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Integrated Approach to Planning the Remediation of Sites Undergoing Decommissioning

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INTEGRATED APPROACH TO PLANNING THE REMEDIATION OF SITES UNDERGOING DECOMMISSIONING

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INTEGRATED APPROACH TO PLANNING THE REMEDIATION OF SITES UNDERGOING DECOMMISSIONING

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Sales and Promotion, Publishing Section
International Atomic Energy Agency
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fax: +43 1 2600 29302
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FOREWORD

The IAEA attaches great importance to the dissemination of information that can assist Member States with the development, implementation, maintenance and continuous improvement of systems, programmes and activities that support the nuclear fuel cycle and nuclear applications, including managing the legacy of past practices and accidents.

Accordingly, the IAEA has initiated a comprehensive programme of work covering all aspects of environmental remediation, including:

(a) Technical and non-technical factors, such as costs, that influence environmental remediation strategies and pertinent decision making;
(b) Site characterization techniques and strategies;
(c) Assessment of remediation technologies;
(d) Techniques and strategies for post-remediation compliance monitoring;
(e) Special issues such as the remediation of sites with dispersed radioactive contaminations or mixed contamination by hazardous and radioactive substance, or the use of monitored natural attenuation;
(f) Strategies for the long term management of nuclear liabilities.

Many fuel cycle and non-fuel cycle sites undergo decommissioning of the infrastructure as and when they are not needed any more. Site remediation will have to be integrated with the decommissioning and the operation of the reminder of the site, possibly making use of existing infrastructure for remediation purposes. The remediation programme should also try to create synergies between the existing activities at a site and the remediation programme in order to use available resources most efficiently.

This publication discusses the issues to tackle the conceptual, management and technical problems of the transition period between decommissioning and remediating a site.

The IAEA wishes to express its thanks to all of the contributors to this report.

The IAEA officers responsible for this publication were W.E. Falck and H. Monken Fernandes of the Division of Nuclear Fuel Cycle and Waste Management.

CONTENTS

SUMMARY

Decommissioning and remediation activities are subject to some common driving forces that influence the ability of decommissioning and remediation programmes to achieve end-states that correspond to planned or anticipated (future) end-uses (i.e. facility or site re-use). In addition, decommissioning and remediation programmes have common resource needs that can result in optimization of available resources to achieve acceptable radiological risk based results faster and at lower costs.

In order to achieve this, it is necessary that the goals of individual decommissioning and remediation activities are aligned and do not conflict with each other while costs are minimized and net health, safety, security and environmental benefits are maximized. Managing the decommissioning and remediation activities in an integrated programme can result in enhanced environmental conditions and/or reduced requirements for additional remediation work, both of which impact the effort to achieve the ultimate site remediation objectives.

The most important step in this process is the establishment of the site remediation objectives, which principally involves selecting the best re-use option for the site. Different technological approaches and different sequences of decommissioning and remediation tasks can be taken to transform the site to achieve its intended end-state.

This report presents a framework in which decommissioning and remediation activities developed altogether (i.e. in an integrated manner) will enhance the outcomes of both tasks.

To achieve this objective, this report addresses:

— Synergies between decommissioning and remediation;
— Life cycle management strategies to design and improve remedial actions;
— Planning tools to support decisions making and remediation

In addition, case studies that illustrate some of the concepts developed in this publication are presented.

Although the focus of this report is on nuclear facilities, the general principles of adopting an integrated approach to planning for decommissioning and remediation apply to many other industrial facilities.

1. INTRODUCTION

1.1. BACKGROUND

Responding to the needs of Member States, the IAEA has launched an environmental remediation guidance initiative dealing with the issues of radioactive contamination world wide. Its aim is to collate and disseminate information concerning the key issues affecting environmental remediation of contaminated sites. This IAEA initiative includes the development of documents that report on remediation technologies available, best practices, and information and guidance concerning;

(a) Strategy development for environmental remediation [1];
(b) Characterization and remediation of contaminated sites and contaminated groundwater [2, 3]:
(c) Management of waste and residues from mining and milling of uranium and thorium, [4]:
(d) Decommissioning of buildings [5, 6];
(e) A database for contaminated sites [7].

The subject of this present report concerns the integration of decommissioning and remediation activities at sites undergoing decommissioning and this fits within the first category of guidance documentation (strategy development).

Worldwide, there are thousands of nuclear facilities[1], generally licensed and non-orphan, that will ultimately require decommissioning[2] and remediation[3]. They range from large nuclear power reactors and complex processing facilities to small research laboratories, nuclear research establishments, uranium and thorium mines, conversion plants, storage facilities and manufacturing plants. The tasks associated with decommissioning a nuclear facility can also vary greatly. They may include large-scale decontamination works, demolition of massive concrete structures or enclosing the facility in a safe condition so as to allow the radioactivity to decay naturally to acceptable levels. At the other extreme, laboratories in which radionuclides have been used may be decommissioned after some modest cleaning and decontamination activities. In all cases, the decommissioning process must be well planned and sufficient resources must be available. Over time, without proper arrangements being made for decommissioning, shut down facilities deteriorate and ultimately

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[1] For the purpose of this report, a 'nuclear facility' is considered to be a *facility* (including associated buildings and equipment) in which *nuclear material* is produced, processed, used, handled, stored or disposed of.

[2] The term 'decommissioning' is defined by the IAEA as the administrative and technical actions taken to allow the removal of some or all of the *regulatory controls* from a *facility* (except for a *repository* or for certain *nuclear facilities* used for the *disposal* of residues from the mining and processing of *radioactive material*, which are 'closed' and not 'decommissioned'). Decommissioning is the process by which a nuclear facility is dismantled after the facility reaches the end of its operational life. The transition from operation to decommissioning involves an intermediate preparatory step where the facility is taken to a safe shutdown state where the hazard sources in the facility are removed and the building systems and facility process equipment that is not needed in support of decommissioning activities are taken out of service. Therefore, the decommissioning of a nuclear facility typically involves the sequenced dismantling of the building systems and structural components after comprehensive radiological surveying is conducted and the identified contamination materials are removed and the contaminated building areas are decontaminated and cleaned. These actions are aimed at ensuring the long term protection of the public and the environment from any residual levels of radioactivity are very low. Under the same protection objective, equipment and materials removed from buildings undergoing decommissioning in order that they can be safely recycled, released and re-used, possibly often after decontamination. The use of the term 'decommissioning' implies that no further use of the facility for its existing purpose is foreseen, but for the purpose of this report the term decommissioning is considered to include re-use of building structures, as appropriate.

[3] The term 'remediation' is defined as any measures that may be carried out to reduce the radiation exposure from existing contamination of land areas through actions applied to the *contamination* itself (the *source*) or to the *exposure pathways* to humans. The remediation process applies to both nuclear and non-nuclear contaminants that have the potential to affect human health and the environment. Remediation is considered to include characterization of the locations of contaminants in the environment, identification of remedial action alternatives, implementation of remedial actions, and ongoing monitoring to assure the confinement or containment of residual contamination.

constitute a radiological hazard to persons in their vicinity from direct exposure to radiation and as a result of radioactive material that may be released to the environment. Structural deterioration may also result in conventional hazards.

Decommissioning activities and remediation activities at nuclear sites are driven by some common driving forces, the most fundamental of which is the protection of humans and the environment from sources of contamination. Safety of decommissioning activities is referred to in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [8]. Article 26 states that "Each contracting party shall take the appropriate steps to ensure the safety of decommissioning of a nuclear facility". Work carried out under decommissioning and remediation programmes is accordingly aimed at achieving end-states that correspond to planned or anticipated (future) end-uses (i.e. facility or site reuse). In addition, decommissioning and remediation programmes have common resource needs and share common activities. These commonalities result in synergies that when identified and fully utilized an integrated decommissioning and remediation programme can lead to the optimization of available resources to achieve (radiological and non-radiological) risk-based results faster and at lower costs. This optimization process is the subject of this report.

In particular, the requirements of regulators to meet radiological exposure constraints and the selection of an acceptable end-state suitable for the site's future use influence the choice of technologies and overall configuration of controls adopted. It must be remembered that when the installation in question was not licensed as a practice the residual exposures will have to be defined by means of optimization process, being an intervention situation. However, there are other factors that influence the decision making process e.g. cost considerations, available resources, and stakeholder concerns. An evaluation of the importance of these driving forces is provided in another document [7]. Because remediation and decommissioning are subject to similar driving forces, the careful identification of opportunities for synergies between remediation and decommissioning may be helpful in optimizing the use of available resources to achieve risk-based results faster and at lower costs. The remediation goals are usually based on radiological and non-radiological risk. Frequently for cost reasons, the remediation is often aimed at achieving 'restricted re-use' or 'fit-for-purpose re-use' as opposed to 'unrestricted re-use'. The remedial objectives for any restricted re-use are then based on meeting appropriate risk criteria associated with the intended land re-use.

Re-use of nuclear sites may come in a number of guises, for example housing, new industry, recreational, museums, or even an authorized disposal facility. Further, the ever-increasing challenge to avoid further exploitation of "*Green field*" sites or undeveloped lands and to restrict new development to sites with a previous industrial history means that cost effective remediation of nuclear sites needs to be undertaken. The same is true of the many chemically-contaminated "*Brown field*" sites outside of the nuclear industry. The evaluation of re-use options is dependent on the extent of remediation that is necessary and feasible in the circumstances. The ideal outcome of land remediation is for the contamination levels to be reduced to the extent that any use of the land is safe, i.e., unrestricted re-use. In the cases where complete remediation (i.e. unrestricted re-use of the land) is not feasible, long-term institutional controls are required to control potential exposures and environmental monitoring is required to confirm the effectiveness of the remedial measures undertaken, whether active or passive in nature. In this case, restrictions on land re-use are imposed until the residual levels of contamination decline (by decay or dispersion) to levels suitable for unrestricted re-use. Accordingly, the future land uses planned for the site should align with the long term stewardship requirements [9]. Examples include the establishment of recreational areas (golf courses, parks) and commercial land developments (shopping centers, industrial parks).

It is important to note that involving the people who will actually benefit from the re-use (as well as other stakeholders) increases the chances of attaining a sustainable end-state for the site. The best approach is to create a sense of 'ownership' in the future land use scenarios.

An important step in exploring the redevelopment potential of a site is to identify these potential key assets and assess their relevance to future development scenarios and particularly the integration of decommissioning activities with site remediation in order to realize the potential of early 'fit-for-purpose' re-use of land. Once identified, these assets need to be protected from deterioration during the transition from the previous use to the new use. This is especially important where the end-use of the land is delayed for a period of time to enable passive remediation to achieve the desired end-state. During the interim period of restricted land use, the risk is that site infrastructure or other land assets may be allowed to degrade, resulting in the ultimate land end-use being less achievable or feasible.

These aspects highlight the importance of implementing a forward-looking planning process for sites requiring decommissioning and remediation. While in the past decommissioning and remediation activities have often been carried out as independent activities, optimization of effort, cost, impacts and risk reductions can be achieved by carrying out decommissioning and remediation activities in an integrated manner. These two different approaches are referred to in this document as the 'non-integrated approach' (independent activities) and the 'integrated approach' (integrated activities).

The differences in these approaches are illustrated in Fig. 1.

The integrated approach requires a change in thinking from non-integrated approaches to decommissioning and site remediation. Under the non-integrated approach, decommissioning is considered in isolation from remediation stages of a site's life cycle. This may result in decommissioning end-points that have ignored the overall aims of site remediation — particularly with respect to the potential impacts on human health and the environment from any residual contamination after the facility is decommissioned. These oversights can be costly in terms of site remediation — particularly with respect to the ability to:

(a) Remediate surface and sub-surface contamination while the decommissioning workforce is still mobilized and project management infrastructure is in place;
(b) Use existing site infrastructure that is required to support remedial actions (liquid and solid waste processing facilities and other 'enabling' facilities);
(c) Realize potential revenues from re-using parts of the site early by remediation to a 'fit-for-purpose' end point at the time a particular facility is decommissioned, as opposed to waiting for all facilities to be decommissioned before the site can be re-used.

Further, the completion of decommissioning activities without consideration of the site remediation objectives can, in some circumstances, result in degraded environmental conditions (e.g. enhanced contaminant mobility), resulting in increased remediation requirements and possibly rendering some site re-use options non-feasible (in turn resulting in potential revenue losses).

These are just a few of the reasons why an integrated decommissioning and remediation programme for a site undergoing decommissioning is probably the most cost-effective in terms of risk reduction.

1.2. OBJECTIVE

The objective of this report is to provide Member States with background information about important aspects of the process for planning the remediation of sites undergoing decommissioning. This document addresses key strategic planning issues. It is intended to provide practical advice and complement other reports that focus on decommissioning and remediation at nuclear facilities. The document is designed to encourage site remediation activities that take advantage of synergies with decommissioning in order to reduce the duplication of effort by various parties and minimize adverse impacts on human health, the environment, and costs through the transfer of experience and knowledge. To achieve this objective, the document is designed to help Member States gain perspective by summarizing available information about:

(a) Synergies between decommissioning and remediation;
(b) Strategic planning and project management;
(c) Planning tools and techniques to support decision making and remediation.

Case studies are also presented as to give concrete examples of the theoretical elements elaborated in the documents.

1.3. SCOPE

This report provides general guidance concerning the planning of remediation activities at sites undergoing decommissioning. As such, the document is intended for individuals interested in the design, selection, review,

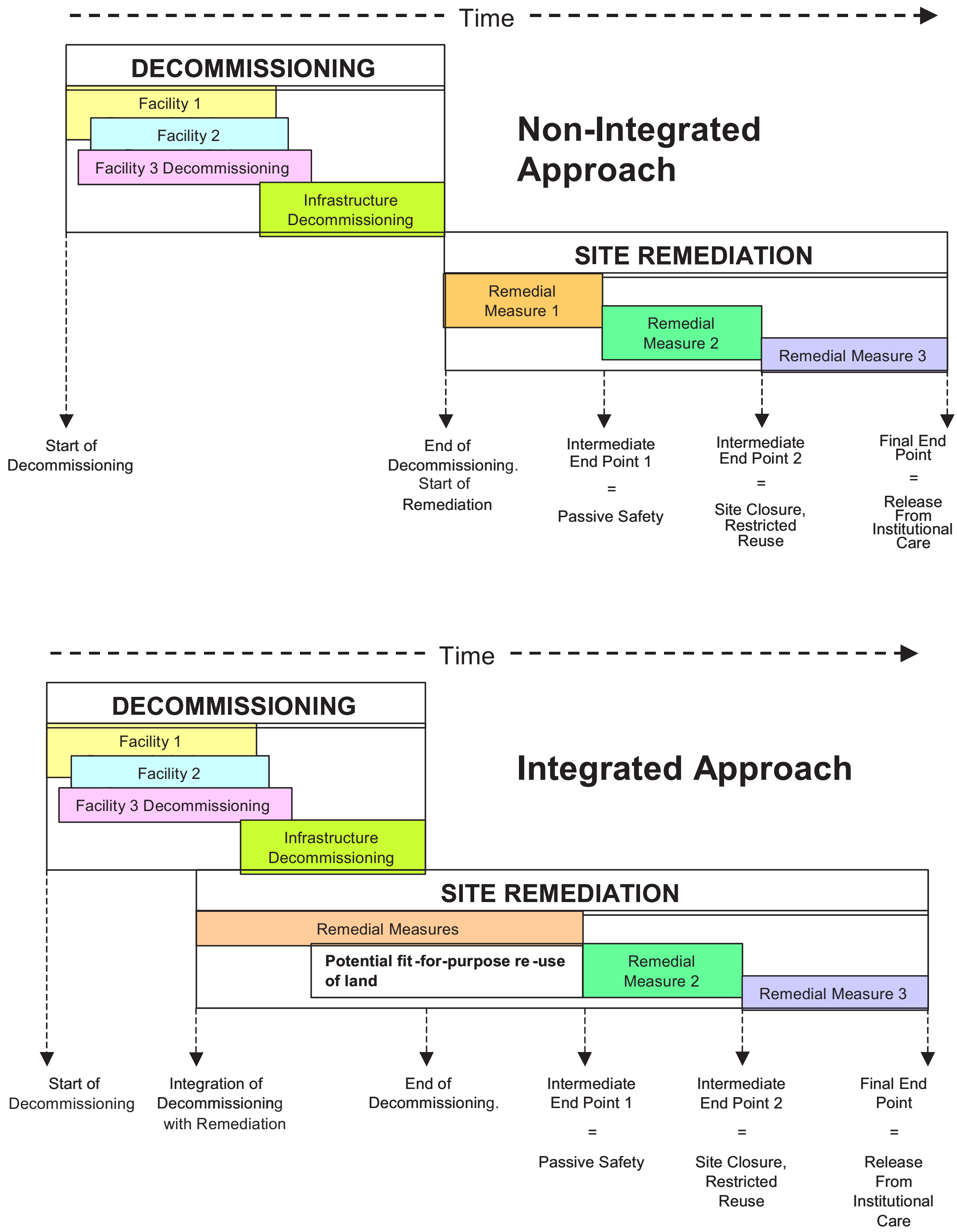

FIG. 1. Non-integrated versus integrated approaches to decommissioning and remediation.

implementation, approval, or oversight of remediation projects at contaminated sites undergoing decommissioning. It is aimed especially at decision makers who are responsible for planning and managing decommissioning and remediation activities applicable to nuclear installations that is or will be under some alternative land use after reaching the end of their operational life.

The guidance provided in this report covers a broad range of aspects in planning a remediation programme in a consistent manner, under the prevailing conditions, including:

(a) Strategic planning and planning tools;
(b) Project management;
(c) Records management.

Although the focus of this report is on nuclear facilities, the general principles of adopting an integrated approach to planning for decommissioning and remediation apply to licensed nuclear sites, sites with naturally occurring radioactive material (NOMR), and non-nuclear sites.

This collection of guidance is intended to promote the development of remediation strategies that are integrated with any associated decommissioning activities in order to contribute to the achievement of satisfactory results in terms of effort, cost, impacts and risks[4].

1.4. STRUCTURE

This report is divided into eight sections:

— Section 1 is the introduction.
— Section 2 describes the conceptual framework for an integrated approach to planning for remediation of sites undergoing decommissioning, including a summary of synergies between decommissioning and remediation.
— Section 3 provides an overview of the process for strategic planning and project management.
— Section 4 describes tools and techniques to assist in strategic planning and project management for identifying and developing remediation activities.
— Section 5 provides information and guidance for optimizing information management processes.
— Section 6 identifies management support systems that are particularly important to remediation activities.
— Section 7 presents general conclusions.
— Annexes that include a series of case studies.

2. CONCEPTUAL FRAMEWORK

2.1. BENEFITS OF INTEGRATED PLANNING

Decommissioning and remediation activities at nuclear sites are subject to some common driving forces, and involve common tasks and interrelated needs for enabling facilities, site infrastructure, workforce and supporting management systems. The integration of decommissioning and remediation activities through the development of a unified strategic plan for site decommissioning and remediation takes advantage of these common driving forces and ensures that;

[4] The term ‘risk’ is used in the text to refer to radiological and non-radiological risks to human health.

(a) The goals of individual decommissioning and remediation activities are aligned and do not conflict with each other;
(b) Costs are minimized,
(c) Net health, safety, security and environmental benefits are maximized.

Experience has shown that managing the decommissioning and remediation activities in an integrated programme that find appropriate synergies between the common driving forces can lead to enhanced environmental conditions, and/or reduce the requirement for additional remediation work, that ultimately impact the effort to achieve the site remediation objectives. Lack of integration can result in increased costs, increased exposures of personnel, and increased duration of the overall effort (which can involve delayed revenues from site reuse). In some cases, degraded site conditions can render certain re-use options unfeasible, creating potential revenue losses and loss of stakeholder confidence. For these reasons, the central premise of this report is that an integrated approach to decommissioning and remediation is necessary in the interest of cost and risk optimization.

2.2. OVERVIEW OF INTEGRATED PLANNING PROCESS

The basic elements of the process of developing an integrated decommissioning and remediation programme for a nuclear facility are shown in Fig. 2. This general process applies to any scale of application; whether an individual facility or a larger nuclear site[5] comprising multiple facilities and contaminated lands. Further, the planning process may be first applied to establish the broad remediation requirements for the site

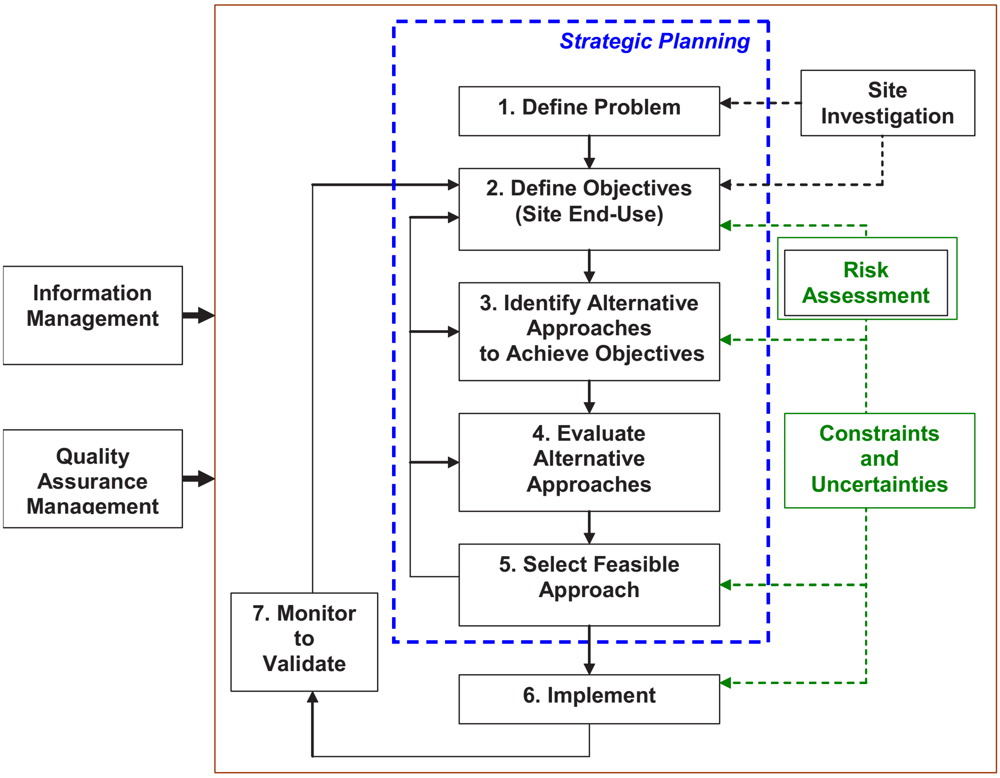

FIG. 2. Decommissioning and remediation planning diagram.

[5] For the purpose of this report, a "nuclear site" is considered to be a geographic region around one or more nuclear facilities that include the nuclear facilities and support services and other infrastructure established at the site and any contaminated lands within or surrounding the site boundaries.

undergoing decommissioning, and then applied repeatedly to establish the remediation requirements for individual decommissioning projects undertaken within the site, thereby enabling the near-term activities to align with the long term objectives.

In general, the planning process involves first defining the overall situation (i.e. characterizing the conditions of the site) through obtaining knowledge of site operational history and undertaking site investigation work. The future end-use of the site is then defined, taking account of the characterization information. The site end-use assumption then forms the basis for the conditions, if any, that apply to the future use of the site. These key assumptions (i.e. remediation objectives) are then used in developing the strategy for the decommissioning and remediation activities. This strategy would typically be a logical sequence of activities that would include not only the necessary decommissioning and remediation activities, but also the planned construction of new facilities to enable the decommissioning and remediation activities to be executed. Alternative approaches to meet the intended site use are typically considered, as there are often alternative technologies for decommissioning and remediation tasks and or alternative sequences of the tasks to consider. These alternatives are evaluated in terms of feasibility, cost, benefit, health and financial and business risks and other evaluation criteria, ultimately ending with the selection of a preferred approach, thus establishing the elements of the site decommissioning and remediation strategy. Because of the evaluation of feasibility of alternative approaches to meet the objective can involve many inputs, some of which are inter-related, the evaluation process is iterative, as indicated by feedback loops in Fig. 2. Stakeholder involvement (i.e., regulatory interactions and public involvement) can be another major cause for iterations in the process, as can other external factors such as resource constraints and technological limitations. These external factors are sources of uncertainty in the process, and for this reason it may be necessary to revise the decommissioning and remediation strategy (planning basis) over time. Through comprehensive and careful integrated planning, however, the potential for significant changes to the planning basis can be minimized. It is through the systematic application of this integrated planning process that the most cost-effective technological solutions to remediation challenges can be found, while taking into account any applicable socio-economic constraints.

The following items describe in greater detail the main elements of the systematic process of developing an integrated decommissioning and remediation strategy. As shown in Fig. 2, the constraints and uncertainties described influence the strategy development process at several points. The figure also shows that the entire planning and execution process is supported by management processes.

2.2.1. Step 1 — Define the overall situation

The situation is defined from a series of investigative actions that would typically include:

(a) A site historical assessment;
(b) Field characterization studies (aimed at identifying the contaminants of concern);
(c) Assessment of the distribution of the contaminants in the environment;
(d) Characterization of site hydrogeology and hydrology;
(e) Assessment of the locations and characteristics of nearby human and ecological receptors.

The information generated from this initial investigative work is used later in the process in the evaluation of potential risks associated with alternative remediation approaches. The characterization of environmental conditions in this stage of the remediation process also forms the baseline for subsequent (continuing) environmental monitoring that is carried out over the duration of the remediation programme, and, perhaps, beyond.

2.2.2. Step 2 — Define objectives of the programme

The broad objectives of a decommissioning and remediation programme are developed from a key decision (assumption) concerning the future uses (end uses) of the site. The selected end-use provides the basis for the end-state, which includes the permissible levels of residual contamination in the environment. A range of alternative end-uses can be considered, with the alternatives including interim uses such as the establishment of an industrial centre during the period of time that decommissioning operations are carried out. The decision on site end-use is made taking into consideration of the characterization information available for the site, as the extent of contamination will influence the feasibility of alternative end-uses [10]. The issue of feasibility forms the basis for conditions, if any, that apply to the future uses of the site.

The site end-use should also be defined in consultation with a wide variety of stakeholders to ensure stakeholder buy-in. The decision on the end state is therefore dependent on political and socioeconomic factors as much as on technical and financial constraints.

The end-use assumption (and any conditions that apply) forms the basis of the site remediation objectives, which are ultimately stated as criteria for the target residual levels of contaminants in the environment at the end of the programme. Once the site end-state has been defined, the strategy for transforming the site from the present state to the required end-state is developed.

As mentioned previously, in an integrated plan, the remediation objectives for the decommissioning of an individual facility within a nuclear site can be influenced by the broader objectives for the site. It is important to note that in addition the objectives for the site (and for individual facilities) can be influenced by national requirements (i.e., guidance or requirements from the national regulatory authorities), which can be influenced by international guidance. This relationship is illustrated in Fig. 3. It is therefore important that guidance and requirements at the national and international scales be considered carefully when the site objectives are established.

2.2.3. Step 3 — Identify alternative approaches to achieve objectives

Once the site end-use and the associated site end-state have been defined, the strategy for transforming the site from the present state to the required end-state is developed. As mentioned previously, this strategy would typically be a logical sequence of activities that would include not only the necessary decommissioning and remediation activities, but also the planned construction of new facilities to enable the decommissioning and remediation activities to be carried out. Alternative approaches to meet the intended site end-use are typically considered, as there are often alternative methods and technologies for decommissioning and remediation tasks and or alternative sequences of the tasks to consider. While this strategic planning step can be complicated (depending upon the number of alternative approaches that apply to the site), there are tools available to assist in this process, such as optioneering analysis, sequence analysis, etc. (see Section 4).

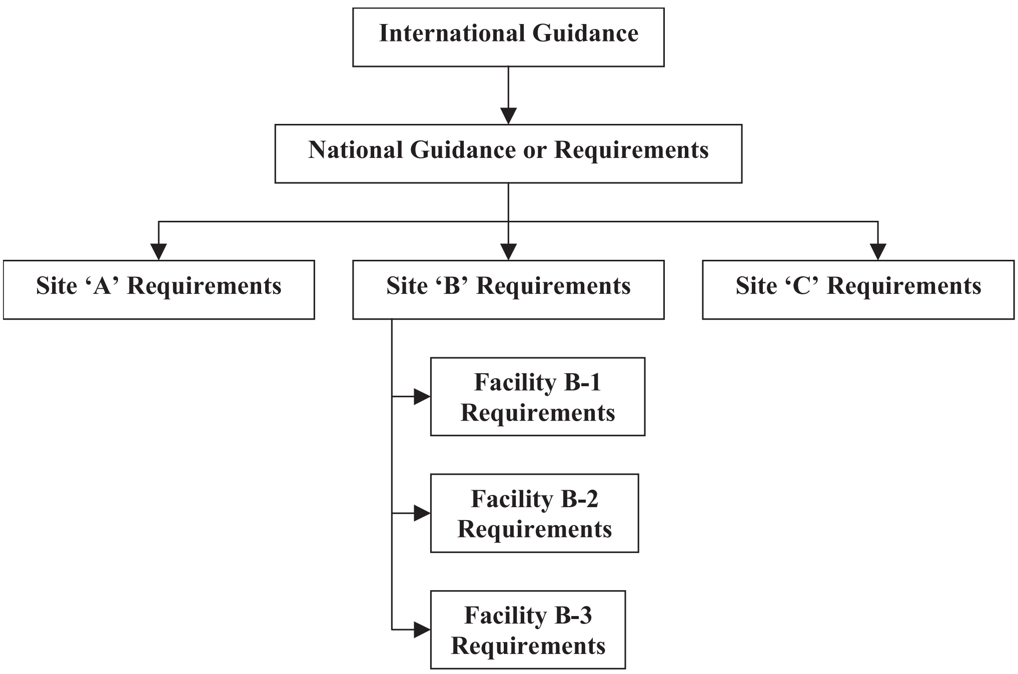

FIG. 3. Tiered requirements for decommissioning and remediation.

With respect to remediation activities, specific remediation techniques are discussed in Ref. [2], but generally they fall into two categories; passive remediation (i.e., allowing natural dispersion and decay to reduce the hazards) and active remediation (e.g., soil removal). There are also mitigative measures that can be implemented to enhance the performance of the adopted remedial measures (e.g. infiltration barriers).

A risk based approach is applied in the process of identifying (and evaluating) alternative strategies, as the underlying requirement for decommissioning and remediating a nuclear facility or site is to reduce the hazards and risks to acceptable levels. Further information on the risk-based approach to strategic planning is presented in Section 3.

2.2.4. Step 4 — Evaluate alternative approaches

Each of the alternative approaches to decommissioning and remediating the site are subject to evaluation to identify and quantify their advantages and disadvantages, as measured by evaluation parameters based on technological limitations, health, safety, security and environmental considerations, cost, business risk and socioeconomic aspects. Components of the evaluation are often carried out using tools that enable automation or simplification of what would otherwise be exhaustive tasks. A variety of tools are available to evaluate the alternatives from different perspectives, whether optioneering analysis, sequence analysis, business risk analysis or cost effectiveness analysis. These tools are discussed in more detail in Section 4. The output of the evaluation process is typically a matrix listing the advantages and disadvantages of the alternative approaches and estimates of the cost or safety performance of the alternatives.

2.2.5. Step 5 — Select feasible and most adequate approach

The selection of the most convenient approach to remediating the site in question, under the prevailing circumstances, is carried out using the evaluation matrix generated in the previous step. The first decision in the selection process is whether any of the alternatives can meet the remediation objectives. If this is not the case (i.e. a technology does not exist, or constraints from stakeholder input are prohibitive), then the remediation objectives must be re-assessed (as indicated in the figure by a feedback loop). Where alternative technological solutions exist, the selection process continues with a comparison of the different evaluation aspects (e.g., cost, safety, socioeconomic factors). Usually the different evaluation aspects are contradictory in indicating the most adequate approach, and as such the selection of the most appropriate approach often must be carried out by applying weighting (importance) factors to the different evaluation aspects. Decision analysis tools can be applied to assist this selection process (discussed in Section 4).

2.2.6. Step 6 — Implement decommissioning and remediation tasks

The implementation step is the execution of the project(s) developed from the selected site remediation approach. The project activities can be carried out in different steps that can occur over different timelines, depending on the selected remediation process (i.e., whether passive or active, or a combination with or without mitigative measures such as infiltration barriers). It is important that decommissioning and remediation activities be integrated in projects in order to enable optimization of costs and risks. Further discussion on project management is provided in Section 3.

Implementation activities are also supported by key management processes that enable the strategic planning and associated project activities to be carried out with due care for quality, health, safety, security and the environment. The retention of records is another management support area that is important in a decommissioning and remediation programme, especially given that such programmes are executed over decades and in some cases centuries. The secure retention of records is a requirement not only for implementation activities, but also for all other strategic planning steps, including (and especially) the facility and site characterization work in the first step. Further information on these management systems is provided in Section 5.

2.2.7. Step 7 — Monitor to confirm that objectives are met

Post-remediation monitoring entails the application of an environmental monitoring programme to ensure that the environmental performance of the remediated site meets the remediation objectives (i.e. the planned end-state). This performance evaluation is carried out using performance indicators, whether groundwater contaminant concentrations or other physical parameters. Where deviations are identified in the performance indicators, investigative actions are triggered, and corrective or mitigative actions are carried out to resume progress towards the remediation objectives. If these actions are not successful, then the remediation objectives must be adjusted, and a revised plan established, possibly with a different (more restrictive) end-use. Thus, the monitoring of conditions is an important source of feedback for the remediation programme.

2.2.8. Influence of constraints and uncertainties

As shown in Fig. 2 as a box beside the sequence of steps involved in developing an integrated decommissioning and remediation programme, a range of constraints influence the viability of different strategic planning approaches, and these constraints can even influence the overall objectives of the programme. These constraints can include, among other things, stakeholder input (public, regulator), technological limitations, and limitations in financial resources, workforce, and the infrastructure required to implement the programme. Many of the workforce and infrastructure requirements for decommissioning and remediation programmes are common to each other; hence the integration of decommissioning and remediation programmes is a key method of optimizing the work

As mentioned previously, as a result of the long time periods over which decommissioning and remediation programmes are executed, changes in these constraints can occur, which is a key source of uncertainty in the programmes. Where changes have an impact on the cost or other factors influencing the viability of the selected remediation approach, the selected approach can be rendered non-viable, resulting in the possible need to reassess the remediation objectives (as indicated in Fig. 2 by the feedback loop).

2.3. SYNERGIES BETWEEN DECOMMISSIONING AND REMEDIATION PROGRAMMES

2.3.1. Identifying synergies

In this report, the term ‘synergism’ refers to the concept that working together or cooperating in a combined effort by sharing information and resources to accomplish some project tasks can produce more benefits than are achieved through independent and consecutive efforts. Synergies are possible between remediation activities and decommissioning activities because each effort is based on a common objective. The primary objective of decommissioning and remediating a nuclear site is to remove (or re-use) the nuclear facilities and to reduce any associated contamination levels to the appropriate ones to (acceptable for) the future use(s) of the site. As a result, the successful design and implementation of remediation and decommissioning projects at nuclear facilities involves a number of common tasks including:

(a) Project management;
(b) Site and facility radiological characterization;
(c) Risk assessment;
(d) Materials and waste management;
(e) Records management;
(f) Quality management programme;
(g) Measures to ensure occupational safety and health;
(h) Measures to avoid environmental degradation;
(i) Administrative measures to ensure regulatory compliance;
(j) Measures to ensure stakeholder involvement.

Identifying potential synergies in each of these activities (e.g. common needs for enabling facilities, site infrastructure, workforce and supporting management systems) may make it possible to complete projects in a more cost effective manner and, perhaps, in a shorter time.

General experience has shown that when a facility or operating site is finally shut down, usually there are a significant number of issues facing management that require attention with some urgency, whether the issue is the need to empty structures containing radioactive liquids, or the need to decommission the shutdown facilities, or to remediate soils contaminated from past practices or accidents. Typically these issues are managed using a strategic planning process that involves first defining the preferred site end-state, then identifying, integrating and scheduling all decommissioning and remediation activities to meet the site end-state objectives. This high-level, strategic planning is another common activity that includes synergies of importance.

For a multi-facility site, strategic planning is the coordination of multiple projects to decommission the buildings and remediate the building sites. It is through this strategic planning process that all decommissioning and remediation activities (projects) can be identified and the steps taken to develop the supporting common tasks in a manner that efforts and costs are minimized and impacts and risks are optimized.

The sections that follow define the common activities listed previously and discuss the synergies between decommissioning and remediation activities.

2.3.2. Project management synergies

The term ‘project management’ refers to a series of management tasks involved in the planning and execution of projects aimed at accomplishing specific objectives. The same general project management tasks apply whether the project is to decommission a specific building, or to remediate the soils at the building site, or whether the project is to construct an enabling facility that will later require decommissioning. These management tasks include establishing a project management structure, creating a work breakdown structure, preparing working procedures, identifying resource requirements, establishing training and monitoring schedules, as well as many of the supporting technical and administrative activities discussed later in this section (e.g. quality management programme, risk assessment, records management, etc.).

For the purpose of this report, projects are considered as detailed planning processes that follow from the broad strategic planning that identifies the needs for the projects, and it is the commonality in the development and execution of projects that creates the synergies between decommissioning activities and remediation activities. As such, there are many opportunities for cost, schedule, impact and risk reduction that exist if decommissioning and remediation activities are developed in an integrated manner. In addition to the common aspects mentioned previously (e.g. management structure, records, quality management), synergies include:

(a) Staff experience and process knowledge (particularly where facility operations staff are used in the decommissioning and remediation activities);
(b) Facilities and other infrastructure required to carry out project activities (e.g., solid and liquid waste treatment facilities);
(c) Management systems required to support the project activities (e.g., records management);
(d) Budgetary approval;
(e) Regulatory approvals.

In general, elements of project planning address, among other things, staff resource requirements, training requirements, environmental protection, safety assessments, working procedures, time schedule, and other technical and administrative aspects. Additional management, technical and administrative personnel may need to be recruited and assigned responsibility for one or more functions, as appropriate. It is important that project staff be technically and professionally qualified and have related practical experience. It is preferable, particularly in the early stages of a project, to include, in the project team, persons who were involved in the operation of the facility/plant/site who would therefore be very knowledgeable of the design and operational history. Further, staffing should be undertaken in an early phase of the project so that effective planning can start early, and the same staff should be retained over the duration of the project to avoid delays related to continuity issues.

When staffing extensive projects, it is helpful to systematically identify important technical, operational and administrative aspects when defining individual management requirements, even if the same personnel eventually manage these aspects. This effort results in a listing of skill sets required to plan and execute the project decommissioning and remediation tasks, and enables the development of a suitable supervisory structure under which it can operate. The required skills list combined with information on the skills and qualifications of project staff provide the basis for the development of an effective project training programme that would ensure that the staff meets the skill requirements. The necessary training of staff to address any gaps provides assurance that the project is executed in accordance with current practices and standards in technology.

It is important that the project manager be appointed before the facility is shut down. This manager would carry the responsibility for undertaking the initial planning, which would include ensuring that the facility is brought to a safe shutdown state before being transferred into the decommissioning programme. The manager needs not necessarily have direct experience in the operation and maintenance of the facility, but this background would be advantageous.

2.3.3. Site and facility characterization synergies

The term ‘facility characterization’ generally refers to the studies carried out to quantify the conditions and hazardous sources remaining within the facility subject to decommissioning, and the term ‘site characterization’ refers to similar studies directed at the land beneath and around the facility [11]. Although there are differences in the characterization requirements for a facility to undergo decommissioning and the requirements for the subsequent remediation of the site, there are also similarities and synergies that minimize redundant work effort. Some synergies are also important in minimizing the generation of radioactive wastes and in minimizing the potential impacts of decommissioning activities on the environment (i.e. influencing site remediation requirements).

A historical site assessment that provides a qualitative characterization of the site based on historical records is usually undertaken first. It provides also an overview of past activities on the site and hence indications of what types of contamination and where they might be expected. Experience shows that information on facility operating performance (e.g. routine and accidental releases of contaminants) is important in directing not only facility characterization work but also site characterization work. Because of this synergy it is important that the scope of the historical assessment work includes information regarding the building site and the assessment provides recommendations for site characterization work.

In order to optimize the historical assessment, it is usually easier to obtain historical information for sites that are still in operation. *In this regard, it is important that historical assessments be conducted while the facility is still in operation to take advantage of the knowledge of facility staff and to have good access to facility records.* Following from the synergy discussed previously, records from site environmental monitoring or excavation work should be reviewed in order to identify contaminants in the environment that may have been released from the facility. The contaminants that are found in the environment should be considered when facility records are reviewed in order to identify the nature of the release.

Facility characterization work involves gathering adequate radiation and contamination measurements (for radiological and non-radiological contaminants) to determine the contaminant species, maximum and average dose rates and contaminant levels of inner and outer surfaces of structures or components throughout the facility. The focus of this work is to identify the requirements for removal of hazardous sources and subsequent decontamination efforts. The results are also used to define the health and environmental protection measures required during decommissioning and remediation, and in particular the hazardous sources encountered during decommissioning that could potentially impact subsequent remediation work. This form of synergy is particularly important, as some decommissioning activities can result in degraded environmental conditions that result in increased remediation requirements. One example is where the removal of a building structure without identifying and remediating contaminants in the soils beneath the facility can result in enhanced contaminant mobility because of the infiltration of rainwater through the soils (otherwise prevented by the building structure). Avoiding the generation of waste in the first place is the most cost-effective way to deal with contaminated land [12].

Facility characterization surveys are also important in facilitating the estimation of potential wastes arising from decommissioning activities, this is important in defining waste storage requirement and the associated cost estimating [13].

Site characterization efforts are aimed at identifying and delineating contamination in the soil and groundwater and, as appropriate, other environmental compartments such as sediments and vegetation. Knowing the types of contaminants and their distributions in the different environmental compartments, the appropriate cost effective remediation solutions can be identified. The characterization information also enables the development of effective environmental performance measures (metrics) that can be applied during the decommissioning and remediation programme. Again, by taking an integrated approach to decommissioning and remediation activities, performance indicators (i.e. the monitoring of key contaminants at specific locations) can be effective in monitoring performance, as without full integration, key parameters may be missed, or contaminant migration tracks (plumes) may be missed.

An integrated approach to environmental performance monitoring is particularly important for correctly predicting future performance in pathway analyses, which is one of the methods to evaluating the effectiveness of active and passive remediation measures. As such, the absence of an integrated approach can result in risk assessment work being incorrect, and the selected remediation approach being only partially effective.

There are other general synergies between site and facility characterization activities that are important. These include:

(a) Common records associated with facility histories, building and land usage, environmental compliance monitoring, unusual incidents;
(b) Common records associated with defining radioactive and hazardous chemical inventories;
(c) Common records associated with facility drawings;
(d) Holistic view of the whole of the decommissioning task and an ability to ensure that the decommissioning survey and remediation survey are sufficient to support the risk management measures necessary to ensure that risks to human health and the environment are sufficiently low for the decommissioned area and the intended future use of the land area;
(e) Stakeholder confidence that the ongoing management of the site clearly demonstrates an intention to control and manage potential risks. This might be seen as part of the contingency arrangements;
(f) Integration of long term monitoring arrangements for any residual sub-surface contamination into the site's life cycle — taking account of those decommissioned areas that are at an intermediate site end-point.

2.3.4. Risk assessment synergies

The term 'risk assessment' refers to the systematic estimation of potential exposures and risks to human health and the environment from concentrations of radionuclides or hazardous chemicals at nuclear facilities. Risk assessment is one of the central elements of remediation and of decommissioning because it can aid decision makers in determining an acceptable end-state suitable for future use. In addition, risk assessment is used as a planning tool to identify and manage possible occupational safety and health risks to workers involved in implementing the remediation and/or decommissioning project by identifying significant pathways [14].

The results of risk assessments may be used to design safety plans that minimize the risks during remediation or decommissioning. The application of risk assessment to determine potential risks that may result from waste management activities, including on-site or off-site transportation, can aid in the identification of risk-minimizing alternatives for managing the residues from remediation or decommissioning. Ecological risk assessment will help to identify potential adverse effects on the environment. Risk assessment may be one of the common activities that offer major opportunities for synergies, especially with respect to sharing site characterization data, conceptual site models, and technical staff who design and conduct risk assessments

Integrating the risk across the full spectrum of the life cycle of nuclear facilities ranging from operation, to decommissioning and remediation, to post-decommissioning can help to reduce overall risk to human health associated with those activities. Separate risk assessment of each activity may lead to risk 'displacement' by the transfer of risk to other activities rather than overall risk reduction. For example, soil removal may reduce on-site risk but create off-site risk associated with transportation (and disposal). Considering those potential risks jointly optimizes protection against exposure to radiological dose.

2.3.5. Materials and waste management synergies

Decommissioning of a nuclear facility generates large amounts of materials and varying volumes of waste during dismantling of structures, systems, and components that are quite different from the normal operational wastes. Through careful planning and sequencing of dismantlement operations, most of the waste can be segregated into inactive materials and (low-level) waste. Dismantling of activated and contaminated components would generate radioactive waste and the volumes of this can be kept low enough through appropriate strategies and technical options. The techniques selected for dismantlement need to be properly evaluated based on considerations of the overall primary and secondary wastes that would be generated [15].

Significant reduction in volumes of wastes generated can be achieved through a well-formulated decontamination programme, appropriate dismantling techniques, contamination control and suitable radiological and administrative control measures. Re-use and recycle strategies can substantially reduce the amount of material that has to be classified as low-level waste.

As compared to decommissioning waste that would be predominantly metallic and superstructure concrete waste, remediation may generate large quantities of contaminated soil. Recent plant design trends aim at minimizing potential environmental damage from abnormal events and to provide for easier mitigation. For instance, pipe work is not put underground, where it is difficult to monitor and repair. In the case of the older nuclear facilities such (chronic) events may have led to the contamination of the surrounding soils, the remediation of which may generate large volumes of waste, etc. These aspects need to be factored into the planning process for remediation.

Minimizing potential waste generation by applying risk management approaches is likely to reduce waste management costs. Recycling and re-use of releasable materials from decommissioning may further reduce remediation costs. Taking measures to limit subsurface contamination and to minimize the footprint during decommissioning is an additional synergy that may reduce the need for future remediation and/or waste disposal. Appropriate timing of decommissioning and remediation can be an additional option, as some contaminants decay or degrade through the period of institutional care, thereby removing the need to manage *ex situ* potentially contaminated materials or soils.

2.3.6. Occupational safety and health synergies

The term ‘occupational safety and health’ refers to the potential hazards and risks to workers involved in implementing the actions involved in decommissioning and remediation activities. Examples of risks include possible death or injury while dismantling buildings, transporting wastes on or off site, operating remediation technologies, or being exposed to radionuclides or hazardous chemicals.

An integrated approach to occupational safety and health maximizes the use of available resources within the constraints imposed by time schedules for project completion. Potential synergies may be obtained by having remediation projects collaborate with the related decommissioning projects in collecting information from safety studies, medical surveillance programmes, epidemiological or toxicological studies, regulatory requirements, and reference sources. Working together to design and collect necessary occupational safety and health data may avoid duplication of staff. It also may make it possible to use shared laboratory and other analytical facilities. This will reduce the overall cost. Such coordination of effort can produce substantial benefits

As well, the synergies between facility and site characterization work (discussed previously) apply, as inadequacies in identifying the hazard sources can be the root cause for personnel exposures.

2.3.7. Records management synergies

Synergy with respect to records management for the integrated decommissioning and remediation approach comes about through:

(a) Identification and rationalization of common data;
(b) Logical structuring of the information management system so that it mimics the remaining life cycle of the nuclear facility;
(c) Consideration of the audience for the record.

The sources, types and form of data (e.g., spreadsheets, CAD files, photographs, diagrams, maps, plans, and word processing files) are generally disparate [15] and the purpose of collection can be completely different for a current or future use. This is particularly true of historic data. Identification of common types of data and their rationalization relative to the requirements of a number of potential users, therefore, enables new data to be collected once, with the intended audience in mind; rather than many times, with only the specific job-in-hand in mind. People requiring access to the data in the integrated approach include:

(a) Site strategists and project planners;
(b) Decommissioning engineers;
(c) Remediation engineers;
(d) Waste management managers;
(e) Future relevant site personnel.

In addition other audiences include:

(a) Regulators;
(b) Current liability owners;
(c) Future site owners or managing agents;
(d) Future site users;
(e) Other stakeholders.

It is unlikely that a single person or department will be responsible for all the data in the records management system. However each record of data needs to have an identified custodian to ensure that the data meets the quality assurance and quality control (QA/QC) requirements of the data management system.

Another important synergistic aspect of managing a large data store is to consider how all the different users might access these data. As mentioned above, the data can be logically structured. Since much of the data relate to facilities or areas of ground, access could also be provided through a geographical interface such as a Geographical Information System. An advantage of this latter aspect is that the geographical interface could be based on a visualization of the site at various times in the future [16].

2.3.8. Quality management synergies

The management responsible for decommissioning and site remediation is generally committed to the implementation of a quality control and quality assurance programmes. These ensure the orderly safe implementation of the planned tasks and compliance of all activities that would have an influence on the execution of decommissioning and site remediation in a safe manner until the release of site from regulatory control. A QC/QA plan would be put in place before start of the decommissioning and remediation to ensure that all the mandatory requirements as stipulated by the regulatory authority are met with regard to safety of the occupational workers, the public and the protection of environment. The plan should have adequate coverage to verify and audit management and performance functions and also ensure that all required permanent records are maintained in a manner so that they are easily retrievable when required for reference and verification until the time of unrestricted release of the site [17].

2.3.9. Administrative measures to ensure regulatory compliance

Regulatory consent for decommissioning and site remediation activities forms an important necessary step as is the case for each stage in the life of a nuclear facility or site, namely site selection, design, construction, commissioning, operation and decommissioning including remediation. Already at an early stage of the life cycle, even when identifying the need for a nuclear facility, one has to keep in mind that ultimately one day the facility will have to be decommissioned and the site may be in need of remediation to become fit for re-use. Hence the regulatory requirement would call for the licensee to put in place a conceptual plan for decommissioning and remediation of the site at the time of design approval. Normally the conceptual plan would be periodically updated taking into account any significant event that has led to spread of contamination at the site.

Towards the end of facility operation, when it is finally shutdown for reasons such as technology obsolescence, economic, significant events or not being able to meet the regulatory requirements for continued operation, the licensee needs to formulate an appropriate strategy and prepare a detailed plan for decommissioning and site clean-up addressing the various issues concerning the safety of occupational workers, the public and environment. The IAEA has developed a set of documents as part of its safety standard series that focus on safety during decommissioning. Further, a document has been developed that provides guidance to the regulatory body and licensees for the remediation of sites undergoing decommissioning [18].

2.3.10. Stakeholder involvement

The term ‘stakeholder involvement’ refers to the activities conducted during the design and implementation phases of the remedial action and/or decommissioning project that attempt to determine the needs and concerns of various parties including elected officials, interested citizens, workers, business, and environmentalists. The goal is to foster a dialogue which helps to create positive relationships between project managers and stakeholders.

While project managers often think about individual projects, stakeholders may have a more general perception of the site that does not necessarily distinguish between remediation and decommissioning. As a result, when feasible due to constraints imposed by time schedules for project completion, synergies may be obtained by having remediation projects collaborate with decommissioning projects in bringing about stakeholder involvement and consultation. Active involvement of stakeholders during the design phase of projects may help in the identification of broadly acceptable end-uses of the site (and accordingly the end state), definition of priorities, and selection of technologies. Indeed, stakeholders may have a vested interest in retaining certain features and infrastructure elements. They may want to re-use buildings or roads, for instance, which will have to be considered in the decommissioning and remediation planning. Another aspect not unusual in mining communities is that locals are so used to certain man-made mining related landmarks, such as characteristically shaped spoil heaps, that they may want to retain them. Stakeholder involvement from the very beginning on may also help to create a sense of ‘ownership’ in the chosen paths and final site uses, thus facilitating the stewardship requirements.

Using a shared staff of public involvement experts may reduce manpower costs and facilitate broader awareness of stakeholder perceptions about acceptable and unacceptable end-states for the site. Such insights may help project managers reduce or avoid misunderstandings, especially when some elements of the overall effort at the site are controversial.

3. STRATEGIC PLANNING AND PROJECT MANAGEMENT

3.1. BACKGROUND

Careful planning and management is essential to ensure that decommissioning and remediation are accomplished in a safe and cost effective manner [19]. Strategic planning provides the broad framework or guidelines that define an organization’s vision and mission. Project management provides the details for implementing the specific projects to accomplish elements of the strategic plan. The strategic plan can identify opportunities for integration. Successful project management that takes advantage of synergies between decommissioning and remediation turns those opportunities into reality. From a technical point of view, it is essential to develop a site-specific strategic plan and approach to project management. The details of the strategic plan and approach to project management would depend on the type and complexity of the facility as well as key data gaps and uncertainties.

In order to ensure safe and effective decommissioning and remediation, it is essential to establish clearly stated, verifiable end-states. This is probably the most important single factor. The end-states must be derived from the goals and objectives of the organization responsible for the tasks and also be acceptable to the organization taking over the facility at the end of decommissioning and remediation and any remaining stakeholders. The end-state must also be readily verifiable and independently measured and reported. If iteration is needed to achieve goals, then this must be taken into account. Sound strategic planning and project management make this possible.

3.2. OVERVIEW OF STRATEGIC PLANNING

Strategic planning is a management tool that helps site managers answer basic decisions about major priorities and actions in order to focus resources on accomplishing large-scale goals. In short, strategic planning is a disciplined effort to produce fundamental decisions about what, why, and how an organization intends to conduct its operations, with a focus on the future, to create desired outcomes. The process is strategic because it involves being clear about objectives and resources, and incorporating both into being consciously responsive to a dynamic environment. The process is disciplined because it raises a sequence of questions that helps planners examine experience, test assumptions, gather and incorporate information about the present, and anticipate the future. The process is about planning because it involves intentionally setting goals (i.e. choosing a desired end state) and developing an approach to achieving those goals by meeting objectives. The process is dynamic because it requires willingness to make and reconsider decisions over time. Strategic planning is an ongoing exercise. It is important to review the plan periodically and adjust the strategic plan to reflect new information as it becomes available.

Strategic planning stresses the importance of making decisions that will ensure the organization's ability to successfully respond to change and uncertainty in order to accomplish its goals and objectives. Strategic planning serves a variety of purposes for sites undergoing decommissioning and remediation, including to:

(a) Clearly define realistic goals and objectives over a specified time frame within the site’s capacity for implementation;
(b) Ensure the most effective use is made of the organization’s available resources by focusing them on the key priorities;
(c) Provide a baseline from which progress can be measured and establish a mechanism or informed change when needed;
(d) Communicate underlying logic for goals, objectives, and actions to stakeholders and regulators.

Unlike project management which focuses on specific programmes and actions within a nuclear site, strategic planning concentrates on fundamental decisions to clarify "the big picture" across the entire site. In order to clarify the big picture, most strategic planning methodologies depend on a four-step process to answer the following questions:

(a) What is the current situation?
(b) What are the goals and/or objectives (desired end state)?
(c) What are the incentives for and barriers to achieving desired end state?
(d) What are effective actions to achieve the goals/objectives?

The strategic planning process emphasizes fundamental decisions and actions because choices must be made in order to answer the sequence of questions mentioned above.

Completing the steps in the strategic planning process provides a roadmap for what the decision makers want to accomplish in the future if everything goes exactly as hoped. The roadmap links goals, objectives, and actions based on priority and timing. It summarizes:

(a) A series of actions that need to be undertaken to meet goals and objectives;
(b) The timing for when actions will start and end;
(c) The resources required for action programmes;
(d) The metrics for measuring programme performance;
(e) The managers who will be in charge of the programme;
(f) The benefits expected from implementing this programme;
(g) The contingency plans.

The roadmap forces managers to identify which elements of the strategic plan are fairly easy to meet and which are very difficult, if not, impossible to attain with available resources. For example, by developing a strategic plan, managers can identify key uncertainties such as the availability of proven technology or whether proposed activities rely on innovative technologies that have not yet been deployed widely. It also forces managers to co-ordinate goals so that they do not conflict with each other. As a result, sequencing from near-term to medium-term to long-term may make it possible to create a strategy that integrates compatible elements across the organization.

In general, strategic plans can fail due to inappropriate strategy or unsuccessful implementation. Inappropriate strategies may arise due to ambiguity in defining end states, developing action plans that are incapable of being implemented, and/or a poor fit between the external environment and site's available resources. Insufficient site characterization and untimely or inadequate stakeholder involvement also can produce flawed strategies. Failure to review and periodically update the strategic plan as new information becomes available can result in a strategy becoming inappropriate over time because it no longer reflects site conditions, resources allocations, etc. Unsuccessful implementation may happen due to over-estimation of capabilities and under-estimation of resource requirements, failure to coordinate activities, and/or lack of ongoing senior management, stakeholder, or regulator support.

3.3. PROJECT MANAGEMENT

Project management focuses on the day-to-day details of designing and implementing a set of activities to accomplish specific goals and objectives developed by the strategic plan. Project management focuses on organizing and directing a specific effort. It typically involves developing a project plan which includes project objectives, tasks, milestones, resources, and timeline. For example, the set of activities associated with removing a structure during decommissioning or the remediation of a groundwater plume are types of projects that occur at some nuclear sites.

Residue management is a common issue facing managers of decommissioning and remediation projects.[6] The activities involved in decommissioning a facility and its associated structures, including subsurface piping, etc. can produce large amounts of contaminated materials with varying levels of radioactivity, as well as contaminated media, primarily soils [20]. Remedial actions leading to reduced exposure to radiation and to an improved environmental and/or economic value of a site are designed to address existing contamination of soil, groundwater, and/or surface water at a site. As a result, the management of contamination, i.e., containment or confinement on-site, removal, similarly can produce contaminated material and also result in incidental contamination of media. An integrated approach to planning and sequencing residues management can afford the opportunity to assess the waste streams in terms of possibilities to combine them for more efficient management, their fit-for-purpose re-use within the project, or opportunities to segregate the wastes in a way that they can be disposed and maintained in possibly less expensive on-site facilities thus avoiding the cost and risks of transport to an off-site licensed low level waste facility. Integrating measures might include:

[6] For the purpose of this report, the term 'residues' in this section covers the primary and secondary waste streams generated by decommissioning and by remediation projects at nuclear facilities. Primary waste streams are generated by the facility operations. Secondary wastes are waste streams generated by the process itself.

(a) Maintenance of existing hardstanding areas (e.g. base slabs from demolished buildings) to cap an area of soil contamination;
(b) Use of existing, redundant hardstanding areas (e.g. baseslabs from demolished buildings) with simple covers to store contained, unconditioned very low level waste (the containers being appropriate to the storage, not necessarily nuclear standard ISO containers);
(c) Use of areas of contamination that have been solidified (and with improved geotechnical and civil engineering properties) to support site remediation infrastructure, e.g. waste stores, treatment centers, or treatment facilities;
(d) To substitute (ex situ) construction materials with suitable or suitably conditioned (very) low active residues to form materials that can be used for construction or holding purposes;
(e) Segregation of very low activity materials, particularly crushed concrete and re-use as: (1) foundations or base layers to cover systems or building foundations (the upper layers may need to be clean material); (2) to backfill the voids between low level waste in containers in a repository; or (3) to form the lower layers to a cap/cover system for a low level waste repository;
(f) Using recovered free-phase oils for their thermal value in on-site thermal remediation technologies, e.g. to generate low temperature heat to aid a biological treatment system or to generate warm air to aid a soil vapor extraction process.

There have been various lessons learned from decommissioning and remediation projects to date that will help future projects. Some of the key elements of safe and effective management planning are:

(a) A good management system that works from day one is put in place at the outset;
(b) Project planning should include participation by strategic planners to ensure the big picture is covered;
(c) Organization should be open to sharing experiences, information, and lessons learned;
(d) Managers study the best practices elsewhere and keep the lessons learnt in mind before planning for decommissioning/remediation and set solid up-front expectations for the workforce;
(e) Integrated task planning is essential;
(f) Coordination between various disciplines involved is a big challenge everywhere. To have effective co-ordination day to day, on-site implementation of tasks is to be carried out from a central place;
(g) It is beneficial to carry out safety related tasks through well written, reviewed and approved step-by-step procedures;
(h) All disciplines, including craft, health physics, industrial safety, and others need to be involved when developing and scheduling job evolutions;
(i) Taking the time to evaluate and understand the level and experience of the workforce and individual awareness of the importance of safety will pay dividends;
(j) It usually proves more efficient and cost effective in the long run to use highly skilled workers for the higher risk tasks to avoid the cost and liabilities associated with training or the consequences of using unskilled workers;
(k) It can be a mistake to ignore the advice of long-time plant employees who understand and know plant characteristics and history;
(l) Detailed pre-job briefings are vital to ensure hazards are avoided during job performance;
(m) Work-in-progress briefings given to work crews at critical junctures during complex high-risk tasks ensure that all job requirements are understood and implemented;
(n) Because the regulatory process for license termination is continuing to develop, it is critical to understand the roles of each organization involved;
(o) Developing working relationships with the key individuals in each regulatory organization will foster open communication and help site-closure activities progress;
(p) It is important to actively involve stakeholders and work to address their concerns and expectations.

The knowledge base acquired during safe operation of a facility is valuable for decommissioning and site remediation. Similarly, the requirement of infrastructure, plant operational records relevant for decommissioning and support services, such as decontamination, waste management facilities, material handling equipments, radiation hazard control, etc., also would be common. Hence, these aspects are to be taken into account in planning and management.

The use of a dedicated project organization is important for decommissioning and remediation. Past experience indicates that decommissioning and remediation are more like construction than operation. This underscores the need to build and sustain relevant expertise in the organization. It is also important, when possible, to incorporate some of the experienced site personnel within the new team so their expertise and corporate knowledge about the facility and its operations can be utilized.

Flexible, short-term planning horizons for projects often make them more tractable. Experience has shown that setting short-term project-specific goals and objectives which may be easily met works best as a way to sequence activities. The short term goals and objectives can serve as stepping-stones to intermediate or long-term goals and objectives contained in a high level overall schedule. This type of project management coupled with an effective data gathering and analysis programme will allow for effective, flexible use of resources.

Decommissioning and remediation are full of surprises. It is not unusual for projects to involve techniques being tried for the first time on a large scale or being adapted to site-specific requirements. Selecting appropriate technologies with high decontamination efficiency for application to decommissioning could reduce the work effort and cost of subsequent site remediation. Further, if decommissioning activities are planned to enable proper integration with the intended site remediation, this makes it possible to optimize the total effort required and to realize the end state in a safe and cost effective manner consistent with stakeholder involvement and regulatory requirements.

3.4. SITE END-STATE OPTIONS

The identification and selection of site end-state options is a central issue that decision makers confront in making the transition from operations to decommissioning. Careful consideration of the life cycle of a site through strategic planning may assist in linking the decommissioning plan to a future end-state indicated in Fig. 4. The planning process functions to provide insights into the options available for decommissioning and remediation that can be implemented during the decommissioning phase. Those actions both constrain and provide incentives for future use. The future use preferred for a site determines its end state for the post-commissioning phase. With many nuclear installations nearing the end of operating life or already shutdown, establishing effective strategic planning provides a way to optimize decommissioning and the transition to stewardship. As a result, the successful design and implementation of decommissioning and remediation projects requires management attention to a common set of tasks discussed in Section 2. Moreover, executing a successful decommissioning or remediation plan is dependent on the technical, political, and economic feasibility of attaining a desired end state.

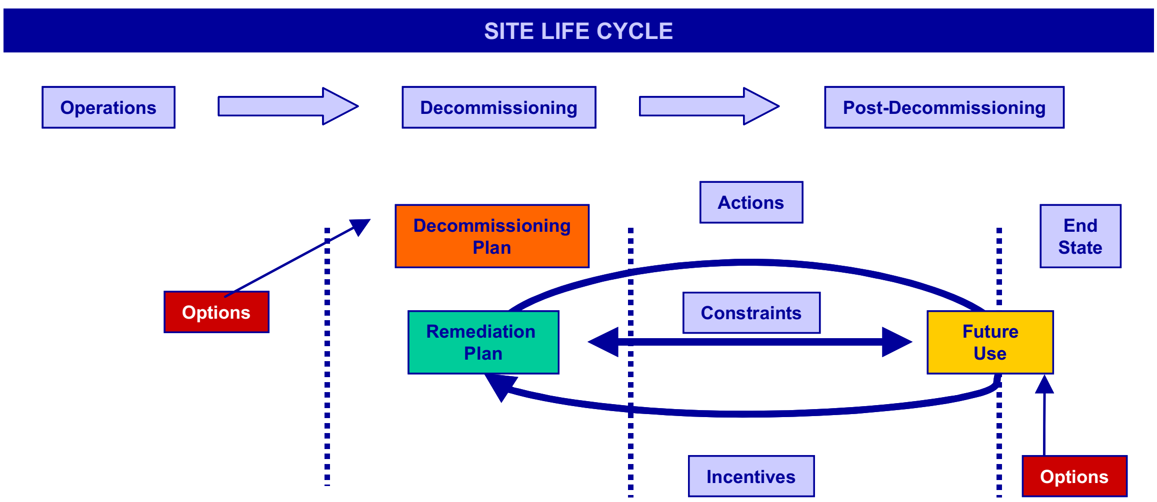

FIG. 4. Synergies between decommissioning and post-decommissioning.

A key aspect in determining the decommissioning and remediation programme and timetable is to determine whether any revenue can be generated by a ‘fit-for-purpose’ re-use of land and/or facilities, while ensuring human health and the environment are adequately and cost-effectively protected. The overall cost of decommissioning and remediation would then be optimized in terms of:

(a) Prolonged decommissioning and remediation with an off-set for income generated by ‘fit-for-purpose’ re-use;
(b) Prolonged decommissioning and remediation with no re-use;
(c) Early decommissioning and remediation with unconditional release of the site and an income generated by unrestricted re-use.

These options would be evaluated during the planning stages of decommissioning and remediation and may well drive the end points and the timescale.

Re-use potential can be considered in terms of desired end-state options that enable the facilities or infrastructure of a nuclear site to be reused. These include:

(a) Enabling redundant buildings that had been used for nuclear purposes to be re-used, e.g. buildings that have gone through, particularly where the reuse might relate to other nuclear activities (e.g. Pocos de Caldas in Brazil);
(b) Enabling ‘clean’ buildings within a nuclear site to be leased to tenants in order to generate a revenue (Oak Ridge Reservation in the USA);
(c) Enabling other nuclear-based industries to develop on the site (e.g., White Shell in Canada);
(d) Taking advantage of site infrastructure or management arrangements on a nuclear site, e.g. a secure site with tightly managed security (e.g. Chalk River Laboratories in Canada);
(e) Using aspects of site infrastructure for the remediation activities, e.g. use of liquid effluent or solids waste conditioning treatment works, or use of radioactive waste disposal arrangements (e.g. Hanford site in the USA);
(f) Preserving a nuclear site for its potential future as a site for the next generation nuclear power generation (INEEL in the USA); and
(g) Converting a nuclear site into a waste-disposal facility (e.g. Elliot Lake mines in Canada).

Restrictions will ensure that any residual radioactivity or hazardous chemicals cannot cause adverse effect on human health and the environment during the period before site closure. After site closure, these restrictions may still need to apply. In those cases, the site enters a period of long term stewardship as its end state. Under those conditions, site re-use options include:

(a) Nature reserve or recreational facility (e.g. portions of Savannah River site in the USA);
(b) Industrial heritage site, particularly the nuclear heritage (e.g. portions of the Hanford site in the USA).

Although the neutral/low maintenance cost options appear to generate no revenue, they may enable other costs associated with more intensive remediation to be off-set, such as those associated with the generation, conditioning and disposal of large volumes of relatively short-lived radioactive waste.

The execution of remediation activities can be influenced by a range of factors, both positive (incentives) and negative (constraints), and therefore site remediation planning need to take into account the factors, as they apply to the specific site. An IAEA publication provides guidance concerning factors influencing re-use [9]. Ideally, the factors would be considered early in the planning process, as otherwise the remedial measures applied might result in an end-state (end-use) that is either not feasible or is ultimately not sustainable.

Where remediation planning is not successful in identifying an appropriate or sustainable end-state, subsequent remedial measures may be required, or the selected end-state may be unfeasible. An un-integrated approach to decommissioning and remediation can result in environmental degradation, possibly rendering sites unfeasible for unrestricted re-use or result in delayed release. This causes land value loss due to requirements for restricted use, especially when sites are located in or near major urban areas where prices for uncontaminated lands are high.

Essentially, the factors take the form of a feedback mechanism from the re-use options (site end-states) to the remediation plan, thereby influencing the remedial actions taken to achieve the preferred re-use option. Because of this feedback mechanism, optimization of remediation activities is more likely attained by careful evaluation of the factors early in the planning process.

The factors that could influence the feasibility or optimization of the future use of the site include, for example:

(a) Infrastructure availability (development assets);
(b) Land value (market value);
(c) Cultural/social values (native, heritage, local);
(d) Technical values (specific uses that the site characteristics are ideally suited for);
(e) Environmental assets (valued ecosystem components);
(f) Regulatory factors (regulatory approval);
(g) Stakeholder values (public acceptance).

Experience shows that the development potential of a redundant site is often dependent on one or two key assets left over from the site's operating life [9]. These assets can provide an important catalyst to a particular development or serve to improve the attractiveness of the site as an investment proposition for developers. Therefore, an important step in exploring the redevelopment potential of a site is to identify these potential key assets and assess their relevance to future development scenarios. Once identified, these assets should be protected from deterioration during the remaining life of the site. In the case of nuclear facilities, these infrastructure assets could include, for example:

(a) High quality electricity grid supply connections;
(b) Airstrips, road, rail or sea access with offloading facilities;
(c) Sewage, district steam heating, potable water systems, and other piping networks;
(d) A partly 'captive' local workforce with a high level of technical skill;
(e) Office space, in particular prestigious old buildings, perhaps with historical significance;
(f) Support services (catering, public transport, etc.);
(g) Non-radioactive machine shops, workshops and general production facilities, especially with large machinery, stocks of spare parts, consumables; or
(h) A large flat site suitable for a substantial manufacturing investment or for a smaller investment while still retaining the future potential for contiguous expansion.

Land value is a broad factor that can involve many of the factors mentioned previously, but for the purpose of this discussion the term is meant to mean not only the market value of the land (property), but also the market value of adjoining properties. Obviously the higher the end-market value of the land, the greater the income from eventually selling the land, offsetting the remediation costs. In the latter case, an end-use that improves area property values will more-likely be acceptable to the public than end-uses that result in diminished values. Market value, in turn is affected by the value of potential development options, which can be influenced by factors such as the existence of natural resources of value (e.g., mining or forestry assets).

Cultural and social values cover a wide range of aspects, as discussed in Ref [7]. Essentially these correspond to the habits, activities and beliefs of the people living in the area, including aboriginal peoples that once inhabited the area and any restrictions on end-uses of the site could have a negative impact on public acceptance.

The term 'technical value' refers to any unique characteristics of the site that would qualify the site for the development of some form of specialized use, e.g., the expansion of an adjacent military base or the sitting of industrial enterprises, or the sitting of a nuclear or hazardous waste repository.

Environmental assets refer to the valued ecosystem components at the site, and to the preservation or enhancement of the components. An incentive in this regard would be the establishment of an ecological reserve to protect or enhance the valued ecosystem components identified at the site. It may be noted here that for instance the buffer zones established around various national laboratories in the USA or around military establishments have developed into what effectively constitutes a nature reserve. Some of these areas have been hardly touched by humans for the past 60 years.

Regulatory factors and stakeholder values refer to the broad range of aspects that influence the likelihood for regulatory approval and public acceptance. Regulatory approval is often driven by demonstrating that the potential exposures to human and ecological receptors during future land use and/or inhabitation are within the applicable criteria. Public acceptance, however, is often driven by a range of non-technical factors such as those discussed previously.

3.5. RISK BASED APPROACH TO PLANNING

The adoption and successful implementation of a plan for achieving an acceptable end-state at a site provides the guiding framework for decommissioning and remediation activities. Ideally, careful strategic planning that is based on a holistic approach to risk management can provide opportunities to ensure that costs are minimized while risk reduction is optimized consistent with the desired end points for the nuclear facility. Adoption of a risk-based approach to planning forces decision makers to identify and evaluate quantitatively or qualitatively the likelihood and severity of estimated adverse effects and tradeoffs associated with each proposed alternative prior to its adoption. It also provides a mechanism for factoring explicit consideration of unknowns (uncertainty) and stakeholder perceptions into the decision process. When all attributes that need to be considered have been specified, it becomes possible to evaluate alternative scenarios using a common metric for comparison (i.e., risk reduction). In addition to human health and the environment, other factors may be relevant. A comprehensive risk-based approach makes it possible to assess the observed or estimated risks to cultural resources and the financial/business risks associated with various end-states. Risk-based planning also enables effective prioritization of decommissioning and remediation (e.g., sequencing of construction for enabling facilities for waste management).

Health and safety risks can occur for workers involved in decommissioning and remediation activities, the general public, and/or subpopulations of the public. Environmental risks represent actual or estimated adverse effects to non-humans such as flora, fauna, wildlife, or domesticated animals. For both human health and the environment, risk is measured by estimates of actual or potential effects attributable to exposures to radiological or non-radiological contamination of human and/or ecological receptors.

To identify health, safety and environmental risks a systematic assessment is carried out involving:

(a) The identification of hazardous sources;
(b) Modeling (estimating) the transport of contamination, from the source location to the receptor locations via the environmental media (e.g. groundwater, surface water, air, etc.);
(c) Determining the potential mechanisms and frequency by which receptors could be exposed to the contamination;
(d) Ecological effects monitoring on indicator species;
(e) Determining the consequence in terms of dose and risk.

This approach is commonly referred to as pathway analysis, environmental compartment analysis, or multi-media modeling. A broad range of guidance on methodology and specific tools is available in the literature and existing models have been used for regulatory purposes. For example, the RESRAD family of computer codes developed by Argonne National Laboratory for use at US nuclear facilities provides a multimedia model for estimating exposure and effects (http://web.ead.anl.gov/resrad) [21]. The RESRAD methodology for risk assessment is cited in US DOE Order 5400.5 for dose assessment and guidelines for remediation of radiologically contaminated sites. The software can be used to evaluate soil contaminated with radionuclides or hazardous chemicals, perform baseline risk assessments, conduct ecological risk assessments, off-site dose assessment, and recycling and re-use of radiologically contaminated metals and equipment. RESRAD has been used widely in the US and has been approved by regulatory agencies including the US Nuclear Regulatory Commission.

FRAMES, developed by Pacific Northwest National Laboratory, provides a software platform for integrating multimedia models to evaluate environmental, safety, and health risks (mepas.pnl.gov/FRAMESv1) [22]. It incorporates MEPAS and GENII modules. The FRAMES platform has been applied to several US DOE sites including the Pantex Plant in Texas.

RESRAD, FRAMES, and similar models use a system of transport and fate equations with initial source term values to estimate contaminant concentrations, exposures, and effects for specified receptors located with on-site or off-site. The models use either default parameters or can use values from site characterization and monitoring as inputs. Relevant input data include:

(a) Source characterization data;
(b) Information on local demographics and human behaviour/habits;
(c) Hydrological and hydrogeological data;
(d) Environmental transfer parameters; and
(e) Information on ecological receptors.

Outputs include:

(a) Exposure estimates and effects estimates, with the significance of both types being evaluated by comparing against criteria such as dose limits/targets/constraints;
(b) Media concentrations, and
(c) Effect threshold values for ecological receptors.

The output information can be used to compare risks for alternative remediation approaches at a specific site under different scenarios, or in strategic planning as mentioned previously.

Financial or business risks arise as a consequence of financial uncertainties that can be caused by:

(a) Inaccurate estimate of the costs of decommissioning and restoration projects;
(b) Use of immature technologies (i.e. techniques that are being developed or have not been widely deployed), or which may be inappropriate for their current application; and
(c) Changes in regulatory requirements.

The financial risks associated with decommissioning and remediation can cause an adverse effect on the short-term or long-term viability of a business or increase costs to society. For example:

(a) The risk of losing business opportunities or requiring more funds from government caused by inadequate provision of funding, or underestimation of costs, or project over-runs: and
(b) The risk from not being able to realize full market values for remediated land as a consequence of perceived (but not actual) risks from residual hazards left in the ground (i.e. 'blight').

The principles of radiation protection illustrate the application of a risk-based approach to planning for decommissioning and remediation. In essence, for sites subject to regulatory controls, it is necessary to demonstrate that the risks to human health from potential exposures to radioisotopes are acceptably low using the principles of ALARA (as low as reasonably achievable) once the site is released from regulatory control. Although the definition of 'acceptably low' generally is specific to the national policy of a particular country with economic and social factors being taken into account, it commonly is based on recommended limitations on levels of estimated exposure to potential radiological hazards [23]. Hence, the protection of human health and the environment against these hazards is the primary consideration for releasing nuclear sites from regulatory control [18]. The IAEA has developed a number of documents as part of its Safety Standards Series that focus on the radiological implications of decommissioning and remediation activities at nuclear facilities [15, 24–27]. IAEA publications provide helpful information about dose criteria for potential human exposure and for the release of material from regulatory control. Human dose constraints are based on ICRP guidance. Materials released from the site must comply with national requirements for radiation protection.

Using a risk based approach to plan the high level strategy for the decommissioning and remediation of a nuclear site facilitates co-ordination of multiple projects in order to ensure that costs are minimized, and impacts and risks are optimized throughout the facility's life cycle. It may become possible to avoid unnecessary or redundant actions by considering decommissioning and remediation simultaneously using a risk-based planning approach. For example, deferring demolition of a building until the site has been characterized can prevent contaminant re-suspension in the air medium or run-off to soils, surface water, or groundwater. Similarly, sequencing or deferring decommissioning until appropriate waste disposal facilities are in place for dual use can avert the need to construct extensive storage facilities that later would require decommissioning and have an environmental impact.

Risk-based planning that integrates decommissioning and remediation can be used to prioritize management of redundant buildings or structures that are waiting final decommissioning, i.e., where a phased decommissioning process is applied at a site. The objective in this type of assessment is to identify the hazard sources in the buildings are characterized, the physical conditions within and surrounding the building are characterized, and then the barriers/features controlling risks are evaluated. Any event that can directly or indirectly lead to contaminant mobilization is closely evaluated (fire, internal and external flooding, animal ingress, etc.), and opportunities for risk reduction are identified. Inputs to this type of assessment include source characterization data, building historical and condition information (condition of building structural elements and services/systems), and site information (for the identification of external events). Depending on the end-point of the assessment, outputs can include potential exposure estimates and costs, and/or risk rankings of different buildings/structures at the same site, and a key output is recommendations for improvements (risk/liability reduction). The output information can be used in the management of individual buildings/structures in storage, or in strategic planning in identifying the selected risk-based priority-sequence of decommissioning and remediation activities.

4. PLANNING TOOLS AND TECHNIQUES

4.1. RATIONALE AND DRIVERS FOR PLANNING

Experience demonstrates that when site operations are terminated or scheduled for shut down there are a significant number of issues that require attention with some urgency. Typically, these issues are managed using a strategic planning process that involves the definition of the preferred site end point followed by the identification, integration and scheduling of all decommissioning and remediation activities to meet the end point objectives.

Effective planning and management is essential in ensuring that decommissioning and remediation are accomplished in a timely and cost-effective manner with due importance given to other key factors such as safety, the legal framework, socioeconomic factors and stakeholder desires. It is advisable to start planning for decommissioning and remediation, some years before final shutdown. The planning process must, however, be flexible enough to cope with possible changes to expected end point definitions.

Programme and project management should make use of scheduling and resource tools that allow plans to be visualized and integrated. These tools should define the life cycle base line and work plans and facilitate cost, progress and schedule variance reporting. They should also be flexible enough to allow easy programming of changes to work scope and demonstrate what effects those changes will have on the overall programme. Some typical project management tools are included in Table 1.

4.2. USING PLANNING TOOLS AND TECHNIQUES

The following section examines a number of techniques and tools that can assist in planning at both a strategic (e.g. site-wide) or at an individual project level (Fig. 5).

TABLE 1. ASSESSMENT TOOLS AND TECHNIQUES

Method	Description
Systematic options assessment tools and multi-attribute analysis.	To define the best option by combining scores of a number of attributes. Commonly used for high level strategic definition (e.g. definition of site end-point).
Expert systems	To assist in planning using experiences from other similar projects.
Critical path analysis	For assessing the duration of interacting activities that constitute the project and for ensuring that potential conflicts in resourcing are identified.
Business and financial risk management evaluation techniques	To identify potential business and financial risks and to assist in developing appropriate contingency plans.
Parametric cost estimating, cost-benefit analysis, cost-effectiveness analysis	To estimate the cost of the project and to justify those costs.
Safety and environmental risk management evaluation techniques	To ensure that the project can be carried out safely and with minimum environmental impact, and that appropriate mitigation methods have been determined.

Planning needs to be targeted towards a clear aim: to decommission and remediate the site to a particular end point. Definition of the site end point and the timescale and process to be used to reach that end point is the first step in the planning process. When this high level strategy is defined, specific decommissioning and remediation projects can be aligned and optimized.

It has become increasingly common to involve various stakeholder groups in decisions about nuclear site decommissioning and remediation — particularly consultation early in the decision process is often the key to the success of an initiative, and to securing cooperation. Inclusion of the local community is particularly important and is coming to be expected by regulators and local authorities.

There are various media that can be used to engage with stakeholders:

— Newsletters;
— Project information centres;
— Opinion surveys;
— Focus groups;
— Public meetings;
— Surgeries/‘open house’;
— Participative workshops;
— BPEO workshops;
— Strategic stakeholder dialogue;
— Community liaison groups.

The extent of stakeholder consultation and the choice of consultation techniques to be employed greatly depend on both the scale of the activity being planned and the local/national culture. During, for example the definition of the groundwater monitoring programme, it may simply be necessary to engage with the relevant environmental regulator. Definition of the site end point, on the other hand may well involve a full public consultation exercise as the decisions taken affect a much wider section of the population.

Several of the techniques described briefly below contain an element of stakeholder participation. It is therefore important to convey information in a way that is understood by the individual stakeholder groups. It is equally important that stakeholders see evidence that their views have been taken into account and feel that they have fully participated. This therefore requires a very good, open and transparent process.

The following section gives a brief description of the tools and techniques. For the purpose of this report they are divided into three categories:

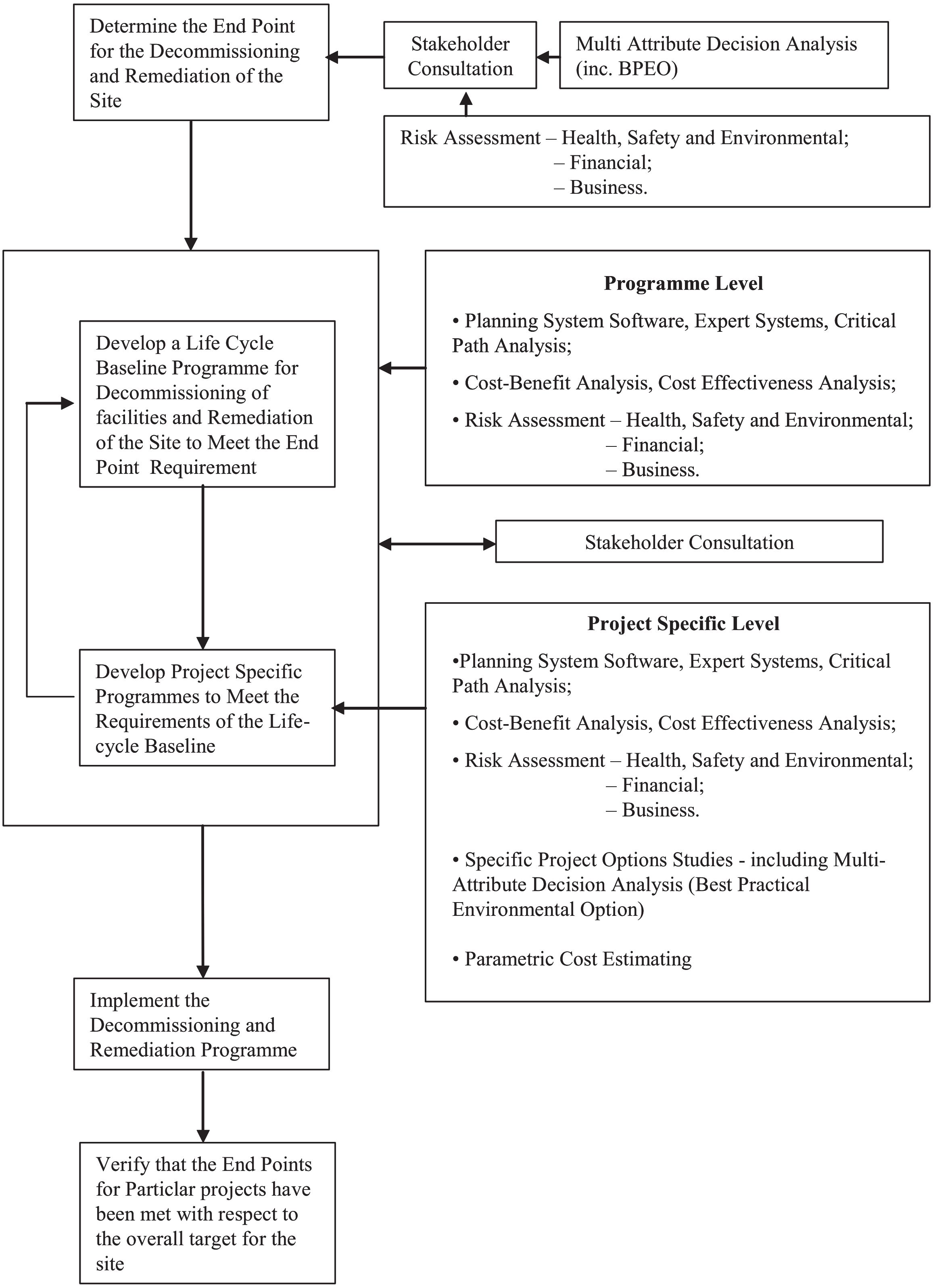

FIG. 5. Process diagram for decommissioning and site remediation to illustrate where planning techniques and tools can be used with the process.

(a) Optioneering tools and techniques;
(b) Network analysis and sequencing tools and techniques;
(c) Cost analysis and cost estimating tools and techniques.

4.3. OPTIONEERING TOOLS AND TECHNIQUES

Optioneering techniques include Multi-Attribute Decision Analysis (MADA) and the best practicable environmental option (BPEO) methodology.

The BPEO concept was first developed in the UK by the Royal Commission on Environmental Pollution [28] which defined BPEO as the outcome of a systematic and consultative process which establishes the option that provides greatest overall benefit for the environment at an acceptable cost. The process therefore involves stakeholder consultation along with options assessment within a cost-sensitive framework. Although the emphasis is on minimizing the impact to the environment, it is common practice to involve a number of attributes in the assessment:

(a) Health and safety impacts (e.g. radiological, chemical and conventional hazards to workers and the public, including transport hazards);
(b) Environmental impacts (e.g. ecology, air quality, water quality, land quality, visual amenity, noise, transport issues);
(c) Practicability;
(d) Waste generation;
(e) Social, economic and security considerations (e.g. local community, culture and heritage, intergenerational equity);
(f) Technical feasibility;
(g) Full cost.

The assessment of these attributes against a defined set of criteria commonly involves MADA. This involves attributes being ‘scored’ either qualitatively, (e.g. high, medium, low) or quantitatively (e.g. out of 10). Overall scores are then aggregated to determine the best option.

Where scores are numeric, it is also possible to add weighting factors that reflect the considered importance of one attribute against another (e.g. health and safety may be given a higher weighting than cost). At key stages (e.g. scoring and weighting stages) within the overall BPEO process, appropriate stakeholders are consulted and their views incorporated.

This type of assessment is systematic and can therefore be readily documented which in turn allows transparency of the decision making process.

4.4. EXPERT SYSTEMS

The primary goal of an expert system is to provide a formal process to make expertise available quickly. Expert systems are knowledge-based applications of artificial intelligence (AI) that use computer algorithms to aid in strategic planning and in making project-specific management decisions. Expert systems combine theoretical understanding and heuristic problem-solving rules that experience has demonstrated are effective in the domain. Reliance on the knowledge base of human experts and the problem solving strategies experts use coupled with a computerized inference engine are the two principle elements of expert systems. By using AI to develop an expert system, it is possible to emulate human expertise and apply ‘rules of thumb’ which specific a set of actions in response to prior knowledge when confronting a decision. For example, expert systems can be used for decommissioning or remediation planning to apply systematically lessons learned from past experience and expert judgment.

4.5. STRATEGIC PLANNING SOFTWARE

Strategic planning software enables the sequencing of interdependent projects to be assessed in terms of resource requirements, wastes generation, time and cost (as a total cost and as a distributed cost). These tools can then be used to:

(a) Identify bottlenecks — such as the need to have available waste stores or waste routes for radioactive decommissioning wastes; and
(b) Assess 'what if' scenarios in order smooth out peaks and troughs where resources and funding need to be relatively evenly distributed.

4.6. CRITICAL PATH ANALYSIS

The functions of planning, organizing, directing and controlling are essential to every project regardless of type, purpose or complexity of its operation. Techniques of management vary and Critical Path Analysis based on networking principles is a useful management technique. For implementation of this technique one first develops a network with activity — event relationship of the various activities to be performed as part of the project. An event is a specific accomplishment that occurs at a recognizable point of time and an activity is the work required to complete a specific event.

For major decommissioning/remediation projects a number of event managers would be identified and sub-networks would be delineated for those who will implement particular tasks. Subsequently these sub networks can be integrated with interface events. All activities would be assigned an optimum time duration based on resources (manpower, financial) availability with time. When events are linked one needs to ensure that there is no conflict (e.g. by using the same resource, or dependency on each other for completion) in sequencing them. Certain activities could be carried out in parallel (resources permitting) and these have to be identified and placed accordingly in the network. The longest path (e.g. most time consuming path) through the network determines the earliest date of the network ending event which is the completion of decommissioning/remediation project.

By using such networks, managers can plan more effectively, anticipate future trouble spots and so cope with them in an orderly manner. Using computer aided tools one can analyze resources requirements and allocate them in the most effective way, carry out network replacing measures, and adjust the project plan to emerging situations with a view to achieving the end goal in a timely and cost effective manner.

4.7. COST–BENEFIT ANALYSIS

Economic considerations are typically a key element in setting priorities for decommissioning and remediation projects at nuclear facilities. Cost–benefit analysis (CBA) is a technique that estimates and sums up the total equivalent monetary value of the benefits and costs identified as being associated with a project or set of projects. The principal characteristic of cost-benefit analysis is that the factors entering the analysis are expressed in monetary terms .This makes it possible to consider the non-market and market benefits from projects at a site. Not only do the benefits and costs have to be expressed in monetary terms, but a specific time point for the value of those benefits and costs should be computed to reflect discounted present value. If the benefits exceed costs, then the net benefits (benefits minus costs) are positive, and the project is efficient desirable from an economic standpoint. Economic efficiency increases as net benefits increase. This allows a manager to identify the marginal increase in benefits associated with a marginal increase in costs.

This makes it possible to use CBA as a strategic planning tool to prioritize multiple decommissioning or remediation projects. For example, a set of proposed options for on-site and off-site waste management could be evaluated using CBA to determine the most adequate solution based on economic tradeoffs. Application of the dominance rule allows for identification of the best option in order to maximize benefits within cost constraints. Options are ranked based on net benefits and the options with the greatest net benefits are dominant. It also can be used as a project-specific tool to identify which elements of a project produce the greatest benefits or highest costs. For example, alternative site re-use options might be possible to achieve by a soil remediation project. Determining which option has the highest net benefits can aid in selecting the remediation level consistent with regulatory requirements.

4.8. COST EFFECTIVENESS ANALYSIS

Cost effectiveness analysis (CEA) is another technique that can be used to evaluate the economic considerations of decommissioning or remediation when resources. Like CBA, the goal of CEA is to determine whether the benefit commonly referred to as an output or effect of a project justifies its cost. Unlike CBA, the benefit of a project is not converted to a monetary value but is expressed in terms of its original units of measurement. This makes it possible to consider the non-market and market benefits from projects at a site without taking the potentially contentious steps of monetizing non-market benefits or discounting the value of future benefits. For example, the number of cubic meters of contaminated soil removed might represent a soil remediation project's benefits. The costs associated with soil remediation would be expressed in monetary terms using the same procedures as CBA. Economic efficiency increases as the cost decreases per unit output.

Cost-effectiveness analyses can, therefore, define either the least costly way of achieving a specified output such as a reduction in exposure or the maximum reduction in exposure that can be attained for a fixed cost. For decommissioning or remediation projects, the lower the cost per output, the higher the cost effectiveness. This allows managers to evaluate whether the project is potentially desirable from an economic standpoint. CEA can be used as a strategic planning tool to prioritize multiple decommissioning or remediation projects using the dominance principle. For example, a set of proposed options for waste management projects could be evaluated using CEA to determine the most adequate solution based on unit costs for volumes of waste. It also can be used as a project-specific tool to identify which elements of a project produce the greatest benefits or highest costs. For example, alternative soil remediation options might be evaluated to determine which one provides the least costly remedy for a soil remediation project consistent with regulatory requirements.

4.9. PARAMETRIC COST ESTIMATING SOFTWARE

Parametric cost estimating software tools are predictive planning tools that translate the costs associated with previous decommissioning and remediation projects into estimated costs for proposed projects. The estimated cost is determined by dividing the project into tasks and then dividing the tasks into units for which a reference cost has been determined based on previous experience (however local conditions may give rise to biased conclusions). The cost of the individual tasks and the total cost of the project can then be estimated by aggregating the unit costs. As individual tasks have a schedule, it is then possible to determine not only cost to completion, but also the projected out turn costs against time

4.10. SOCIAL IMPACT ANALYSIS

Social impacts are often, erroneously, assumed to be synonymous with economic impacts. Although economic analysis can be considered as one part of social science analysis, economic impact analysis addresses how efficiently investments of capital and other resources are returned in present and future benefits to society (i.e., whether the economic benefits of an action or policy outweigh the costs). Though social and economic impact assessments overlap and are related, they differ considerably in focus, underlying questions, methods, and approaches. Thus, the same data may be analysed and interpreted differently depending on whether the analysis is economic or a Social and Economic Impact Analysis (SIA). An SIA provides an objective analysis and assessment of known social factors relative to all the stakeholders, their communities and the issue at hand. The SIA thus embraces information from a variety of sources in a systematic, scientifically verifiable manner, and presents this information in a form that a decommissioning/remediation manager can use. This holistic approach is necessary to ensure that all stakeholders' interests and needs are systematically considered and incorporated in the analysis. The SIA is based on a scientific analysis of the baseline case (status quo) and evaluation of probable social impacts of electing to maintain the status quo or selecting any reasonable alternative to it. A method to assess social impact consists of parameters chosen, e.g., population trends, occupation trends, employment type, and income status, followed by estimating of their individual values and finally a number of scenarios are evaluated in order to get a range of possible impacts.

5. INFORMATION REQUIREMENTS AND RECORDS MANAGEMENT

5.1. BACKGROUND

Reporting relevant information and keeping records of all phases of a facility life cycle is important for the success of the decommissioning and remediation processes, especially the historical operational records. Mechanisms for recording and storing information for the decommissioning and remediation phase should be established during the operation of the facility. Existing data and records of the facility can provide useful information about the radiological and conventional pollutant conditions of the facility and this enables decommissioning planning. The records produced during decommissioning preserves information related to: the types, distribution and amount of contamination remaining and the areas where radioactive materials were used or stored. Subsequently all records from operational and decommissioning phases can be used for planning the remediation of the site. After the site is released for restricted or unrestricted use it will be necessary to keep the records safely stored for many years. Any changes in legislation, technology, and stakeholder opinion may be captured in records review. Records must ultimately show that:

— The condition of the site is appropriately safe, hazards have been controlled and potential environmental impacts are acceptably low in the present and in the future; and wastes have been assessed, conditioned and appropriately disposed of.

5.2. RECORDS

Decommissioning and remediation of nuclear sites generally takes place over many decades. Thus, it is particularly important that records are preserved with near to medium term use and storage in mind. Records should ideally be:

(a) Comprehensive and tagged with a mark that reflects their quality;
(b) Up to date and securely stored;
(c) Controlled — particularly with respect to authorization for read-write access for any amendments and revisions (Note: it may be necessary to archive previous versions of a record. The reasons for the revisions should also be recorded);
(d) Accessible (but access may be restricted to certain user groups);
(e) Protected against tampering and loss (e.g. fire, theft, or misplacement);
(f) Owned — records within an information management system can come from a number of sources. The originator and all further custodians of the record should be identified.

The media on which information is recorded should be resistant to chemical or physical degradation, robust and should not rely on single people, organizations, or technologies to store and maintain them. Technologies in this context include equipment required to access media on which the record is stored. The structure of the information management system must be open and clear, i.e. not a ‘black box’. Best software tools are ‘open source’ that allow export of the data in a structured and standardized form.

In the context of integrating decommissioning with remediation and fit-for-purpose reuse, it is important to remember that the footprint of activities carried out in a re-used part of the site may bear no relationship to previous uses. In addition, the restrictions for a fit-for-purpose re-use of one part of the site may be different to another, and may also change with time as some of the residual radionuclides decay, or some hazardous chemical compounds naturally degrade. Also, where decommissioning and remediation enables the release of parts of a site, records should be retained by the original owner and copies should be transferred to the new owner. It may also be important for certain types of record to be deposited with an appropriate agency in a Member State.

With respect to quality assurance and ownership the following typical issues in managing records have been encountered [17]:

(a) Absence of the record or missing information;
(b) Lack of checking and errors;
(c) Inaccuracies in the record;
(d) Wrong interpretation of information contained in the records;
(e) Loss of records due to records deterioration or outdated electronic support;
(f) Incorrect labeling of storage location.

Table 2 presents a suggested template of the types of record which could be retained for a site. It is noted that, where possible, these records need to indicate which are considered as factual data (e.g. an analysis) and which are interpretive (e.g. a risk assessment). For most types of record it is important to ensure traceability e.g. to particular methods, national or international standards and verification processes. Many analytical and assessment software methods will develop through time. It is important, therefore, to ensure that the particular version of the method or assessment software also recorded. For assessment software, it may also be necessary to have to access to original computer code and the various versions.

Any information management system should be designed within budget limitations. Records types therefore need to be prioritized so ensure that only the most relevant records are maintained. The record categories in Table 2 represent the ideal and it may not be possible to maintain the complete dataset.

The individual records identified in Table 2 include the history of the site, and notably its changing condition with respect to buildings and land. These records will not only serve as the foundation to decommissioning and remediation projects but may also be needed for many years as a permanent record of the site [15]. Where other parts or the whole of the site are to be sold, these records form the basis of information required about the site. In addition, where sites are to be managed for very long periods of time before release, they also form the back-bone to stewardship requirements. Thus these records should be retained in perpetuity. However, it should be borne-in-mind that many of the items of data identified in Table 2 may not have been collected and archived for the purpose for which they are now being considered. It is important, therefore, that the contents of a site archive are reviewed and retention schedules revised to meet all potential contexts. The significance of the data also needs to be classified with respect to its importance and with respect to the context. Ideally, to make it easy to access data, each item would also be summarized and referenced with accompanying 'meta data' (data about the data).

At the end of a decommissioning and remediation project it is common practice to prepare a post-decommissioning report. This is effectively a document structured so that it follows the headings indicated in Table 2, and fully referencing the records to which it refers. When making reference to particular parts of the records in the summarized text, it is a good practice to highlight the particular part referred to (e.g. page number and paragraph number) rather than just a general reference to the particular document. This makes any future auditing of the summary document less time consuming than trying to wade through a whole report searching for specific information.

Although these records are likely to be used in the near and medium term, it is recognized that they may also form part of the requirements for the longer term, particularly where sites will be moving into a period of long term stewardship. It is therefore appropriate to consider the very long term storage of these records. There is considerable discussion of the most appropriate way of storing records that may be needed in the medium to long term, particularly the media on which they is stored and their access in the future. There is a view that records stored electronically may not be accessible in the future, as the media used to capture the record, and the

TABLE 2. RECORDS ASSOCIATED WITH DECOMMISSIONING AND SITE REMEDIATION

	Information/data
Area of land within the original site boundary	Summary information on land status: — Present use of the land area — Location of the land area (generally related to a national coordinate system) — Statement of land-use restrictions — Summary of the previous uses of the land area — Summary of decommissioning and remediation performed — History of routine and anomalous activities in the area — Relevant maps — Relevant photographs Factual — Area measurement of the land parcel; — Summary of land usage within the parcel — present and past; — Current visual appearance; — Current and past human-made features and their current status (includes drainage systems); — Soils, superficial deposits (including made ground), geology, hydrology, hydrogeology; — Environmental samples data (soil, aerosols, vegetable samples, superficial water, sediments, etc) wherever applicable; — Details and results of environmental sampling in the area of concern; — Relevant maps; — Relevant photographs. Interpretive — Conceptual model for the land parcel; — Quantitative assessment of risks to human health and the environment (include validation information on any models used). Remediation — Remedial actions in the land parcel which are not covered by the facility description below (and details of warranties, guarantees, etc.); — Description of procedural and institutional controls e.g. excavation controls or restrictions; — Details of any discharge consents from the area; — Contract details and warranties; — Relevant maps; — Relevant photographs.

TABLE 2. RECORDS ASSOCIATED WITH DECOMMISSIONING AND SITE REMEDIATION (cont.)

	Information/data
Facilities in the area of concern	Status — Buildings in the location with grid references (to a national grid system); — Buildings usage present and past; — Details of the decommissioning status of each building; For each building that currently exists or existed in the area 1. Statement of current status with respect to: — Functional buildings (and their use); — Decommissioned facilities; — Man-made drainage systems; — Residual structures left in the ground from decommissioning (e.g. foundations); — Areas of known residual contamination (radiological and chemical); — Relevant maps; — Relevant photographs. 2. Design, construction and modification documentation — Complete drawings and technical descriptions of the facility as built; — Construction photographs with detailed captions; — Schedules of any construction modifications and their drawings; — Facility construction materials and samples; — Facility design inventories of chemical and radiological material flow sheets — Quality certifications; — Safety cases for the operation of the facility; — Environmental impact statements; — Pre-operational facility testing and commissioning records; — Licensing documentation and operating requirements. 3. Operational, shutdown and post-shutdown documentation — The licence and licensing requirements; — Safety analysis reports; — Reports of modifications to the safety case; — Technical manuals; — Details of environmental releases – authorised and unauthorized; — Facility logbooks; — Facility radiological survey reports, units used for measurement, instruments used, limits of detection and calibration information; — Operating and maintenance procedures and records; — Abnormal occurrence reports including evidences of accidental releases, and/ore spills, leakages, etc.

TABLE 2. RECORDS ASSOCIATED WITH DECOMMISSIONING AND SITE REMEDIATION (cont.)

	Information/data
	— Decontamination plans and close-out reports; — Design change reports and updated drawings; — Hazardous material inventories; — Process and service interfaces with other facilities; — Process flowsheets, including for services; — System, structure and component inspection records — On-facility waste management records; — Post decommissioning records particularly with respect to removal of drains, underground storage tanks and wastes, equipment terminations (e.g. piping and cables); — QA records; — Fuel geometry, performance (i.e. damage) and accounting records; — Records of neutron fluxes and distributions; — Records of waste management strategies and locations of waste; — Records of radiation sources and their locations; — Samples of irradiated and embrittled materials; — Relevant laboratory test reports together with descriptions of analytical methods, calibration, limits of detection, accuracy and precision, proficiency testing; — In-fill materials and the associated QA/QC — e.g. where demolition construction materials have been crushed and used to fill voids from decommissioning activities, or where soils from one part of the site may have been used to landscape areas that have been decommissioned; — Drawings of structures left in the ground post-decommissioning e.g. deep foundations, services, underground storage tanks or drains; — Post- decommissioning monitoring records associated with the surface and subsurface — to verify that the decommissioning end point has been met, or to provide data to a post-decommissioning risk assessment which demonstrates that the land condition meets the regulatory risk criteria; — Decommissioning environmental impact assessment; — Contract details particularly where there are warranties; — Relevant maps; — Relevant photographs.
Global site information	Site decommissioning and remediation plan — Socioeconomic aspects of decommissioning and remediation; — Stakeholder issues of concern and records of decisions; — A summary of the regulatory regime and appropriate remediation criteria;

TABLE 2. RECORDS ASSOCIATED WITH DECOMMISSIONING AND SITE REMEDIATION (cont.)

Information/data
Setting — Geographical setting of the site, grid reference to a national grid system; — Current name of the site, historic names of the site; — Current visual appearance; — Geographical setting with respect to the adjacent area including topography, areas of archaeological, heritage and/or ecological significance; — Area measurement of the site; — Soils, superficial deposits (including made ground), geology, hydrology, hydrogeology; — Meteorological information; — Relevant maps; — Relevant photographs.
History — Summary of the history of the site from pre-nuclear operation through operation to present day – including historical maps and photographs. Also owners of the site — past and present; — Map showing boundaries; — Land use of neighbours past and present; — Relevant historic maps; — Relevant photographs.
Infrastructure — Maps, diagrams, photographs, descriptions of services, man-made drainage (e.g. soakaways, land drains, active and inactive drains) and natural drainage systems — historic and current; — Maps, diagrams of roadways, footpaths; — Maps, diagrams, descriptions of material stores (e.g. solvent stores), waste stores (radioactive and chemical) and waste disposal areas; — Details of waste transfer transport routes; — Maps, diagrams of underground storage tanks and above ground storage tanks (e.g. for fuels), sumps, major below ground features; — Relevant photographs.
Environmental monitoring and sampling — Records of environmental monitoring on-site and off-site; — Records of discharge consents; — Information of global radiological and hazardous chemical surveys; — Relevant maps; — Relevant photographs.

system used to read them may become obsolete [29]. A possible solution is to keep at least two copies of records; one on a stable media and another in digital form.

5.3. INFORMATION MANAGEMENT SYSTEMS

An information management system to manage records requires:

(a) Procedures and resources to be available for ongoing maintenance and retention. A detailed discussion of information management issues is provided in Ref. [15];
(b) Resources (people, time and money) for ongoing maintenance and retention.
It needs to ensure that [15]:

(1) Current and future stakeholders have access to, at least a summary of the information;
(2) Procedures are in place to ensure that information is not lost;
(3) Data are in a form such that they can be presented to a variety of stakeholders in a variety of forms e.g., pictures, aerial photographs, maps and others.

In addition, data need to be recoverable and therefore the indexing system used to store and manage the data needs to be linking all types of data. The indexing system needs to, therefore, reflect a dynamically changing site, where there may be:

(a) Different restrictions on land re-use for different parts of the site, which may also change with time;
(b) Potentially different, and multiple, site owners as parts of the site might be released before others– as they meet site closure criteria earlier.

Increasingly records are managed using a Geographical Information System. This is because the common attribute of all the data collected on a site are associated with a location – e.g. building number, road number, borehole location etc.

Without adequate records of operational and decommissioning activities, site characterization and remediation is much more difficult, costly and dangerous.

6. MANAGEMENT SUPPORT SYSTEMS

6.1. BACKGROUND

Most major industrial sites today operate a variety of systems which include written procedures to manage:

(a) The health and safety of staff, visitors to the site, and the public protection;
(b) The environmental aspects of site operations;
(c) The quality of the work undertaken; and
(d) Site security (e.g. protection against theft, terrorism, etc.).

Management systems may be designed to comply with the general requirements of the International Organization for Standardardization (for example, ISO 9001 for quality management, or ISO 14001 for environmental management), or with the standards developed by the relevant national bodies (e.g. the British Standards Institute). Other examples can be seen in [30].

Management systems are generally designed to ensure compliance with all legal requirements and that there is demonstrable continued improvement in, for example, health and safety performance. Although traditionally such systems have been developed separately, there is a growing international trend to integrate systems in order to make use of synergies between, for example, health, safety and environmental issues. This is reflected by the increased level of communication and co-operation between various regulatory bodies at the national level.

The complexity of the management systems is generally tailored to the complexity of site operations or decommissioning and remediation programmes. Any individual remediation project needs to develop (under the umbrella of the site system) a set of procedures which is relevant to that project. The project system may include: a health and safety plan, risk assessments, method statements, etc.

The management systems should be designed and operated to promote strong values and safe working practices (i.e. a safety culture) which are common to all site workers. The highest level of safety is achieved only when all site workers are part of the safety culture. The management systems must provide adequate flexibility while maintaining consistency with accepted standards. For example, the site safety management system will contain provisions for internal audit to ensure that operations comply with site procedures and therefore with regulatory requirements. The audit process must not, however, unduly affect on-going operations (assuming operations are being undertaken in compliance with procedures).

6.2. MANAGEMENT SUPPORT SYSTEM REQUIREMENTS

The management support systems generally include a number of elements which are common to most systems. Although it is beyond the scope of this document to present detailed requirements, it is worthwhile noting these common elements:

(a) A statement of policy which acts as an umbrella under which the rest of the management system sits;
(b) An organizational structure describing key posts along with the responsibilities associated with the post and the qualifications and experience required of the post-holder;
(c) Planning to define objectives and targets and implementation procedures such as hazard identification and risk assessment methods along with risk mitigation methods;
(d) Performance measurement against a set of standards, for example environmental monitoring of effluent discharges;
(e) Site and project audits to assess compliance with operational procedures; and

Review of the system which should include recommendations for continued improvement.

Since decommissioning and remediation of a nuclear facility involves handling of radioactive and other hazardous materials on a large scale, the management system needs to take into consideration a number of aspects for adequate accounting of radioactivity:

(a) All information and records relating to radioactivity and other hazards are collected and documented prior to decommissioning and remediation;
(b) For remediation with a restricted reuse as end-point, the records pertaining to location, configuration, quantities and types of radioactive and hazardous materials remaining on the site are periodically updated; and
(c) All radioactive and hazardous materials that were present at site at the commencement of decommissioning are properly accounted for until they have been relocated to their ultimate destination.

6.3. USE IN DECOMMISSIONING AND REMEDIATION

It is common at some nuclear sites to continue to use operational management systems even when site operations have ceased and true decommissioning has begun. It is important, therefore, to continually review procedures to ensure that they are up to date and reflect the hazards and risks associated with current activities. Regular reviews should include:

(a) The legal requirements associated with site activities;
(b) Health and safety hazards and risks;
(c) Environmental hazards and risks;
(d) The qualifications and experience of the workforce;
(e) Waste management requirements;
(f) Security requirements; and
(g) Monitoring requirements and records management.

At large nuclear establishments, the various management system activities (e.g. production of safety cases, updating procedures, auditing etc.) are generally coordinated by staff in one department or group, variously entitled assurance, quality, or safety. These individuals would ensure that system documentation is current, guide the remediation personnel on how to apply it, monitor their compliance with the management systems and ensure that adequate records are being kept of their activities. This team may also oversee verification of the decommissioning and remediation activities through independent testing and review of records. It also needs to have sufficient authority and organizational freedom to identify 'assurance' problems, to initiate, recommend or provide solutions and where necessary to define further action when non-compliance is identified. The assurance team is commonly the liaison between decommissioning and remediation project managers and the site's regulators.

Typical activities of members of the assurance team include but are not limited to:

(a) Review of best practice and legislation changes and coordination of updates to policy and procedures;
(b) Definition of management functions, including establishment of an organizational structure of trained and certified personnel with functional responsibility and levels of authority with clear lines of communication;
(c) Checking that all decommissioning and remediation activities are performed after adequate planning and with well prepared, reviewed and approved procedures;
(d) Verification that decommissioning and remediation activities are carried out in a safe manner and as planned and intended;
(e) Periodic audits to identify possible non-compliance and recommend improvement actions;
(f) Checking to see if corrective actions have been taken and are adequate; and
(g) Verification that all required information is well documented and is stored in a retrievable manner for future reference.

The size of any assurance team will be related to the complexity of both the site decommissioning and remediation activities and the regulatory regime in which the site operates in addition to any cost constraints.

7. CONCLUSIONS

7.1. RATIONALE AND BENEFITS OF INTEGRATED PLANNING

Decommissioning and remediation activities at nuclear sites are subject to some common driving forces, and involve common tasks and inter-related needs for enabling facilities, site infrastructure, workforce and supporting management systems. The integration of decommissioning and remediation activities through the development of a unified strategic plan for site decommissioning and remediation takes advantage of these synergies and ensures that;

(a) The goals of individual decommissioning and remediation activities are aligned and do not conflict with each other,
(b) Costs are minimized,
(c) Net health, safety, security and environmental benefits are maximized.

Experience has shown that managing the decommissioning and remediation activities in an integrated programme that utilizes the synergies can result in enhanced environmental conditions, and/or reduce the requirement for additional remediation work, both of which impact the effort to achieve the ultimate site remediation objectives. Lack of integration can result in increased costs, increased exposures to personnel, and increased duration of the overall effort. These escalations can also delay the influx of revenues from early re-use of the site (or parts of the site). In some cases, degraded site conditions can render favorable re-use options unfeasible, resulting in reduced re-use potential, reduced land value or revenue potential and loss of stakeholder confidence. For these reasons, the central premise of this report is that an integrated approach to decommissioning and remediation is necessary in the interest of cost and risk reduction.

Among the sequence of steps involved in developing an integrated plan for decommissioning and remediating a nuclear site, the most important step is the establishment of the site remediation objectives, which principally involves selecting the best re-use option for the site (which drives the site end-state requirements). For large nuclear sites, re-use can occur in stages, and ideally the earlier stages can be planned to be revenue-generating. Therefore, there can be a range of alternative re-use scenarios to consider.

Another important aspect of the strategic planning process is that different technological approaches and different sequences of decommissioning and remediation tasks can be taken to transform the site to intended end-state. These alternatives are evaluated in terms of feasibility, cost, benefit, risks and other evaluation criteria, ultimately ending with the selection of a preferred approach, thus establishing the elements of the site decommissioning and remediation strategy. Because this evaluation involves many inputs, some of which are inter-related, the evaluation process is iterative. Stakeholder involvement can be another cause for iterations, as can other external factors such as changing resources, technological advancements, and new environmental characterization information. These external factors are sources of uncertainty in the process, and for this reason it is necessary to periodically re-evaluate and re-confirm the decommissioning and remediation strategy (planning basis). Accordingly, strategic planning is a dynamic process. Through comprehensive and careful integrated planning, however, the potential for significant changes to the planning basis can be minimized.

7.2. NEED TO USE APPROPRIATE TOOLS

Because a wide variety of tools and techniques are available to support planning exercises, the choice of tools and techniques used is a critical decision. Each tool or technique has specific data requirements, underlying assumptions, and outputs. That is, they are designed to address specific types of analytical issues and support specific types of decisions about decommissioning and remediation at nuclear sites. For example, economic analysis techniques such as cost benefit analysis or cost effectiveness analysis are only appropriate for evaluating cost issues. Similarly, critical path analysis is designed to address the identification of key sequencing issues. As a result, it is impossible to select appropriate tools and techniques for planning purposes unless the key questions to be answered are clearly defined at the very start of the planning process. Moreover, because planning and project management are dynamic, the emergence of new information and issues over time requires managers to re-visit periodically which tools and techniques are appropriate to use. Thus, it is essential to document fully the justification for why specific tools and techniques are used for decommissioning and remediation planning.

7.3. STAFF EXPERTISE ADEQUATE FOR PLANNING

It is important that project staff be technically and professionally qualified and have related practical experience. It is preferable, to include, in the project team, persons who were involved in the operation of the facility/plant/site who would therefore be very knowledgeable of the design and operational history. Specific knowledge and skills will be necessary for decommissioning and remediation activities and specialized organizations and companies can provide the related services. However, one of the key of success can be the training and qualification of the operational staff in order to get the expertise required for some specific decommissioning and remediation activities. The necessary training of staff to address any gaps provides assurance the project is executed in accordance with current practices and standards in technology. It has also been noted on several occasions that one of the major weakness in decommissioning and remediation projects is poor or inadequate planning and management leading to time and cost overruns. It is important that the project manager be appointed before the facility is shut down. This manager who would carry the responsibility for undertaking the initial planning, who need not necessarily have direct experience in the operation and maintenance of the facility, but such knowledge and experience would be advantageous.

7.4. OPEN COMMUNICATION CHANNELS

In order to fully integrate remediation and decommissioning programmes, it is very important to have effective communication at a number of levels both within and without the site operations. The final decommissioning/remediation programme, for example, must be effectively communicated to regulators and external funding bodies, and internal communication must be effective between decommissioning, remediation and waste managers to allow full integration of activities. The organizational structure must therefore promote both internal and external communication at appropriate levels. In many organizations there are written and/or unspoken rules which restrict effective communication (e.g. between departments). To ensure that synergies between decommissioning and remediation are fully realized the site management and organizational structure should promote effective communication. This could be facilitated through the use of communication protocols or internal/external stakeholder communication networks, etc. The methods used to facilitate communication will depend on a number of factors and may be unique to any site. Effective communication, however, should be employed at all decommissioning and remediation sites.

7.5. MEANINGFUL STAKEHOLDER INVOLVEMENT

Stakeholders include those groups or individuals who are directly affected by site activities (e.g. members of the local community), or those that can directly affect site activities (e.g. regulators, funding bodies) and those who are interested in site activities (e.g. retired workers now living outside the region). Stakeholders therefore include a wide cross section of the population. It is becoming increasingly common that stakeholders are invited to participate in the strategic decisions at early stages in decommissioning and remediation programmes. Although early involvement is encouraged, the stakeholder process must not start too early (i.e. stakeholders must have some initial material, options or ideas to consider).

The extent of stakeholder involvement and the form of the consultation process will vary from site to site and state to state but it must be relevant to the activities and outcomes at hand. Large-scale decommissioning and remediation projects which have potentially far-reaching impacts on the local or national community may require an extensive stakeholder engagement programme to, for example, define the site end state and site re-use. On the other hand, smaller scale projects within a decommissioning site (e.g. decommissioning of individual facilities and remediation of adjacent land in preparation for re-development to support waste management activities) would potentially require a much smaller stakeholder engagement process which may simply be limited to consultation with internal stakeholders (e.g. waste management, finance, etc) and external bodies such as regulators or other affected parties. It is clear, however, that the relevant stakeholders must be involved in the decision-making process and that process must be transparent and the outcomes recorded and communicated effectively.

7.6. ADOPT LIFE CYCLE MANAGEMENT

It is generally agreed that incorporating decommissioning and site remediation requirements into the design of new facilities or the remaining life cycle of existing nuclear facilities can help to ease future decommissioning activities. In the case of new starts, this encompasses site selection, design, construction and operation. Further, the life cycle management concept does not address each stage in the life of a facility or site as an isolated event. Instead, one phase in its overall life is viewed as having a bearing on the future phases. Thus, planning does not cover each phase individually but is a continuing activity taking into account the actual and projected developments holistically.

This enhances the recognition that site re-use constitutes the final post-decommissioning phase in a site's life cycle. As a result, decommissioning and remediation activities are an opportunity to achieve re-use objectives consistent with site release criteria. For example, it would be inefficient to adopt a total dismantling policy for a nuclear facility, which implies demolishing all structures and removing the materials from the site, if some buildings could be used in the future as part of the site's new use. This may be especially the case for buildings such as cafeterias, warehouses, and administrative services that are not contaminated or laboratory facilities that are not highly contaminated. In such instances, it may be feasible to adopt a selective decontamination and dismantling policy that retains the viability of some structures for redevelopment. Such an approach reduces the 'footprint' (area subject to decommissioning) at a site, thereby reducing waste volumes. Similarly, following the concept of restricted re-use, it may be feasible to limit soil remediation to a level appropriate for industrial redevelopment or a nature reserve, if residential re-use is not feasible in the future. Alternatively, the buffer zone separating the operational area of the nuclear facility from public access may be suitable for redevelopment for residential or other unrestricted uses after decommissioning. After decommissioning and active remediation, when risks to human health and the environment are acceptably low regardless of the future uses of the land, then this may enable a site to be released from any controls (e.g. release from site license conditions). For sites, or areas of land on a site, where protection of human health and the environment requires on-going management and control, then the site moves into a post-decommissioning stewardship phase, or period of institutional care (see Ref. [9] for further details on issues and the requirements for long term stewardship).

7.7. SHARING EXPERIENCES AND LESSONS LEARNED

There have been various lessons learned from the decommissioning and remediation projects to date that will help future projects. Integrating lessons learned from facilities and sites that are undergoing decommissioning and remediation into the decision process can help to avoid or minimize future adverse situation. Recording of positive and negative experiences and information, and sharing lessons learned are important for undertaking optimized future decommissioning and remediation projects. One has to have in mind that decommissioning/remediation is a learning process for all the parties involved: operator, regulatory authorities, State agencies and the public.

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Annex I

SANTO AMARO MINERAL SAND MILL DECOMMISSIONING

This site of 16 503 m^2 held a monazite processing plant and in the metropolitan area of Sao Paulo, which is the largest city in Brazil. The plant operated for more than 60 years. As it has not been classified as a nuclear installation the facility was not controlled by the national regulatory authority. As a consequence of the operations carried out at the site, it became contaminated with residues from mineral sands processing.

Mineral sands were mined in the south-eastern Brazilian coast. Physical processing used to take place at the mining site. The concentrate was then transported to the Santo Amaro mill (USAM) in order to be chemically processed. The final product was a Rare Earth Chloride solution that was sent to another facility located in the same city — the Interlagos Mill (USIN) — in which light rare earth metals were separated from the heavy ones.

Over time, the area became densely populated and developed into a residential neighborhood. This was one of the driving forces leading to cessation of the industrial operations. Also contributing to this decision was the fact that the industrial processes had become obsolete and the company also faced economical issues. Decommissioning activities started in 1994 and finished at the end of 1998. Decommissioning was carried out in five stages: (1) initially suitable packaging of contaminated material and waste removal took place; (2) decontamination and dismantling of equipment; (3) decontamination of floors and walls and demolition of the buildings (built area was about 13 000 m^2); (4) land radiological characterization; 5) site clean-up. As long as Brazil does not have a national repository for low and intermediate level wastes, some of the generated wastes (about 60 m^3) had to be stored in an adapted building at the Interlagos Mill site.

The residual concentration levels were derived by pathway analysis. Site clean-up operations generated 2 300 m^3 of contaminated solid material (mainly soil), that — with the exception of the material stored in USIN - were dumped at a municipal landfill (concentrations below 70 Bq/g). Pictures of the USAM site before and after the clean-up activities are shown in Figure I-1.

The total costs of the operations were estimated to be about US$1.2 million. The site was released for unrestricted use, and sold at the market price of $12 million. Six towers with 26 floors each were built at the site.

The situation described above encompasses some of the typical features of old facilities and sites that have to be decommissioned and remediated. These characteristics include [II-1].

(a) Operation taking place under a less restrictive environment (or even lack of regulatory control);
(b) Poorly documented site operational history;
(c) Deteriorated engineered structures posed a safety hazard to workers and the environment;
(d) Waste retrieval and disposal were not considered in the operational life of the facility; and;
(e) No previous identification of possible approaches to implement site remediation.

FIG. I-1. USAM site before and after decommissioning and site clean-up.

Presently the most serious issue to be solved regards the final destination of the generated wastes. They are stored at a facility that will have to be closed and remediated. In such cases, i.e., whenever a permanent disposal option is not available, wastes should be retrieved and conditioned for safe storage.

Had decommissioning and remediation activities of the facility been thought about in an integrated manner, some techniques should have been implemented (like soil sorting and washing) in order to reduce the volume of the generated wastes and make the storage of the material easier.

REFERENCE TO ANNEX I

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Annex II

DECOMMISSIONING AND REMEDIATION OF THE URANIUM PRODUCTION CENTRE OF POCOS DE CALDAS — POTENTIAL BENEFiTS OF AN INTREGRATED APPROACH

II-1. INTRODUCTION

The uranium industry in some emerging countries, like Brazil, is sometimes associated with providing fuel for its own nuclear power plants. As a result its development has been so far very much attached to the concept of some sort of national strategic planning.

One of the main consequences of this approach is that costs based on market values are sometimes disregarded and the mining of low grade ores may be favored. By doing so, the generation of large areas to be remediated may take place, as the sole aim of the project may have been the exploitation of the uranium deposit without taking into consideration future environmental remediation costs. When the ore deposited is exhausted and/or mining and milling operations need to be terminated, operators (generally state owned companies) will eventually not be able to afford the burden of remediation programmes. The necessary expenditures will have to compete with other social needs and remediation projects will suffer delays in their implementation. Meanwhile, expenditures with water treatment, for example, may take place.

The lack of experience in decommissioning and remediation programmes is another important issue as the release of sites holding nuclear activities is only a mature practice in those countries with a number of completed decommissioning and remediation projects.

Indeed, experience gained in the decommissioning and remediation of sites in developed countries may not be readily transferred to developing ones due to numerous specific conditions, as it will be discussed further.

This case study is aimed at illustrating how an integrated approach to decommissioning and remediating a uranium mining and milling facility would have helped the operator to minimize costs and optimize outputs if the elements discussed in the document had been taken into consideration. Even at the present stage, the ideas developed in this study case will be very useful. On a broader perspective, the intention here is to give readers concrete elements that may contain some similarities to on-going projects in some Member States and by doing so help in the future implementation of integrated decommissioning and remediation works.

The case study addresses the remediation of the first uranium mining and milling facility in Brazil which ceased uranium production operations in 1997.

II-2. THE MINING SITE OF POCOS DE CALDAS

The alkaline geological complex in which the mining and milling site is located at corresponds to a circular volcanic structure which formation began in the upper Cretaceous (87 ma) and evolved in successive steps until 60 ma (Fig. II-1). This intrusion was rounded by the leveling of bedrocks, consisting of granites and gneisses. These rocks are frequently cut by diabase dykes, amphibolites and gneisses.

These igneous-policyclic activities, of alkaline nature, associated with intense metassomatic processes and a strong weathering, gave rise to a variety of rock types belonging to the Nepheline-Syenite family and to uranium mineralization.

The uranium enrichment in Poços de Caldas mine is related to hydrothermal events (primary mineralization) and to later weathering processes (secondary mineralization).

The mine pit covers an area of about 2.5 km^2 and has been divided into three mineralized units designated as ore bodies A, B and E for mining purposes.

The mining and milling facilities began commercial operation in 1982. However, the original intended production of 500 t of U_3O_8 per year was never reached. The uranium deposit is defined as being of low grade associated with a primary mineralization of Zr–RE–U–Th–Mo (bodies A and B) and with a secondary mineralization caused by hydrothermal processes (body E). Uranium occurs in the form of pitchblende, although brannerite ($UTiO_6$) has also been identified in marginal proportions [II-1]. The rocks are known as potassic rocks with varying proportions of mafic and nefeline syenite minerals. As of 1995, 1 172 t of U_3O_8 were produced. This

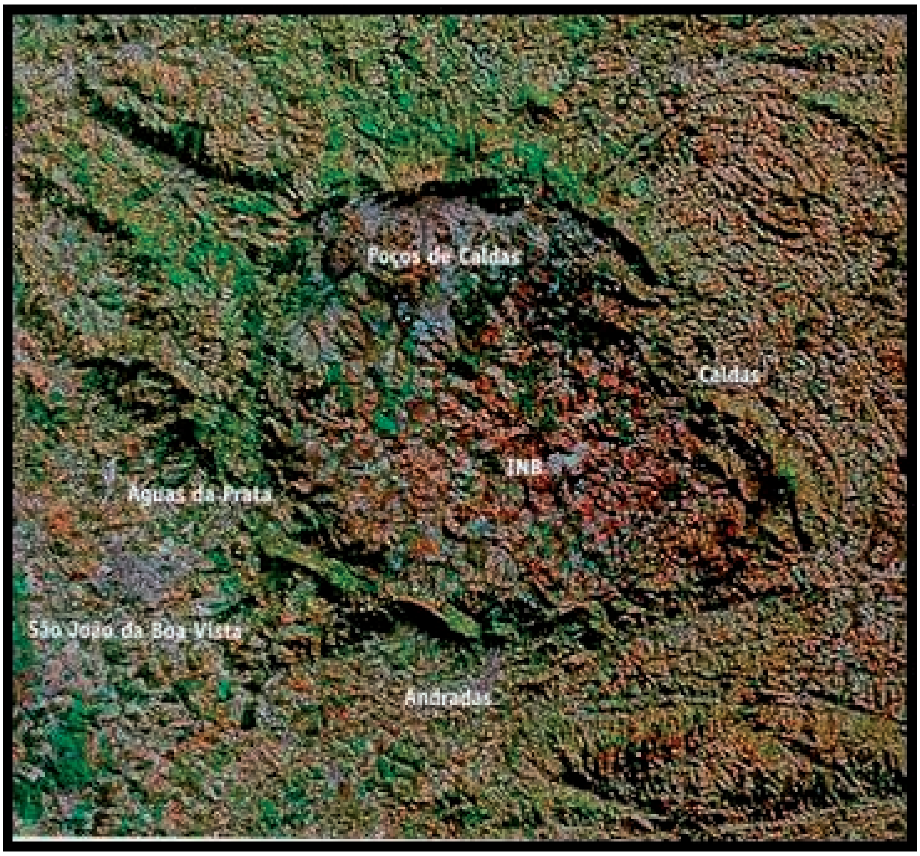

FIG. II-1. Poços de Caldas volcanic crater.

amount corresponds to a uranium concentration in the range of 675 – 1700 mg.kg^{-1}. In the development of the mine 1.11 $\times 10^8$ t of rock were removed. From this amount, 10 million t were used as building material (roads, ponds, etc). The rest was disposed into two major rock piles, waste rock pile 8 (WRP-8) and 4 (WRP-4).

The milling process consisted of the addition of an oxidant (pyrolusite) to the ore and subsequent sulphuric acid leaching. Then the uranium was extracted from the liquid solution with an organic solvent and precipitated with NH_4OH. The chemical processing produced large quantities of liquid and solid wastes, which were neutralized by $CaCO_3$ and CaO to pH 9 and then discharged into the tailings dam for solid deposition. After 15 years (1982–1997) the uranium mining and milling operations ceased. However, the chemical plant in charge of the liquid effluent treatment is still active.

Seepage that percolate through the waste rock piles are pumped to the mine pit. From there, the accumulated acidic waters are pumped to the chemical treatment plant. In the past, the slurry from the drainage treatment was deposited in the tailings dam. Recently, due to the exhaustion of the capacity of the tailings dam to receive additional wastes, the precipitate from the chemical treatment is being deposited in the mine open pit (Fig. II-2). The effluent from the tailings dam is treated with $BaCl_2$ to remove radium isotopes from solution. The solids (precipitate) settle in two holding tanks and the overflow is discharged into the environment. Average annual precipitation in the area is 1800 mm/year.

Table II-1 shows the amount of waste rocks deposited in the different piles; piles number 4 and 8 being the largest. These two piles together contain about 60% of the total amount of rocks removed during mining operations.

Regarding the tailings, it has been estimated that in the period between 1982 and 1992 approximately 2.05 $\times 10^6$ t of wastes were deposited in the tailings dam. The amounts of the different materials deposited in the tailings dam are depicted in Table II-2. The average elemental composition of the deposited wastes is shown in Table II-3.

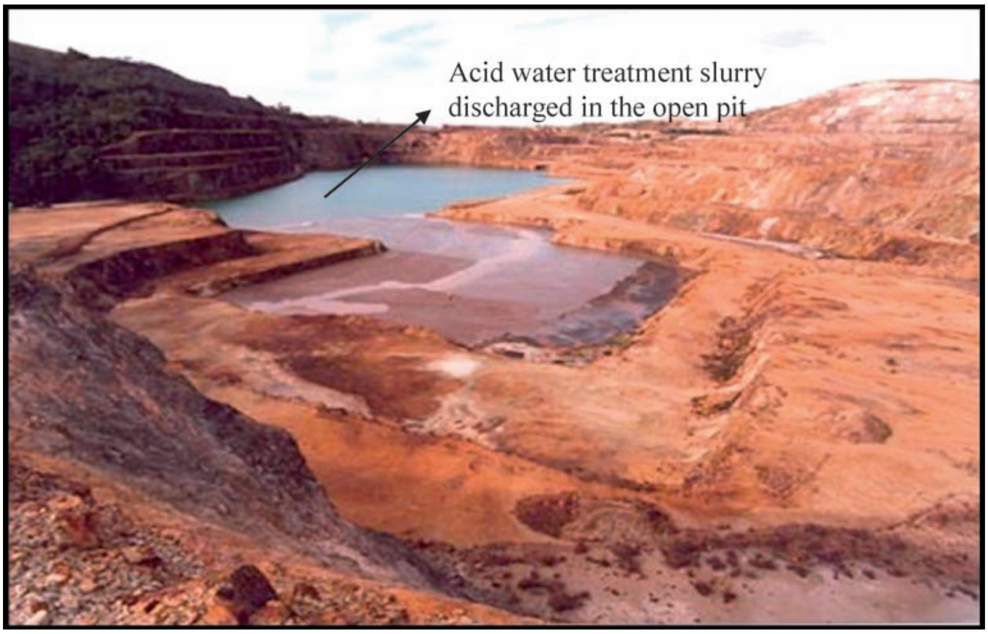

FIG. II-2. Open pit with the deposition of the slurry from the acid water treatment in detail.

TABLE II-1. OVERVIEW OF THE CHARACTERISTICS OF THE WASTE ROCK PILES

WRP	Volume	Surface area	Main source of material
	10^6 m^3	10^4 m^3	
1	4.4	25.5	Overburden
3	9.8	20.5	Overburden
4	12.4	56.9	Waste material from body B+Overburden
7	2.4	5.3	Overburden
8	15.0	64.4	Waste material from body (B+E)+Overburden
WRP inside the mine pit	0.56	9.87	Waste material from bodyE

TABLE II-2. INVENTORY OF THE WASTES DEPOSITED IN THE TAILINGS DAM

Material	Mass (t)
Milled ore	1 764 976
Sulphate	135 168
Pyrolusite	35 049
Phosphatic rock	6 770
Lime	109 950
Total	2 052 913

TABLE II-3. AVERAGE COMPOSITION OF THE WASTES IN THE TAILINGS DAM

Species	Concentration (%)
ZrO_2	0.15
MoO_3	0.02
Al_2O_3	23.4
K	11.2
SiO_2	54.0
CaO	0.25
SO_4^{2-}	2.3
S^{2-}	0.5
Fe_2O_3	3.9
Mn	0.02
P_2O_5	0.09
U	0.018
Th	0.004
^{226}Ra (Bq/g)	2.5
^{210}Pb (Bq/g)	3.4
^{228}Ra (Bq/g)	1.4

II-3. DECOMMISSIONING AND REMEDIATION STRATEGY

The overall situation combines two of the most relevant issues in decommissioning and remediation programmes, i.e. lack of sound operation mining and milling development plans prior to the operations and resource constraints (both human and financial). Had decommissioning and remediation activities been adequately considered, prior or at least during the mining and milling operations, the decommissioning and remediation work could have been optimized.

It is clear that decommissioning of all the industrial facilities may not take place before the remediation of the mining and milling area is properly addressed. As such, the integration of both activities is necessary.

The decommissioning and remediation plan shall be compatible with the local ecosystem and take into account possible future land uses. The plan may be subdivided into four parts in order to address the following entities:

(1) Tailings dam and its area of influence;
(2) Waste-rock dumps;
(3) Open pit; and
(4) Industrial area (that shall consider the dismantling of buildings as well as equipment and general material decontamination with the specification of the clearance levels – to be set by the Regulatory Authority).

For each one of the above entities, remediation plans will have to be detailed, in such a way that the intended objectives will have to be specified as well as the intended strategies and expected performance. Cost effectiveness analysis (or any other technique described in Section 4) will have to be presented as well. Physical and financial schedules will have to be discriminated, in such a way that the regulators may monitor each of the on-going activities and identify the synergies in both activities (decommissioning and remediation).

II-4. INTEGRATING DECOMMISSIONING AND REMEDIATION

The first step involves a site characterization (survey) and data collection/interpretation. The synergies between the activities to be performed for decommissioning and decontamination and remediation can be seen in Section 2.3.3. Facilities characterization has to go along with site characterization. As pointed out previously, the optimization of the historical assessment would have been easier if undertaken while the site was in operation. In the particular case of a mining project the recovery of historical data includes, among other things the quantification of wastes deposited in dumps; the origin of the rocks (i.e. ore bodies) and their mineralogical composition; granulometry and other physical and chemical information. Regarding the tailings dam, useful information would include amounts of different types of wastes deposited in the dam; composition; geotechnical properties, etc. Many of these pieces of information will be used as input data in the mathematical models to be used in the risk assessment work that will take place further. Model predictions will ultimately determine the kind and extent of interventions and remediation that will have to be put in place. The characterization of the facilities will be important in the sense that this information will help in the definition of an overall waste management plan for the site.

II-4.1. Risk assessment and geochemical processes

Two of the major relevant sources of pollutants to the environment are the waste rock piles and the tailings dam. The open pit will also represent a relevant environmental aspect to be considered, as waters accumulated in the pit may contain significant amounts of pollutants that could contaminate ground waters. The important mechanism in pollutant mobilization from the rocks accumulated in the waste dumps is pyrite oxidation that leads to the generation of acid drainage.

Acidic water will leach radionuclides and heavy metals from the rocks that will ultimately end up in the nearby water courses. The presence of pyrite in the rock material explains the low pH values in the drainage. Uranium is being preferentially mobilized relatively to ^{226}Ra. Elevated concentrations of ^{238}U along with those of Al and F and the low pH values preclude the release of these drainage water into the environment without prior treatment.

The supply of oxygen is the limiting force in pyrite oxidation. Bacterial activity may also play an important role in the process (Eqs II-1, II-2)

$$FeS_2 + 8H_2O + 14\, Fe^{3+} \rightarrow 2SO_4^{2-} + 15\, Fe^{2+} + 16H^+ \qquad \text{(II-1)}$$

$$Fe^{2+} + \tfrac{1}{4}\, O_2 + H^+ \rightarrow Fe^{3+} + \tfrac{1}{2}\, H_2O \qquad \text{(II-2)}$$

The oxygen removed from the system in the process of pyrite oxidation will create a concentration gradient in the rock pore spaces. A high oxygen demand will promote a pressure gradient inside the pile that will lead to the transport of the air mass into the pile as a result of oxygen removal. At lower oxygen demands the transport of oxygen will be governed by diffusion. Ritchie (1994) [II-2] introduced the concept of intrinsic oxidation rate (IOR), which is simply the rate of oxygen consumption in the material forming the pile in its prevailing conditions. The most practical unit to express the IOR is kg (O_2) m^{-3} s^{-1}. Table II-4 shows some values of IOR and relevant characteristics associated with these values.

Available results [II-2] reveal IOR values on the order of 10^{-9} kg(O_2).m^{-3}.s^{-1}. As a consequence, it has been estimated that more than 500 years would be necessary for the pollutant concentrations in the drainage to decrease to acceptable values, i.e., values associated with marginal environmental/health risks.

As the acid drainage generation will last for centuries, the collect and treat strategy can not be faced as an acceptable solution. In the long run it would be a costly strategy that will require the functioning of a water treatment plan and overall associated infrastructure for this significant period of time. In addition, presently the slurry from acidic waters treatment is being disposed of in the mine pit, as the operator is no longer allowed to deposit any further waste/residues in the tailings dam. If the problem of acid generation is not dealt with, the open pit will continue to receive the treatment slurry. In conclusion, it is evident that the abatement of acid drainage generation is of primary importance in the overall remediation and decommissioning plan.

TABLE II-4. SIGNIFICANCE OF THE IOR VALUE MAGNITUDE

IOR kg $m^{-3}s^{-1}$	Time for pyrite consumption (year)	Time for the consumption of rock bearing carbonates	Time for the consumption of O_2 initially present in rock pore spaces	Heat Generation Rate (W m^{-3})	Sulphate concentration in the drainage (mg/L)	Relevance of the IOR
10^{-5}	0.167	2.4 d	—	129	—	Rate observed in laboratory experiments of biological oxidation
10^{-6}	1.67	3.4 weeks	0.9 d	12.9	—	Rate necessary for running bio-oxidation heaps.
10^{-7}	16.7	0.66 a	1.3 weeks	1.29	—	Effective extremely high rates for some waste-rock piles.
10^{-8}	167	6.57 a	13.1 weeks	0.129	21 600	Rate typically found in waste-rock piles
10^{-9}	1670	65.7 a	2.52 a	0.013	2160	Typically low rates found in some waste-rock piles
10^{-10}	16 700	657 a	25.2 a	—	216	Rates associated with marginal environmental problems

Regarding the tailings dam, the computational code RESRAD [II-3]was used to examine the risk of the occupation of the tailings dam area by “intruders” those who would build houses over the tailings. Doses as high as 40 $mSv.a^{-1}$ were predicted. In addition to this the residual pyrite remaining in the milled ore also results in acid generation in the tailings environment similar to what happens in the waste rock piles. The main geochemical mechanisms taking place in the tailings environment have been described [II-4]. It was suggested that oxygen diffusion would be taking place through the first 1 m layer of the tailings. Metals like Fe, Al and U would be transported downward by the percolating waters but Ra isotopes and ^{210}Pb would not. In this upper zone, pH values are as low as 3.0. However, pH values increase with depth (varying in the range of 5.0 to 6.0), as a consequence of the past discharges of the milling effluents with high pH values (in the range between 10 to 12) during the operation of the industrial plant. It has been postulated [II.4] that this deeper region of the tailings dam would function as a buffer zone that would neutralize the acidic percolating fluids moving downward. As a result, the migrating elements would precipitate in this higher pH zone. It has also been estimated that the release of effluent into the environment, without any treatment, would result in doses as high as 8.0 $mS.a^{-1}$ to members of the potentially most exposed population (critical group). This value is unacceptably higher than the primary limit established by the Brazilian regulatory authority, i.e., 1.0 $mS.a^{-1}$.

II-5. TECHNICAL ASPECTS OF THE REMEDIATION OPTIONS

Removal of the source, i.e., returning the waste-rock material (and eventually the tailings) back to the open pit was examined as a possible solution. The costs related to this option based on [II-5] are: hauling of the materials — $1.5 per t of rock; landfill operations — $3.0/per t of rock, and re-vegetation — $5 000.$ha^{-1}$. A rough estimation of the overall cost for this option, taking into account the material deposited in the WRP 4, would amount about $70 million. This seems to be a very high expenditure, therefore this option would not be recommended as an effective strategy to remediate the site.

Immobilization techniques may be effective in reducing migration of radionuclides from tailings, but not from the waste-rock piles. As a result of the above considerations, capping would be the preferred strategy. In order to evaluate the effectiveness of capping in the attenuation of acid generation, modelling exercise has to be implemented. In such cases capping the waste-rock pile with a material with a lower oxygen diffusion coefficient than the rocks forming the pile would be an effective manner to halt the input of oxygen into the system and consequently reduce the concentration of pollutants in the drainage. The attenuation factor will depend more on the properties of the capping material than on the properties of the waste material itself [II-6]. The practical problem to be addressed is to design an appropriate capping system in such a way that its physical stability can be maintained in the long term. For a cap of inactive material with thickness equal to X_c and diffusion coefficient D_c the oxidation rate can be determined using the following expression [II-6]:

$$GOR = \sqrt{2C_0DS^*}(\sqrt{\alpha + n} - \sqrt{\alpha + n - 1}) \tag{II-3}$$

Where

$$\alpha = \left(\frac{X_c}{D_c}\right)^2 \left(\frac{S^*D}{2C_0}\right) \tag{II-4}$$

GOR = global oxidation rate ($kg_{O2}m^{-2}.s^{-1}$)
X_c = Thickness of the inactive material cap (m)
S* = Intrinsic oxidation rate ($kg_{O2}.m^{-3}.s^{-1}$)
C_0 = Oxygen concentration in air ($kg.m^{-3}$)
D = Total oxygen diffusion coefficient in the pile ($m^2.s^{-1}$)
D_c = Oxygen diffusion coefficient in the cap material ($m^2.s^{-1}$)

With the aid of Eq. (II-4), values of GOR were simulated as well as the sulfate load for different capping thickness while varying values of oxygen diffusion coefficients. It was assumed that the infiltration rate would be of the order of 50% of the total precipitation (equivalent to 0.85 $m.a^{-1}$). It has been demonstrate however, that the infiltration rates may be reduced to values as low as 1 to 5% of the total precipitation rates with an effective capping. The resulting values are pictured in Fig. II-3.

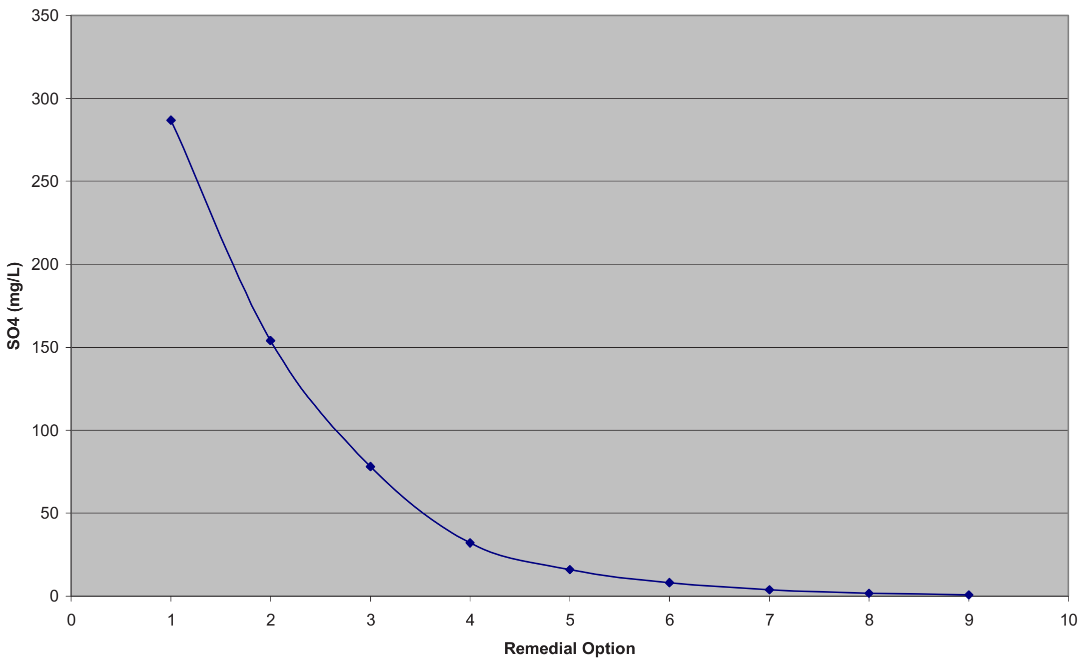

FIG. II-.3. Sulfate concentration x *remedial option.*

It is well known that costs of remediation increase linearly with the attenuation of the environmental impacts. Figure II-3 suggests that capping the waste rock pile 04 with a material with an oxygen diffusion coefficient of 10^{-9} $m^2.s^{-1}$ and a thickness of 0.5 m (option 4) would be the most effective solution to reduce the concentrations of pollutants in the drainage leaving the system because, increasing the thickness of the capping material or using materials with lower oxygen diffusion coefficients would not be more effective than what is obtained from option 4. Regarding ^{238}U activity concentrations, it was assumed that the radionuclide varies linearly with sulfate as suggested by [II-7]. If the same reduction level is applied to the other pollutants (e.g. Al and F^-) the concentrations in the mixing zone of the receiving water body will be lower than the Brazilian legislation standards.

One of the issues regarding the capping of waste rock piles has to do with the erosion of the capping material. If clay is used as the capping material some sort of protective barrier should be applied. A general scheme to be put in place in those situations is a three layer barrier consisting of a bottom granular layer, an intermediate one — the capping material itself, and a third layer consisting of gravel to protect the capping layer against erosion. The total cost would be about \$10 million for the remediation of only one of the existing waste rock piles in the Poços de Caldas mining site. These costs may be reduced if a less costly capping material (clay) can be obtained from neighbouring areas.

The rehabilitation costs at the Woodlawn site in Australia, with similar problems to those of Poços de Caldas were of the order of \$22 000.ha^{-1} [II-8]. Decommissioning strategies adopted in different countries show average capital costs in the range of US\$3 to 15 million depending on the complexity of the installation [II-9]. Reported costs for remediation of waste rock piles were \$0.30 per t of deposited material. Applying this figure to waste rock pile 04 we would have a value of about \$7.0 million, which is similar with the estimated costs presented here.

The effect of the application of a cap material over the tailings has been also evaluated. As input data to the code RESRAD, a material with the same properties of that used in the waste rock remediation was tested, i.e., a material with an oxygen diffusion coefficient of 10^{-9} m^2-s^{-1}. It was assumed that radon gas would be diffusing through the cover at rates equal to oxygen.

It was observed that the cap would reduce the doses (both exposure to radon and gamma radiation) effectively to zero. The increase after 1 000 years would be due to the erosion of the cap material. In the absence of site-specific information the erosion rate of 6.0×10^{-5} $m.a^{-1}$ was adopted. According to [II-3] this value would be typical of a soil not subjected to any agricultural practice. Values in the range of 10^{-7} –10^{-4} $m.a^{-1}$ are reported in the literature, and depends, in addition to the vegetation on the slope of the land, its use and type of cap material.

The costs associated with this strategy are estimated as being of the order of approximately \$3.7 million if the same scheme used in the application of a cover in the waste rock pile 04 is adopted in the tailings dam. Additional geotechnical work would be required for the tailings dam, and this additional work may result in extra costs not projected in this work. Details of the application of a dry cover to a tailings dam can be seen in [II-10].

II-6. OVERALL STRATEGY

Taking all the elements discussed above into consideration, a phased approach has to be put in place. This means that decommissioning and remediation work will need to be integrated and that a substantial part of the site may be released prior to the end of institutional control of the whole site.

The concept of a phased approach leads to the division of the whole site in the four above mentioned areas. Site categorization according to the operation history and/or the likelihood of contamination will be of key importance in this process. One may assume that office areas, restaurant, library, and even the sulphuric acid plant for example are not expected to contain any residual radioactivity, or at least may contain levels of residual radioactivity at a very small or negligible fraction of the release criteria to be adopted. On the other hand, areas where mining and milling wastes were disposed of will have to be dealt with special consideration, due to the long half-lives of the involved radionuclides will be unavoidably subjected to further institutional control.

Meanwhile, the dismantling of the non-contaminated premises can take place with the transfer of equipment and machinery to another production centre.

Taking into consideration the lack or resources and the increasing price of uranium in the international market, an alternative course of action, that still integrates remediation and decommissioning in the phased approach would involve the use of the former industrial area, with the appropriate adaptation, to process uranium from different sources or to produce rare earth concentrates. This strategy has the advantage that the site already store radioactive waste (this strategy is known as re-use of the site). A negative aspect is that it would also involve the commissioning of another tailings dam.

Another option would be the recovery of uranium from the acidic waters. Preliminary feasibility studies regarding the recovery of uranium from acidic waters have shown that about 30 t per year of U_3O_8 can be recovered. Revenues from this strategy would be used in the remediation of the site. The challenge here is to establish an efficient way to extract uranium from these waters. An ionic exchange technique has been adopted in similar situations elsewhere and is a mature technology. The most important exchangers use synthetic polymers to which the active functional groups are attached. Ionic inorganic exchangers, or zeolites, are also available [II-5]. Critical to the success of ionic exchange resins in treating acid drainages is to identify the exchangers that will exhibit a specific selectivity for the metal of interest over those that are not to be separated like Fe, Al and Ca. [II-5] makes an assessment of the removal of metals from acid mine drainage. It is concluded that most of the investigated resins do not show a well-defined selectivity for the metals of interest — Sb, Cd, Cu, Ni and Zn — and that only the co-extraction of Fe was an obstacle for the application of resins to acid drainage.

The use of ionic exchange resins in the extraction of uranium from water has been reported [II-1, II-11]. It has been estimated that capital costs involving the construction of an ion extraction plant would be about $1.6 million [II-12].

The proposed scheme to be applied in the case of the Poços de Caldas site would have to include the removal of iron from solution. That should be achieved by means of the aeration of the solution and the elevation of the pH to 4.5.

If it is assumed that the process has an efficiency of 90% and if the costs of uranium in the international market are taken into account, i.e., $113/lb, it can be roughly estimated that about $6.8 million per year would be gained from the recovery of uranium from the acid drainage. It was reported by the operator that about $2.6 million were spent on water treatment or approximately $145 000 per year. As a result it can be proposed that the revenue obtained with uranium recovery could be deposited in a fund to be used in future remediation of the site.

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Annex III

LIFE CYCLE BASELINE OVERVIEW FOR BERKELEY

III-1. INTRODUCTION

Berkeley power station, situated on the bank of the UK's River Severn Estuary in Gloucestershire, is the first commercial nuclear power station in the UK to be decommissioned after 27 years of operation. Berkeley Power Station was one of the UK's first nuclear power stations. Electricity generation started in 1962 with two natural uranium-fuelled Magnox reactors - the type that first produced commercial electricity in the UK. The two reactors with four turbogenerators supplied a total of 276 megawatts of electricity until Reactor 2 was shutdown in October 1988 followed by Reactor 1 in March 1989. It has largely been decommissioned and should be one of the first Magnox power stations to enter care and maintenance.

In addition to the power station, the nuclear licensed site also houses shielded facilities previously used for examination of nuclear materials which are also being decommissioned. A large area of land adjacent to the power station was delicensed in December 2006. Options for reuse of this land and the various offices and laboratories which stand on it are being explored with Stakeholders.

Under current plans, the assumed end-point for the site is a delicensed site with removal of all surface structures and subsurface structures down to 1 m. Residual human-made contamination will be removed to the clearance criteria defined by the regulator, thus allowing the site to be released from regulatory control (i.e. delicensed).

III-2. OVERALL STRATEGY

Berkeley is currently well advanced into decommissioning with much work already completed. The three remaining phases are the completion of care & maintenance preparations (C&M Preps), care & maintenance (C&M) and final site clearance (FSC). The life cycle baseline (LCBL) describes the activities to be undertaken within these phases. The work contained in the Decommissioning & Termination category includes all activities undertaken on a site to decommission facilities starting from the end of defuelling, through to the agreed or assumed end state for the facilities and the site. Also included are contaminated land studies and any resultant remediation and post-decommissioning activities.

Through partial site de-licensing it is hoped that demolition of many conventional buildings cease to be a pre-requisite for entry into C&M. During the quiescent C&M period, work within this category will mainly consist of monitoring and maintenance activities as operation of the site is centered on the safe containment of the residual activity and radioactive wastes on the site. It is estimated that between 2046 and 2049 the packaged ILW will be removed from site and transported to a suitable repository.

During Final Site Clearance (FSC), the reactor buildings will be 'de-planted' and decontaminated before demolition. All structures on the site will be removed and work undertaken to ensure all contamination is removed from the site. This will facilitate the de-licensing of the licensed site, and ensure the site is suitable for reuse.

The work is described by Operating Units (OUs) which span three phases of C&M preps, C&M and FSC (Fig. III-1).

The operational waste management OU contains two projects key to hazard reduction on site. The Active Waste Vaults Retrieval (AWVR) plant which will retrieve, process and package ILW stored in the waste vaults since the electricity generation phase of the power station will be built and demolished whilst the Cesium Retrieval Plant (CRP) will process ILW and Low Level Waste (LLW) contained within it prior to decommissioning and demolition. Packages will be produced for long term storage on-site in purpose built store. In addition, the project will also process ILW from the Shielded Area facility and ILW Post Irradiated Examination (PIE) store Work relating to the CRP and the Shielded Area Facility also plays a major role in the reduction of the on site hazards. The completion of these activities represents a major role step towards the completion of works to allow Berkeley to enter into C&M and a significant reduction in the hazard on site.

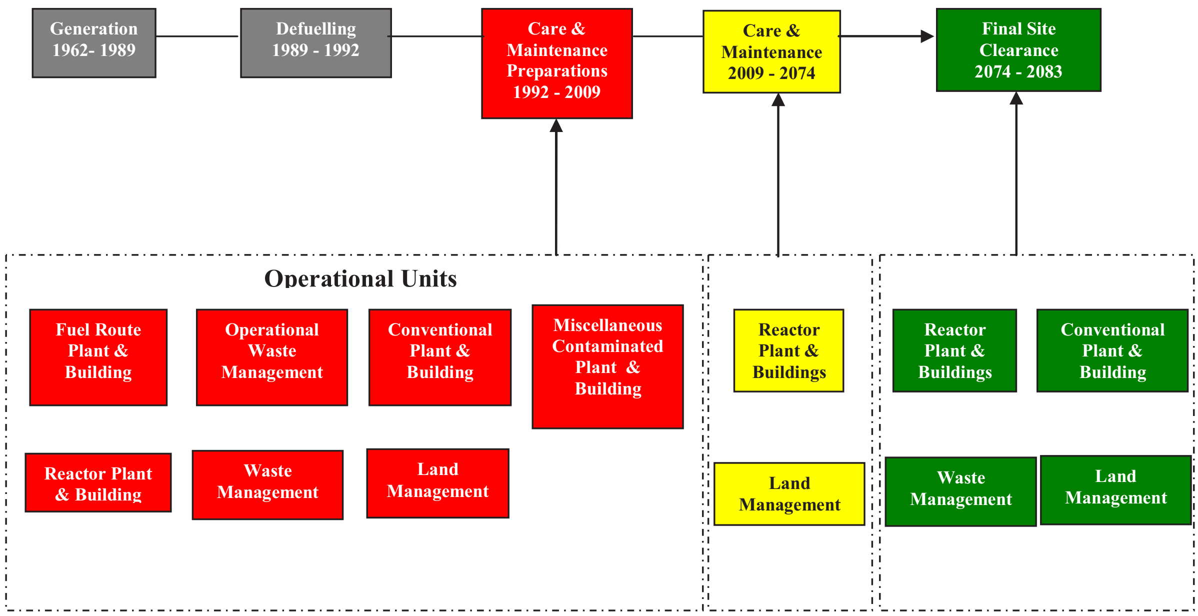

FIG. III-1. Decommissioning and termination scope of work by key phases.

The Miscellaneous Contaminated Plant & Buildings OU contains work in the Shielded Area Facility to remove radioactive material and subsequently decontaminate, de-plant and demolish the building. It also includes the de-planting and demolition of the Berkeley Power Station (BPS) Active Effluent Treatment Plant (AETP), transfer and discharge lines, deplanting and demolition of the Main Change Unit (MCU) and the decommissioning of the Mobile Bowser.

The Reactor Plant & Building OU describes the activities required to place the reactor plant and buildings in quiescent storage for C&M, the inspection and maintenance activities to be performed throughout C&M, and the dismantling of the heat exchangers, primary gas circuits, reactor vessel and reactor building during FSC.

The Fuel Route Plant & Buildings OU work prepares the plant for C&M. This includes the de-planting of redundant pile cap equipment and modifications to the lighting system.

The Waste Management OU describes activities to decommission and demolish Waste Management Facilities (WMF) and stores during C&M Preps and FSC.

The Conventional Plant & Buildings OU describes partial site de-licensing and the demolition or modification of the licensed site's conventional buildings during C&M Preps.

The Land Management OU is integrated in the overall decommissioning process as it contains work in all three phases. During C&M Preps a strategy for achieving entry into C&M will be provided, necessary land remediation, survey and management will take place and the site condition finally defined. Throughout C&M, activities are required to carry out radiological and environmental monitoring both on site and off site, ensuring compliance with regulatory bodies and authorizations. During the FSC phase, activities comprise the remediation of contaminated land, radiological clearance and landscaping.

The work within this category is comprised of projects related to hazard reduction. This includes the decontamination, de-plant and demolition of buildings and facilities on site, and studies to ascertain whether any land remediation is necessary. Remediation will involve simple excavation of contaminated ground, packing and sending as LLW to a national repository. A post-remediation validation survey will confirm results. The site radiological clearance survey is necessary to demonstrate that the site complies with environmental management requirement and is suitable for de-licensing. On completion of this survey and any work resulting from it, final landscaping work can be completed to enable the site to be returned to a visually cleared site suitable for alternative reuse, including non-industrial reuse. It also involves the monitoring and any necessary maintenance to the reactor buildings during C&M.

Figures III-2 and III-3 show the estimated costs of the seven operational units for Berkeley and Hunterston.

It can be seen that costs involved on the operations at each site can vary significantly. Costs required to place the reactor plant in quiescent storage and subsequent dismantling of the heat exchangers, primary circuits, reactor vessel and reactor building during FSC are the highest in both sites accounting for more than 40% of the total costs. On the other costs with land management can be very different, being roughly six times higher in Hunterston in comparison to Berkeley. Costs with Operational Waste Management and Fuel Route Plant &

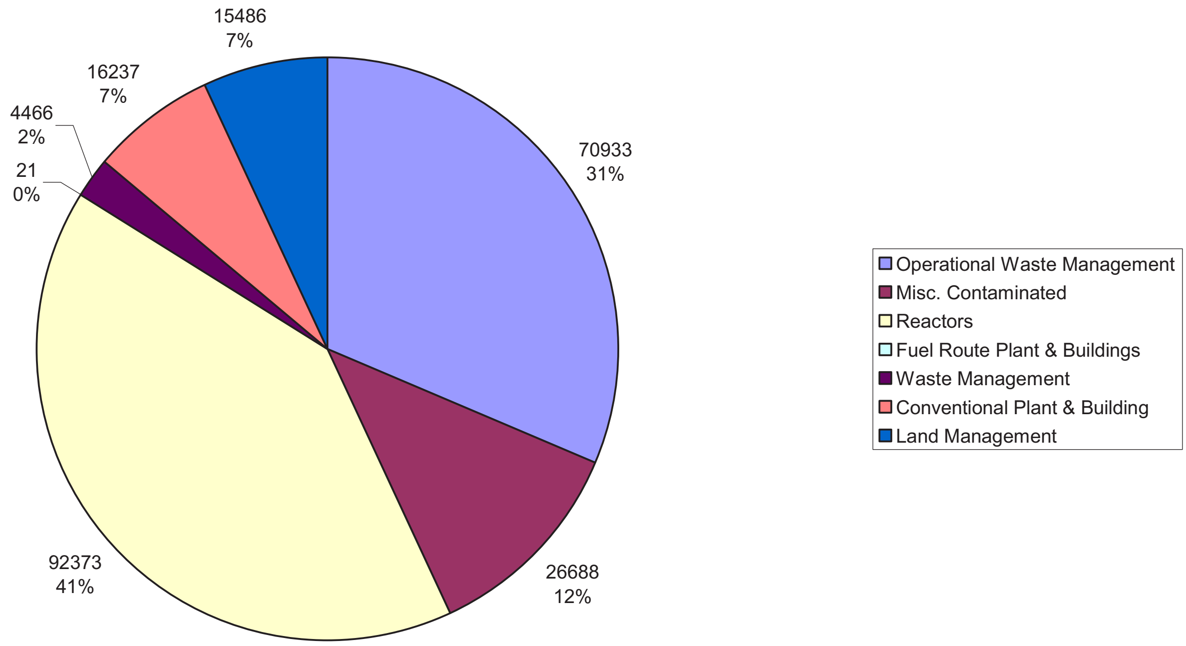

FIG. III-2. Split of costs between the operating units in Berkeley.

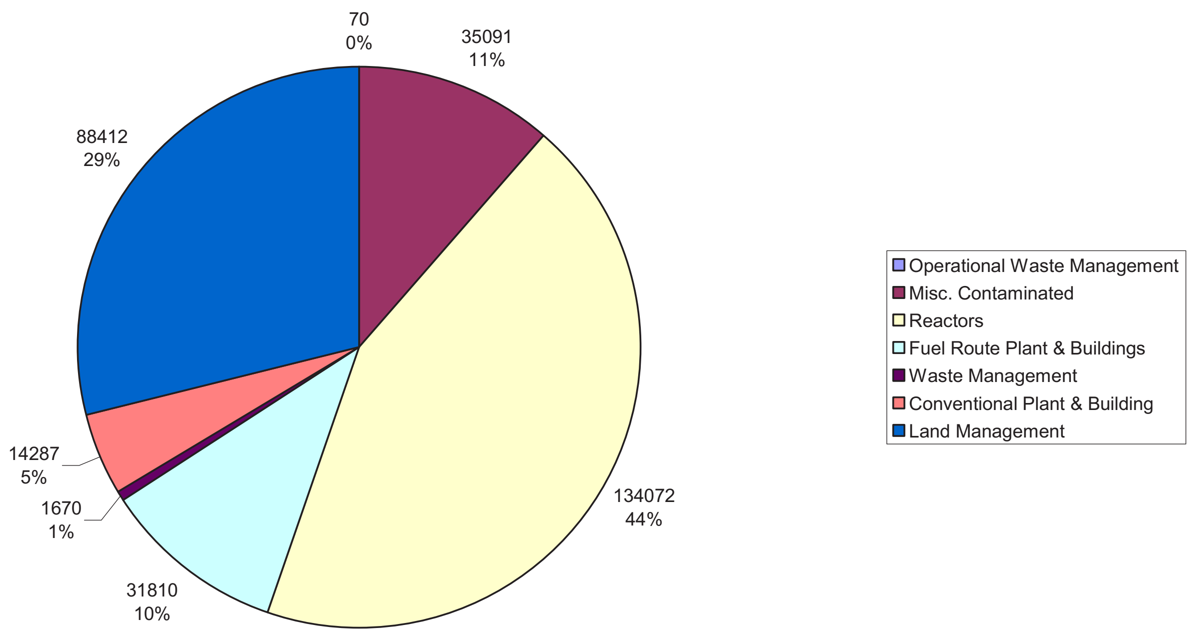

FIG. III-3. Split of costs between the operating units in Hunterston.

Buildings are also different from in both cases whereas costs with Miscellaneous Contaminated Plant & Buildings, Waste Management and Conventional Plant & Buildings are virtually very similar. The difference observed in the total cost amounts roughly £81 x 10^6, being higher in the case of Hunterston.

It can also be estimated that costs distribution in the three phases (C&M preps; C&M and FSC) will be lower during the C&M phase accounting for 11% and higher during C&M preps and FSC, 47 and 42% respectively.

Annex IV

OAK RIDGE NATIONAL RESERVATION

IV-1. INTRODUCTION

The US Department of Energy (DOE) Oak Ridge Reservation (Fig. IV-1) is located on 37 000 acres in east Tennessee. The Oak Ridge facilities include the Oak Ridge National Laboratory (ORNL), the Y-12 National Security Complex and the East Tennessee Technology Park (ETTP - originally built as a uranium enrichment facility for defense programmes). The ETTP was originally named “The Oak Ridge Gaseous Diffusion Plant”. After World War II this plant was renamed Oak Ridge K-25 Site and produced enriched uranium for the commercial nuclear power industry from 1945 to 1985. It was renamed ETTP in 1987.

The Reservation was established in the early 1940s by the Manhattan district of the U.S. Army Corps of Engineers. The organization played a major role in the production of enriched uranium for the Manhattan Project. Soon after World War II, the U.S. Atomic Energy Commission (predecessor to DOE) was formed to transfer nuclear enterprise to civilian control.

The situation at this site is characterized by hundreds of contaminated buildings in deteriorating conditions: 14, 140 ha reservation and 2100 ha of contaminated land; 28 ha of Y-12 burial grounds and 18,120 ton

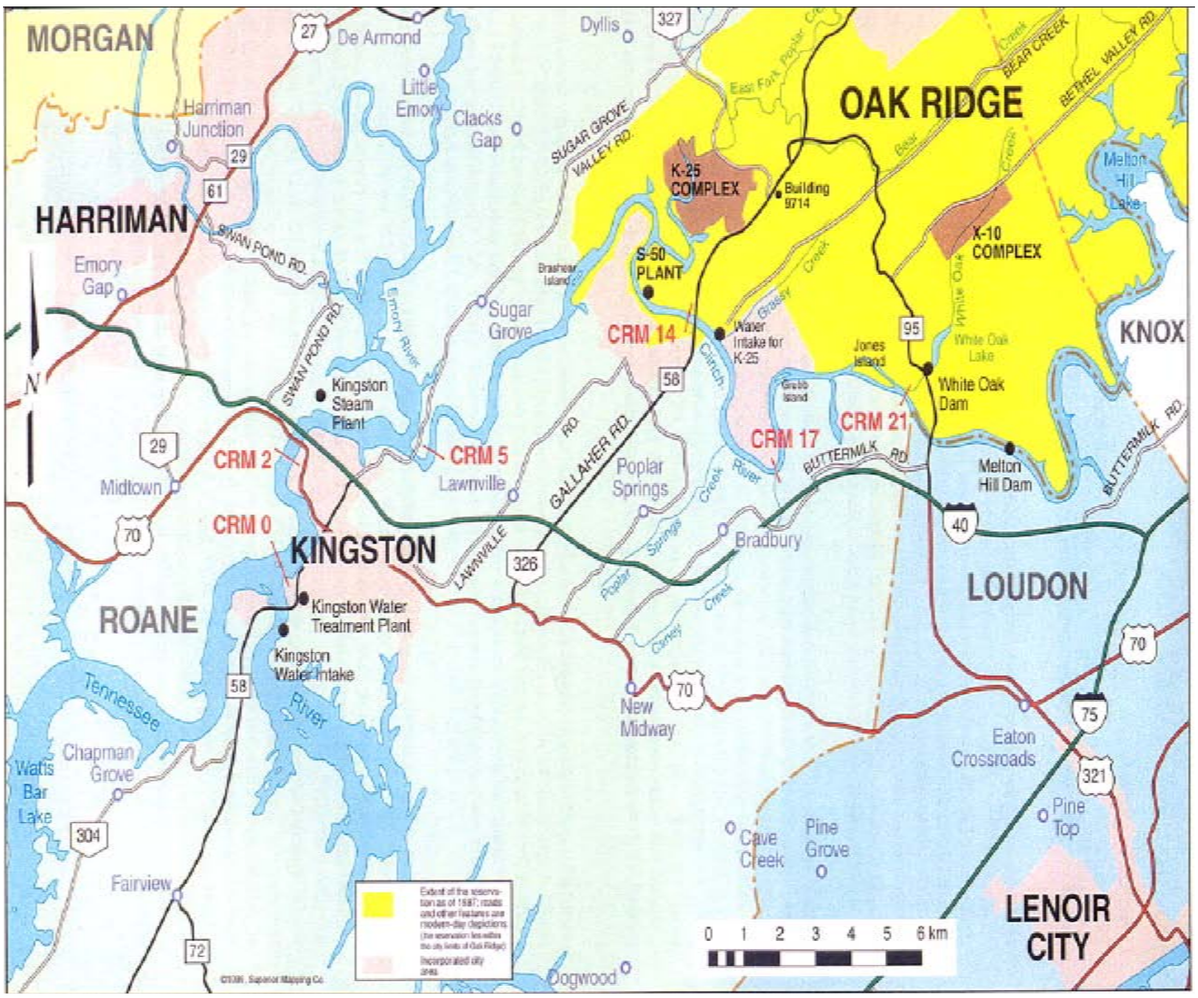

FIG. IV-1. Location of the Oak Ridge Reservation.

of uranium. The water table is shallow at the site implying a short travel time of the contaminants. There are 56.6 ha of ORNL burial grounds and 65.4 x 10^{15} Bq of radioactivity.

IV-2. OVERALL STRATEGY

The overall strategy for cleanup of the Reservation is based on surface water considerations as the Reservation encompasses five distinct watersheds. In fact, surface water is the predominant pathway of contamination migration because shallow groundwater typically discharges to the nearest surface water body. The Clinch River is the major surface water feature around the Reservation, bounding it from three directions. It is the primary receiver of any releases from contaminant sources from the Reservation. There are three primary discharge points including White Oak Creek (downstream from ORNL), Bear Creek (downstream from Y-12), and Poplar Creek (adjacent to ETTP).

The cleanup strategy is a risk-based approach that focuses first on those contaminant sources that are the greatest contributors of risk. The watershed approach is used to determine which sources are the worst contributors and therefore should be cleaned up as early as possible.

At the end of site cleanup, planned by 2015, the Oak Ridge National Laboratory will continue to operate as a world-class research facility. Y-12 will continue to operate, fulfilling its national security mission. As cleanup of the East Tennessee Technology Park is completed DOE will transfer ownership of the uncontaminated buildings to the Community Reuse Organization of East Tennessee (CROET) which in turn will lease this property for immediate private industrial use.

To further refine the overall cleanup strategy, a prioritization system has been developed to help guide decisions where investments should be made. The general priorities are as follows:

(a) Mitigate immediate onsite and offsite risks;
(b) Reduce offsite migration of contaminants;
(c) Remediate sources of surface water and groundwater contamination;
(d) Remediate remaining onsite contamination;
(e) Demolish excess facilities.

Cleanup actions to date have mitigated immediate risks and reduced offsite migration of contaminants that posed unacceptable risks under current land use. While risk reduction is certainly the major cleanup driver, another factor that must be considered is mortgage reduction since there is a finite amount of funding available to accomplish the job. Historically, a significant amount of funding went toward maintenance of infrastructure, primarily at the shutdown ETTP. In fact, nearly $60 million a year is required for utilities, security, fire protection and surveillance and maintenance activities. Therefore, the overall Reservation cleanup strategy takes into account both risk reduction and mortgage.

The reduction of mortgage costs provides dramatic benefit due to the reinvestment of these saved funds into accelerated risk reduction. Therefore, an enabler to accelerating risk reduction is elimination of the mortgage costs by demolishing the facilities that drive these costs. Further, as mortgage reduction increases, the need for Cleanup Account funding diminishes. This integration between remediation and decommissioning aimed at risk reduction is of utmost strategically relevance. This reinvestment strategy is depicted in the following figure (Fig. IV-2).

Other factors such as execution logic and the efficient use of resources also are considered. Execution logic takes into consideration the logical sequence in which activities must be performed. For example: before a cap can be constructed on a burial ground, facilities in the way must be demolished.

Execution logic also enables efficient resource utilization to reduce costs. An example of the efficient use of resources is to couple the demolition of several buildings in the same geographic area into one contract even though their relative prioritization varies. The combined cost will be less than if contracted separately.

Over the last 3 to 5 years sufficient data have been compiled and assessed in the five distinct watersheds to understand the risk posed. These data indicate that the releases from Melton Valley pose the greatest risk to public, workers and environment. By combining the risk-based prioritization of environmental problems with

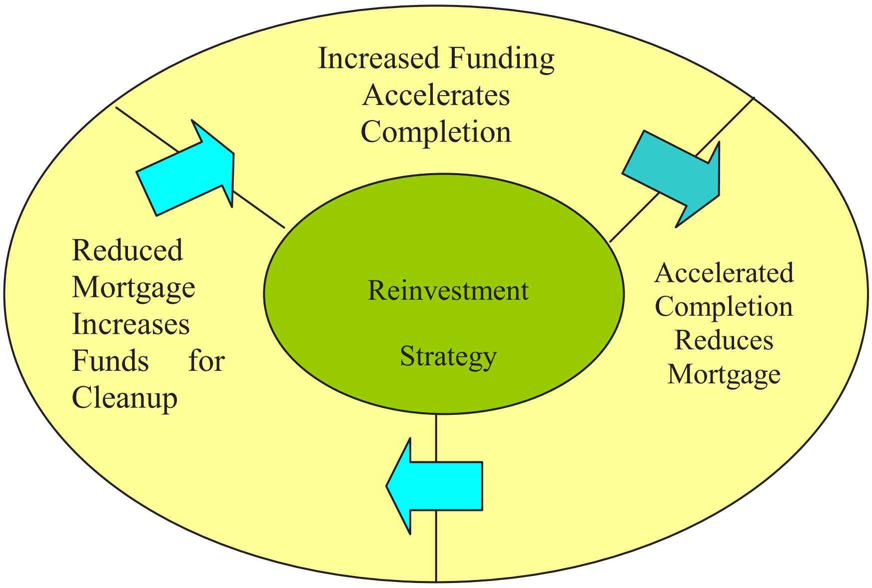

FIG. IV-2. Reinvestment strategy.

the practical considerations of execution logic, efficient usage and mortgage reduction, the overall prioritization strategy was developed as shown in the table bellow (Table IV-1).

The stored legacy waste is integrated with the actions at the ETTP and Melton Valley because its disposal is a predecessor activity to facility demolition and burial ground capping, respectively. Although not in the way of these actions, all of the remaining legacy waste stored at ORNL and Y-12 will be disposed simultaneously to take advantage of economics of scale and to reduce storage costs.

The schedule logic, using the prioritization framework, focuses on the high risk reduction activities and completes the highest risk projects as soon as possible (priorities 1 – 3), In parallel, one must also reduces the high mortgage cost by closing ETTP (priority 4) to make funding available to accelerate completion of the balance of the programme (priorities 5 – 13).

As mentioned in the main body of the text, any decommissioning/remediation work may be improved, adopt alternative approaches and utilize innovative techniques. Bellow, some examples are given:

IV-3. IMPROVED WORK FLOWS

(a) Restructure reindustrialization programme so that the ETTP site demolition schedule establishes the date for title transfer decisions;

(b) Consolidate Melton Valley capping contracts to achieve project execution efficiencies including utilization of existing cap designs;

(c) Return responsibility for newly generated waste treatment and disposal to Office of Science and National Nuclear Security Administration;

(d) Utilize an innovative procurement approach called “reverse auction” which uses on-line software that allow remedial action contractors to bid against each other in real time;

(e) Develop a streamlined regulatory decision-making process to ensure early identification of issues and timely decision making to facilitate the acceleration of cleanup activities;

(f) Use a voluntary cleanup approach for the Whiterspoon offsite cleanup projects which significantly reduces paperwork, accelerates field activities, and minimizes surveillance and maintenance costs. In this approach, DOE will cleanup the sites without obtaining formal regulatory approval in advance. Instead, informal agreement will be reached and final approval will be obtained when cleanup is completed to the agreed-upon levels.

TABLE IV-1. OAK RIDGE RESERVATION CLEANUP PRIORITIZATION

Priority	Scope	Basis for Priority
1	Melton Valley	Greatest source of offsite contaminant releases. Continued well plugging and abandonment, decontamination and decommissioning of the New Hydrofracture Facility are among the remediation activities planned for Melton Valley. Between the 1960's and mid 1980's, the process of deep waste injection was used at ORNL to dispose of radioactive liquids and sludge in mixtures of waste with dement-based grout and various additives. Two test injection wells were constructed, along with boreholes and wells, so that the behaviour of the injected grout in the injection zone bedrock could be observed. At these two test sites, small quantities of radionuclides were added to the injected grout in the injection zone bedrock could be observed. At these two test sites, small quantities of radionuclides were added to the injected grout to make the grout sheets detectable by gamma detectors. The third and fourth injection wells, located within the Old Hydrofracture Facility and New Hydrofracture Facility, respectively, were constructed for large-scale waste disposal. More than 18 x 10^3 m^3 of liquid waste-grout mix, containing approximately 43 x 10^{15} Bq of activity, were injected into artificially induced fractures in a shale formation at depths of 91 to 300 m. All large scale disposal were at depths greater than 238 m. Contamination levels in hydrofracture monitoring wells have been reported as high as 3.0 million Bq/L gross beta. These surplus wells are potential pathways for the migration of contaminated fluids from the grout sheets and from deep groundwater to shallower groundwater zones. To prevent this migration, a remedial action was initiated in 2001 to plug and abandon 111 wells consisting of 4 injection and 107 monitoring wells. As of the end of 2003, 110 of the 111 wells had been plugged and abandoned. Plugging and abandonment of the remaining well which is located within the New Hydrofracture Facility has also been dealt with.
2	Off site	Private property with public access and risk to current industrial workers
3	High-risk reduction projects in Bethel Valley and UEFPC	Next highest sources of offsite contaminant releases. Groundwater engineering study should be conducted to satisfy data needs for the design of several remedial actions related to groundwater including (1) deep groundwater extraction; (2) in situ biodegradation at East Bethel Valley volatile organic compound plume; (3) groundwater monitoring in West Bethel Valley; and (4) soil excavation at known leak sites to minimize impacts to groundwater.
4	ETTP	All buildings at the ETTP are scheduled for demolition. The K-25 building, built during the Manhattan Project is the largest building on the Oak Ridge Reservation. The U-shaped building covers 0.15 km^2 and contains 3,018 stages of gaseous diffusion process equipment and associated auxiliary systems which are to be removed and disposed of. The deteriorated condition of facilities poses a significant physical risk to maintenance workers. Landlord cost will be significantly reduced, freeing up funds for other remediation efforts. Contaminated soils are a source of contaminant migration to surface water and groundwater. Construction logic dictates that the buildings be demolished prior to soil remediation
5	ORNL building 3026 demolition	This facility presents a current industrial hazard due to its deteriorated condition, and it requires high landlord cost.
6	MSRE (Molten Salt Reactor Experiment)	Unlike most current commercial reactors that have fuel confined to fuel rods, MSRE was fuelled by molten salt that flowed through the reactor chamber, where the nuclear chain reaction produced heat. This facility presents a safety hazard and requires high landlord cost. Fuel is to be removed and flushing the salt is under way.

TABLE IV-1. OAK RIDGE RESERVATION CLEANUP PRIORITIZATION (cont.)

Priority	Scope	Basis for Priority
7	Bear Creek Valley	Release of uranium to Bear Creek. Both radiological and non-radiological wastes were disposed of at this site, which continued receiving wastes until 1970. Wastes were placed either on the surface or in unlined trenches and set on fire. The area was also used for storing abandoned equipment which resulted in surface contamination. The remediation of a 80 x 10^3 m^2 disposal area in Bear Creek, was completed in 2003. A total of 61 490 m^3 of waste was excavated, of which 46 680 m^3 were disposed of at the EMWMF and 12 800 m^3 of lower levels of contaminated waste were consolidated and capped on site. The excavation of waste will permanently remove and/or isolate uranium-contaminated material from surface water and groundwater, thereby reducing the migration of contamination to Bear Creek. Remedial actions were divided into three phases. Phase I consisted of the remedial design. Phase II included the hydraulic isolation to reduce the contaminant flux entering Bear Creek, to dry the site in preparation for the Phase III work, and to remove the Oil Lands Land farm Soils Containment Pad Structure and disposal of the soils at an off-site facility. Phase III consisted of excavation and disposal of wastes.
8	Bethel Valley	Integrate with ORNL revitalization programme. Soil contamination poses potential risk to workers. Construction logic dictates that soil remediation follow building demolition
9	Upper East Fork Poplar Creek	Integrate Y-12 modernization programme. Remediation of this watershed is being conducted in stages using a phased approach. Phase 1 addresses interim actions for remediation of mercury-contaminated soils, sediment, and groundwater discharges that contribute contamination to surface water. The focus of the second phase is remediation of the balance of contaminated soil, scrap, and buried materials within the Y-12 Complex, the major contaminated area in the Upper East Fork poplar Creek Watershed.
10	Groundwater	Logic dictates delaying until all sources are remediate
11	Chestnut Ridge	Onsite contamination with known release
12	White Wing Scrap Yard	Onsite contamination with known release
13	Clinch River/Poplar Creek record of decision	Receptor for entire Reservation; logic dictates delaying until remediation of all sources is complete. At ETTP, the Central Neutralization Facility treated more than 35 million gal of wastewater in 2003. The facility is ETTP's primary wastewater treatment facility and processes both hazardous and non-hazardous waste streams arising from multiple waste treatment facilities and remediation projects. The facility removes heavy metals and suspended solids from the wastewater, adjusts pH, and discharges the treated effluent into the Clinch River. Sludge from the treatment facility is treated, packaged, and disposed of off site

IV-4. ALTERNATIVE TECHNICAL APPROACHES

(a) Obtain a treatment variance for the East Chestnut Ridge Waste Pile to eliminate the high cost of Resource Conservation and recovery Act waste treatment and disposal;
(b) Dispose of ETTP enrichment converters directly instead of cutting up the converters prior to the disposal (this avoid the hazards of worker exposure and cutting operations);
(c) Excavate soils in Melton Valley to protect ecological and human receptors only if they exceed and agreed-upon level in the Melton Valley Record of Decision that can be measured in real time using field instrumentation.

IV-5. INNOVATIONS

(a) Dispose of clean demolition debris in building basements versus disposal in the industrial landfill;
(b) Dispose legacy low level waste that meets the waste acceptance criteria in the onsite disposal cell [Environmental Management waste Management Facility (EMWMF);
(c) Convert uranium hexafluoride (UF_6) cylinders at a commercial facility if DOE conversion facilities are not constructed in time to support ETTP closure;
(d) Stabilize and dispose Molten Salt Reactor Experiment fuel salt as waste instead of converting the ^{233}U for potential re-use.

CONTRIBUTORS TO DRAFTING AND REVIEW

Audet, M.	Atomic Energy of Canada Ltd, Canada
Dennis, F.	Golder Associates UK Ltd, United Kingdom
Falck, W. E.	International Atomic Energy Agency
Monken Fernandes, H.	International Atomic Energy Agency
Lauria, D.C.	Instituto de Radioprotecao e Dosimetria, Brazil
Nokhamzon, J. G.	CEA/DEN/DPA, France
Pearl, M.	United Kingdom Atomic Energy Authority, United Kingdom
Regens, J. L.	University of Oklahoma Health Sciences Center, United States of America
Sankar, S.	Bhabha Atomic Research Centre, India

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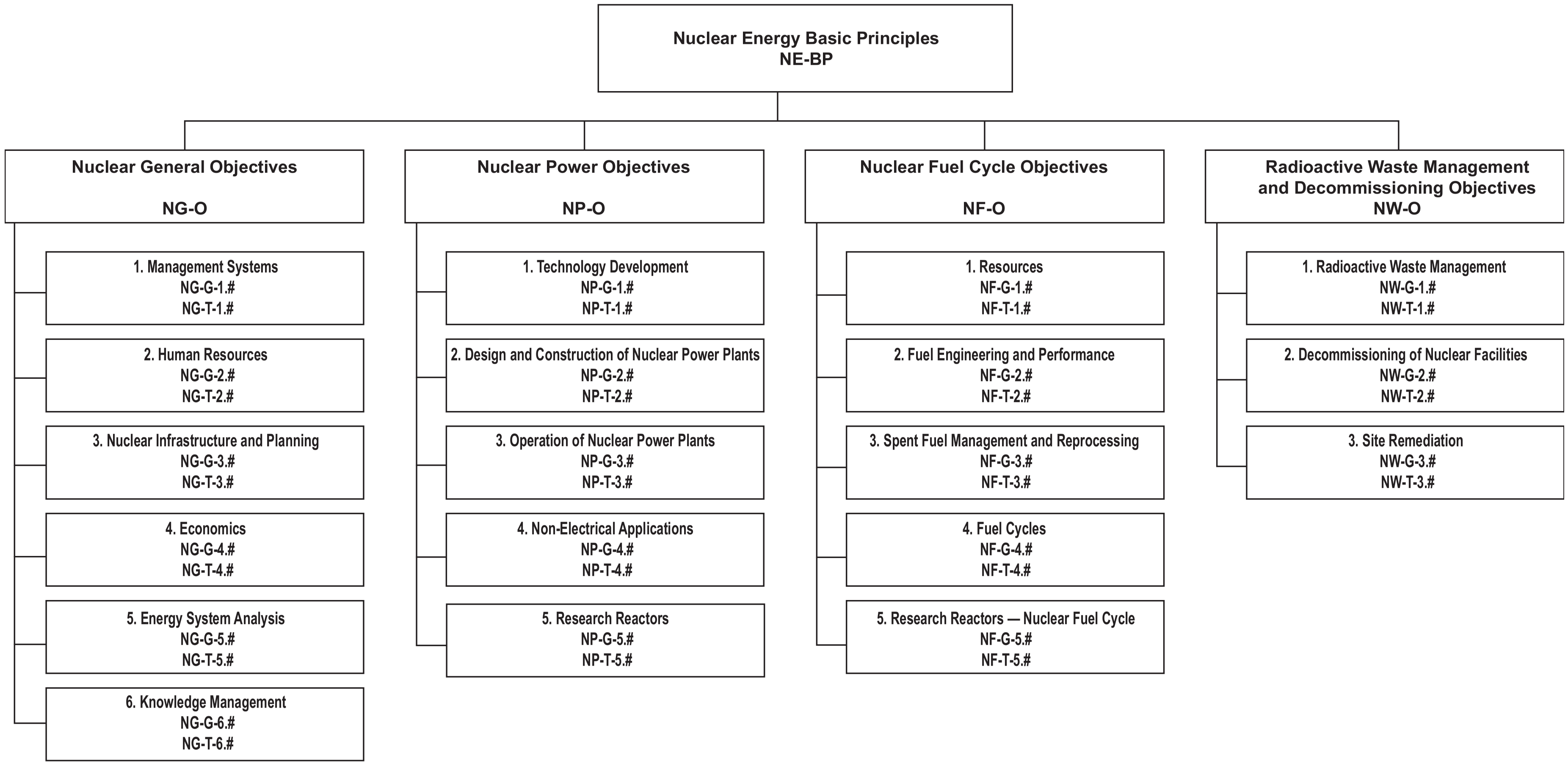

Key

BP: Basic Principles
O: Objectives
G: Guides
T: Technical Reports
Nos. 1-6: Topic designations
#: Guide or Report number (1, 2, 3, 4, etc.)

Examples

NG-G-3.1: Nuclear General (**NG**), **G**uide, Nuclear Infrastructure and Planning (topic **3**), **#1**
NP-T-5.4: Nuclear Power (**NP**), Report (**T**), Research Reactors (topic **5**), **#4**
NF-T-3.6: Nuclear Fuel (**NF**), Report (**T**), Spent Fuel Management and Reprocessing, **#6**
NW-G-1.1: Radioactive Waste Management and Decommissioning (**NW**), **G**uide, Radioactive Waste (topic **1**), **#1**

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