M cost (US $)	52 966	52 966	341 127	341 127
Remedial design cost (10% or US $10 000)	10 000	10 000	16 516	20 903
Total marked up cost (US $)	105 075	112 576	522 803	571 061
Amount treated (L)	198 939 600	198 939 600	4 973 490 000	4 973 490 000
Unit cost (US $/10 000 L)	5.28	5.66	1.05	1.15
GW technology: Ex situ air stripping — packed tower				
Influent flow rate (L/min)	189.25	189.25	1892.5	1892.5
O&M duration (years)	2	2	5	5
Ex situ air stripping marked up construction cost (US $)	56 304	105 433	124 371	301 156
O&M cost (US $)	60 346	60 346	388 942	388 942
Remedial design cost (10% or US $10 000)	6 756	11 598	13 681	30 116
Total marked up cost (US $)	123 406	177 377	526 994	720 214

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES (cont.)

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
Amount treated (L)	198 939 600	198 939 600	4 973 490 000	4973 490 000
Unit cost (US $/10 000 L)	6.08	8.98	1.06	1.32
GW technology: Passive/reactive treatment walls				
Gate length (m)	30	30	182	182
Gate width (m)	0.608	0.608	0.608	0.608
Gate depth (m)	4.56	4.56	7.60	7.60
Peat moss (m^3)	49.70	0.00	917.52	0.00
Iron fillings (m^3)	0.00	48.52	0.00	895.68
Media replacement frequency (months)	120	120	120	120
O&M duration (years)	2	2	5	5
Passive/reactive treatment walls marked up construction cost (US $)	96 889	128 843	954 942	1 526 539
O&M cost (US $)	4 885	6 813	278 475	603 659
Remedial design cost (US $)	5 813	7086	42 972	61 062
Total marked up cost (US $)	107 587	142 742	1 276 389	2 191 260
Treatment wall size (m^3)	85	85	849	849
Treatment wall cost (US $/$m^3$)	1 267	1 681	1 503	2 580
Groundwater volume treated (m^3)	520 119.15	520 119.15	13 002 978.75	13 002 978.75

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES (cont.)

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
Groundwater treatment cost (US \$/m^3)	0.21	0.27	0.10	0.17
GW technology: Phytoremediation				
Area of remediation (m^2)	12 150	12 150	243 000	243 000
Phytoremediation marked up construction cost (US \$)	43 148	67 480	556 722	1 037 020
Natural attenuation (sampling) cost (US \$)	151 541	149 886	594 330	594 330
O&M duration	n.a.	n.a.	n.a.	n.a.
Remedial design cost (US \$)	10 000	11 095	59 020	90 886
Total marked up cost (US \$)	204 689	228 461	1 210 072	1 722 236
Unit cost (US \$/m^2)	16.85	18.80	4.98	7.09
Soil technology: Soil flushing				
Subtotal cost (US \$)	34 844	57 612	91 278	134 266
Design cost (US \$)	10 000	10 000	10 953	14 769
Total marked up construction cost (US \$)	44 844	67 612	102 231	149 035
Amount processed (m^3)	1 061.3	1 061.3	4 243.5	4 243.5
Unit cost (US \$/m^3)	42.26	63.71	24.09	35.12
Soil technology: Bioventing				
Contaminated volume (m^3)	63.08	63.08	1 266.92	1 266.92

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES (cont.)

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
Bioventing marked up construction cost (US $)	16 547	18 919	41 044	76 171
O&M cost (US $)	40 237	40 237	53 954	53 954
O&M duration (years)	2	2	5	5
Remedial design cost (US $)	2 317	2 649	5 336	9 141
Total marked up cost (US $)	59 101	61 805	100 334	139 266
Unit cost (US $/$m^3$)	937	980	79	110
Soil technology: Soil vapour extraction				
Contaminated soil (m^3)	64	64	382	382
Duration (years)	2	2	2	2
O&M cost (US $)	51 689	62 094	78 404	180 087
Remedial design cost (10% or US $10 000)	10 000	10 000	10 000	17 125
SVE marked up construction cost (US $)	18 606	21 442	64 585	171 253
Total marked up cost (US $)	80 295	93 536	152 989	368 465
Unit cost (US $/$m^3$)	1 275	1 485	405	975
Soil technology: Solidification/stabilization				
Type of waste	Solid	Sludge	Solid	Sludge
Quantity of waste (m^3)	764.6	764.6	38 230	38 230

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES (cont.)

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
Time per batch (min)	20	20	20	20
Waste disposal volume (m^3)	971.0	1 022.3	48 542.2	51 117.3
Cement to waste ratio	0.15 : 1	0.40 : 1	0.15 : 1	0.40 : 1
Water to cement ratio	0.40 : 1	n.a.	0.40 : 1	n.a.
Proprietary chemicals to waste ratio	0.01 : 1	0.01 : 1	0.01 : 1	0.01 : 1
Solidification/Stabilization marked up cost (US $)	149 546	171 663	4 280 064	6 555 059
Remedial design cost — detailed on-site (US $)	16 450	18 883	342 405	458 854
Total marked up cost (US $)	165 996	190 546	4 622 469	7 013 913
Unit cost (US $/$m^3$)	216	248	124	190
Soil technology: Thermal treatment				
Contaminated soil quantity (m^3)	4 245	4 245	12 735	12 735
Subtotal cost (US $)	257 050	310 305	441 586	574 864
Design percentage	10	10	10	11
Design cost (US $)	25 705	31 031	44 159	51 738
Total marked up cost (US $)	282 755	341 336	485 745	626 602
Unit cost (US $/$m^3$)	66.70	81.09	37.93	49.70

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES (cont.)

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
Soil technology: Chemical extraction				
Quantity of material (m^3)	760	760	38 000	38 000
Treatment duration (months)	1	1	12	23
O&M duration (years)	n.a.	n.a.	n.a.	n.a.
Chemical extraction marked up cost (US $)	1 093 102	1 186 027	12 363 101	12 480 085
O&M cost (US $)	n.a.	n.a.	n.a.	n.a.
Remedial design (10% or US $10 000)	109 310	118 603	1 236 310	1 248 009
Total marked up costs (US $)	1 202 412	1 304 630	13 599 411	13 728 094
Soil technology: Incineration				
Total volume of waste material (m^3)	11 469.00	11 469.00	76 460.00	76 460.00
Moisture content (%)	20	55	20	55
Ash content (%)	78	40	78	40
Mobilization distance (km)	80	80	80	80
O&M duration (years)	n.a.	n.a.	n.a.	n.a.
O&M cost (US $)	n.a.	n.a.	n.a.	n.a.
Remedial design (3%, US $)	347 647	511 396	2 024 029	3 096 904
Incineration marked up cost (US $)	11 588 242	17 046 523	67 467 651	103 230 123

TABLE 2. COST ESTIMATES OF DIFFERENT GROUNDWATER AND SOIL REMEDIATION TECHNOLOGIES (cont.)

	Small site		Large site	
	Easy	Difficult	Easy	Difficult
Total marked up cost (US $)	11 935 889	17 557 919	69491 680	106 327 027
Unit cost (US $/m^3)	1 047	1 540	914	1 399
Soil technology: Phytoremediation				
Contaminated volume (m^3)	382.3	382.3	7 646	7 646
Phytoremediation marked up construction cost (US $)	26 181	26 181	272 226	272 226
Natural attenuation (sampling) cost (US $)	176 367	770 691	770 720	3 079 798
O&M cost (US $)	29 590	83 255	39 191	297 578
O&M duration (years)	5	20	5	20
Remedial design cost (US $)	7 344	7 554	39 709	41 888
Total marked up cost (US $)	239 482	887 681	1 121 846	3 691 490
Unit cost (US $/m^3)	626	2322	147	483

Note: All costs are given in US dollars (2007 cost values). GW — groundwater; O&M — operations and maintenance; n.a.— Not applicable.

3.4.3. Detailed analysis of alternatives

Cost estimates developed during the detailed analysis phase are then used to compare different alternatives and support the selection of remedial options. Remedial action alternative cost estimates for the detailed analysis are intended to provide a measure of total costs over time (i.e. 'life cycle costs') linked to any specific alternative. Therefore, these estimates are usually based on more refined information and should provide an enhanced level of accuracy in comparison to screening level estimates. The detailed analysis level accuracy range is typically in the order of –30 to +50 per cent.

3.4.4. Steps of the cost estimate process for the selected remedial option (final design stage)

Before starting a cost estimate exercise, a series of relevant questions needs to be addressed regarding the scope of the project. These questions can be grouped in defined steps, as shown in Fig. 8. Each of these steps asks key questions that need to be answered to complete an estimate.

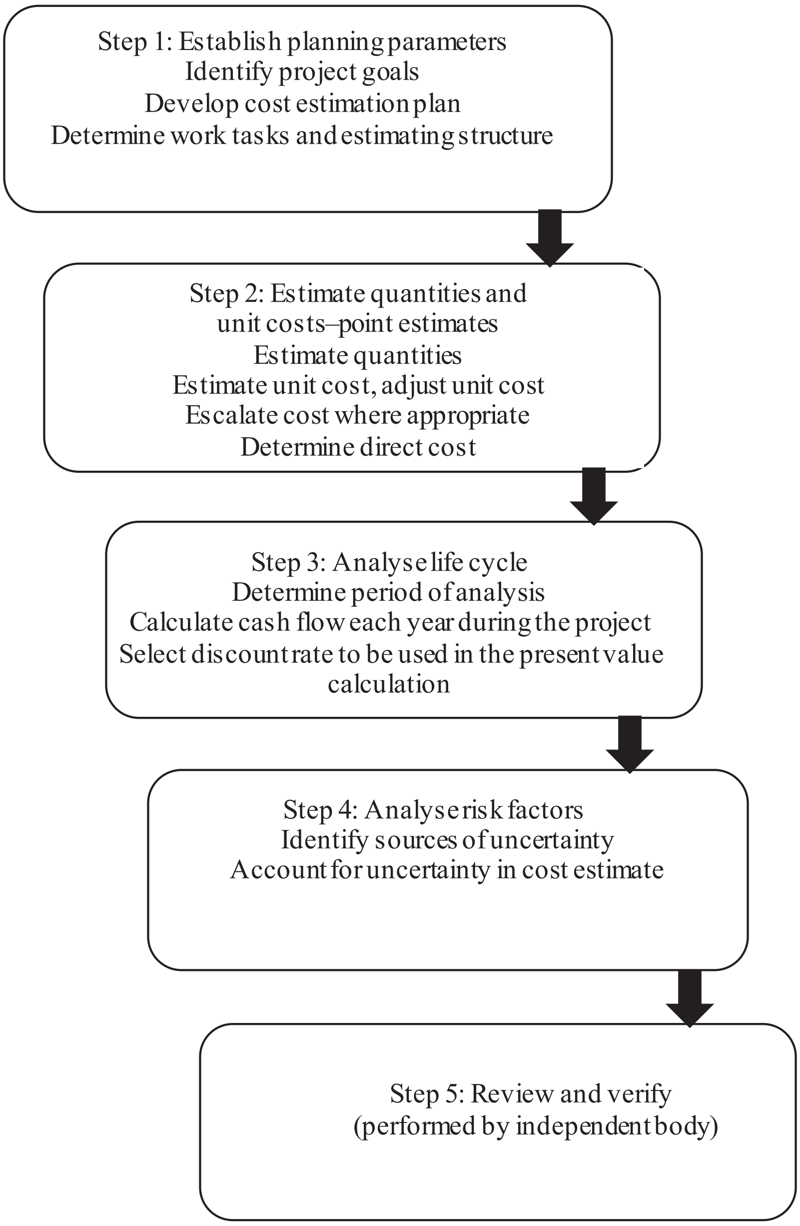

FIG. 8. Steps for the cost estimate process for the selected remedial option.

3.4.4.1. Step 1: Establishing planning parameters

The cost estimate can be considered as good as the accuracy of the scope. The initial step in completing the cost estimate is to develop a detailed project scope. One key component to an accurate scope of the project is making sure that the level of detail is sufficient for developing the cost estimate. For an accurate cost estimate of a specific project, required details include:

— Project goals;
— Cost estimate plans;
— Work tasks and estimating structure;
— Schedule of activities.

(a) Identifying project goals

The first step is identifying the goals and objectives of the project. Examples of common goals for a project include:

— Identifying the nature of the contaminant species on the site;
— Determining the extent of contamination, both horizontally and vertically (and eventually the volume of contaminated medium);
— Identifying the migration pathways, exposure pathways and potential receptors;
— Identifying site properties that affect choices of remedial options (e.g. aquifer characteristics, soil characteristics);
— Collecting data of the type and quality that can be used for cost recovery purposes;
— Protecting the health and safety of workers at the site and nearby residents/workers during the project;
— Complying with environmental regulations.

(b) Developing a cost estimating plan

Developing a good cost estimate requires established programme requirements. This includes access to detailed documentation and historical data, well trained and experienced cost analysts, a risk and uncertainty analysis, the identification of a range of confidence levels, and adequate contingency and management reserves. Cost estimates are often developed with a precise knowledge of what the final technical solution will be. Therefore, the cost assessment team must manage a great deal of risk, especially for programmes that are highly complex or on the cutting edge of technology. In order to address the uncertainties and complexities in a project, professional cost evaluators highly recommend that a cost estimating plan be developed at the beginning of the project. The plan establishes the roles, responsibilities, scope and the assumptions to be used in the cost estimate as well as the documentation, quality control and data management requirements. An example of a cost estimating plan is given in Appendix II. Appendix III provides an example of cost breakdown related to an alternative of in situ treatment involving the technique of air sparging in combination with SVE to treat soil and groundwater in the source area.

In some cases, projects may not have sufficient resources to assemble the complete project team described in Appendix II. Project managers can use historic cost data to augment their cost estimating knowledge and to account for uncertainties in the conceptualization of the remediation process. For example, parametric tools can allow a user to prepare a detailed cost estimate by selecting presumptive technologies and then entering minimal site or project specific information. Inputs could include:

— Depth to groundwater (relevant for well construction);
— Number and types of wells to be constructed (relevant for groundwater monitoring);
— Number of soil samples to be collected (relevant for site characterization);
— Analytical suite apparatus (relevant to determine the nature of site contamination);
— Volumetric extent of contamination in the vadose zone (relevant for SVE systems);
— Volume of contaminated groundwater and expected flow rate of a groundwater extraction well (relevant for a groundwater pump and treat system);

— Duration of operation (relevant for long term operational costs);
— Distance from logistics centres (relevant for staffing and equipment transportation costs).

The project specific information will then be used by the expert system in a historic cost estimating model to calculate project specific staffing requirements, equipment needs, materials and O&M costs from a database that contains current unit prices for staffing, equipment and materials. For example, in addition to providing a summary of costs such as capital costs, O&M costs and LTM costs, RACER provides a record known as a RACER assembly, which is a summary of the unit prices and requirements that serve as the basis for the costs. This assembly information can serve as an information source in the cost estimating plan which may be able to supplant expertise not otherwise available on a project team.

(c) Determining work tasks and estimating structure

Ultimately, the entire project will have to be broken down into its smallest individual components to develop an accurate cost estimate. The first step in doing this is identifying the main tasks. For the actual field activities, this will include broad items such as:

— Sample collection and analysis;
— Monitoring well installations;
— Contaminated soil excavation;
— On-site waste sources removal (e.g. drums);
— On-site treatment systems installation.

A typical way of developing a cost estimate is to develop a detailed WBS (see also Appendix IV). Every task is then broken down into its components. For the site characterization phase, this will include, but may not be limited to:

— Type and quantity of materials required to purchase;
— Professional and technical staff needed, with number of hours and hourly cost, travel grant and per diem;
— Environmental media targeted for investigation;
— Quantity of analyses for individual media, including the analytical suite, data quality needs and required turnaround times;
— Waste volumes that will be generated and their management, including disposal;
— Field equipment mobilization and demobilization (e.g. drilling equipment or mobile laboratory).

For remediation projects, the cost elements may include:

— All the elements mentioned for investigation projects;
— The area and volume of affected media involved;
— The mode of transportation and the distance to be covered in shipping residual waste to a disposal or treatment facility;
— On-site stabilization/treatment cost;
— Duration of the O&M;
— Duration of the LTM and management.

For each field activity, a variety of office based planning and analysis tasks are required, including:

— Revision of existing data, maps and reports;
— Development of work sampling, health, safety and quality assurance plans;
— Procurement of field and laboratory contractors, ranging from simple phone contacts and purchase orders to development of design specifications and bid packages;
— Acquisition and/or maintenance of field sampling and health and safety monitoring equipment;

— Data analysis activities, including contaminant mapping and modelling, data validation and risk assessment calculations;
— Attendance at all project meetings and meetings with regulators;
— Development of final reports and/or designs, including quality assurance/quality control.

(d) Determining when activities will occur

It may be appropriate to organize activities in different categories based on the time they are expected to occur. One example deals with activities that are performed at the beginning of a project during initial construction and operation. These could be separated from those activities associated with the annual O&M of a functional remedy. Similarly, periodic activities occurring in 'out years', such as equipment replacement, can also be separated from the first two categories of work. It is appropriate that activities be structured using the following three categories (discussed below), in as much detail as possible:

— Category 1: Initial activities are construction activities associated with a remedial action project. These activities include those associated with the initial design and implementation of a remedial action, but do not include those necessary to operate or maintain the remedy throughout its lifetime. The costs related to these activities are usually denominated by capital costs.
— Category 2: Annual activities are post-construction O&M activities necessary to ensure the continued effectiveness of a remedy. Costs associated with these activities are usually referred to as O&M costs.
— Category 3: Periodic activities are those that take place once every few years (e.g. remedy evaluations once in every 5 years, equipment replacement once in every 10–15 years) or only once during the entire duration of the project (e.g. site close-out, remedy failure/replacement). Costs associated with activities of this nature can be seen as either O&M costs or as new capital costs.

3.4.4.2. Step 2: Estimating quantities and unit costs (point estimates)

Now that the project activities and schedule have been determined, the extent of the various activities and their unit costs must be estimated.

(a) Estimating quantities

The estimation of quantities relates to the quality and quantity of site characterization data. The amount of soil or groundwater that must be cleaned up to achieve a cleanup goal will depend upon the data collected to determine the nature and extent of the contamination. Quantity calculations used to support a cost estimate need to be adequately documented. Information can involve chemical analysis of boring as well as logs and scaled drawings to show the lateral and vertical extent of contamination and to determine physical characteristics such as dry unit weight and porosity that affect the quantity estimate. Assumptions used to estimate quantities should be clearly presented.

Examples would be the number of areas of clearing and grubbing, monitoring wells, volume of reactive media and length of piping. Annual activities would include such things as the number of months of operations, labour for the pumping system and groundwater sampling events for site monitoring.

(b) Estimating unit costs

Costs are assigned to specific activities (initial, annual or periodic) consisting of either capital or O&M costs. Unit cost data can be selected from a variety of sources, including:

— Cost estimating guides/references;
— Vendor or contractor quotes;
— Experience with similar projects;
— Cost estimating software/databases such as RACER.

Cost estimating guides or references (e.g. unit price books) provide costs for a broad range of construction activities. These include activities related to site cleanup. Some of these guides are customized to estimate costs for environmental remediation projects. Cost data in these references are sometimes divided into equipment, labour and material categories and may or may not include contractor markups. Generally, each cost is linked with a specific labour and equipment crew and production rate. Costs are commonly provided on a national average basis for the year of publication of the reference. Quotes from construction contractors or vendors can provide values that are more site specific than the costs taken from standard guides and references. These quotes usually include contractors' markups (instead of being categorized as labour, equipment or materials) and typically provide the total cost. More than one vendor's quote should be obtained, ideally.

Quotes provided by various sources can be averaged. It is also possible to use the highest quote for the cost estimate if one suspects that the collected quotes tend to (or seem to) be at the low end of the industry range. Design related information can be obtained from vendors or contractors. Information on operating capacity, production rates, operating life and maintenance schedules that may impact O&M costs can also be obtained from these sources.

The experience obtained with similar projects, including both estimates and actual costs, can also be a source of cost data. On the other hand, engineering judgement should be practised by taking into account site or technology specific parameters if cost data from another project are considered as an indicator.

Finally, databases and cost estimating software can be used as sources of cost data. Most of the available software tools are designed to estimate the cost for selected or all cost elements of an alternative.

(c) Adjusting unit costs

Some adjustments should be made to unit cost data in case they are from different sources, to allow for their inclusion in the project cost estimate:

— Apply productivity factors per the safety and health level of protection;
— Apply area cost factors;
— Revise costs to the base year of the estimate;
— Add contractor markups.

Note that as the level of safety and health protection (e.g. monitoring requirements, personal protective equipment) increases, productivity decreases and, as a result, costs increase. Therefore, factors that reflect the decrease in productivity as a result of the increase in health and safety levels of protection should be applied to labour and equipment costs. Unit costs that are obtained from sources that are one year old or more need to be updated or revised to the base year, which is usually the current year. Seasonal variations of unit costs may be relevant. Similarly, area cost factors should be applied to unit costs from sources based on a national average (e.g. standard cost guides) or from other geographic locations (e.g. similar projects).

Contractor markups (overhead and profit), which may vary between activity costs, should be added. Markups will include overhead and profit for the prime contractor and any subcontractors. Markups should be applied to the cost of individual activities but can also be applied to the total of those activity costs if the source of cost data for each is the same. Attention is to be paid to avoid duplicating markups or applying them to costs that have already been marked up.

The source of cost data will dictate how or whether markups should be applied. A vendor or contractor quote might include overhead and profit whereas a unit price that was taken from a standard cost estimating guide might not. Costs taken from pricing guides typically will have overhead and profit added. Overhead includes two main types:

(1) General conditions (e.g. job or field office overhead);
(2) General and administrative (G&A) costs (e.g. home office overhead).

Field office overhead can include costs for office personnel and field supervision, utilities and temporary facilities, telephone and communications, licences and permits, travel and per diem, personal protective equipment, insurance, quality control, taxes and bonds. The contractor's overall cost of doing business is taken as home and field office overhead, shared by the project. The return on the contractor's investment in the project will be the profit.

(d) Escalating costs, where appropriate

If it is necessary to implement cost escalation for inflation, projects can be divided into two types:

(1) One stage, short time frame projects: This category includes investigation projects and remediation works such as soil removal (when all contamination is removed from the site). These activities are expected to last no longer than a year. Therefore, escalation of the costs of different parts of the project is not required. Here, the cost of the entire project will be escalated based on the date of the beginning of the project versus the date that the cost estimate was prepared.
(2) Multistage or very long time frame projects: These projects involve remediation projects that need a very long time (such as groundwater remediation) to accomplish the intended goals. Projects which require periodic monitoring activities over years are also included in this category. For these projects, different parts of the project need to be escalated using various escalation factors. For single cost items such as lab costs, the costs are usually valid for a certain period. The typical time period for which the costs are valid must be determined; usually this ranges from one to six months.

(e) Determining direct costs

Direct costs refer to material/equipment rental and/or purchase, professional and field technician salaries, travel, waste management (including disposal), and analysis.

Material and equipment costs typically include:

— Purchase of project planning materials (maps, reports and aerial photographs), personal protection equipment (PPE) (boots, gloves and coveralls), well materials (PVC, bentonite and pumps), sampling equipment (bailers, sample jars and decontamination fluids), monitoring equipment (e.g. pH meters), drums for waste storage and construction materials (backfill soil, capping soil, fencing and riprap).
— Rental of drilling or construction equipment, including, but not limited to, drill rigs, generators, pumps, bulldozers, graders and other earthmoving equipment, tanks for well testing, geophysical equipment and backhoes. These costs are usually given per hour, day or week, but may also be combined with cost for crews and operators.

Costs for professional and technician time typically include those for:

— Engineers, geologists and other professionals to develop project plans (work plans, health and safety plans, quality assurance plans), procure and manage field and analytical subcontractors, conduct and/or oversee field activities, provide data analysis (contaminant mapping, data validation, risk assessment, computer modelling, cost estimating and remedial alternatives analysis), provide community relations support, attend project planning and status meetings with the client and regulators, and write reports. The direct labour costs consist only of the salaries paid to personnel, typically provided on a per hour basis.
— Field technicians involved in field sampling, well installation, geophysical survey and construction activities. These costs are either shown as direct hourly costs or are combined as part of the total rental cost for equipment.

Costs for travel typically include:

— Accommodation and per diem for field personnel;
— Air travel, car rental and/or car mileage costs.

Estimating these costs depends on precise determination of the number of field personnel, rental equipment amount and types, vehicles, and the duration they will be in the field.

Costs for waste treatment and/or disposal will likely involve transportation of contaminated media off the site and the disposal of waste, contaminated PPE, well purging or development water, drill cuttings, decontamination fluids and waste materials (e.g. drums, contaminated soils and contaminated groundwater).

Off-site disposal of contaminated materials (wastes) represented the largest portion of remediation costs on several occasions. Therefore, it is extremely relevant not only to develop a reasonable estimate of these costs but to examine any applicable options for reducing them. One usual way to reduce disposal costs is to implement waste segregation. Therefore, the follow-on remedial design may include procedures during waste excavation for the sampling and segregation of hazardous waste materials from the rest of the waste. Using waste segregation throughout the implementation of a remediation project may lead to significant cost savings. Costs for sample analyses typically include:

- Analyses of environmental media, with the aim of identifying and delineating contamination during investigation. This could include samples from surface and subsurface soil, groundwater, surface water, sediment, air, biota, or waste sources.
- Analyses of waste, contaminated soils and fluids used in decontamination processes, as well as monitoring well development water and other media for hazardous waste characterization.
- Analyses of samples from the walls of an excavation and/or from soils beneath a waste source to check that the contaminated portion of the material has been removed.
- Analyses of surface or groundwater as part of LTM in place of or following a remedial action.
- Analyses of appropriate background and quality assurance/quality control (QA/QC) on samples.
- Rental or purchase of other on-site equipment for field monitoring, sampling and testing.

Costs for analysis vary widely, based on:

- Numbers of samples, which may be difficult to estimate. Numbers of background and QA/QC samples required when costing a project (typically 10% of the total sample set) should be considered.
- Suite of analyses: Costs can be limited by running only a limited suite.
- Data quality needs versus timely results: Field screening analyses which provide real time information on the presence or absence of a contaminant are usually costed per sample and are inexpensive. Mobile laboratories, which can provide full analyses in a short time, are commonly available at a daily or weekly charge. Greater precision can be obtained from fixed laboratories, but these require a longer turnaround for the regular price schedule. Quicker turnaround times on fixed lab results increase the standard cost. Expedited results are available at a significantly increased cost.

In general, analytical costs are a significant portion of the budget for site characterization and remediation projects. This cost can be lowered by reducing the number of samples, range of analyses and required QA/QC. The determination of background levels is very important for delineating the extent of the contamination. Reducing analytical costs is the most common method of lowering the costs of an investigation. These are also the most common cause of cost and schedule overruns, as additional sampling rounds are required by an investigation.

(f) Calculating indirect costs

When using a cost data source to calculate a cost estimate, it is important to understand whether the data source lists either both direct and indirect costs or just the former. The components of indirect costs to be taken into consideration for contractors are:

- Overhead: This involves the contractor’s costs for office space and other facilities, contract administration, computers, management, insurance, marketing, and other costs of staying in business.
- General administration: These costs are related to the contractor’s administrative support (e.g. accounting and contracting). G&A can consist of items ranging from taxes, depreciation, legal and conference fees, to bid and proposal expenses. These costs will be different for every company or organization.

— Procurement and handling: In most situations, contractors add a fee onto the direct cost of items or materials that are purchased for a specific job.
— Profit.

When a cost item is retrieved from a data source that only includes direct costs, the indirect costs have to be estimated and added. In some cases, a cost source does not clearly indicate if the costs are direct or are fully loaded. In those cases, one has to use judgement and make expedited comparisons to figure out known costs and thus determine whether a listed cost has been loaded or not. The difference between direct and indirect costs is explained further in the following two subsections.

(g) Including additional costs

Additional costs include technical and professional services such as project management and design. These costs can be taken as a percentage of the total cost, or itemized according to the specified activities. The following are some examples:

— Project management: Includes planning and reporting, stakeholder engagement and communication support during construction or O&M, contract or bid administration, permitting (not already provided by the construction or O&M contractor) and different legal services outside of institutional controls (e.g. licensing).
— Remedial design: Might involve the pre-design collection and analysis of field data, an engineering survey for design, a treatability study (e.g. pilot scale), and several design components, such as design analysis, plans, specifications, cost estimates and schedules at the different project phases (e.g. preliminary, intermediate and final design phases).
— Construction management: Includes review of submittals, design modifications, construction observations or oversights, engineering surveys for construction and preparation of O&M manuals, record drawings and documentation of quality control/quality assurance.
— Technical support: Includes oversight of O&M activities, update of O&M manuals and progress reporting.

(h) Accounting for revenues and partial offsets of remediation costs

In addition to estimating the costs of a remediation project, consideration has to be devoted to the economic benefits of remediation, which may help recover some of the expenses. These may include, but are not limited to, the following:

— Using buildings and infrastructure to develop alternative business activities;
— Recovering the value of metals (scrap);
— Obtaining revenues from tourist activities on a rehabilitated site;
— Recovering valuable resources from wastes (e.g. tailings, waste dumps) by means of re-processing.

However, the legal aspects and prevailing regulatory framework of these opportunities should be assessed so as not to lead to overly optimistic expectations. In addition, these opportunities must be critically evaluated on a site specific basis.

3.4.4.3. Step 3: Analysing life cycle

Environmental remediation projects generally involve both costs that are expended at the beginning of a project (e.g. initial capital costs) and costs in following years that are oriented to the implementation and maintenance of the remedial solution after the initial construction period (e.g. annual O&M costs, periodic costs).

Present value analysis is a way to aggregate expenditures that will be incurred over different time periods. This standard methodology permits cost comparisons of different remedial alternatives on the basis of a single cost figure for each of the considered alternatives. This single number, referred to as the present value, is the amount that will need to be set aside initially (the base year) to guarantee that funds will be available as they are needed, taking into consideration a set of economic conditions.

(a) Determining period of analysis

The period of analysis to be considered is essentially the period over which the present value is calculated. In general, the period of analysis should be equivalent to the project duration, resulting in a complete life cycle cost estimate for implementing the remedial alternative. The project duration generally begins with the planning, design and construction of the remediation alternative. Then it continues throughout the short and long term O&M, eventually ending with project completion and close-out. Each remedial alternative may have a different project duration.

(b) Calculating the cash flows for each year of the project

The following step in present value analysis is to add up the annual cash flows for the project. These will include initial capital costs associated with the remedial alternative, annual O&M costs for the remedial alternative over its planned life, and periodic costs for those costs that occur only once every few years. They may also include revenues from the sale of assets. Usually, most or all capital costs are incurred during the construction and startup of the project (i.e. before annual O&M begins). Despite the fact that the present value of periodic costs is small for those costs that are incurred towards the end of the project (e.g. close-out costs), these costs should be considered in the present value analysis.

Cost analyses begin with an assumption that the duration of initial construction and startup will not be longer than one year (i.e. construction work will occur in 'year zero' of the project). This 'year zero' assumption can be modified in case a preliminary project schedule has been developed and it is understood that capital construction costs will be expended beyond one year.

(c) Selecting a discount rate to use in the present value calculation

The next step is to select a discount rate (similar to an interest rate). A discount rate is used to account for the time value of money. The overall idea behind this is that a unit of currency is worth more today than it will be in the future because, if invested in an alternative use today, the money could earn a return (i.e. interest). Therefore, discounting will reflect the productivity of capital. If the capital will not be employed in a specific use, it will have a productive value in alternative uses. The discount rate also reflects the effect of price inflation.

The choice of a discount rate will be a very important decision because the selected rate directly impacts the present value of a cost estimate, which is then used in selecting a remediation option. The higher the discount rate, the lower the present value of future cash flows.

Discount rates that decline with time can also be applied. The rationale behind this choice is that uncertainty about the future growth rates can be an issue. As a result, it is possible to adopt a time declining discount, which reduces the problem of decreasing values of consequences that occur in the (distant) future. However, another approach is to rely on Office of Management and Budget (OMB) Circular No. A-94, which provides a recommended discount rate for the estimate of costs for projects with different time scales [20]. The circular provides a recommended discount rate for projects with a life cycle of 3, 5, 7, 10, 20 and 30 years. There is no absolute need to use the same discount rate for all the costs and benefits (e.g. economic and health).

(d) Calculating the net present value

The final step in the process is to calculate the NPV. The NPV of a remedial alternative represents the sum of the present values of all future expenditures associated with the project. The present value of a future payment is the actual value that will be disbursed, discounted at an appropriate rate of interest. NPV for payment C_t in year t at a discount rate of i is calculated using this formula:

$$\mathrm{NPV} = \sum_t C_t (1+i)^{-t}$$

The operand $(1 + i)^{-t}$ can be seen as a 'discount factor'. This method of NPV calculation takes into consideration that the total expenditures for a given year will occur at the beginning of that year.

TABLE 3. EXAMPLE OF A PRESENT VALUE CALCULATION FOR A REMEDIAL ALTERNATIVE

Year	Capital cost (US $)	Annual O&M costs (US $)	Periodic annual costs (US $)	Cost by year (US $)	Discount factor at 7%	Net present value cost at 7% (US $)
0	1 800 000	0	0	1 800 000	1.000	1 800 000
1	0	50 000	0	50 000	0.935	46 800
2	0	50 000	0	50 000	0.873	43 700
3	0	50 000	0	50 000	0.816	40 800
4	0	50 000	0	50 000	0.763	38 200
5	0	50 000	10 000	60 000	0.713	42 800
6	0	50 000	0	50 000	0.666	33 300
7	0	50 000	0	50 000	0.623	31 200
8	0	50 000	0	50 000	0.582	29 100
9	0	50 000	0	50 000	0.544	27 200
10	0	50 000	50 000	100 000	0.508	50 800
Total	0	500 000		2 360 000		2 183 900

Table 3 gives an example of the calculation of NPV for an alternative with construction costs of US $1 800 000 in year zero, annual O&M costs of US $50 000 for ten years, and periodic costs of US $10 000 in years five and ten and US $40 000 in year ten.

Alternatively, one can create a spreadsheet with anticipated yearly cash flows for the duration of the project and then use an embedded formula to calculate the NPV. For example, Microsoft Excel can calculate the NPV based upon annual cash flows predicted for the life cycle of a project.

Figure 9 depicts a spreadsheet summary of a project with a 31 year life cycle. The 31 year cost in current dollars is US $1 550 123. The NPV of those costs is US $938 544. As noted in the formula bar, this value was derived using the NPV formula found in Excel. In this case, the calculation is based upon a discount rate of 4.5%.

3.4.4.4. Step 4: Analysing risk factors

(a) Identifying sources of uncertainty

There are several factors that present difficulties in developing accurate cost estimates and contribute to uncertainty and risk:

— Incomplete or inaccurate project WBS;
— Regulatory uncertainty;
— Lack of reliable cost data sources;
— Delays in project planning and execution.

Clipboard	Font		Alignment	
B17	f_x= NPV(0.045,D14:AH14)			
A	B	C	D	E
			Cover over time report (With mark-ups)	
Phase	Phase name		Calendar year 1 2014	Calendar year 2 2015
Monitor 18 wells once (baseline)			US $36 624	
Monitor 10 wells 2 × S for five years				US $33 505
Monitor 7 wells 1 × S for twenty-nine year design			US $28 214	
O&M for extraction wells, stripper NPDES monitoring and periodic five year review				US $1491
Construction extraction well, install stripper			US $116 073	
Total cost			US $180 911	US $34 996
With 35% contingency			US $244 230	US $47 245
31 years total cost	US $ 1 550 123			
Present value cost	US $ 938 544 (61% of total cost)			

FIG. 9. Spreadsheet depiction of net present value calculation for a project with 31 years of costs. NPDES — national pollutant discharge elimination system; O&M — operation and maintenance; S — year.

(b) Incomplete or inaccurate project WBS

In developing an accurate cost estimate, it is key to ensure that the project WBS is accurate, detailed and completely defined. Items that are typically forgotten or otherwise misjudged include:

— Professional time to develop and write work plans, attend meetings, analyse data and write reports is underestimated.
— Site data are inaccurate or inadequate. Examples may include poor estimates of waste volumes, flow rates from mines or other field characteristics of great impact on the total cost estimate.
— Background and QA/QC samples are inadequate in number.
— Field mobilization and de-mobilization times and costs are underestimated.
— Detailed costs for PPE, sampling equipment, etc., are not accounted for.
— Full range of field decontamination issues are not accounted for (e.g. construction of a decontamination pad, decontamination time and collection, off-site disposal of decontamination water).
— Items required for site restoration after a removal action or excavation project has been completed are not accounted for.

(c) Regulatory uncertainty

Environmental remediation projects require compliance with a broad range of national, regional and local environmental regulations. Different aspects can have impacts on project costs, such as the following:

— Time required to obtain approvals and permits: This requires sufficient professional time spent to develop regulatory permit or management documents.
— Correction of defects before approval is granted: May need to change the design of some field features to account for compliance issues and/or construction of additional facilities required for compliance.
— Insufficient understanding of applicable regulations: Failing to identify and take care of compliance issues before the beginning of the project frequently delays implementation of the project and negatively affects costs.
— Ambiguously defined (or lack of) regulations and standards: Without a clear regulatory framework, implementers will never be able to ascertain whether acceptable end states have been achieved.
— Conflicting or changing responsibilities of authorities involved: Different regulators may have different perspectives on the same aspect, resulting in different (sometimes conflicting) demands.
— Insufficient understanding of the project by regulatory bodies and other permitting authorities: Without a clear understanding of the technical aspects involved in a project, regulators tend to assume a conservative attitude. This can increase the time needed for project completion and eventually incur cost overruns due to delays in project construction, completion and implementation.

(d) Lack of reliable cost data sources

This situation will unavoidably lead to difficulties in estimating the true costs of capital in the appraisal of individual projects or in comparing sets of alternative technologies to be used in the project. Failure to account adequately for inflation, price increases and increases in salary levels will affect the overall cost of the project. Unit cost data can be selected from a variety of sources, as can be seen in Table 4.

All cost data should be verified and updated so that the most recent rates are reflected and extrapolations are correctly applied with respect to scale and time.

TABLE 4. SOURCES OF UNIT COST DATA

• Cost estimating guides/references	→	Regional and seasonal variations must be considered
• Vendor or contractor quotes	→	Ensure that assumptions under which previous quotes were developed are applicable to the present project
• Experience with similar projects	→	Projects must be comparable with respect to scope and complexity
• Cost estimating software/databases	→	Databases must be applicable for the project in question, which requires understanding the types of activities and materials used, inclusion of overheads and mobilization/ demobilization costs, etc.

(e) Delays in project planning and execution

Any delays in project planning and/or execution contribute to the uncertainty of cost estimates, mainly for the following reasons:

- Expectations of stakeholders and regulators may change. A new regulator may wish to change a consensus reached earlier. It is also possible that community preferences for the remedial solution will change.
- Industrial and/or domestic wastes may be dumped on a legacy site. That would increase the amount of waste or contaminated area that needs to be dealt with.
- Contaminant plumes that were originally restricted to a relatively small area may disperse with time. As a consequence, more contaminated groundwater may need to be pumped and treated.
- New planning needs may require changing or updating designs.
- Decision, public consultation and permitting procedures may need to be re-started.

All these elements require an expeditious implementation of the necessary planning, permitting and project execution steps.

(f) Account for uncertainty in the cost estimate

There are different ways that uncertainty in a cost estimate can be accounted for. A first option involves quantitative sensitivity analysis that can be performed at the end of the estimating process. Sensitivity analysis can focus on all factors that have a relevant degree of uncertainty and only a small change in their value which could dramatically impact the overall cost of the project. Outputs of a sensitivity analysis should be documented in such a way that there is a better appreciation for the uncertainty associated with the project cost estimate.

Another factor embedding uncertainty into the environmental remediation project cost estimate is ‘contingency’ cost. Contingency is used in a cost estimate to cover unknowns, unforeseen circumstances or unanticipated conditions that cannot be evaluated from the data in hand when estimating the cost. It reduces the risk of cost overruns. A 35% contingency was used for the costs incurred for each year in the example depicted in Fig. 9. Using the 35% contingency, the remedial action cost of US $180 911 results in US $244 230. Alternatively, a probabilistic approach may be applied.

For cost estimates that have been performed in the early stages of a project’s life cycle, contingency is generally applied as a percentage of the total cost rather than individual activities or line items (although this type of analysis would certainly be possible with more data). Engineering judgement can be used in determining the contingency percentage for early cost estimates.

There are two main types of contingency: scope and bid. Scope contingency covers unknown costs that may result due to changes in the scope of a project during the design stage. Bid contingency deals with unknown costs linked with the construction or implementation of a given project scope. Scope contingency deals with project risks that are associated with an incomplete design. This type of contingency represents costs that can be taken as unforeseeable and become known as the remedial design proceeds. Therefore, scope contingency is sometimes termed ‘design’ contingency. Generally, scope contingency should decrease as design progresses and approach the value of zero per cent at the completed design stage. A low scope contingency implies that the project scope will probably undergo minimal change during design. A high scope contingency means that the project scope may change considerably between the options and final design.

3.4.4.5. Step 5: Review and verification by independent body

It is important at this point to verify calculations to ensure the assumptions made are clearly documented and nothing is missing. Questions to be raised at this point include:

- Has a clear description of the alternative been provided?
- Have the initial, annual and periodic activities of the alternative and associated capital and O&M costs been identified?
- Have quantities for activities been estimated with sufficient backup?

— Have unit costs for activities been estimated with sufficient backup?
— Has contingency been applied to the total of initial, annual and periodic activities costs?
— Have other costs been added appropriately?
— Were guidelines followed for the NPV analysis?
— Is there sufficient uncertainty for key factors to warrant a sensitivity analysis? If a sensitivity analysis was done, are results presented clearly in terms of NPV of the alternative?

As soon as the review and verification stage is concluded, a summary of the complete estimate can be given.

3.4.5. Cost checklist

Checklists are used to assist in the evaluation of capital and O&M costs for each remedial action alternative. They are also used to reduce the possible exclusion of important cost elements. A cost estimate generally will be more 'complete' if one can account for as many cost elements as possible, even though uncertainty may remain about their quantity or unit cost. Checklists also allow for consistency between estimates. Examples of checklists are provided in Appendix III for capital, annual O&M and periodic cost elements, respectively. The checklists are designed to be flexible and, by design, do not follow any standard WBS or numbering system. The checklists are not all-inclusive and, therefore, the listed cost elements should not be assumed to apply to every remedial action alternative. Rather, the checklists can be used to identify applicable cost elements, which can then be added to or modified as needed.

3.4.6. Documenting the cost estimate

It is important for the project team to document the cost estimate as it evolves over the life cycle of the project. The way a cost estimate for a project is documented and presented to stakeholders will depend on the specific needs of the project and the transparency expected/required by the stakeholders. Completed cost checklists or a summary of content in the WBS are approaches that can be used to document the cost estimate. Regardless of how documentation is accomplished, steps 1 to 5, as depicted in Fig. 8, need to be recorded and made available for easy review and communication to stakeholders.

4. FUNDING

4.1. FINANCING SOURCES FOR ENVIRONMENTAL REMEDIATION PROJECTS

The sources of financing for environmental remediation projects are varied and depend on the size, scope and location of the specific project. They include, but may not be limited to:

— Governments;
— International financial institutions (IFIs);
— Funds set up by operators for environmental remediation;
— Trust funds set up by operators but administrated by independent trustees or government agencies;
— Responsible parties.

The government of the country where the project is sited is likely to play a major role in financing the environmental remediation project as the manager of the project and a major contributor to the remediation. Governments can finance environmental projects using a variety of methods. Governments can raise funds through the imposition of targeted taxes, fees or royalty charges on activities in a specific industry. Some governments can tap environmental trust funds created specifically to finance environmental remediation projects. Governments may also levy fines for violation of environmental laws or recover funds through litigation against operators responsible for environmental malfeasance. Governments may also be able to obtain funding from insurance policies, bonds or letters of credit posted for remediation of the site.

IFIs such as the World Bank and the regional international development banks are other sources of finance. Additional sources of funding include foreign aid from other countries, private bank lending and funds from NGOs or individuals.

Because the mission of these IFIs is to stimulate development and improve the standard of living in various countries, they are primary sources of funding for such projects, particularly if there is a significant risk that the project loan will not be repaid in full. IFIs often impose rigorous funding requirements and rules for the operation of an environmental remediation project before providing funding. Moreover, other financing sources may use the IFIs to monitor the disbursement of finance to a particular environmental remediation project to which both the IFI and other financing sources are providing funding.

An option to provide seed funding for starting environmental projects and conducting preliminary assessments, as well as additional funding during the engineering phase of a project, is through international governmental organizations and NGOs.

4.2. FINANCING FOR LONG TERM STEWARDSHIP COSTS

The scope of remediation for some projects will require LTM and stewardship of the site. Long term remediation activities require adequate funding; otherwise, there is a risk that the environmental gains made in completing the primary portion of the remediation project could be reversed. Depending on the project, the long term stewardship costs could be significant, particularly if costs are high for open-ended activities (e.g. pumping and treating large volumes of water over an extended period). It is vital that the entity supervising the environmental remediation project consider the sources of funding for future stewardship costs early on in the planning process as access to long term funding may have an effect on selecting an appropriate remediation strategy, given the availability of funds.

IFIs and NGOs may be willing to provide long term financing commitments for stewardship costs; however, they are generally leery of making open-ended long term financing commitments that could run over decades. The national and local governmental entities where a project is located are therefore the most likely sources of funding for long term stewardship costs.

4.3. EXTERNAL OVERSIGHT FROM FINANCING SOURCES

When international, governmental or non-governmental entities provide financing for environmental remediation projects, it is standard practice for them to require external oversight of the project to ensure that the funding is being used to further project goals and is not diverted or squandered. In addition to external oversight of a project's financial matters, a financing source may impose additional obligations as a condition for providing funds to the environmental remediation project. Most environmental remediation projects with funding from the national or local government where the project is located will be subject to the financial controls and oversight unique to the institutions of that country.

4.4. PROJECT BENCHMARKING BY FUNDING SOURCES

Benchmarking is the process of comparing a project's process and performance metrics — both qualitatively and quantitatively — to best practices from the same or similar industries. For environmental remediation projects, benchmarking typically focuses on the costs, schedule and quality of work performed on a project compared with other similar projects (the 'peer group'), as defined for the benchmarking exercise. Lenders or other financing sources typically use benchmarking to ensure that a project is performing according to the plan specified for that particular project and will compare a particular project against others in the peer group.

Appendix I

POTENTIAL REMEDIATION OPTIONS

The list of remedial options in Table 5 depicts potentially applicable technologies for a remediation project. These are grouped by chemical, physical, thermal and biological treatment, and are applicable for either soil or groundwater remediation. The contaminants that can be addressed by a specific technology are also specified.

TABLE 5. POTENTIAL REMEDIATION OPTIONS

Treatment type	Technology	Medium	Contaminant	Brief characterization
Chemical	In situ solidification	Soil, sludge	Radionuclides, heavy metals	Aims to lower the mobility of contaminants by injecting binding materials (cement, supersaturated salt solutions with controlled precipitation, or organic or inorganic polymers) that react with the contaminant, the water and/or the soil to produce a low solubility solid.
	Ex situ solidification	Soil, sludge	Radionuclides, heavy metals, (organic compounds)	A low solubility solid is produced from the contaminated soil, etc., by mixing it with a reactive binder (cement, gypsum, or organic or inorganic polymers). The solid material may be disposed of in situ or at a designated repository.
	Ex situ chemical treatment	Groundwater	Radionuclides, heavy metals, (organic compounds)	Ion exchange, precipitation, reverse osmosis, etc., are applied to concentrate contaminants for further conditioning.
	Reactive barriers	Groundwater	Compounds, heavy metals, radionuclides	In situ method of funnelling the natural or enhanced groundwater flow through a physical barrier containing reactive chemicals (for oxidation or precipitation), metal catalysts (for redox reactions), bacteria (for biodegradation) or adsorbents.
	In situ chemical oxidation	Soil, groundwater	Organic compounds (heavy metals, radionuclides)	The injection of ozone (O_3), hydrogen peroxide (H_2O_2) or chlorine compounds induces a redox reaction that chemically converts contaminants into less toxic compounds. This may reduce the mobility of contaminants throughout a plume.
Physical	Excavation	Soil, sludge	All types	Contaminated materials are removed from the site and transferred to a designated disposal site. Conditioning may be required before disposal.
	Pump and treat	Groundwater	All types	Groundwater is pumped to the surface and treated by a variety of methods. The efficiency depends on the type of contaminant and concentrations.
	Funnel-and-gate systems	Groundwater	All types	The pump and treat methods and reactive barriers can be improved by constructing impervious walls and/or funnelling the water flow towards the well or the reactive barrier.

TABLE 5. POTENTIAL REMEDIATION OPTIONS (cont.)

Treatment type	Technology	Medium	Contaminant	Brief characterization
	Isolation	Soil	All types	Installation of physical barriers such as slurry walls or sheet piling to prevent movement of contaminants.
	Physical segregation	Soil	Radionuclides, heavy metals	Often contaminants (including radionuclides) adsorb to fine grain sized fractions in the soil. Size fractionation by sieving or flotation thus may result in a much smaller volume of contaminated material to be treated.
	In situ soil washing	Soil	All types	Consists of flushing contaminated materials in situ. Entails the injection and extraction of acidic or basic solutions with added surfactants, chelates, etc., to dissolve, desorb and remove contaminants.
	Ex situ soil washing	Soil	All types	This ex situ technique uses pH-controlled solutions with the addition of acid or base, surfactants or chelates to dissolve, desorb and remove contaminants. Organic solvents may be used for organic contaminants. Preceding size fractionation improves the efficiency and reduces the volumes of material to be treated.
	Ex situ filtration	Groundwater	Radionuclides, heavy metals	Contaminated groundwater or surface water is passed through a filter column to remove contaminated suspended solids. The resulting filter cake requires further treatment and disposal.
Thermal	Vitrification	Soil, sludge	Radionuclides, heavy metals	The contaminated material is mixed with glass-forming constituents and fluxes to give solid glass blocks or slag-like products.
	In situ vitrification	Soil, sludge	Radionuclides, heavy metals	Soil is vitrified in situ to immobilize contaminants by applying electrical resistance or inductive melting.
Biological	Biosorption	Surface water and groundwater	Radionuclides, heavy metals	Certain microorganisms take up metal ions in their cell walls or on their surface, a process that can be used to concentrate these contaminants. Plants can be designed as bioreactors or sewage treatment plants (organic stationary phase).
	Constructed wetlands	Surface water and groundwater	Radionuclides, heavy metals	Contaminated waters are routed into artificial ‘swamps’, where the metals are taken up by plant tissue. The plants are harvested and incinerated. The resulting ashes are disposed of.

Appendix II

EXAMPLE COST ESTIMATE DEVELOPMENT PLAN

II.1. EXAMPLE COST ESTIMATE DEVELOPMENT PLAN FOR URANIUM SEQUESTRATION TESTING

II.1.1. Purpose of the estimate

This plan outlines the work needed to produce an estimate for the testing of uranium sequestration using drip-system infiltration of phosphate solutions from the ground's surface and well injection into the deeper vadose zone. Phosphate solutions have been demonstrated to reduce the solubility, and consequently the mobility, of uranium in the vadose zone and groundwater during earlier, smaller scale testing at the site. Should testing demonstrate that this methodology is effective at reducing the leachability of uranium then the necessary risk reductions could be achieved at a significant cost savings over traditional 'dig and haul' methods.

The estimate will include design, construction, startup, O&M and summary conclusions associated with this uranium sequestration testing. The estimate accuracy and the associated effort to produce this level of accuracy would be determined by the most restrictive use of the estimate, which is the independent government estimate (IGE) for the contract modification. Ideally, an IGE for acquisition would be at least a class 2 (control or bid/tender), having an expected accuracy range of –15% to –5% and +5% to +20%. However, this class of estimate requires a fairly advanced state of project design. Due to the timing of the contract modification, the project design will be conceptual at best. Consequently, this estimate will be class 4 or class 3 at best and potentially have a range of accuracy between –20% to –15% and +20% to +50%. Considering this is a cost reimbursable contract, this level of accuracy is considered acceptable. The definition of the different classes can be seen in Table 6.

TABLE 6. GENERIC COST ESTIMATE CLASSIFICATION AND PRIMARY CHARACTERISTICS [21]

Cost estimate classification	Primary characteristics	
	Level of definition (% of complete definition)	Cost estimating description (techniques)
Class 5 Concept screening	0–2%	Stochastic: most parametric, judgement (parametric, specific analogy, expert opinion, trend analysis)
Class 4 Study or feasibility	1–15%	Various: more parametric (parametric, specific analogy, expert opinion, trend analysis)
Class 3 Preliminary, budget authorization	10–40%	Various: including combinations (detailed, unit cost or activity based, parametric, specific analogy, expert opinion, trend analysis)
Class 2 Control or bid/tender	30–70%	Various: more definitive (detailed, unit cost or activity based, expert opinion, learning curve [a])
Class 1 Check estimate or bid/tender	50–100%	Deterministic: most definitive (detailed, unit cost or activity based, expert opinion, learning curve)

[a] The 'learning curve theory' has stemmed from the observation that experience makes repetitive tasks easier to perform. When a particular task or sequence of work is repeated without interruption, subsequent operations require reduced time and effort.

The estimate development and approval will be a level C per the graded approach to estimate development [21]. This determination of a level C is based on the analysis below:

- — Longevity of the estimate: IGE is a one-time event and the budget request and life cycle report are done one year before the contract modification is in place.
- — Degree of importance for management decision making: Will be used by Department of Energy headquarters to go forward with the project.
- — Significance in the management process: IGE has a minor role in the cost price analysis report but the use for planning purposes could be significant since it may play a role in line item project determinations.
- — Significance in the budget process: May be used for the fiscal year (FY) budget.

Due to the potential use for the FY budget in management decisions, the level C graded approach is required.

II.1.2. Key estimate development milestones

The various estimate scope steps have data gathering and approach decision activities that must be accomplished prior to or during development of the estimate. These critical path activities are identified in Table 7 for each estimate stage.

TABLE 7. KEY ESTIMATE DEVELOPMENT MILESTONES

Action	Milestone date
Develop and submit estimate development plan	Mar 9
Revise/approve estimate development plan	Mar 12
Obtain consensus on needed scope	Done
Meet with contractors' representatives	Mar 13
Obtain requested contractor information	Mar 14
Secure vendor quotes and current pricing information	Mar 19
Use US Army Corps of Engineers (USACE) cost estimating expertise, as needed (e.g. electrical costs)	TBD
Build micro-computer aided cost estimating system (MCACES) assemblies	Mar 23
Obtain initial consensus on results	Mar 26
Formally submit estimate for senior estimator QA/QC review	Mar 27
Revise as needed HR-3 — D area — Build MCACES assembly for O&M and estimate for agreed upon duration	Mar 28
Obtain final estimate approval by estimate manager	Mar 29
Revise as necessary (i.e. when record of decision capacities and durations is finalized)	TBD

II.1.3. Estimate development team

The team members and products consist of:

- A lead cost estimator to develop estimates for the pump and treat systems' expansion design, construction, acceptance testing and O&M cost;
- Staff estimator aid, as needed;
- Subject matter expert for technical direction for scope;
- Management concurrence;
- Cost estimating and spreadsheet model developments and calibration;
- Additional cost estimating subject area expertise for mechanical, electrical and civil portions of the estimate (if required);
- An estimating manager to estimate development plan revisions, approval and tracking, and to ensure the final deliverable's quality acceptance.

II.1.4. Project scope and execution plan summary

The scope to be estimated:

- Design of the phosphate delivery system;
- Issuance of construction designs and specifications;
- Construction and oversight;
- 57 new injection wells to 152 cm (952 cm × 952 cm area, wells on 127 cm centres) and six down gradient monitoring wells to 190 cm;
- Distribution, manifold and transfer lines;
- Chemical costs;
- Laboratory sampling costs;
- Operation and maintenance costs;
- Demolition and disposal;
- Summary conclusion report.

II.1.5. Acquisition plan

The estimate will be based on design and construction performed by subcontractors and O&M performed by the prime contractor.

II.1.6. Project execution schedule basis

This work is planned for design and installation in a given fiscal year (US $280 000 currently in baseline for remedial design/remedial action (work plan)). Infiltration will begin in the third quarter of the fiscal year, and testing will happen through the third quarter of the fiscal year. The actual schedule is contingent upon funding.

II.1.7. Estimate development methodology for direct work

The estimates will be primarily either analogous (assuming past costs are indicators of future costs) and/or cost factored, based on treatment capacity ratios of present to future flow through rates. Recently issued pump and treat construction contracts will be compiled and reviewed for applicable unit pricing. Subcontractors experienced with site operational requirements will be consulted for current cost estimating information.

Prices for design will be a lump sum of US $200 000, based on estimator experience and contractor inputs. (A full 90% of design drawings and specifications have been assembled. This technology's application is almost identical to the drip infiltration planned herein.)

Costs for chemicals and the delivery system will be based on current vendor quotes, based on pricing in the specified year and escalated to the project year at a rate of 2.8% per fiscal year. Well drilling costs will be estimated using the cost estimating model developed for that purpose. O&M costs will be based on phosphate applications in the spring and autumn (when the groundwater levels are at their highest and lowest, and the flow is changing direction). This will provide the greatest ‘contact time’ for the phosphate to react with the uranium. During the balance of the year, the lines and tanks will be drained.

Application is assumed to be at a rate of 300 gallons (1136 L) per minute of a 52mM phosphate solution (12.3% monosodium, 77.4% disodium and 10.3% tripolyphosphate; 2.43, 15.30, and 2.045 g/L, respectively). Dilution water is assumed to be readily available from nearby city potable water sources.

Direct labour costs for project management and engineering support will be based on the historic range of 11.5–14% of total project costs, as has been tracked for the US $271 million spent on pump and treat construction projects. Laboratory analysis costs will be based on a contractor-supplied testing schedule, escalated to the appropriate years.

A summary leachability reduction analysis report is assumed to cost a lump sum of US $500 000, based on estimator experience and contractor inputs.

II.1.8. Estimate methodology for indirect costs

Site services are not to exceed the IGE, but will be applied outside the estimate software as a markup rate for the life cycle report and budget request in the selected year. Usage based services such as laboratory analyses will be estimated directly based on historical data.

II.1.9. Pricing year and escalation markups

It is anticipated that the year of pricing may vary for the material and subcontract unit prices. Escalation markups will be applied individually in the estimating programme to each material and subcontract item to bring all prices in that file to a common price level. The estimating programme files used for the estimates will all be prices for the relevant fiscal year.

II.1.10. Estimate software

The estimate will be developed using the micro-computer aided cost estimating system (MCACES) second generation software, MII.

II.1.11. Labour rates and equipment rates

Typically, the government estimate for contract modification IGE would use the exact labour rates that the contractor is using for the proposal (i.e. currently approved rates). However, in this situation, it is not known when the request for proposal for the modification will be issued. Consequently, the estimate will be based on rates in the fiscal year that is used for the life cycle baseline.

II.1.12. Work breakdown structure

The estimates will use the site contractors’ WBS that reflects the most current operable unit configurations for the area.

II.1.13. Funding profile assumptions

The life cycle baseline and the selected year’s life cycle report have regulatory compliant funding profiles. As such, there is no target funding limit. Whatever activities are specified in the pending record of decision and are needed to meet milestones are assumed to be funded.

II.1.14. Estimating approach for anticipated risks

A separate risk analysis will be developed and will identify risks and apply a Monte Carlo analysis (not in the scope of this estimate development plan).

II.1.15. Estimate file and backup information location

Given the potential use of this estimate for a wide variety of purposes, the MCACES–MII software files and backup information files will be archived for immediate anticipated local use.

Appendix III

EXAMPLE COST ESTIMATES RELATED TO AN ALTERNATIVE IN SITU TREATMENT

This appendix gives an example from Ref. [10] on the costs related to an alternative in situ treatment involving the technique of air sparging in combination with SVE to treat soil and groundwater in the source area. The technique also includes a passive treatment wall along the leading edge of the plume to treat groundwater migration off site. Capital costs occur in year zero. Annual O&M costs occur in years 1 to 15. Periodic costs occur in years 5, 10 and 15. The following information is taken from section 4 of Ref. [19].

Air sparging is an in situ technology in which air is injected through a contaminated aquifer. The injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone where a vapour extraction system is usually implemented in conjunction with air sparging to remove the generated vapour phase contamination. This technology is designed to operate at high flow rates to maintain increased contact between groundwater and soil, and to strip more groundwater by sparging. Oxygen added to contaminated groundwater and vadose zone soils can also enhance biodegradation of contaminants below and above the water table. Air sparging has a medium to long duration which may last up to a few years. The target contaminant groups for air sparging are volatile organic compounds (VOCs) and fuels. Only limited information is available on the process. Methane can be used as an amendment to the sparged air to enhance co-metabolism of chlorinated organics.

Factors that may limit the applicability and effectiveness of the process include:

- Ununiform airflow through the saturated zone, which may imply uncontrolled movement of potentially dangerous vapours;
- Depth of contaminants and specific site geology;
- Air injection wells that are not designed for site specific conditions;
- Soil heterogeneity that may cause some zones to be relatively unaffected.

Characteristics that need to be determined include vadose zone gas permeability, depth to water, groundwater flow rate, radial influence of the sparging well, aquifer permeability and heterogeneities, presence of low permeability layers, presence of dense non-aqueous phase liquids (DNAPLs), depth of contamination and contaminant volatility and solubility. Additionally, it is often useful to collect air saturation data in the saturated zone using a neutron probe during an air sparging test.

This technology is demonstrated at numerous sites, though only a few sites are well documented. Air sparging has demonstrated sensitivity to minute permeability changes, which can result in localized stripping between the sparge and monitoring wells.

The key cost driver information and cost analysis shown in Tables 8–11 was developed in 2006 using the RACER software. Key cost drivers are: (a) surface area (contaminant orientation) — the primary cost driver, which directly affects the quantity of air sparge points; and (b) depth to contamination — the secondary cost driver, which increases with depth since it impacts the drilling costs.

TABLE 8. CAPITAL COSTS

Actions	Quantity	Unit	Unit Cost (US $)	Total (US $)	Notes
Mobilization/demobilization					
Construction equipment and facilities	1	LS	8 829	8 829	Excavators, loaders, etc.
Submittal/implementation plans	1	1	33 761	33 761	Quality assurance project plan (QAPP), small scale hydro power (SSHP), etc.
Temporary facilities and utilities	1	1	49 664	49 664	Fence, roads, signs, trailers, etc.
Post-construction submittals	1	1	14 469	14 469	Post-construction reports
Subtotal-1				106 723	
Monitoring, sampling, testing and analysis					
Monitoring wells — SVE	7	EA	1 577	11 040	Install to water table depth
Monitoring wells — treatment wall — shallow	5	EA	2 965	14 826	Shallow well at each of five clusters
Monitoring wells — treatment wall — deep	5	EA	6 212	31 061	Deep well each of five clusters
Geotechnical testing	17	EA	230	3 910	Monitoring well screen interval soil samples
Subtotal-2				60 838	
Site work					
Clearing and grubbing	2	ha	2 900	5 800	Work area
Seeding/mulch/fertilizer	2	ha	3 570	7 140	Revegetate work area
Subtotal-3				12 940	
Air sparging (AS)/soil vapour extraction (SVE)					
Mobilize SVE system	1	EA	1 534	1 534	Mobile unit
Impermeable surface cover	9 755	m^2	9	88 200	Low density polyethylene liner
SVE extraction wells	8	EA	3 725	29 803	10 cm wells to water table depth
AS injection wells	2	EA	4 645	9 290	Well depth = midpoint of aquifer
SVE system	1	EA	93 510	93 510	Mobile unit (400 Nm^3/hr)
AS blower	1	EA	5 712	5 712	
SVE piping	122	m	28.40	3 464	Pipe, valves, fittings, etc.

TABLE 8. CAPITAL COSTS (cont.)

Actions	Quantity	Unit	Unit Cost (US $)	Total (US $)	Notes
AS piping	30.5	m	16.5	503	Pipe, valves, fittings, etc.
Electrical hook-up	0.3	m	9 898	9 898	
Startup and testing	1	LS	10 936	10 936	
Subtotal-4				252 850	
Passive treatment wall					
Construct slurry trench	1 376	m^3	245.25	337 460	Operate excavator/clamshell
Install reactive media	1 376	m^3	1 229	1 691 104	Prepare and inject iron/guar gum slurry
Subtotal-5				2 028 564	
Off-site treatment/disposal					
Off-site transport of soil cuttings	25	EA	15	375	Transport of drums to solid waste land fill (SWLF)
Disposal of soil cuttings	25	EA	35	875	SWLF drum disposal fee
Wastewater discharge/testing	1 135	1	0.26	300	City fee — development water
Subtotal-6				1 550	
Total of subtotal (1–6)				2 463 464	
Contingency for the above	25%			615 866	10% scope + 15% bid
Total-I				3 079 330	
Project management	5%			153 967	
Remedial designs	8%			246 346	
Construction management	6%			184 760	
Institutional controls					
Institutional controls plan	1	EA	5 000	5 000	Describe controls/implementation
Groundwater use restriction	1	LS	3 200	3 200	Legal fees
Site information database	1	LS	4 800	4 800	Set up data management system
Total-II				598 073	
Total capital cost = Total (I+II)				3 677 403	

Note: AS — air sparging; EA — each; LS — lump sum; SVE — soil vapour extraction.

TABLE 9. ANNUAL O&M COSTS

Description	Quantity	Unit	Unit cost (US $)	Total (US $)	Notes
Performance monitoring					
SVE vapour monitoring	96	EA	308	29 532	1 sample/month of 8 extraction wells
SVE emissions monitoring	12	EA	308	3 692	1 sample/month — SVE exhaust
Treatment wall — groundwater sampling	4	QTR	2 449	9 795	Sample 10 wells/quarter
Treatment wall — groundwater laboratory analysis	4	QTR	5 714	22 856	Analysis for above
Subtotal-1				65 875	
Site monitoring					
Groundwater sampling	4	QTR	1 820	7 280	Samples and wells/quarter VOCs WQ, metals
Groundwater laboratory analysis	4	QTR	5 460	21 839	Analysis for above
Subtotal-2				29 119	
Air sparging/soil vapour extraction					
Operation labour	12	Month	6 120	73 440	136 human-hours/month
Maintenance labour	12	Month	720	8 640	16 human-hours/month
Equipment repair	1	LS	500	500	
Utilities	12	Month	1 928	23 134	Electricity and fuel
Subtotal-3				105 714	
Off-site treatment/ disposal wastewater discharge/testing	6 150	L	0.26	1 600	City fee, purge and knockout water
Total of subtotal (1–3)				202 308	
Contingency for above	30%			60 692	10% scope + 20% bid
Total-I				263 000	
Project management	5%			13 150	
Technical support	10%			26 300	

TABLE 9. ANNUAL O&M COSTS (cont.)

Description	Quantity	Unit	Unit cost (US $)	Total (US $)	Notes
Institutional controls — site info database	1	LS	3 600	3 600	Update and maintain database
Total-II				43 050	
Total annual O&M cost = Total (I+II)				306 050	

Note: EA — each; LS — lump sum; O&M — operation and maintenance; QTR — quarter; SVE — soil vapour extraction; VOC — volatile organic compound; WQ — work quality.

TABLE 10. PERIODIC COSTS

Description	Year	Quantity	Unit	Unit cost (US $)	Total (US $)	Notes
Five year review report	5	1	EA	12 000	12 000	Report at end of year 5
Update institutional controls plan	5	1	EA	2 800	2 800	Update plan
Subtotal-1					14 800	
Five year review report	10	1	EA	12 000	12 000	Report at end of year 10
Update institutional controls plan	10	1	EA	2 800	2 800	Update plan
Subtotal-2					14 800	
Demobilize AS/SVE system	15	1	LS	21 375	21 375	Remove equipment and piping
Well abandonment	15	27	EA	350	9 450	
Contingency for above		25%			7 706	% of construction activities
Project mgt. (% of sum + cont.)		5%			1 927	% of construction + contingency
Remedial action report	15	1	EA	8 000	8 000	
Subtotal-3					48 458	
Total periodic costs = Total of subtotal (1–3)					78 058	

Note: AS — air sparging; EA — each; SVE — soil vapour extraction.

TABLE 11. PRESENT VALUE ANALYSIS

Cost type	Year	Total cost (US $)	Total cost per year (US $)	Discount factor (7%)	Present value (US $)
Capital cost	0	3 677 404	3 677 404	1.000	3 677 404
Annual O&M cost	1–15	4 590 765	306 051	9.108	2 787 511
Periodic cost	5	14 800	14 800	0.713	10 552
Periodic cost	10	14 800	14 800	0.508	7 518
Periodic cost	15	48 458	48 458	0.362	17 542
Total cost		8 346 000			
Total present value					6 501 000

Appendix IV

EXAMPLE WORK BREAKDOWN STRUCTURE FOR ENVIRONMENTAL REMEDIATION COST ESTIMATES

IV.1. INTRODUCTION

The WBS shows what work the project encompasses. It is a tool which helps to easily communicate the work and processes involved in executing the project. The WBS is used to develop the project schedule, resource requirements and costs. This appendix provides a variety of layouts that can be used as well as an example of a remediation design WBS.

In order to save space in this template, WBS examples are shown down to only the third level. In a real project, the WBS would be down to a much more detailed level using the 8 to 80 rule (where the WBS is broken down to a work package containing between 8 and 80 hours of work to complete).

IV.2. OUTLINE VIEW

The outline view is an easily viewable and understandable layout for the WBS. It is also a good layout to use when developing the WBS because one can easily make changes, especially since the autonumbering feature in word processors will generate the WBS code automatically, at left.

1. Widget management system

    1.1. Initiation
        1.1.1. Evaluate and make recommendations
        1.1.2. Develop project charter
        1.1.3. Submit project charter
        1.1.4. Review project charter (by sponsor)
        1.1.5. Sign/approve project charter

    1.2. Planning
        1.2.1. Create preliminary scope statement
        1.2.2. Determine project team
        1.2.3. Kick off meeting for project team
        1.2.4. Develop project plan
        1.2.5. Submit project plan
        1.2.6. Receive project plan approval

    1.3. Execution
        1.3.1. Kick off meeting for project
        1.3.2. Verify and validate user requirements
        1.3.3. Design system
        1.3.4. Procure hardware/software
        1.3.5. Install development system
        1.3.6. Test
        1.3.7. Install live system
        1.3.8. Train users
        1.3.9. Go live

1.4. Control
- 1.4.1. Project management tasks
- 1.4.2. Project status meetings
- 1.4.3. Risk management tasks
- 1.4.4. Project management plan update

1.5. Close-out
- 1.5.1. Procure audit
- 1.5.2. Document lessons learned
- 1.5.3. Update files/records
- 1.5.4. Gain formal acceptance
- 1.5.5. Archive files/documents

IV.3. HIERARCHICAL STRUCTURE

The hierarchical structure shown in Table 12 includes a column that indicates the level of step in the WBS. It is more cumbersome to make a word processor's autonumbering work in this format.

IV.4. TABULAR VIEW

The tabular view shown in Table 13 is a nicely organized table view that visually segregates the levels of the WBS. It is a good option for organization which prefers table formats. Numbering (setting codes) can be automated by the word processor.

IV.5. TREE STRUCTURE VIEW

The tree structure view shown in Fig. 10 is the most popular format for the WBS. It presents an easy way to view the WBS; however, it is also tricky to create without an application specifically designed for creating this organizational chart structure. The tree structure in Fig. 10 was created using only Microsoft Word and the SmartArt graphics option found under the Insert tab of the ribbon.

TABLE 12. HIERARCHICAL STRUCTURE EXAMPLE

Level	WBS code	Element name
1	1.	Widget management system
2	1.1.	Initiation
3	1.1.1.	Evaluate and make recommendations
3	1.1.2.	Develop project charter
3	1.1.3.	Submit project charter
3	1.1.4.	Review project charter (by sponsor)
3	1.1.5.	Sign/approve project charter
2	1.2.	Planning
3	1.2.1.	Create preliminary scope statement
3	1.2.2.	Determine project team
3	1.2.3.	Kick off meeting for project team
3	1.2.4.	Develop project plan
3	1.2.5.	Submit project plan
3	1.2.6.	Receive project plan approval
2	1.3.	Execution
3	1.3.1.	Kick off meeting for project
3	1.3.2.	Verify and validate user requirements
3	1.3.3.	Design system
3	1.3.4.	Procure hardware/software
3	1.3.5.	Install development system
3	1.3.6.	Test
3	1.3.7.	Install live system
3	1.3.8.	Train users
3	1.3.9.	Go live
2	1.4.	Control
3	1.4.1.	Project management tasks
3	1.4.2.	Project status meetings

TABLE 12. HIERARCHICAL STRUCTURE EXAMPLE (cont.)

Level	WBS code	Element name
3	1.4.3.	Risk management tasks
3	1.4.4.	Project management plan update
2	1.5.	Close-out
3	1.5.1.	Procure audit
3	1.5.2.	Document lessons learned
3	1.5.3.	Update files/records
3	1.5.4.	Gain formal acceptance
3	1.5.5.	Archive files/documents

TABLE 13. TABULAR VIEW EXAMPLE

Level 1	Level 2	Level 3
1. Widget management system	1.1. Initiation	1.1.1. Evaluate and make recommendations 1.1.2. Develop project charter 1.1.3. Submit project charter 1.1.4. Review project charter (by sponsor) 1.1.5. Sign/approve project charter
	1.2. Planning	1.2.1. Create preliminary scope statement 1.2.2. Determine project team 1.2.3. Kick off meeting for project team 1.2.4. Develop project plan 1.2.5. Submit project plan 1.2.6. Recieve project plan approval
	1.3. Execution	1.3.1. Kick off meeting for project 1.3.2. Verify and validate user requirements 1.3.3. Design system 1.3.4. Procure hardware/software 1.3.5. Install development system 1.3.6. Test 1.3.7. Install live system 1.3.8. Train users 1.3.9. Go live
	1.4. Control	1.4.1. Project management tasks 1.4.2. Project status meetings 1.4.3. Risk management tasks 1.4.4. Project management plan update
	1.5. Close-out	1.5.1. Procure audit 1.5.2. Document lessons learned 1.5.3. Update files/records 1.5.4. Gain formal acceptance 1.5.5. Archive files/documents

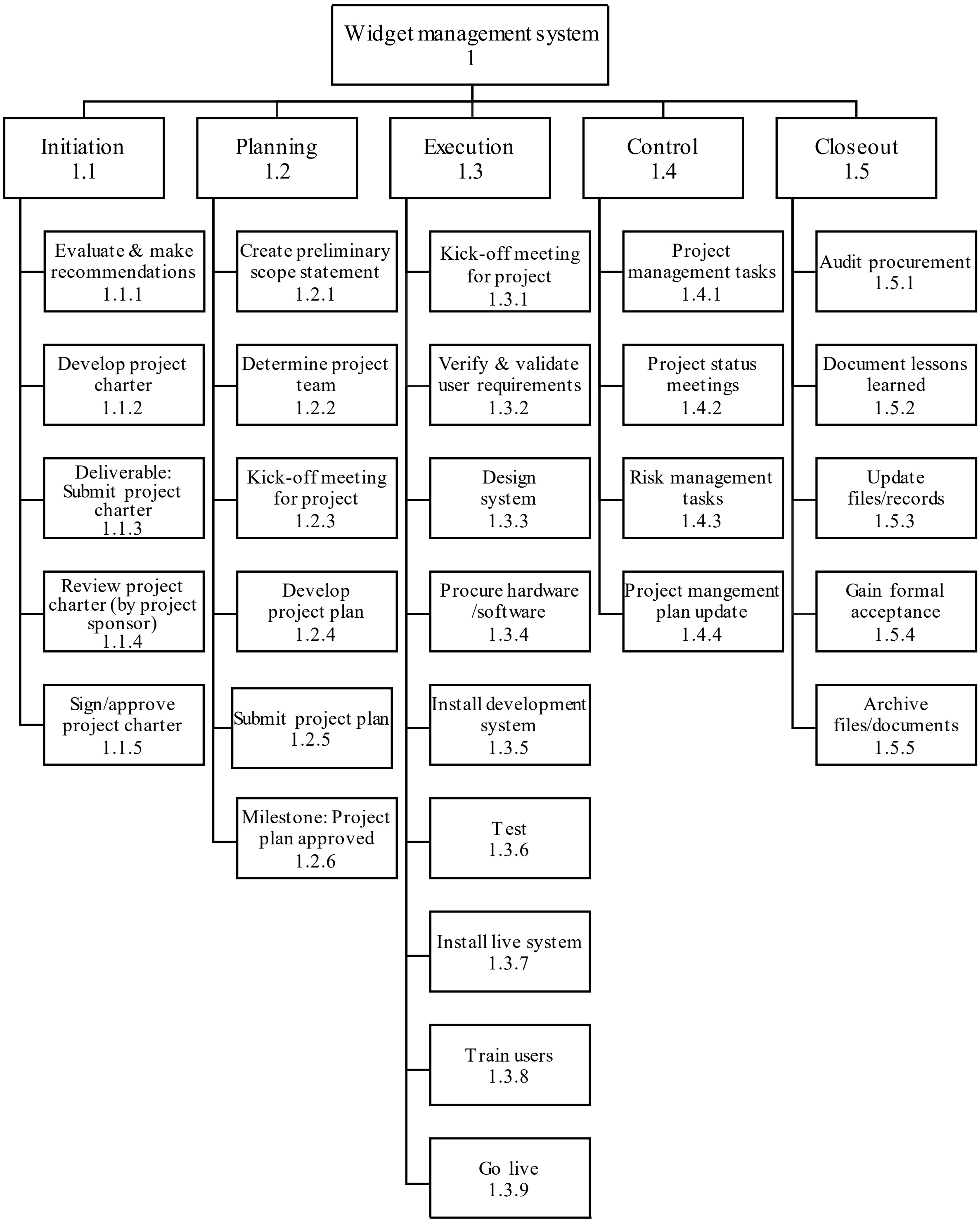

FIG. 10. Tree structure view.

Appendix V

REMEDIATION TECHNOLOGY COSTS

This appendix is aimed at providing an overview of the costs of specific remedial technologies and the factors that affect those costs. Information is extracted mainly from table 2-7 of Ref. [19] and from Ref. [22]. Readers are highly encouraged to dedicate time to reviewing these references in detail to learn more about the considered technologies, performance, cost and so on. Identifying costs for a specific technology will usually be undertaken as part of a broad effort to document total project costs. Some technology specific costs are subsets of overall project costs that are derived by disaggregating project-wide figures.

Capital cost items for technology include many of the fixed costs that are incurred during construction and startup of a remedial activity, such as mobilization and demobilization of technology equipment and personnel to and from a site, site preparation and purchase of equipment. O&M costs include many of the ongoing or recurring costs of a remedial activity, such as the costs of labour, materials and utilities.

Table 14 shows an example of elements that contribute to the cost formation of a given remediation technology. The format is based on documentation of capital costs and O&M costs for the technology application. Under those major categories, Table 15 shows the types of element that typically should be considered, such as equipment and appurtenances under capital costs, and labour, materials and utilities under O&M costs.

Calculated unit costs are used to compare and contrast remediation technologies. In general, unit costs should be expressed as a total cost for the technology specific application, divided by an appropriate unit of measure. Unit costs are highly dependent on site specific conditions and need to be extrapolated to other sites with caution. To achieve consistency in calculating unit costs, it is important that the basis used to develop the total cost and the basis used to develop the unit of measure be consistent. To simplify the calculation of unit costs, only capital and O&M cost elements need to be included in a calculation of technology specific unit costs. The total cost for an application should not include other project phases/activities such as preliminary assessment/site investigation, RI/FS, remedial design or post-closure surveillance and LTM. As already mentioned, the appropriate basis for calculating the unit of measure for each application will vary by site, depending on the remediation technology used, the media treated and the performance data available.

Typical unit costs for groundwater remediation are cost per thousands of cubic metres of water treated and cost per kilogram of contaminant removed. For soil remediation, typical unit costs are cost per cubic metre of soil treated and cost per kilogram of contaminant removed.

Unit costs need to be calculated and reported for a specific technology application with enough information (with a detailed explanation of the unit cost basis) so as to enable a level comparison of calculated unit costs with those of other remedial technology applications.

In a study performed by the US Environmental Protection Agency to analyse costs for the various remediation technologies, the following items were considered [24]:

— Identification of projects for which cost data were available for each technology;
— Identification of projects for which fully defined costs were available for each technology;
— Normalization of the total cost projects with fully defined cost data for time and location;
— Determination of unit costs for projects with fully defined cost data;
— Implementation of a cost analysis for each technology.

The study made it possible to formulate general conclusions, which are presented below.

Correlations between unit costs and quantity treated or mass removed were evident for four of the studied technologies. Economies of scale were observed for the four technologies for which unit costs decreased as larger quantities were treated. The higher unit costs for lower quantities are attributed to the effect of fixed costs (the baseline costs of constructing and installing the technology). Costs of technology applications are site specific and are affected by many factors. The relatively high variability indicates that a number of factors potentially impact the cost of a technology application, that those factors vary by technology, and that the impact of those factors is site specific. Examples of other factors include properties of the contaminant present and characteristics

TABLE 14. COST ELEMENTS OF A REMEDIATION TECHNOLOGY [23]

Cost category/element	Example items
Capital cost for technology	
Technology mobilization, set-up and demobilization	Includes the transportation (freight on board) or delivery of equipment, facilities and personnel to and from a site, as well as the set-up of temporary facilities and utilities necessary for the construction and startup of the remedial technology.
Planning and preparation	Includes permits and licences, including air emission and water discharge permits; licence fees associated with use of a technology; regulatory interaction; and various written plans, such as work plans, sampling and analysis plans, health and safety plans, community relations plans and site management plans.
Site work	Includes all work necessary to establish the physical infrastructure for a technology application and activities necessary to restore a site to pre-contamination conditions or to meet the specifications of a site restoration plan. Includes activities associated with preparing a specific site, such as clearing and grubbing; earthwork; and construction of utilities, culverts, treatment pads, foundations and spill control structures.
Equipment and appurtenances; structures; process equipment and appurtenances/construction; other	Includes structures and appurtenances; construction or installation of remedial technology components and materials, including technology parts and supplies to make the technology and appurtenances operational; purchase (amortization), rental or lease of equipment; and plant upgrades, modifications or replacement. For containment, this should be broadly interpreted as including structures such as slurry walls or caps; for pump and treat, this includes construction and installation of extraction wells.
Startup and testing	Includes activities associated with the startup of the treatment technology, such as establishment of operating conditions, shakedown and training of O&M personnel.
Other (includes non-process equipment)	Includes all other capital costs associated with the specific technology that has not been identified above. Generally, this would include costs for non-process equipment. Non-process equipment includes office and administrative equipment, such as data processing and computer equipment, safety equipment and vehicles.
O&M cost for technology	
Labour	Includes labour to operate and maintain the technology and associated equipment, labour supervision and payroll expenses. Covers ongoing operations as well as preventive and corrective maintenance activities.
Materials	Includes consumable supplies, process materials, bulk chemicals and raw materials. Covers ongoing operations, as well as preventive and corrective maintenance activities.
Utilities and fuel	Includes consumable energy supplies, such as fuel, electricity, natural gas and water. Covers ongoing operations as well as preventive and corrective maintenance activities.
Equipment ownership, rental or lease	Includes purchase (amortization), rental or lease of equipment necessary for O&M of remedial technology components.

TABLE 14. COST ELEMENTS OF A REMEDIATION TECHNOLOGY [23] (cont.)

Cost category/element	Example items
Performance testing and analysis	Includes monitoring, sampling, testing and analysis related to evaluating the performance of a technology. Does not include similar activities related to demonstrating compliance with applicable regulations and permits specific to the technology application.
Other (includes non-process equipment)	Includes all O&M costs associated with a specific technology that were not identified above. Costs generally include non-process equipment overhead and health and safety associated with equipment overhead and the O&M of a technology. Non-process equipment overhead includes maintenance and repair of office and administrative equipment, such as data processing and computer equipment, safety equipment and vehicles. Health and safety costs include those for personal protective equipment and monitoring of personnel for health and safety.
Other technology specific costs	
Compliance testing and analysis	Includes monitoring, sampling, testing and analysis related to demonstrating compliance with applicable regulations and permits specific to the technology application. Does not include similar activities related to monitoring the performance of a technology.
Soil, sludge and debris, excavation, collection and control	Includes activities associated with excavation, collection or control of contaminated soil, sludge and debris prior to ex situ treatment, including staging of contaminated media. This element includes collection of drums containing contaminated media.
Disposal of residues	Includes activities associated with disposal of primary and secondary waste residues from the operation of the technology, such as treated soil disposed of off-site. Covers both on- and off-site disposal of waste residues.
Other project costs	Includes all activities associated with remediation of a contaminated site that are not attributed directly to a specific technology, such as mobilization and demobilization, site work and site restoration activities. These costs may be helpful in comparing costs of entire remediation projects and in comparing costs for a specific technology to that of the entire project.

of the matrix treated; concentrations of contaminants and distribution of contamination in the subsurface; type and properties of the soil; and hydrogeology of the site, including characteristics of the aquifer. Several additional factors affect remediation technologies. Other factors that affect costs for all remediation technologies include market forces such as supply and demand, the state of development of the technology, and regulatory requirements. The specific impact of such factors on project costs is difficult to quantify because they may vary by location and change over time.

Regarding individual technologies, for types of bioremediation treatment other than bioventing, no quantitative correlation between unit cost and quantity of soil or groundwater treated has been observed. Cost data for various types of bioremediation projects (in situ soil, ex situ soil, and in situ groundwater) were limited. While no quantitative correlation was evident, unit costs for bioremediation are potentially affected by other factors, including soil type and aquifer chemistry, site hydrogeology, type and quantity of amendments used, and type and extent of contamination.

For groundwater pump and treat systems, a correlation between unit cost and quantity of groundwater treated was observed for both the unit capital cost and the unit average annual operating cost. The unit capital cost decreased from approximately US $60–700 per 3785 litres per year for projects treating up to 114 million litres of groundwater per year to less than US $20 per 3785 litres per year for projects treating relatively larger quantities of groundwater. The unit average annual operating cost decreased from US $10–120 per 3785 litres per year for projects treating less than 76 million litres of groundwater per year to less than US $5 per 3785 litres per year for projects treating larger quantities of groundwater.

For permeable reactive barriers (PRBs), data were not available to perform a quantitative analysis of unit cost compared with the quantity of groundwater treated because of a lack of information about the quantity treated. Capital costs were available for 16 PRB projects and annual operating costs were available for two projects. However, the case studies for PRBs do not provide information about the anticipated longevity of the project or about the quantity of groundwater treated or the mass of contaminant removed and do not report unit costs or information needed to calculate unit costs. While no correlations could be performed, unit costs for PRBs are potentially affected by other factors, including properties of the contaminants and extent of contamination, the need for source control, the hydrogeologic setting and the geochemistry of the aquifer.

Table 15 gives an overview of the technologies used for the remediation of environmental media contaminated by radionuclides. Specific site and contaminant characteristics may limit the applicability and effectiveness of any of the technologies and treatments listed in the table. The site alerts to the fact that the matrix should always be used in conjunction with the referenced text sections, which contain additional information that can be useful in identifying potentially applicable technologies.

In situ physical/chemical treatment — Solidification/stabilization

Costs for auger/caisson and reagent/injector head system processes vary widely according to the materials or reagents used, their availability, project size and the chemical nature of contaminants (e.g. types and concentration levels for shallow applications). The in situ soil mixing/auger techniques average US $50 to US $80 per cubic metre (US $40 to US $60 per cubic yard) for the shallow applications and US $190 to US $330 per cubic metre (US $150 to US $250 per cubic yard) for the deeper applications.

The shallow soil mixing technique processes 36 to 72 metric tonnes (40 to 80 tonnes) per hour on average, and the deep soil mixing technique averages 18 to 45 metric tonnes (20 to 50 tonnes) per hour.

TABLE 15. TREATING TECHNOLOGIES SCREENING MATRIX — TREATMENT OF RADIONUCLIDES [19]

Technology	Development status	Use rating	Applicability	Reliability	Cleanup time	Technology function
Soil, sediment and sludge						
In situ physical/chemical treatment						
Solidification/stabilization	Full	Limited	Better	Average	Average	Immobilize
Ex situ physical/chemical treatment						
Solidification/stabilization	Full	Limited	Better	Better	Better	Extract/ Immobilize
Groundwater, surface water and leachate						
Ex situ physical/chemical treatment (assuming pumping)						
Ion exchange	Full	Wide	Average	Better	Average	Extract
Precipitation/coagulation/ flocculation	Full	Wide	Average	Better	Average	Extract
Separation	Full	Limited		Average	Better	Extract
Deep well injection	Full	Limited	Average	Average	NA	Immobilize

The cost for grout injection varies depending on site specific conditions. Costs for drilling can range from US $50 to US $150/30 cm and grouting from US $50 to US $75/30 cm, not including mobilization, wash disposal or adverse site condition expenses. For in situ vitrification (ISV), average costs for treatability tests (all types) are US $25 000 plus analytical fees. Equipment mobilization and demobilization costs are US $200 000 to US $300 000 combined. Vitrification operation cost varies with electricity costs, quantity of water and depth of process. Estimated vitrification costs at US $415 to US $472 per tonne of soil treated were proposed; other estimates give values of vitrification costs around US $350 per m^3.

Ex situ physical/chemical treatment — Solidification/stabilization

The key cost driver information and cost analysis are driven by the type of waste and the size of the mobile system:

- Type of waste:
  - Moisture content in the sludge drives up costs compared to solids;
  - Contaminant concentration and type determine the number of reagents added to the waste to attain the required treatment standards.
- Size of the mobile solidification/stabilization system:
  - Correct size of mobile solidification/stabilization system to adequately handle the throughput of waste volume.

Costs related to ex-situ treatment in four different scenarios are shown in Table 16.

Ion exchange

The cost for a typical ion exchange system ranges from US $0.08 to US $0.21 per 1000 L treated [19, section 4.48].

Precipitation/coagulation/flocculation

Table 17 represents estimated costs (by common unit of measure) to apply precipitation/coagulation/flocculation technology at sites of varying size and complexity.

Separation

Typical costs for filtration range from US $0.36 to US $1.20/1000 L treated. The cost of frozen crystallization is estimated to be only US $8 per 1000 L for a 150 L per minute facility.

Deep well injection

Costs are not available for this technology.

TABLE 16. COST OF TREATMENT [19]

Parameters	Scenario A	Scenario B	Scenario C	Scenario D
	Small site		Large site	
Cost per cubic meter (US $)	216	248	124	190

TABLE 17. ESTIMATED COSTS TO APPLY PRECIPITATION/COAGULATION/FLOCCULATION TECHNOLOGY [19]

Groundwater technology	Precipitation/Coagulation/Flocculation	
Unit	Scenarios A and B	Scenarios C and D
	Small site	Large site
Volume (1000 L/a)	40 000	130 000
Cost per 1000 L/a (US $)	11	4

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Annex I

WORK BREAKDOWN STRUCTURE DICTIONARY

The WBS dictionary presented in Table I–1 contains all the details of the WBS that are necessary to successfully complete the project. Most importantly, it contains a definition of each work package, which can be thought of as a mini scope statement. Resources on the project will look at the WBS dictionary to determine the scope of the work package they have been assigned, so it is important to be clear when writing the definition. Most WBS dictionaries contain more information than is shown in the sample below. These usually include level of effort, cost control numbers, resource assignments and responsibility assignments, just to name a few.

TABLE I–1. RELEVANT TERMS IN A WORK BREAKDOWN STRUCTURE

Level	WBS code	Element name	Definition
1	1	[Widget management] system	Code 1 is the name of the project. In this example, it names all the work necessary to implement a new [widget management] system.
2	1.1	Initiation	The work to start the project.
3	1.1.1	Evaluate and make recommendations	A working group evaluates the solution sets and makes recommendations.
3	1.1.2	Develop project charter	A project manager defines the parameters, principles and purposes of the project.
3	1.1.3	Submit project charter	The project charter is delivered to the project sponsor.
3	1.1.4	Review project charter (by sponsor)	The project sponsor reviews the project charter.
3	1.1.5	Sign/approve project charter	The project sponsor authorizes the project manager to move to the planning process.
2	1.2	Planning	The work of planning the project.
3	1.2.1	Create preliminary scope statement	The project manager describes the parameters of the project in terms that may be revised as more information is gathered.
3	1.2.2	Determine project team	The project manager determines the members of the project team and requests their participation.
3	1.2.3	Kick off meeting for project team	The planning process is officially started with a project kick off meeting that includes the project manager, project team and project sponsor (optional).
3	1.2.4	Develop project plan	Under the direction of the project manager, the team develops the project plan.
3	1.2.5	Submit project plan	The project manager submits the project plan for approval.
3	1.2.6	Receive project plan approval	The project manager gets permission to proceed according to the project plan.

TABLE I–1. RELEVANT TERMS IN A WORK BREAKDOWN STRUCTURE (cont.)

Level	WBS code	Element name	Definition
2	1.3	Execution	The work involved carrying out the project.
3	1.3.1	Kick off meeting for project	The project manager conducts a formal kick off meeting with the project team, project stakeholders and project sponsor.
3	1.3.2	Verify and validate user requirements	The original user requirements are reviewed by the project manager and team, and then validated with the users/stakeholders. This is where additional clarification may be needed.
3	1.3.3	Design system	The technical experts design the system.
3	1.3.4	Procure hardware/software	The obtainment of all hardware, software and facility needs for the project.
3	1.3.5	Install development system	The team installs a development system for testing and customization of user interfaces.
3	1.3.6	Test	The system is tested with a select set of users.
3	1.3.7	Install live system	The actual system is installed and configured.
3	1.3.8	Train users	All users are provided with a training class. Additionally, managers are provided with an additional class to cover advanced reporting.
3	1.3.9	Go live	The system goes live with all users.
2	1.4	Control	The work involved in checking against the project’s specifications.
3	1.4.1	Project management tasks	The overall project management for the project.
3	1.4.2	Project status meetings	Weekly team status meetings in which everyone is updated on progress, difficulties encountered and next steps.
3	1.4.3	Risk management tasks	Risk management efforts as defined in the risk management plan.
3	1.4.4	Project management plan update	The project manager updates the project management plan to account for new challenges and revised estimates as the project progresses.
2	1.5	Close-out	The work to finalize the project.
3	1.5.1	Procure audit	An inventory of all hardware and software obtained for the project ensures that everything is accounted for and is in the asset management system.
3	1.5.2	Document lessons learned	The project manager, along with the project team, holds a lessons learned meeting and documents knowledge and understanding gained in the project that should be taken into account in the future.
3	1.5.3	Update files/records	All files and records are updated to reflect the project realities and status.
3	1.5.4	Gain formal acceptance	The project sponsor formally agrees that the project is complete by signing the acceptance document included in the project plan.
3	1.5.5	Archive files/documents	All project related files and documents are formally archived.

Annex II

COST ESTIMATE CHECKLIST OF A REMEDIATION PROJECT

A ‘cost estimate checklist’ is intended to assist estimators, project managers, implementers and other relevant professionals to develop both preliminary and detailed cost estimates and consider all related remediation activities. Its main purpose is to ensure that no scope items are missed from the final estimate. The handy checklist in Table II–1 is appropriate for any remediation project. The checklist ensures that all the bases are covered when compiling an estimate and ensures the consistency of the final estimating product/deliverables.

TABLE II–1. COST ESTIMATE CHECKLIST

Cost element	Description	Example sub-elements
Professional/technical services for construction		
Project management	Services to support construction or installation of remedial action not specific to remedial design or construction management	— Planning; — Community relations; — Bid/contract administration; — Cost and performance reporting; — Permitting; — Legal; — Construction completion report.
Remedial design	Services to design the remedial action, including pre-design activities to collect the necessary data	— Field data collection and analysis. — Design survey. — Treatability study: • Trench scale; • Pilot scale; • Field scale. — Preliminary/intermediate/final design: • Design analysis; • Plans and specifications; • Construction cost estimate; • Construction schedule.
Construction management	Services to manage construction or installation of remedial action, excluding any similar services provided as part of construction activities	— Submittal review; — Change order review; — Design modifications; — Construction observation; — Construction survey; — Construction schedule tracking; — QA/QC documentation; — O&M manual; — Record drawings.

TABLE II–1. COST ESTIMATE CHECKLIST (cont.)

Cost element	Description	Example sub-elements
Institutional controls	Non-engineering measures (i.e. administrative or legal) to reduce or minimize potential for human exposure to site contamination or hazards (i.e. limit site access or restrict site access)	— Planning; — Community relations; — Bid/contract administration; — Cost and performance reporting; — Permitting; — Legal; — Construction completion report; — Field data collection and analysis; — Design survey; — Treatability study; — Preliminary/intermediate/final design; — Submittal review; — Change order review; — Design modifications; — Construction observation; — Construction survey; — Construction schedule tracking; — QA/QC documentation; — O&M manual; — Record drawings.
Construction activities		
Mobilization/ demobilization	Bringing equipment and personnel to the site (mobilization) or removing equipment and personnel (demobilization) for purposes of constructing or installing the remedial action. Includes set up or construction and/or removal of temporary facilities and utilities. Does not include mobilization or demobilization specific to constructing or installing an on-site treatment facility	— Construction equipment. — Submittals/implementation plans: • Air monitoring plan; • Construction quality control plan; • Construction schedule; • Environmental protection plan; • Materials; • Handling/transportation/disposal plan; • Permits; • Sampling and analysis plan; • Site safety and health plan; • Site security plan; • Site work plan; • Storm water pollution prevention plan; • Training and medical certifications. — Temporary facilities: • Office trailers; • Storage facilities; • Security fencing and signs; • Roads and parking; • Decontamination facilities. — Temporary utilities. — Temporary relocation of roads/ structures/utilities. — Post-construction submittals: • As-built drawings; • O&M manuals; • QA/QC documentation. — Site security personnel.

TABLE II–1. COST ESTIMATE CHECKLIST (cont.)

Cost element	Description	Example sub-elements
Monitoring, sampling, testing and analysis	Sampling, testing on- or off-site analysis, data management and quality assurance/quality control. Includes monitoring to evaluate remediation performance and/or compliance with regulations	— Meteorological monitoring; — Air monitoring and sampling; — Radiation monitoring; — Health and safety monitoring; — Personal protective equipment; — Monitoring wells; — Geotechnical instrumentation; — Soil sampling; — Sediment sampling; — Surface water sampling; — Groundwater sampling; — Radioactive waste sampling; — Asbestos sampling; — Laboratory chemical analysis; — On-site chemical analysis; — Radioactive waste analysis; — Geotechnical testing; — Chemical data management.
Site work	Activities to establish the infrastructure necessary for the project (i.e. site preparation). Also includes permanent site improvements and restoration of areas or site features disturbed during site remediation. Site work is generally assumed to be 'clean work,' meaning that there is no contact with contaminated media or materials. Excludes all site work specific to constructing or installing an on-site treatment facility	— Demolition. — Clearing and grubbing. — Earthwork: • Stripping; • Stockpiling; • Excavation; • Borrow pit excavation; • Grading; • Backfill; • Topsoil. — Roads/parking/curbs/walks. — Vegetation and planting: • Topsoil; • Seeding/mulch/fertilizer; • Sodding; • Erosion control fabric; • Shrubs/trees/ground cover. — Fencing/signs/gates. — Utilities: • Electrical; • Telephone/communications; • Water/sewer/gas. — Storm drainage/subdrainage. — Sediment barriers.
Surface water collection or containment	Collection or containment of contaminated surface water. Excludes treatment, off-site transportation or off-site treatment/disposal of contaminated surface water	— Pumping; — Draining; — Channel/waterway; — Berm/dike; — Lagoon/basin/tank.

TABLE II–1. COST ESTIMATE CHECKLIST (cont.)

Cost element	Description	Example sub-elements
Groundwater extraction or containment	Extraction or containment of contaminated groundwater. Excludes treatment, off-site transportation or off-site treatment/disposal of contaminated groundwater	— Extraction/injection well: • Vertical; • Horizontal. — Extraction trench. — Pumps. — Piping. — Lagoon/basin/tank. — Subsurface drains. — Subsurface barrier: • Slurry wall; • Grout curtain; • Sheet piling.
Soil excavation	Excavation and handling of contaminated soil. Excludes treatment, off-site transportation or off-site treatment/disposal of contaminated soil	— Excavation; — Hauling; — Stockpiling.
Sediment/sludge removal or containment	Removal or containment of contaminated sediment or sludge. Excludes treatment, off-site transportation, or off-site treatment/disposal of contaminated sediment or sludge	— Excavation; — Dredging; — Vacuuming; — Lagoon/basin/tank.
Demolition and removal	Demolition/removal of contaminated or hazardous materials or structures. Excludes treatment, off-site transportation or off-site disposal of contaminated or hazardous materials or structures	— Drum removal; — Tank removal; — Piping removal; — Structure removal; — Asbestos abatement; — Contaminated paint removal; — Ordnance removal and destruction.
Cap or cover	Construction of a multi-layered cap or covering over of contaminated materials or media (e.g. soil, sediment or sludge) to prevent or reduce exposure and minimize infiltration of surface water and production of leachate	— Subgrade preparation; — Gas collection layer; — Low permeability clay layer; — Bentonite; — Geosynthetic clay layer; — Geotextile; — Geomembrane; — Granular drainage layer; — Geonet; — Waste placement (cut/fill); — Protective soil layer; — Asphalt/concrete pavement; — Topsoil; — Erosion control fabric; — Seeding/mulch/fertilizer.
On-site treatment	Construction or installation of a complete and usable on-site facility for treatment of contaminated media (e.g. soil, solids, sediment, sludge, surface water or groundwater), including in situ and ex situ techniques. Includes all mobilization and site work required for the treatment facility	— Mobilization/demobilization; — Site work; — Structures; — Process equipment and appurtenances; — Non-process equipment; — Startup and testing; — Equipment upgrade/replacement.

TABLE II–1. COST ESTIMATE CHECKLIST (cont.)

Cost element	Description	Example sub-elements
Off-site treatment/disposal	Final placement of contaminated media, material or treatment residuals at off-site commercial facilities, such as solid or hazardous waste landfills and incinerators, that charge fees to accept waste	— Material handling/loading; — Transportation to off-site facility; — Treatment/disposal fees.
Contingency	Costs added to cover unknowns, unforeseen circumstances or unanticipated conditions related to construction or installation of the remedial action	— Scope contingency; — Bid contingency.
Annual O&M activities		
Monitoring, sampling, testing and analysis	Sampling, testing, on- or off-site analysis, data management and quality assurance/quality control during O&M. Can include monitoring to evaluate remedy performance, compliance with regulations or monitoring to track migration of contaminant plume	— Meteorological monitoring; — Air monitoring and sampling; — Radiation monitoring; — Health and safety monitoring; — Personal protective equipment; — Monitoring wells; — Soil sampling; — Sediment sampling; — Surface water sampling; — Groundwater sampling; — Process water sampling; — Process air sampling; — Laboratory chemical analysis; — On-site chemical analysis; — Chemical data management.
Extraction, containment or treatment systems	O&M of on-site systems to extract, contain or treat contaminated media (e.g. soil, sediment, sludge, surface water and groundwater)	— Operations labour; — Maintenance labour; — Equipment upgrade/replacement/ repair; — Spare parts; — Equipment ownership/rental/lease; — Consumable supplies; — Bulk chemicals; — Raw/process materials; — Utilities.
Off-site treatment/disposal	Treatment and/or disposal of waste generated during O&M (e.g. on-site treatment residuals, monitoring waste) at off-site commercial facilities, such as solid or hazardous waste landfills and incinerators	— Material handling/loading; — Transportation to off-site facility; — Treatment/disposal fees.
Contingency	Funds to cover unknowns, unforeseen circumstances or unanticipated conditions associated with annual O&M of the remedial action, usually calculated as a percentage of the project subtotal	— Scope contingency; — Bid contingency.

TABLE II–1. COST ESTIMATE CHECKLIST (cont.)

Cost element	Description	Example sub-elements
Professional/technical services for O&M		
Project management	Services to manage O&M activities not specific to technical support listed below	— Planning; — Community relations; — Cost and performance reporting; — Permitting; — Legal.
Technical support	Services to monitor, evaluate and report progress of remedial action	— O&M manual updates; — O&M oversight; — Progress reports.
Institutional controls	Annual update or maintenance of non-engineering measures to reduce or minimize potential for exposure to site contamination or hazards	— Institutional controls plan; — Restrictive covenants; — Zoning; — Property easements; — Deed notice; — Advisories; — Groundwater use restrictions; — Site information database.
Periodic O&M activities		
Remedy failure or replacement	Construction activity to replace an installed remedy or key components of the remedy	— Mobilization/demobilization; — Site work; — Structures; — Process equipment and appurtenances; — Non-process equipment; — Startup and testing.
Demobilization of on-site extraction, containment or treatment systems	Construction activity to dismantle or take down extraction, containment or treatment facilities or equipment upon completions of remedial action	— Demolition and removal; — Well abandonment.
Contingency	Funds to cover unknowns, unforeseen circumstances or unanticipated conditions associated with O&M activities, usually calculated as a percentage of the project subtotal	— Scope contingency; — Bid contingency.
Professional/technical services for periodic O&M activities		
Five year reviews	Services to prepare five year review reports (if hazardous substances, pollutants or contaminants remain on-site above levels that allow for unrestricted use and unlimited exposure)	— Site visit; — Field data collection; — Data review and analysis; — Report preparation.
Groundwater performance and optimization study	Services to analyse and optimize ongoing groundwater pump and treat systems	— Site visit; — Field data collection; — Data review and analysis; — Report preparation.
Remedial action report	Services to prepare remedial action report upon completion of remedial action	— Site visit; — Field data collection; — Data review and analysis; — Report preparation.

TABLE II–1. COST ESTIMATE CHECKLIST (cont.)

Cost element	Description	Example sub-elements
Institutional controls	Periodic update or maintenance of non-engineering measures to reduce or minimize potential for exposure to site contamination or hazards	— Institutional controls plan; — Restrictive covenants; — Zoning applications; — Property easements; — Deed notice; — Advisories; — Groundwater use restrictions; — Site information database maintenance.

GLOSSARY

The following terms are often used when discussing cost estimates, and some may be used interchangeably.[1]

actual cost. The costs actually incurred and recorded in accomplishing work.

budgeting. A process for allocating estimated resource costs into accounts (i.e. the cost budget) against which cost performance will be measured and assessed. Budgeting often considers time phasing in relation to a schedule or time based financial requirements and constraints.

capital costs. The total expenditures required to implement a cleanup action.

contingency. An amount added to an estimate to mitigate unforeseen costs. Generally, the contingency factor should decrease as the design documents are refined and the site investigation progresses. Contingencies are generally expressed as a percentage of the total direct and indirect costs and can range from 0 to 10% (100% design and completed site investigation) to in excess of 50% at the preliminary design and investigation stage.

contractor. A person, organization, department, division or company having a contract, agreement or memorandum of understanding with another party.

cost estimate. (a) A documented statement of costs to complete a project or a defined portion of a project; (b) an input to budget, contract or project management planning for baselines and changes against which performance may be measured.

cost estimating. A process used to quantify, cost and price the resources required by the scope of an asset investment option, activity or project. As a predictive process, estimating must address risks and uncertainties. The output of estimating is used primarily as input for budgeting, cost or value analysis, decision making in business, asset and project planning or project cost and schedule control.

direct construction costs. Costs directly associated with the project, including labour, material, equipment and subcontractor costs, as well as design contingencies.

direct labour cost. This is based on the total available human-hours per year (2080 hours) and includes costs for vacation, holidays and sick leave. This is usually determined through published federal wage rate tables, which establish the minimum rate per hour and applicable fringe benefits in the geographic area of the proposed work.

discount rate. The interest rate used in calculating the present value of expected yearly benefits and costs.

escalation. The provision in actual or estimated costs for an increase in the cost of equipment, material, labour, etc., due to continuing price level changes over time. Inflation may be a component of escalation but non-monetary policy influences, such as supply and demand, are often components.

escalation factors. Because the impact of inflation should be considered when developing the independent government cost estimate, escalation should be added to any cost estimate that includes work to be performed in the future. To forecast the out year(s) cost (i.e. the cost in the year after the current fiscal year), appropriate

[1] Terms were taken from the following publications: INNIS, P.S., Overview of Cost Estimating for Abandoned Mine Lands and Hazardous Materials Cleanup Projects, Technical Note 441, Bureau of Land Management, National Operations Center, Denver, CO (2011), and UNITED STATES DEPARTMENT OF ENERGY, Cost Estimating Guide, DOE G 413.3-21, USDOE, Washington, DC (2011).

escalation factors are applied to the cost elements to bring them up to realistic values. An average factor between 2% and 4% each year would generally be considered 'reasonable'.

FAR (Federal Acquisition Regulation). The principal set of rules in the Federal Acquisition Regulation regarding government procurement in the United States of America.

general and administrative (G&A)/overhead costs. Costs, including any management, financial or other expenses, incurred in the overall operation of a business, such as utilities, compensation packages, employee training, business taxes, liability and other business insurance, legal costs, and non-contract specific leases, equipment and supplies. These costs are distributed equally across all contracts, the government and the private sector. Although G&A costs vary based on the type of contract, ownership of facilities, location of work site, etc., 15% is typical unless more specific information is available.

general conditions. Field related tasks incurred by the contractor while performing the work that include, but are not necessarily limited to, the following (unless otherwise broken out as a specific estimate line item cost): site administration and supervision, bonds, permits, travel, stipend/per diem, vehicles, trailers/furnishing/office equipment, sanitary and health facilities, temporary construction, security, safety, power, telephone, water, waste disposal, quality control/testing/inspections and surveying. General conditions have a usual cost range expressed as 4% to 20% of the sum total of direct costs (dependent on the project size, location, complexity and other variables).

government other direct costs. Government costs that are needed for the project such as government furnished services, items and equipment, government supplied utilities (if directly metered) and applicable waste disposal fees.

historical cost information. A database of information from completed projects normalized to some standard (geographical, national average, etc.) and time based (e.g. brought to current year values) using historical cost indices.

IGE. Independent Government Estimate.

indirect cost. Costs incurred for common or joint objectives which cannot be identified with a particular activity or project.

labour burden. The related cost of employees beyond salary, including payroll taxes, unemployment taxes and various forms of insurance, worker's compensation and employee benefits. Labour burden factors are fairly consistent with the acquisition policies and regulations for service contracting; therefore, they may be consolidated to form one line item expressed as a percentage of total cost. For general estimating purposes, this can be expressed as 50% to 60% of the direct labour costs.

level of effort. The baseline scope of a general or supportive nature for which performance cannot be measured or is impracticable to measure using activity based methods. Resource requirements are represented by a time phased budget scheduled in accordance with the time the support will likely be needed. The value is earned by the passage of time and is equal to the budget scheduled in each period.

life cycle. The stages of an object's or endeavour's life. A life cycle presumes a series of beginnings and endings, with each ending implying a new beginning. In life cycle cost or investment analyses, the life cycle is the length of time over which an investment is analysed.

life cycle cost. (a) The overall estimated cost for a particular programme alternative over the life of the programme, including direct and indirect initial costs plus any periodic or continuing cost of O&M; (b) the sum total of the direct, indirect, recurring, non-recurring and other costs incurred or estimated to be incurred in the design, development, production, operation, maintenance, support and final disposition of a major system over its anticipated useful lifespan. Where system or project planning anticipates the use of existing sites or facilities, restoration and refurbishment costs should be included.

mobilization costs. These include the direct costs associated with the transport of equipment, material and personnel and the set-up/teardown of equipment and support facilities associated with construction contract work. Mobilization is usually identified as a separate line item in an estimate and is dependent upon site access/location and associated transportation costs. For preliminary estimates (unless more specific site information is available) this amount can be expressed as 10% of the sum total of direct costs.

nominal interest rate. A rate that is not adjusted to remove the effects of actual or expected inflation. Market interest rates are generally nominal interest rates.

optimization. This technique analyses a system to find the best possible result. Finding an optimum result usually requires evaluating design elements, execution strategies, methods and other system inputs for their consequence on cost, schedule, safety or some other set of outcomes or objectives; employs computer simulation and mathematical modelling.

other direct costs (ODCs). Costs not previously identified as a direct material cost, direct labour cost or indirect cost. Any materials used in direct support of the contract, such as vehicles, computers, office furniture, travel, lease of equipment, per diem, etc., should be included in ODCs. ODCs can generally be estimated at 2% to 4% of the total labour costs.

payment bond. A legal guarantee that there is money to pay subcontractors and suppliers.

performance bond. A legal guarantee that the contractor will complete the contract according to its terms, including price and time.

preliminary design. This work continues the design effort using conceptual and project design criteria as bases for project development; develops topographical and subsurface data and determines the requirements and criteria that will govern the definitive design; and includes preparation of preliminary planning and engineering studies, preliminary drawings and outline specifications, life cycle cost analyses, preliminary cost estimates and scheduling for project completion. Preliminary design identifies long-lead procurement items and analysis of risks associated with continued project development.

price estimate. A dollar amount predicted for the cost of supplies, equipment and simple services that are routinely available on the open market at competitive prices. A price estimate is not broken down into cost elements and is generally based on catalogue prices or market information.

profit or fee. The dollar amount over and above any allowable costs paid to a contractor for performance. The purpose of both is to compensate the contractor for risks assumed during contract performance and to stimulate efficient contract performance. In the absence of other data, a reasonable percentage for profit on fixed price contracts is approximately 5% to 10% for large businesses and 10% to 15% for small businesses.

programme. An organized set of activities directed towards a common purpose or goal undertaken or proposed in support of an assigned mission and characterized by a strategy for accomplishing definite objectives, which identifies the means of accomplishment, particularly in quantitative terms, with respect to labour, materials and facilities requirements. Programmes usually include an element of ongoing activity and are typically made up of technology, projects and supporting operations.

project. A unique effort that supports a programme mission, having defined start and end points, undertaken to create a product, facility or system and containing interdependent activities planned to meet a common objective or mission. A project is a basic building block in relation to a programme and is individually planned, approved and managed. A project is not constrained to any specific element of the budget structure (e.g. operating expense or plant and capital equipment). Construction, if required, is part of the total project. Authorized, and at least partially appropriated, projects can be divided into two categories: major system projects and other projects. Projects include planning and execution of construction and remediation.

reconciliation. Comparison of a current estimate to a previous estimate to ensure that differences between them are appropriate and reasonably expected. A formal reconciliation may include an account of those differences.

remediation. Any measures carried out to reduce the radiation exposure from existing contamination through actions applied to the contamination itself (the source) or to the exposure pathways to humans. Remediation involves the management of contamination either by removal, fixation, treatment or monitoring. The remediation process applies to both radiological and non-radiological contaminants that have the potential to affect human health and the environment. Remediation does not necessarily involve the complete removal of the contamination, nor returning a site to its pre-industrial state.

risk. Any factor, element, constraint or course of action that introduces uncertainty of the outcome, either positively or negatively. This definition for risk is strictly limited to project management applications in the development of the overall risk management plan and its related documentation and reports.

risk acceptance. An informed and deliberate decision to accept consequences and the likelihood of a particular risk.

risk analysis. Process by which risks are examined in further detail to determine the extent of the risks, how they relate to each other and which ones are the highest risks.

risk analysis method. Technique used to analyse the risks associated with a project. Specific categories of risk analysis methods are: (a) qualitative — based on project characteristics and historical data (checklists, scenarios, etc.); (b) risk models — combination of risks assigned to parts of the estimate or project to define the risk of the total project; (c) probabilistic models — combining risks from various sources and events (e.g. Monte Carlo, Latin hypercube, decision tree, influence diagrams).

risk assessment. Identification and analysis of project and programme risks, ensuring an understanding of each risk in terms of probability and consequences.

risk assumption. Any expectations pertaining to the risk itself.

risk category. A method of categorizing the various risks on the project to allow grouping for various analysis techniques such as risk breakdown structure or network diagram.

risk documentation. Includes the recording, maintaining and reporting of assessments, handling analysis and plans, and monitoring results.

risk event. Any potential (identified or unidentified) condition (threat or opportunity) that may or may not occur during a project.

risk handling. Strategies developed with the purpose of eliminating, or at least reducing, the higher risk levels identified during the risk analysis. The strategies may include risk reduction or mitigation, risk transfer/share, risk avoidance and risk acceptance.

risk handling strategy. A process that identifies, evaluates, selects and implements options in order to set risk at acceptable levels given project constraints and objectives. Includes specific actions, timeline, ownership and cost.

risk identification. Process to find, list and characterize elements of risk.

risk management. The handling of risks through specific methods and techniques.

risk management plan. A document covering how the risk processes will be carried out during the project.

risk mitigation. Process to reduce the consequence and/or probability of a risk.

risk modelling. Creation of a physical representation or mathematical description of a risk. Cost estimate and critical path schedule development should be considered modelling practices and not exact representations of future costs, progress and outcomes.

risk monitoring and tracking. The process of systematically watching the evolution of the project risks and evaluating the effectiveness of risk handling strategies against established metrics.

risk owner. The entity responsible for managing a specified risk and ensuring effective treatment plans are developed and implemented.

risk planning. The process of developing and documenting an organized, comprehensive and interactive strategy and methods for identifying and tracking risk, performing continuous risk assessments to determine how risks have changed, developing risk handling plans, monitoring the performance of risk handling actions, and assigning adequate resources.

risk register. Database for risks associated with a project. (Also known as risk database or risk log.)

risk transfer. The movement of risk ownership to another organizational element. To be successful, the risk should be accepted by the organization to which it is being transferred.

scope. The sum of all that is to be or has been invested in and delivered by an activity or project. In project planning, the scope is usually documented (i.e. the scope document), but it may be verbally or otherwise communicated and relied upon. Generally limited to that which is agreed to by the stakeholders in an activity or project (i.e. if not agreed to, it is out of scope). In contracting and procurement, scope includes all that an enterprise is contractually committed to perform or deliver.

startup cost. One-time costs incurred during the transition from construction completion to facility operation.

statement of work (SOW). A narrative description of contracted products or services.

surety bonds. A legal guarantee by a third party that the principal/contractor will perform a specified obligation or compensate the project owner for failure to do so. Surety bonds may cover payment of workers as well as completion of the task.

uncertainty analysis. An analysis that considers all activities associated with one cost estimate and its associated risks. This may also be considered part of a risk analysis or risk assessment.

work breakdown structure (WBS). A product oriented grouping of project elements that organizes and defines the total scope of the project; a multilevel framework that organizes and graphically displays elements representing logical relationships among work to be accomplished. Each descending level in the structure represents an increasingly detailed definition of a project component (products or services). The structure results in a code for each element that is integrated, relates all project work (technical, schedule and cost) and is used throughout the life cycle of a project to identify and track specific work scope. Note: WBS should not be developed or organized along financial or organizational lines. It should be broken into organized blocks of work scope and scope related activities. Financial and/or organizational identification needs should be attached as separate codes that relate to the WBS element.

WBS code. A unique identifier assigned to each element in a WBS for the purpose of designating the element's hierarchical location within the WBS.

WBS component. An element of a WBS, located at any level. It can be a work package or a WBS element as there is no restriction on what a WBS component is.

WBS element. A single WBS component and its associated attributes located anywhere within a WBS. A WBS element can contain work, or it can contain other WBS elements or work packages.

work package. Any deliverable or work component at the lowest level of the WBS structure.

CONTRIBUTORS TO DRAFTING AND REVIEW

Adams, V.	United States Department of Energy, United States of America
Al-Masri, M.S.	Atomic Energy Commission, Syrian Arab Republic
Bayer, P.	University of Zurich, Switzerland
Charles, A.	International Atomic Energy Agency
Day, J.	CH2M HILL, Germany
Dutra, M.	UX Consulting, United States of America
Dzhumabaev, A.	Disaster Hazard Mitigation Program, Kyrgyzstan
Harrington, M.	United States Army Corps of Engineers, United States of America
Howard, B.	University of Lancaster, United Kingdom
Johansson, M.V.	University of Stockholm, Sweden
Kunze, C.	AMEC, United Kingdom
Martino, L.	Consultant, United States of America
Monken-Fernandes, H.	International Atomic Energy Agency
Morse, J.	United States Department of Energy, United States of America

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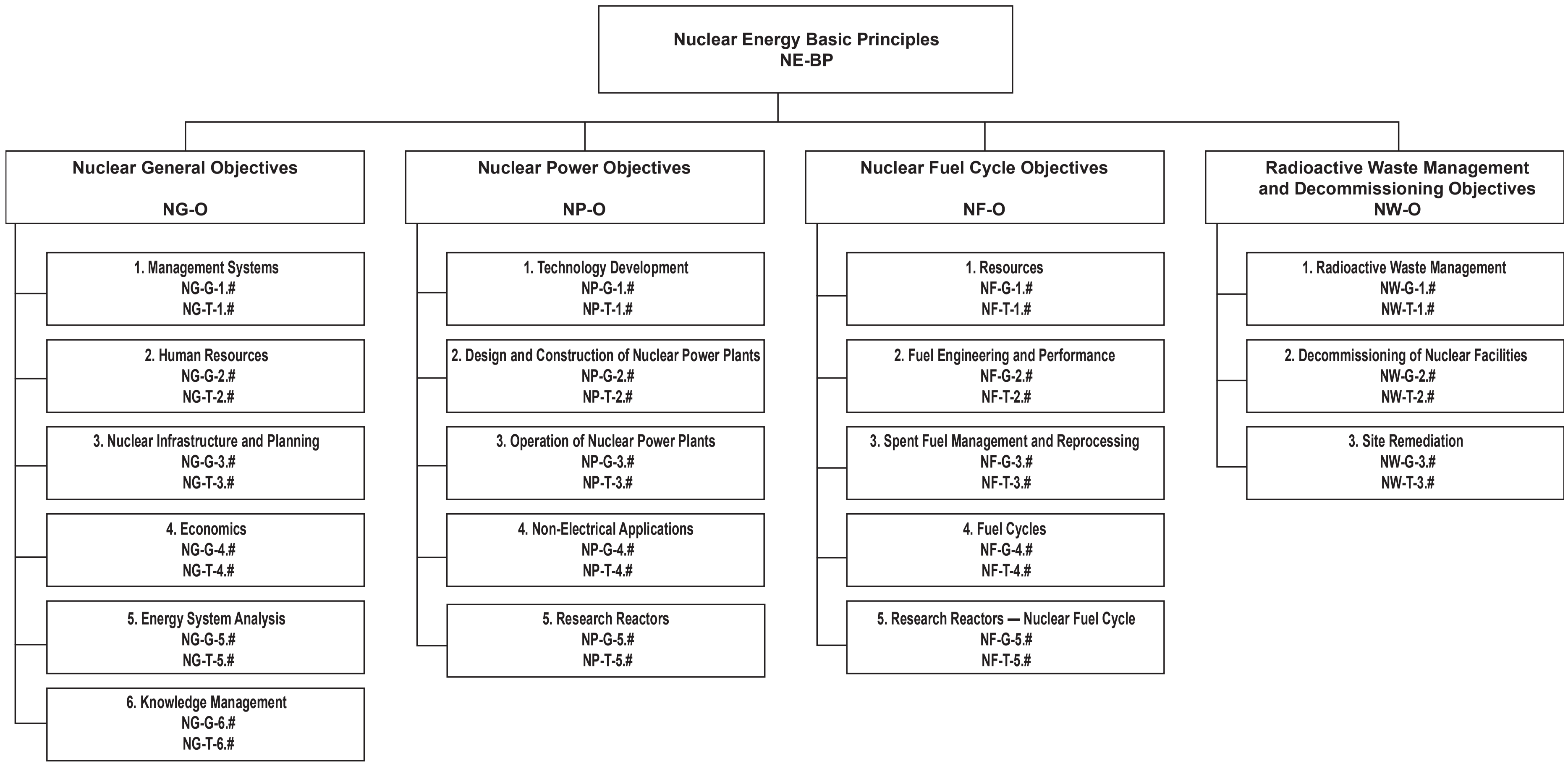

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