IAEA Nuclear Energy Series

No. NW-G-3.2

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DETERMINATION OF ENVIRONMENTAL REMEDIATION END STATES

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

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FOREWORD

The IAEA's statutory role is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Among other functions, the IAEA is authorized to "foster the exchange of scientific and technical information on peaceful uses of atomic energy". One way this is achieved is through a range of technical publications including the IAEA Nuclear Energy Series.

The IAEA Nuclear Energy Series comprises publications designed to further the use of nuclear technologies in support of sustainable development, to advance nuclear science and technology, catalyse innovation and build capacity to support the existing and expanded use of nuclear power and nuclear science applications. The publications include information covering all policy, technological and management aspects of the definition and implementation of activities involving the peaceful use of nuclear technology. While the guidance provided in IAEA Nuclear Energy Series publications does not constitute Member States' consensus, it has undergone internal peer review and been made available to Member States for comment prior to publication.

The IAEA safety standards establish fundamental principles, requirements and recommendations to ensure nuclear safety and serve as a global reference for protecting people and the environment from harmful effects of ionizing radiation.

When IAEA Nuclear Energy Series publications address safety, it is ensured that the IAEA safety standards are referred to as the current boundary conditions for the application of nuclear technology.

Action could need to be taken on sites with radioactive contamination to protect people and the environment and to enable their transitions to different future uses. These sites may include nuclear power plants, existing or former nuclear research facilities, uranium mining and processing sites, other naturally occurring radioactive material (NORM) industry sites, defence sites or areas affected by past activities or emergencies involving the release of radioactive material. These sites could be those managed under current regulations, sites not operated in accordance to current standards and/or abandoned sites. To support environmental management of these sites, a process is presented to determine the end state of the site and implications for the site's future use and necessary controls.

The stepwise decision making process for determining a site end state includes consideration of the site hazards, site radiological and non-radiological contamination, potential exposure conditions, regulations and the social, economic and environmental factors. The decision making process is facilitated by key enablers and site specific inputs. Key enablers for management of radioactive contamination include national policy and strategy (i.e. for environmental remediation), a national waste management strategy, and a legal and regulatory framework, including general and specific requirements and guidance. Another key enabler is engagement of interested parties and incorporation of their input throughout the process to build confidence in the process of determining the site end state, associated decisions and management of uncertainties. In addition to characterizing the site contamination and physical attributes, site specific inputs are needed to describe the site context, challenges and uncertainties, with consideration of social, economic and environmental factors. Equally important is the identification of the key values, drivers and external constraints that affect the development of candidate end state options. End state options and implications for future site uses and associated controls that have been developed from this site specific information are then evaluated in a two step process. In the first step, screening criteria are applied to focus on those options that are feasible and can be implemented successfully. The second step is a holistic evaluation over the lifetime of the options based on agreed evaluation criteria and processes. This holistic evaluation includes consideration of all relevant factors, not just radiological protection, and considers options in terms of an overall balance of risk and benefit within the allowable bounds of the regulatory requirements to select an acceptable end state.

This publication describes the process of determining an end state and the procedural and site specific factors that need to be considered. The intention of the process is to facilitate decision making to determine an appropriate end state in a way that decreases uncertainties affecting the decision and builds confidence for all interested parties, including participants in the decision making process. This publication is for use by operating organizations for a site, regulatory bodies, policy makers and other interested parties involved in the decision making processes needed to determine an appropriate site end state. It describes the primary elements of the process for end state determination and is consistent with guidance in other IAEA publications, including application of the radiation protection principles of justification, optimization and limitation.

The IAEA wishes to express its thanks to all those who contributed to the drafting and review of this text. The IAEA officer responsible for this publication was H. Monken-Fernandes of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Sites with radioactive contamination[1] may need interventions to protect people and the environment against the harmful effects of ionizing radiation and eventually enable their transition to a different use. These sites can include those with nuclear power plants and other facilities of the nuclear cycle, sites hosting nuclear research facilities, uranium mining and processing sites, naturally occurring radioactive material (NORM) industry sites, defence sites, or areas affected by a nuclear accident or radiological emergency.

At sites where past activities were never subject to regulatory control or that were subject to regulatory control but not in accordance with current requirements [1], the term 'legacy site'[2] has commonly been applied. Legacy sites, or other sites where contamination already exists and a decision on the need for control needs to be taken, are examples of 'existing exposure situations'[3] and can be addressed through 'remediation'[4]. There are also sites hosting installations

[1] The term contamination is defined as "*Radioactive substances* on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the *process* giving rise to their presence in such places" [2]. The term contamination gives no indication of the magnitude of the hazard involved.

[2] To maintain flexibility, the IAEA Safety and Security Glossary [2] does not provide any formal definition for the term 'legacy site'. Relevant information for legacy sites is discussed as part of the IAEA International Working Forum on Regulatory Supervision of Legacy Sites.

[3] These situations of exposure already exist when a decision on the need for control needs to be taken. Existing exposure situations include exposure to natural background radiation that is amenable to control; exposure due to residual radioactive material that derives from past practices that were never subject to regulatory control; and exposure due to residual radioactive material deriving from a nuclear or radiological emergency after an emergency has been declared to be ended.

[4] Remediation is defined as "Any measures that may be carried out to reduce the *radiation exposure* due to existing *contamination* of land areas through actions applied to the *contamination* itself (the *source*) or to the *exposure pathways* to humans" [2].

and activities[5] that have been contaminated due to operations that are now subject to regulatory control in line with current international standards.

For remediation that is primarily undertaken to address existing exposure situations (but can also be needed in some situations that are characterized as planned exposure situations), the type and extent of remediation takes into consideration plans for use of the associated land and whether it can be used in the future with or without restrictions[6]. Restrictions can include elements such as consumption advisories, access, use for particular activities (e.g. house building, growing or harvesting particular foods) or prescription of particular procedures (e.g. materials may only be recycled or reused within a facility). In some circumstances, release of a site for unrestricted[7] use is not feasible until after a long period of restricted use. In this case, some sort of institutional controls[8] will need to be established and long term stewardship of the site maintained, consistent with the IAEA Safety Standards [1, 4] until a site is released from regulatory control for restricted or unrestricted use. The timescales involved in institutional controls can vary from years to decades. Institutional control needs to be justified carefully in relation to the expectations of interested parties for the site (e.g. the potential for unrestricted uses).

Remediation at a site needs to consider the relevant characteristics of the site. Thus, developing a remediation approach includes addressing both radioactive contamination in the environment and the presence of other hazards and/or non-radioactive contaminants, such as heavy metals and organic contaminants. Evaluating economic, sustainability and social factors is also important in developing a remediation strategy.

To guide remediation, decisions need to consider the objectives for the condition of the site after remediation is complete with respect to (1) protection

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[5] ‘Facilities and activities’ is a “general term encompassing *nuclear facilities*, uses of all *sources* of *ionizing radiation*, all *radioactive waste management activities*, *transport* of *radioactive material* and any other *practice* or circumstances in which people may be subject to *exposure* to *radiation* from naturally occurring or artificial *sources*” [2]. ‘Facility’ means buildings, and their associated land and equipment, in which radioactive material was or still is produced, processed, used, handled or stored on a scale with such a degree of hazard and risk that consideration of protection and safety is required. ‘Land’ includes the surface, subsurface soil horizons and any surface or subsurface water or aquifers potentially affected by radioactive material [3].

[6] ‘Restricted use’ is defined as “The use of an *area* or of materials subject to restrictions imposed for reasons of *radiation protection and safety*” [2].

[7] ‘Unrestricted use is defined as “The use of an *area* or of material without any radiologically based restrictions” [2].

[8] Institutional control can be defined as “*controls* placed on a site that has been released from *regulatory control* under the condition of observing specified restrictions on its future use to ensure that these restrictions are complied with” [2].

of the public and environment and (2) the future use of the site in the context of the expectations of the responsible party and other interested parties. These conditions after remediation reflect the site ‘end state’, which is defined as the final status of a site at the end of activities for remediation, including approval of the radiological and physical conditions of the site and remaining structures [2].

In this publication, while maintaining consistency with the definition expressed for the site that is appropriately protective of people and the environment in accordance with the IAEA safety standards [1, 2], end state is taken as the final status which complies with relevant (applicable) regulations and meets the needs for the intended future use(s) of a site. This definition is useful for both decommissioning and remediation of a site, with a key element of connecting the end state to the future use of the site. This linkage is important so that intended future uses (e.g. preferences of the interested parties) will have associated cost, waste and logistical factors for achieving the corresponding site end state. In some cases, end states supporting a desired future use may not be easily achievable or may require excessive costs or the generation of large amounts of waste for disposal. Hence, there are situations where determining what end states are achievable will drive what future uses are possible. Another consideration for end states highlighted in this publication is the possibility that interim states may be necessary as steps towards reaching a final end state. In this report, an interim state is used to denote that end points of progressive remediation steps over time (e.g. as described in Ref. [1]) may be used in managing the overall process of reaching a final end state whereby interim objectives and metrics are set to guide a stepwise series of activities at a site where a single step to the final end state is difficult to obtain or manage.

1.2. OBJECTIVE

The objective of this publication is to provide a process for making an informed and transparent decision on a mutually agreed end state for a site. It is intended to provide practical examples of how to apply key terms and concepts so that interested parties involved in the decision making process work from a common base with shared understanding. The determination process is structured to be iterative and capture the inputs from site owners, responsible parties, regulators, local communities, governmental organizations and other interested parties.

This publication is intended to facilitate the decision making needed for environmental remediation of sites contaminated with radionuclides. It is intended for use by those who could have input and/or interest in the decisions, including site owners, operating organizations, regulatory bodies, policy makers, members of the public, special interest groups and other interested parties for a specific site.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.3. SCOPE

This publication describes the process of determining an end state of remediation in an existing exposure situation and the procedural and site specific factors that need to be considered. Remediation can be undertaken to address sites and areas affected by past activities or events where there has been a loss of control of radioactive material [1]. This publication focuses on the environmental remediation of sites with radionuclide contamination from past activities in the nuclear fuel cycle, from NORM activities, uranium mining and processing through nuclear power generation and waste management. It also addresses contamination associated with nuclear research facilities, defence sites and sites affected by a nuclear accident or radiological emergency. Facilities for decommissioning in a planned exposure situation are out of the scope of this publication, but could benefit from its contents, especially when there is contamination external to facilities and the site remediation activities could be similar to those that might be applied in an existing exposure site. Therefore, considerations on remediation in the context of planned and existing exposure situations are included in the report. The end state determination process provided in this publication is intended for use in addressing all the hazards at a site, including those related to ionizing radiation.

1.4. STRUCTURE

This publication provides a structured approach to decision making, planning and inputs needed for determining a site end state. The following elements are included in the publication:

(a) A flow chart of the end state determination process:
   - (i) A description of elements in the flow chart and links to other references and resources that may need to be considered in the process.
   - (ii) Importance of the involvement of interested parties in the process described by the flow chart.

(b) Approaches for describing the characteristics of different end states and associated implementation options so that they can be qualitatively or quantitatively compared in terms of a balance of risk, and the costs and benefits in selecting the most appropriate course for the site specific conditions.
(c) A discussion of the need to build confidence among decision makers and other interested parties during the process of determining the end state.
(d) A description of approaches for optimization of protection and safety that can be integrated into the end state determination.
(e) Information about how to consider uncertainties in the end state determination process.
(f) A description of how the use of interim states as adaptive steps towards a final end state could provide benefits for implementation under some site situations.
(g) Consideration of life cycle stages of a facility or activity in reaching the end state.
(h) Approaches for documentation of decisions that facilitates planning and transition to implementation of remediation.

Key concepts relevant to end state determination are provided in Section 2. Section 3 describes the end state determination process. Section 4 provides considerations for implementing the decision making process. Conclusions are provided in Section 5.

2. KEY CONCEPTS RELEVANT TO END STATE DETERMINATION

Determination of a site end state needs to be conducted in the context of the site situation, considering national policy and strategy and national regulatory requirements. The IAEA Safety Standards highlight the relevance of establishing the end state in the context of a remediation project. Throughout this process, it is important to consider the context of the site situation and engage interested parties to build confidence in the process and the decision on the site end state.

The IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [5] set out the general responsibilities, roles and management needs for radiation protection and safety, whereas in Ref. [1] those specifically related to remediation are provided. The three general principles of radiation protection are provided in Ref. [3]. They involve justification, optimization of protection and application of dose limits, which are expressed in IAEA Safety Standards No. SF-1, Fundamental Safety Principles [6]. These three principles can be applied in the context of intra- and intergenerational equity [6]. The principles apply for current conditions and in the future to address needs for the prevention of accidents, emergency preparedness and response or protective actions applied to reduce existing or unregulated radiation risks. The following sections are intended to articulate these principles, which are important in the process of determining a site end state.

The following section addresses the difference between the end state in the context of decommissioning and remediation as the determination of the end state is something relevant in both cases and that situation is often a source of confusion. In a previous IAEA publication on remediation of areas affected by past activities and accidents, IAEA Safety Standards Series WS-G-3.1, Remediation Process for Areas Affected by Past Activities and Accidents [7], the term end state was not spelled out a single time. However, in the scope of Ref. [1], which supersedes Ref. [7], the concept of end state is widely mentioned. End state also appears in the IAEA Safety Standards Series No. SSG-47, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities, which covers decommissioning [8]. Therefore, it is important to demonstrate, the differences between the frameworks behind the concept of end state in both situations.

2.1. EXPOSURE SITUATION IN THE CONTEXT FOR END STATE DETERMINATION AND ASSOCIATED CRITERIA

It is important that the definitions and contexts for planned exposure situations and existing exposure situations are understood in the process of end state determination.

According to GSR Part 3 [5], a planned exposure situation is:

> “a situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source. Since provision for protection and safety can be made before embarking on the activity concerned, the associated exposures and their probabilities of occurrence can be restricted from the outset. The primary means of controlling exposure in planned exposure situations is by good design of installations, equipment and operating procedures. In planned exposure situations, a certain level of exposure is expected to occur”.

An existing exposure situation is:

"a situation of *exposure* that already exists when a decision on the need for *control* needs to be taken.

ⓘ *Existing exposure situations* include exposure to *natural background* radiation that is amenable to *control*; exposure due to residual *radioactive material* that derives from past *practices* that were never subject to *regulatory control*; and exposure due to residual *radioactive material* deriving from a *nuclear or radiological emergency* after an *emergency* has been declared to be ended" [2].

The radiation protection approaches used in the scope of planned exposure situations and existing exposure situations are different, although they are used for achieving the same objective:

"Dose constraints and reference levels are used for optimization of protection and safety, the intended outcome of which is that all exposures are controlled to levels that are as low as reasonably achievable, economic, societal and environmental factors being taken into account" [5].

In the case of planned exposure situations, dose constraints[9] are applied. Dose constraints are used in connection with dose limits that shall be interpreted as a value of a quantity used in certain specified activities or circumstances that ought not to be exceeded:

"For public exposure in planned exposure situations, the government or the regulatory body ensures the establishment or approval of dose constraints, taking into account the characteristics of the site and of the facility or activity, the scenarios for exposure and the views of interested parties" [5].

Figure 1 provides a schematic depiction of the different approaches that are used in the scope of planned exposure situations (e.g. decommissioning) and

[9] A dose constraint is "A prospective and *source* related value of *individual dose* that is used in *planned exposure situations* as a parameter for the *optimization of protection and safety* for the *source*, and that serves as a boundary in defining the range of options in *optimization*."; "For *public exposure*, the dose constraint is a *source* related value established or approved by the government or the *regulatory body*, with account taken of the *doses* from planned operations of all *sources* under *control*."; "The dose constraint for each particular source is intended, among other things, to ensure that the sum of *doses* from planned *operations* for all *sources* under *control* remains within the *dose limit*" [2].

existing exposure situations (where remediation is applied). The lower value in the range of values to be adopted as reference level (1–20 mSv/y) corresponds to the dose limit to be applied in planned exposure situations.

For an area affected by past activities or an event, the reference level is the starting point for the optimization of protection and safety through remediation. Reference levels should be used in the remediation planning and, optimization of protection and safety together with the end state criterion. This will serve as a benchmark for evaluating the overall effectiveness of the remediation that has been implemented [9].

The ICRP recommends that reference levels, established in terms of individual dose, are to be considered in combination with the implementation of the optimization process for exposures in existing exposure situations [9]. The idea is to implement optimized protection strategies, or eventually a progressive set of such strategies, with a view to reducing individual doses to below the reference level.

In the decommissioning of a facility, typically the limits and constraints that prevailed during the operation of the facility will be complied with after the facility is decommissioned. As stated in Ref. [4] for the unrestricted use of a site after decommissioning, optimization of protection ought to ensure that the effective dose to a member of a critical group is kept below the dose constraint of 300 μSv in a year. For the restricted use of a site, optimization of protection ought to ensure that, with restrictions in place, the effective dose ought not to exceed the dose constraint of 300 μSv in a year. In addition, for restricted

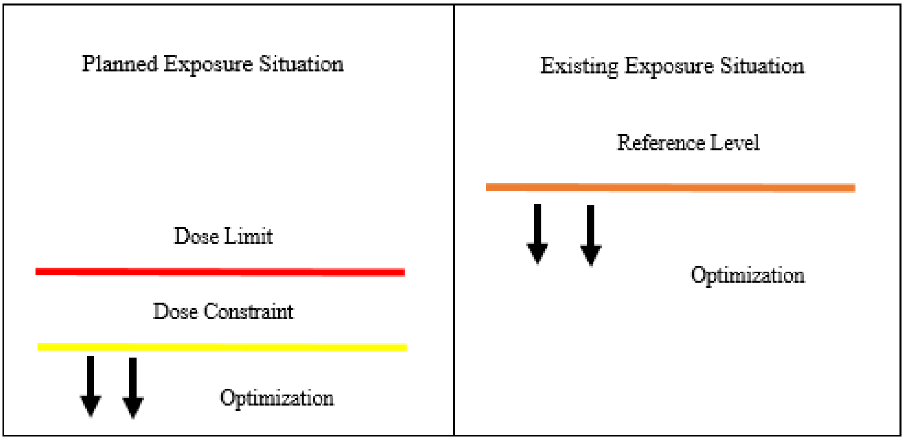

FIG. 1. Illustration of radiation protection approaches for planned exposure situations and existing exposure situations. Note that the relative position of these elements is arbitrary, that is, for the sake of illustration only.

use, if the restrictions were to fail in the future, the effective dose ought not to exceed 1 mSv in a year. The application of dose limitation to the unrestricted and restricted use of a site under a planned exposure situation is shown in Fig. 2 [4].

In the case of existing exposure situations, it is not appropriate to plan to allow exposures to occur. It is very important to note that the following sentence clearly defines that existing exposure situations, in which remediation is applied, include consideration of management practices:

> "Reference levels shall typically be expressed as an annual effective dose to the representative person in the range of 1–20 mSv or other corresponding quantity, the actual value depending on the feasibility of controlling the situation and on experience in managing similar situations in the past [5]."

In this context, remediation and environmental management are intertwined. This perspective is important in the context of determining a site end state and links the process with the concepts of sustainability and future use.

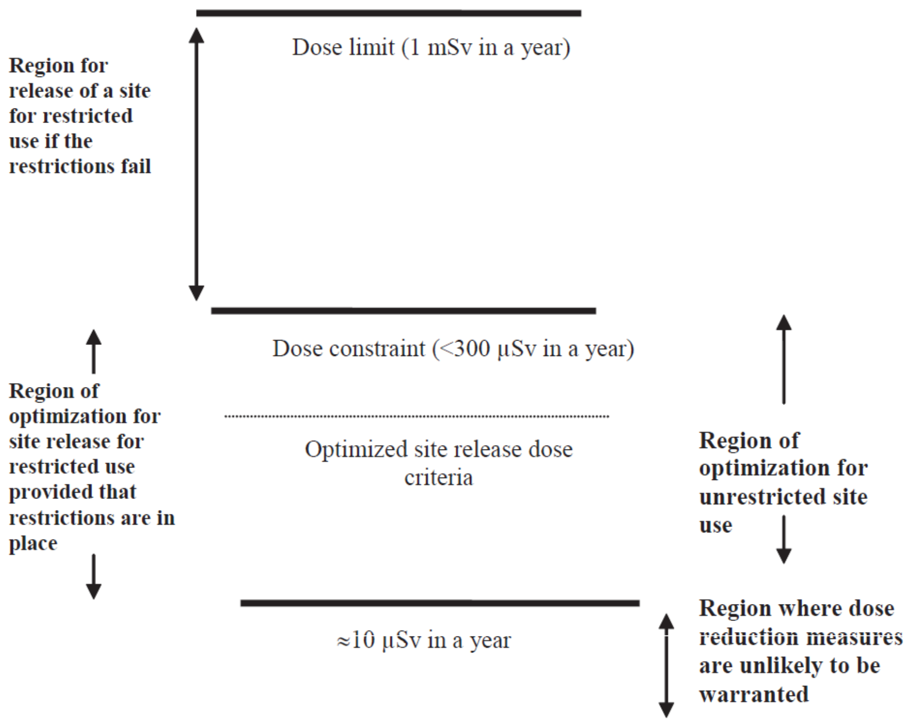

FIG. 2. Constrained optimization and regions of effective dose for members of the representative person in the release of sites, adapted from Ref. [4].

The above considerations are important in the determination of a site end state with respect to radioactive contamination. For example, the above considerations demonstrate that it is not to be expected that environmental remediation will always involve removing all radioactive contamination and making the site suitable for any use (‘unrestricted use’). Remediation will not necessarily achieve reference levels that are the same as the dose limits or constraints that are applied in the release of a planned exposure situation site after decommissioning. A desired and practically achievable site end state for an existing exposure situation may be different from these maximum expectations. Thus, although the type of remediation methods applied for planned and existing exposure situations can be similar, the end state of sites could be quite different with respect to the targeted dose objective. It is to be noted that some sites can have a mixture of planned and existing exposure situations. All in all, the framework that applies to environmental remediation (existing exposure situation) is not to be applied in the case of decommissioning (typically a planned exposure situation).

2.2. POLICY AND STRATEGIES IN THE DETERMINATION OF SITE END STATE

Principle 1 of the IAEA Fundamental Safety Principles [6] states that “**the prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks.**” As stated in Ref. [1], “the national policy for remediation should establish the basic premises that guide the approach to remediation in the State and that should be addressed in the national strategy and the legal and regulatory framework for remediation”.

As long as a facility or activity is properly authorized and regulated, responsibility for environmental remediation during and after the operational phase lies with the responsible party. Even in the case of an accident resulting in environmental contamination, the owner of the facility is liable for the costs related to remediation within the ‘polluter pays principle’ [10]. However, in the case of legacy sites or when the owner of the facility that caused the contamination is no longer identifiable or is unable to pay for the costs of remediation, responsibility for environmental remediation of the site could become an issue. Under current standards, operators and responsible parties are required to hold sufficient resources to cover the cost of decommissioning and environmental remediation so that an agreed upon end state can be reached. In the case of remediation in a post-accident scenario, the legal person that was responsible for the event may be the person who is liable for the recovery work, depending on government decisions and the legal and regulatory framework in the Member State. It may be the case, as in the accident at the Fukushima Daiichi nuclear power plant, that the government will need to provide financial resources for the remediation efforts, which will then be recovered afterwards from the entity responsible for the accident [11]. However, in the case of legacy sites (i.e. sites affected by past activities), this situation is far less certain, and often the government will have to provide funding, either from budgetary sources, or contracted from international donors or multi-lateral organizations, for the costs of remediation projects.

As discussed in IAEA Nuclear Energy Series No. NW-G-3.1, Policy and Strategies for Environmental Remediation [10], policy and strategies for environmental remediation are needed to provide clarification for responsibility issues and are needed for input in determining the site end state. Principle 2 of SF-1 [6] relates to the responsibility of a government to establish a policy and implement a legal framework under which that policy could be enforced. Established policies for the nuclear industry and possibly other industries associated with radiation risks would state the position of government on radiation risks. The governmental regulatory framework states the requirements for the approval and oversight of a facility or activity, including environmental remediation. Regulations provide technical and administrative requirements for the protection of people and the environment from physical hazards as well as chemical and radiological contaminants. At the site specific level, the legal and regulatory framework needs to allow for the identification of an organization to be responsible for achieving the selected site end state. The strategy to reach an end state may involve distinct phases with interim states whereby interim objectives and metrics are set to guide a stepwise series of activities towards the final end state. An interim state would be defined by specified site conditions that meet an interim goal (e.g. stabilization of facilities or containment of waste) as a step towards obtaining a final end state. The government is also responsible for making provisions for post-remediation stewardship and institutional control (inspections, monitoring and corrective action), which are frequently required to ensure that the site end state is achieved sustainably. Depending on the national policy, responsibility for post-remediation stewardship may rest with the government, be assigned to the operator or owner of a site or be transferred to a third party.

NW-G-3.1 also states that typical elements of a national policy on environmental remediation will include allocation of responsibilities, provision of resources, safety and security objectives, and public information and participation [10]. Unfortunately, many countries do not yet have policy and strategies for environmental remediation, which will hinder the process of determining a site end state for remediation.

2.3. JUSTIFICATION OF ENVIRONMENTAL REMEDIATION

The first step in planning environmental remediation towards achieving the end state for a site is the justification of remediation [1]. As stated in Ref. [1], justification involves determining whether the benefits of remediation (e.g. benefits to individuals and society) outweigh the detrimental effects that might be caused by it. In simple terms, justification is a process of determining whether a protective or remedial action (to reduce a dose) will produce more good than harm.

The following aspects are usually considered when determining whether a site requires environmental remediation:

(a) Radiological safety;
(b) Non-radiological safety and security;
(c) Geotechnical and erosion stability of wastes and infrastructure and/or other physical hazards;
(d) Environmental protection;
(e) Regional and local development, scarcity of land, visual impact;
(f) Ethical and cultural factors, including those of indigenous peoples (e.g. First Nations);
(g) Socioeconomic factors and job creation;
(h) Risk perceptions and other interested party concerns.

In some cases, it is not necessarily the radiological factors that will be the key drivers in determining the need for remediation. Instead, non-radiological contamination (e.g. asbestos, toxic metals) and physical hazards, such as geotechnical stability of wastes or regional development aspects can be significant drivers. At such sites, radiation safety aspects may only need to be addressed after a decision to start environmental interventions due to non-radiological hazards has been taken. In this case, the presence of radionuclides will lead to the need to use appropriate management approaches to deal with materials that contain radionuclides.

2.4. OPTIMIZATION OF PROTECTION AND SAFETY

GSG-15 states “Once remediation and the associated remedial actions have been justified, the form, scale and duration of remedial actions or protective actions are required to be optimized, in order to make the best use of resources in reducing radiation risks” [1]. This optimization process also considers economic and social factors in relation to determining the level of protection and safety. Applying optimization and ALARA is not synonymous with returning conditions ‘back to background’. Optimization seeks to maximize the net benefit. GSR Part 3 [5] states that the selection of the value for the dose constraint or the reference level that ought to be applied can be based on the characteristics of the exposure situation, including:

(a) The nature of the exposure and the practicability of reducing or preventing the exposure;
(b) The expected benefits of reduced exposure to people, or the benefits of avoiding preventive measures or protective actions that would be detrimental to living conditions, as well as other societal criteria relating to the management of the exposure situation;
(c) National or regional factors, together with a consideration of international guidance and good practice elsewhere.

Note that not all factors for this decision can be appropriately quantified and some factors will have to be assessed qualitatively during the optimization process [12].

Because of the need to balance factors as part of the optimization process, the concept of diminishing returns is applicable. The reduction in the residual dose (or other types of contamination or sources of risk) is typically not linearly correlated with remediation costs (Fig. 3). This situation is important in many cases because of funding constraints for remediation activities.

FIG. 3. Conceptual depiction of non-linear relationship between cost of remediation and reduction of dose.

2.5. SUSTAINABILITY OF ENVIRONMENTAL REMEDIATION

The principles set out in the United Nations' Rio Declaration on Environment and Development in 1992 [13] encompass concepts that are important to the application of sustainable remediation, such as intergenerational equity, environmental protection and waste minimization. In a more recent publication [14], sustainable remediation was defined as:

> "Remediation actions that deliver a net benefit and are informed by the short- and long-term impacts on safety and the environment society and the economy, natural resources and climate change".

That definition relates to the principle of justification for remediation, in that;

> "If the remediation activities cause greater impact to the well-being of people and the environment than the contamination they seek to address then they would not be considered to be sustainable" [14].

When defining the end state, there are two levels at which the principles of sustainability are considered. At a strategic level, the end state could be influenced by local or regional sustainability factors, such as land use planning, economic and/or social regeneration, and waste disposal management capabilities and capacities. At a tactical level, the principles of sustainability will also influence the remedial techniques selected to implement the end state. At the tactical level, factors such as energy use, physical impact on workers, members of the public and sensitive habitats, and the number of people employed may be relevant. These two levels for sustainability are interlinked, and it would be difficult to define one without an understanding of the other. Thus, the process of determining an end state in this publication includes consideration of these factors while also accounting for the evaluation for the site specific situation.

2.6. FUTURE USES OF SITES

A key variable in determining a site end state is the intended use of the site after remediation. In this regard, an end state may allow for unrestricted or restricted use.

The IAEA Nuclear Safety and Security Glossary uses the following descriptions for unrestricted use [2]:

> "The use of an *area* or of material without any radiologically based restrictions.

! There may be other restrictions on the use of the *area* or material, such as planning restrictions on the use of an *area* of land or restrictions related to the chemical properties of a material.

! In some situations, these restrictions could, in addition to their primary intended effect, have an incidental effect on *radiation exposure,* but the use is classified as *unrestricted use* unless the primary reason for the restrictions is radiological."

The IAEA Nuclear Safety and Security Glossary uses the following descriptions for restricted use [2]:

"The use of an *area* or of materials subject to restrictions imposed for reasons of *radiation protection and safety*.

ⓘ Restrictions would typically be expressed in the form of prohibition of particular *activities* (e.g. house building, growing or harvesting particular *foods*) or prescription of particular *procedures* (e.g. materials may only be recycled or reused within a *facility*)."

In some cases, it could be difficult to assign a future use for a site; therefore, it is necessary to refine the plan as more information becomes available over time. Thus, not all sites have a detailed planned use and the determination of the site end state cannot always be based on a detailed use scenario. Nevertheless, a site end state needs to be defined to enable meaningful and timely progress on site remediation. For these sites, or because of technical or financial constraints, interim states may be needed whereby interim objectives and metrics are set to guide a stepwise series of activities towards the final end state. In Ref. [1] the concept of end point is used to represent this situation. In addition, the iterative nature of remediation and the need for each step to be assessed against remediation end point criteria are recognized.

In some situations, such as extended or deferred remediation programmes, the end state may not be achieved for several decades. For remediation programmes over long timescales, the process of determining the end state may need to be iterative and adaptive to account for new information that arises during site characterization, changes in the site context or interested party concerns, and changes in factors that currently constrain remediation, such as affordability and the availability of waste routes.

Interim states provide an important way to manage progress through the iteration of the end state process. Interim state(s) can be designed to allow progression to a defined end state by achieving discrete actions (e.g. stabilization of facilities or containment of waste) that are necessary steps towards a final end state or for the range of end states to be narrowed as remediation progresses. An interim state may coincide with a period of quiescence. Interim state(s) are useful markers of progress as defined shorter term achievements for the site where the timescale for remediation is several decades. For example, during periods when natural attenuation is occurring the site can be used for some purposes, but it could be necessary to restrict how the site can be used for a period until the final end state is achieved.

Where the end state will not be reached for several decades, it may be appropriate to pursue more than one end state to avoid excluding options too soon. This could be facilitated by identifying (1) the elements of remediation that are common to all end state options and (2) the decisions that will need to be made in the future in order to narrow down the end state options. This will inform the selection of nearer term interim state(s) and the associated decision making schedule.

3. PROCESS AND GUIDING PRINCIPLES FOR DETERMINING THE END STATE OF A SITE

End state descriptions have been included in other publications, for example Ref. [1], for several types of environmental applications. In IAEA publications, end state is an important aspect of the decommissioning of nuclear power plants and other nuclear facilities. It is important to establish an 'end state criterion' to verify that the overall remediation plan and associated remedial actions have led to achieving the defined end state. The end state criterion is a set of conditions that are required to be met for verifying that remediation has been completed and the defined end state result has been achieved [1].

Further, in Ref. [3] it is stated that decommissioning actions are considered completed when the approved end state of the facility has been reached. Requirement 10 of this publication for planning of decommissioning states that [3]:

> "**the licensee shall prepare a decommissioning plan and shall maintain it throughout the lifetime of the facility, in accordance with the requirements of the regulatory body, in order to show that decommissioning can be accomplished safely to meet the defined end state.**"

This statement implies that the end state, at least to a certain degree, is defined in the decommissioning plan, which is prepared at the design stage. In this case, the radiological component of the end state needs to consider the dose constraints established for the authorization of operation of the facility as appropriate for a planned exposure situation. In relation to remediation, the requirements contained in Ref. [5] and the former supporting safety guide — Ref. [7], now replaced by Ref. [1] — do not describe a site end state. This publication provides information on end states to complement these other publications and define the process of end state determination for environmental remediation activities.

This section describes the general process of determining an end state and describes important factors in this process. These factors can either be external to the process (e.g. uncertainties) or need to be actively managed as part of the end state determination process (e.g. involvement of interested parties). While this publication provides an overall process for end state determination, it may be appropriate to adapt the process to reflect site specific situations and needs. In any case, it is important that decisions are made to progress through the process. Site specific aspects are applied in this process through:

(a) Input of the information that defines the physical and administrative setting of the site being evaluated;
(b) Variation in the emphasis needed on specific elements of the process (e.g. depending on the regulatory context for a site).

The level of effort involved in determining an end state will vary from site to site. Sites using this process need to consider the rigour needed at each step based on the political, cultural and economic situations of the site. The process needs to be applied in a proportionate manner, for example reflecting the potential for harm, the level of uncertainties and the concern of interested parties. The process can also involve iteration and adaptation over time. In addition, the process of end state determination needs to reflect the principle of optimization, one of the pillars of radiation protection.

Figure 4 summarizes the key steps in the process of determining a site end state (central column) and highlights the key enablers (left hand column) and site specific inputs (right hand column) that facilitate successful implementation of the process. Each of the steps and their inputs are described in the following sections. Because stepping through the process may not be straightforward in practice, Section 4 describes some of the complicating factors and suggests ways of managing them.

3.1. RECOGNIZE AND SCOPE THE ISSUE AND RESPONSIBILITIES

Consistent with the phases of remediation described in Ref. [1], an evaluation is needed to determine whether remediation is justified. To support a decision regarding this based on the evaluation (Section 2.3), Fig. 4 identifies the initial elements involved in determining whether action needs to be undertaken. The elements of this step include identifying whether radioactive contamination exists or has the potential to exist. Its existence may be known or suspected, for example as a consequence of the site's history, characterization data and/or concerns raised by interested parties. Once an issue has been raised, basic information about a site (desk based or otherwise) will enable an evaluation

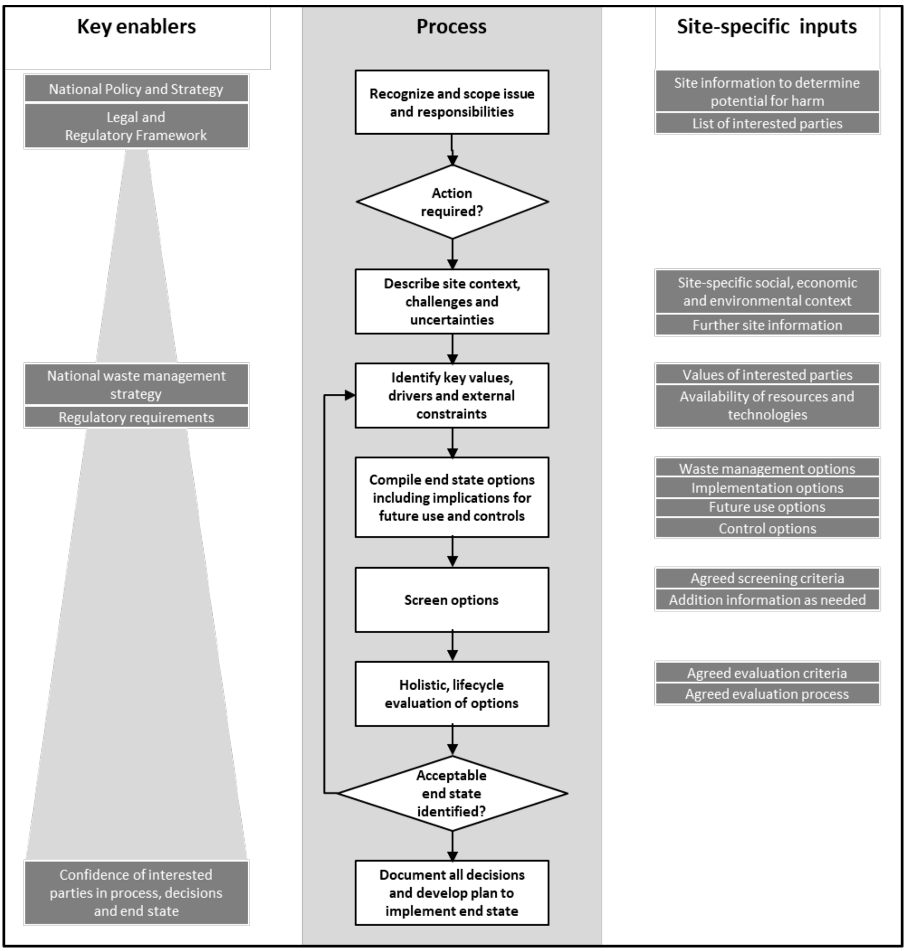

FIG. 4. End state determination process.

of whether the site has the potential to harm people or the environment now or in the future. In such cases, action and, therefore, efforts to determine the end state could be justified. The remainder of the end state determination process is intended to be implemented to inform remediation planning (i.e. integrating with the elements depicted in figure 1 of Ref. [1]).

The first step in the end state determination process is to identify the parties who will be involved. The decision making process for end state determination needs to be designed such that it is a transparent and open process for all parties and input from all parties will be respected. This engagement is a key step towards the success of this process and towards building confidence in it and the outcome.

The following principal elements comprise this step:

(a) Identify decision makers, responsible parties and how other interested parties can be involved in the end state determination process.
(b) Develop and share initial available site information, such as the inventory of contaminants, contaminant distribution over the area of interest, the potential exposure/risk situation and preliminary technical–social–economic considerations. This information provides a foundation for subsequent steps and initiates communication about the site situation as a first step in promoting confidence among the involved parties.
(c) Establish site specific factors that will need to be addressed in the decision making process.
(d) Correlate the site situation and potential approaches for remediation with national policy (if available), relevant regulatory requirements and international standards.
(e) Assess the economic situation of the site and funding mechanisms.
(f) Initiate documentation that will be used throughout the process.

It is very important at this stage to recognize that as additional site information is collected, some changes might need to made to the agreed course of action. The uncertainties intrinsically associated with the process need to be stated so that in later stages all parties understand how and why the process may need to change.

For successful engagement during the end state determination process, the process needs to allow for two way communications between parties without assumptions about what each party wants in terms of a site end state. The following list provides some considerations for successful communication and engagement during the process:

(a) Start communication and engagement early in the process;

(b) Identify how interested parties can be involved in the end state determination process early in the process [15];
(c) Provide timely information and make information available, as requested, to those who join the process late so that they can participate fully;
(d) Use public and open communication of project information in a form that is easily understood by experts and laypeople alike (including use of tools such as websites);
(e) Use local authority expertise (if possible and available) during public consultation (e.g. in designing questionnaires and assessing the responses);
(f) Engage in early discussion with local authority planners and local government so the review process is informed by local policy on land use;
(g) Use terminology and analogies that are understood when communicating with interested parties, without diminishing the content;
(h) Track commitments, status of actions and correspondence during the project;
(i) Regularly post information and reports on the status of the project in central community locations or broadcast throughout the region;
(j) Incorporate consideration of local business, training and employment opportunities related specifically to the project;
(k) Establish and communicate a clear and realistic schedule for elements of the process;
(l) Monitor and regularly evaluate the effectiveness of consultation and engagement.

3.2. DESCRIBE SITE CONTEXT, UNCERTAINTIES AND CHALLENGES

A successful process for determining a site end state needs to rely on a sound understanding of the conditions of the site (its physical state) and its context. The Section 3.1 activities use initial general site information. Additional, more detailed information is now needed to support subsequent activities. This information needs to refine the knowledge of site specific conditions, identify how knowledge about the site has been recorded, compile information about events that could have caused contamination of the environment and provide a basis to develop a conceptual site model [16] that will support the decisions. In some situations, only limited information could be available or obtainable, especially in the early stages of the process. Therefore, it could be necessary to agree on a mechanism to manage uncertainties (see Section 4.4). Targeted characterization of the site and its context will ensure that the level of understanding is appropriate for each step in the process.

3.2.1. Physical state of the site — the role of the conceptual site model

The physical state of the site can be presented in the format of a conceptual site model (CSM), which is a written or pictorial representation of an environmental system. Relevant information in a CSM will include, but is not restricted to:

(a) Sources of contamination (both radioactive and non-radioactive contamination) based on historical use of the site;
(b) Scale (level and extent) of contamination relative to the background;
(c) Contaminant migration pathways (through the ground, surface water, air or biota);
(d) Physical, geological, or constructed features that are important to consider in the end state or potential remediation processes (e.g. presence of subsurface voids);
(e) Site history and former use as it applies to understanding the current condition of the site;
(f) Receptors (e.g. potentially affected members of the public and non-human biota).

There are numerous guides for developing a CSM [16] and the importance of a CSM is recognized in GSG-15 [1]. It is important when developing the CSM to identify data gaps and the relative importance of these gaps to establish a reliable foundation on which an end state decision can be based. Data gaps need to be addressed by an appropriate site investigation. In preparing the CSM and assessing data gaps and challenges, all parties need to provide input on the weight they attribute to the information needed in order to build confidence in understanding of the site conditions with respect to making an end state decision. This discussion supports the use of the CSM in subsequent steps of the end state process that will need to include consideration of uncertainties in the CSM and the relative merit of site characterization versus a bias towards taking actions to advance either interim or final end state objectives. This discussion is intended to incorporate optimization principles as described above and provides a basis for defining when the site is sufficiently understood to support an end state decision and subsequent initiation of environmental management action (e.g. remediation). In subsequent steps, sites may need to refine the CSM to include appropriate quantitative elements that support the evaluation of risks and mitigation approaches.

3.2.2. Social, economic and environmental context

The appropriate end state for a site in one location or country will not necessarily be the same as the appropriate end state for a site with similar conditions in another location. There could be important social, economic and environmental context differences in terms of the decisions that will need to be made. It is important to clarify these differences with respect to why actions taken in other circumstances for another site may not be appropriate for the current situation. Important aspects of site context include the following examples:

(a) Population density (relative remoteness);
(b) Current use of neighbouring land;
(c) Market value of land in the region;
(d) Plans of local government for use of land in the area;
(e) Reliance of local community on the site (e.g. jobs on and around the site);
(f) Local infrastructure (e.g. road, rail);
(g) Distance to waste management facilities;
(h) Proximity of sensitive or protected habitats;
(i) Cultural significance of site and its surroundings;
(j) Vulnerability to flooding, coastal erosion and other consequences of climate change;
(k) Ownership of the site and associated financial liability (responsibility for funding);
(l) Financial constraints.

The social, economic and environmental items above are interrelated and need to be defined so that these factors can be considered in the end state determination process. It is important to make clear to the interested parties that these factors can change over time and that the uncertainties in all of them will need to be managed (see Section 4.4).

3.2.3. Site specific challenges

Some aspects of a site and its context will be more challenging than others. These challenges can be technical, regulatory, economic, or social issues. It is useful to identify these aspects because they will influence the development and evaluation of options. For example, if a site is located above an aquifer that supplies drinking water for a community, or if a site is the centre of the local community where no other sources of employment exist, then the focus of environmental management will be different. It is helpful to establish the relative importance of different challenges with respect to reaching an end state decision.

3.2.4. Site specific sources of uncertainty

It is common for the physical state of a site to be uncertain; for example, because of poor records of prior practices; inaccurate drawings of subsurface structures; and/or, limited characterization or monitoring data. There can also be uncertainty regarding the site context, particularly when the site end state is not likely to be delivered for many years or decades. For example, it might be difficult to predict the availability of waste management facilities or the aspirations of the local community in decades to come.

In some cases, the facilities or sites could have been abandoned without proper documentation, which can make description of the physical state of the site more difficult. During operation of these facilities, regulations could have been insufficient, or insufficiently enforced, which has often contributed to environmental pollution requiring remediation. More rigorous site investigation may be needed in these situations to enable development of an adequate CSM and refinement of the CSM to add quantitative evaluation of the site conditions and predictive analysis where needed.

Elucidating data and information gaps is important to prioritize characterization of the site and its context. All parties can contribute to establishing the extent of information needed to reduce uncertainty and adequately support the process of identifying and evaluating end state options.

3.3. IDENTIFY KEY VALUES, DRIVERS AND EXTERNAL CONSTRAINTS

In addition to gathering information about the site and its context, it is also necessary to understand the motivations and external constraints that will influence the evaluation of options.

3.3.1. Values and drivers

A first step is to understand the values of interested parties, that is, what is important to them. Potential values depend on the site and its context and include the following:

(a) Ensuring the safety and well-being of people during implementation of the end state, for example:
   - (i) The safety of workers excavating and sorting waste;
   - (ii) The safety of road users during transportation of waste and importation of clean material;

(iii) Minimization of waste transportation nuisance.

(b) Protecting public and future users of the site after the end state has been achieved.

(c) Protecting environment, for example, local water course, groundwater or habitat.

(d) Minimizing waste transport.

(e) Creating new jobs.

(f) Removing stigma or blight.

(g) Minimizing overall cost.

These values can be used to develop drivers or outcomes that the end state needs to aim to deliver. However, one needs to recognize that values may need to be prioritized if all cannot be physically satisfied (i.e. addressing some values can inhibit addressing others). This overarching view is extremely helpful at a time when a detailed end state is difficult to determine; for example, because of uncertainties present at that time (see Section 4.4 for guidance on managing uncertainties). An agreed set of drivers or outcomes will facilitate the decision making process.

3.3.2. External factors

There will be external factors that can make it difficult to deliver certain end states. External factors include the following examples:

(a) End states will need to be consistent with national policy and strategy and the national legal and regulatory framework;

(b) End states will need to be consistent with regulatory requirements;

(c) Logistics (e.g. availability of space, waste routes and other infrastructure);

(d) Resources (e.g. availability of access to funding, skilled workers, equipment);

(e) Technology (e.g. availability of relevant technologies);

(f) Confidence of interested parties.

Understanding these external factors will help screen out options that are undeliverable or unachievable (see Section 3.5), but it is important to note that constraints can change over time (e.g. the availability of waste routes and regulatory requirements).

3.4. COMPILE END STATE OPTIONS AND IMPLICATIONS FOR FUTURE USE AND CONTROLS

In this step, end state options are compiled. In practice, the end state and future use are strongly related and so need to be considered together. In some cases, the future use of the site is already defined, in which case the site conditions need to be made suitable for that use. In other cases, the future use may not be that clear, which provides an opportunity to consider a wide range of options (i.e. different combinations of end state and site use). When the future use is not clear, it can be easier to start the identification of the end state options by considering different physical states; for instance, across the spectrum of options, from leaving contamination on site to removing it and having it managed as waste. If candidate site end states will enable redevelopment, involvement of funding agencies and site developers and/or investors may be needed to describe the end state adequately.

Making a site safe for future use can involve the application of controls to limit exposure of people and the environment to residual contamination. Consequently, end state options need to be described in terms of the following characteristics:

(a) The physical state of the site (including landscape);
(b) The future use(s) that the site will be able to accommodate (can vary over time due to radioactive day and natural attenuation);
(c) The controls that will be required to protect people and the environment from residual contamination for an agreed period.

Broad categories of future use include:

(a) Industrial and commercial:
    (i) Waste management facility;
    (ii) Research facility.
(b) Recreational and nature conservation.
(c) Residential.
(d) Agricultural.

A site can be made safe:

(a) For all the above uses without any need for controls (unrestricted use);
(b) For a subset of uses, which will inherently require some form of control (restricted use);
(c) Through relying on controls to prevent use of the site.

Typically, the description of any controls will include timescales (e.g. land use will be restricted to industrial use for 30 years), as well as who is responsible for maintaining them. Controls may also be required to ensure that the owner of any financial liability is clearly defined now and in the future, in case further remediation proves to be necessary. Note also that different portions of the site could have different intended future uses and associated end states (e.g. areas of the site could be used for commercial or industrial purposes, while other areas could be used for recreation or nature conservation).

Having identified the end state options, it is then necessary to describe the options in a manner that will allow screening (Section 3.5) and full evaluation (Section 3.6). For screening, the focus is on screening out options that are clearly not deliverable or credible, so descriptions need to discuss the extent to which options are affected by constraints (discussed above in Section 3.3). This process may require discussion with interested parties; for example, consulting with the relevant regulatory and planning authorities to identify any restrictions and assess the commercial viability of potential future uses.

For evaluation, the focus shifts to comparing the relative benefits and detriments of different options. This means that descriptions need to include information about the value of an option (i.e. impacts on people, the environment, society and lifetime cost).

The performance and achievability of each option depend not only on the end state and future use, but also on how the end state will be achieved (e.g. the approach to environmental and waste management) and the resources, infrastructure and timeframe required to deliver them.

Compiling end state options needs to consider whether interim states and associated environmental management approaches are appropriate to consider for the site. In this case, it is necessary to describe the relation between the interim state and the final end state and how to manage the progression from the interim state to the final end state, including time factors, performance objectives and metrics for the interim state. Use of interim states may be appropriate, depending on the uncertainties at the site and the relative merit of characterization versus a bias in favour of action. For actions that require long timescales, the process of determining the end state may need to be iterative and adaptive and conducted in conjunction with interim actions. This approach makes it possible to account for new information that arises in site characterization or remediation, changes in the site context, changes in constraint factors such as availability of waste routes, and changes in the preferences of interested parties based on site progress. Interim states provide an important way of managing progress. In some cases, interim states may be required for attenuation (e.g. decay) to occur after active remediation ceases to reach a condition that is acceptable for public access.

In summary, end state options need to be described in terms of their physical state, including the implications for future use and ongoing controls. The description of each end state option needs to discuss not only what will be delivered but how it will be delivered. The options can range from (1) allowing unrestricted use through (2) restricted use to (3) relying on controls to prevent use of the site.

3.5. SCREENING OPTIONS

The purpose of screening the options is to eliminate any options that are clearly not deliverable or credible to prevent expending resources (time and money) on characterizing and evaluating them unnecessarily. The screening criteria need to be discussed openly and need to be agreed on with interested parties so that there are no surprises in the screening evaluation.

Screening criteria include the following examples:

- Is the option legal?
- Does the option meet regulatory requirements?
- Do proposed waste management approaches exist?
  - In some cases, proposed waste management approaches may not be available.
- Are proposed technologies available and can they be proven on required timescales?
  - Some technology approaches may not be available or mature for the site application.
- Does a framework for provision of proposed controls exist?
  - If controls are to be used, there needs to be a mechanism for implementing and administering them.
- Does the proposed approach align with national policy?
  - National policy may preclude some approaches.

As noted in Section 3.3.2, external factors can change over the timescales of a site project. Therefore, it may be appropriate to keep a record of options that are currently unachievable in case they become achievable in the future. This approach is described more thoroughly in Section 4.4 (dealing with uncertainty).

3.6. EVALUATION OF OPTIONS

The options that remain following the screening process above need to be evaluated holistically to select a sustainable solution using a life cycle perspective. Evaluation involves a logical comparison of alternative options, considering a range of factors, with the aim of identifying a single preferred option. To incorporate a life cycle perspective, the evaluation of options needs to consider more than the near term impacts on the site; it needs to consider impacts on and off the site both currently and in the future. Optimization principles also need to be incorporated into the evaluation (see Section 2.4).

There is often a conception that the ‘do nothing’ option is the easy one. A holistic life cycle assessment will help determine the reality of whether land use restrictions are manageable and the burden of maintaining controls is justified for an approach based on access controls without active site remediation. Conversely, there can be a preconception that removing all contamination is in the best interests of members of the public (the community) and the environment; however, removing the contamination does not destroy it, the contamination is simply moved elsewhere.

The evaluation needs to consider the balance of benefits and consequences associated with the options. Technical, regulatory, economic, environmental and social factors need to be weighed in relation to one another and evaluated in the context of needs to meet regulatory compliance requirements. Timeframe also needs to be considered in the balance of benefits and consequences, because there can be long term costs and required activities that need to be balanced against short term benefits for some options. On-site and off-site waste disposal is another important consideration in relation to the range of interested parties (e.g. local versus those along the waste transport route and near off-site waste disposal facilities). Interim states and associated interim actions may also need to be considered as part of an option and can provide advantages for making near term progress and adaptively managing efforts towards the final end state.

3.6.1. Assessment approach and evaluation criteria

An option needs to be evaluated in terms of both its likely performance (the benefits and detriments of an option relative to aspects of value) and the level of confidence in its implementability. For instance, it is feasible that a less favourable option will be selected because there is greater confidence in its implementability. Evaluation criteria, including performance and implementability elements, need to be discussed and determined openly. The evaluation criteria are likely to reflect the values of the interested parties (see Section 3.3.1) and include the following aspects:

(a) Legal and regulatory compliance:
   (i) Protecting people (health and safety);
   (ii) Protecting the environment.
(b) Security.
(c) Social and economic impacts.
(d) Risk and uncertainty for implementation.
(e) Cost and time required for realizing the benefits of the end state and associated intended future use.

Criteria for assessing delivery confidence are likely to reflect the external factors identified earlier in the process (see Section 3.3.2) and include aspects of policy, regulations, resources, technology and the confidence of interested parties.

Evaluation criteria need to aim to be comprehensive to support all aspects of a holistic evaluation. As far as possible, evaluation criteria need to be discrete to avoid double counting.

3.6.2. Holistic life cycle assessment

Evidence based comparison of options identifies the preferred option in decision making. The option assessment can be either qualitative (based on discussion) or quantitative (based on some form of numerical scoring), or a combination of both.

The full life cycle implications of an option need to be considered, including the impact of doing the work and the impact of the work having been done. For example, a life cycle assessment will consider the safety of workers delivering the end state as well as risks to the public from residual contamination. Similarly, a life cycle assessment will consider emissions to the environment (including waste handling and transportation) during delivery of the end state as well as the risks to the environment from residual contamination.

Life cycle assessment also needs to consider impacts on- and off-site. Simply moving the impact off-site to an alternative location does not remove the impact. Moving the contamination can impact on people and the environment while it is in transit and in its new location. Conventional health and safety, nuisance (noise, vibration, dust), public amenity and broader environmental impacts also need to be considered.

The evaluation needs to be conducted based on information about options that includes an understanding of the necessary technologies and approaches, associated innovations versus mature approaches, the use of phasing or graded approaches during implementation, uncertainty in achieving results, and the type of performance metrics that can be applied during implementation and to identify attainment of the end state. The evaluation needs to consider how options address regulatory requirements and provide risk reduction. Information to support the evaluation needs to be compiled to describe the options and their properties in a form that is suitable for communication to decision makers and interested parties. The evaluation needs to consider prioritization of decision making factors in selecting an end state based on the site specific situation, in the regulatory context, and considering interested party input.

The following items are examples of factors to consider in a holistic evaluation of end state options:

(a) Benefits of actions to reduce risk:
   (i) What future uses are enabled and how do these uses provide social and economic improvements?
   (ii) What protection of human health and the environment is gained?
(b) Impacts of conducting the remediation project:
   (i) Infrastructure (e.g. waste haul roads, equipment);
   (ii) Socioeconomic impacts (e.g. cultural, local economy damaged or enhanced);
   (iii) Environmental footprint (e.g. number of haul trucks, area impacted, waste disposal approach);
   (iv) Compatibility with adaptive or future remediation (e.g. enabling or preventing a future option);
   (v) Remediation cost.
(c) Long term management needs:
   (i) Residual risk (integrity of long term remaining structures or waste disposal areas, residual contaminant level);
   (ii) Institutional control requirements (monitoring, maintenance);
   (iii) Archival, data management requirements.
(d) Expectations of interested parties:
   (i) Future use;
   (ii) Remediation process activities, risks, benefits and consequences.
(e) Categories of intended future use, including consideration of human use and environmental use (natural resource protection):
   (i) Unrestricted use;
   (ii) Restricted use (permitted use, industrial, recreational):
      — Prohibited use (exclusion zone with limitations for access).
(f) End state relation to intended future use:
   (i) The end state could include different conditions for different portions of the site if these are consistent with the intended future use(s);
   (ii) The end state could include contamination remaining at the site that does not impede the selected intended future use.

(g) Legal and regulatory requirements:
   (i) National and local laws and regulations;
   (ii) International and multi-party agreements (e.g. a two-country cross-border agreement or an agreement between a government and an indigenous people):
      — In some instances, there can be transboundary impacts of a radiological release due to an existing situation or a planned activity. According to Ref. [17], these transboundary issues can be resolved in the form of multiparty agreements, which include details about the following: (1) the source of contamination, (2) the steps required to remove or reduce the source and any off-site contamination and (3) the financial arrangements in place to accomplish the detailed steps. Such agreements are essential to defining the roles and responsibilities of different players in achieving a given end state.

(h) Roles and responsibilities:
   (i) The IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [18] can be referred to for roles and responsibilities information;
   (ii) Principle 1 of SF-1 [6] states that "**the prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks.**" If the facility or activity is properly licensed and regulated, upon the termination of its operation it will undergo a process of decommissioning and therefore the responsibility for decommissioning work lies with the licensee. In the case of the remediation of other non-licensed, unregulated sites, responsibilities may be more complicated. Typically, the owner or generator of the contamination will have responsibility for remediation. However, there could be situations where the government or national policy may need to determine responsibility or accept responsibility for environmental remediation and the related radiation safety aspects;
   (iii) Principle 2 of SF-1 [6] describes the responsibility of a government to establish a legal framework for radiation safety under which a regulatory framework is developed.

(i) Sustainability and equity:
   (i) The principles set out in the United Nations' Rio Declaration on Environment and Development of 1992 [13] encompass concepts that are important for the application of sustainable environmental management, such as intergenerational equity, environmental protection and waste minimization;

(ii) When defining the end state, there are two levels that can reflect the principles of sustainability. At a strategic level, the end state can be influenced by local or regional sustainability factors, such as land use planning, economic and/or social regeneration and waste disposal management capabilities and capacities. At a tactical level, the principles of sustainability will also influence the environmental management techniques selected to implement the end state. At the tactical level, factors such as energy use, physical impact on workers, members of the public and sensitive habitats, and number of people employed may be relevant. These two aspects are interlinked, and it would be difficult to define one without an understanding of the other;

(iii) The Brundtland Report for the World Commission on Environment and Development [19] defines sustainability as “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainability is commonly supported by three pillars: social, economic and environmental.

(j) IAEA’s and other international standards and guidance.

3.7. DOCUMENT ALL DECISIONS AND DEVELOP A PLAN TO IMPLEMENT THE END STATE

It is important to document the end state decision because it will serve as the objective and planning basis for the site. To facilitate this documentation, good record keeping during the determination process is recommended. Records need to include explanations for screening and evaluation decisions (e.g. why an approach was screened out). The following categories of records are needed as part of the end state decision:

(a) Description of the determination process and associated decision bases.
(b) Description of which parties were involved in the decision making process.
(c) Description of the selected end state (physical state, including location of residual contamination and waste, controls and administrative elements).
(d) Record of historic site information and environmental monitoring results.
(e) Information to support transition to next use or landowner (e.g. records for due diligence).
(f) Record of who is responsible for managing ongoing controls, including how long controls are required.

(g) Record of who is financially liable if further remediation is required in the future:
   (i) The record needs to be clear in relation to current responsible party (parties);
   (ii) The record needs to detail strong transition criteria.

(h) Metrics that can guide implementation and determine when the end state has been achieved.

(i) Follow-up actions for site management associated with developing plans that include resource assessments and implementation monitoring based on the established metrics.

While some of the information is quantitative, such as cost, quantity of remediation wastes expected, radiological doses and concentrations of contaminants in soil or water, much of it may not be. Qualitative information could include, for example, narratives on site development perspectives, ethical and cultural considerations, risk perceptions and other inputs from interested parties. Consolidating and evaluating quantitative and qualitative information to arrive at a decision may be a challenging process. The involvement of an independent facilitator may be required.

It is essential that all information is analysed with respect to its potential impact on the chances and risks of achieving a desired end state. Where uncertainties exist that are critical for the decision making process, further studies may need to be commissioned to remove or at least reduce uncertainties and increase confidence in the end state decision. In some cases, additional in-depth research and development could be warranted to close data or information gaps or uncertainties.

Where possible, the end state needs to be described in measurable, quantifiable terms so that clear metrics for completion of remediation measures can be defined. However, not all aspects of the end state may be quantifiable. Some aspects of the end state could require narratives to describe the desired end state condition.

3.8. DEVELOPING A PLAN TO IMPLEMENT THE END STATE

After the end state decision is finalized, a plan is needed to implement the approach and describe the performance metrics to be used for attainment of the end state. The implementation plan may need to incorporate interim states (e.g. whereby interim objectives and metrics are set to guide a stepwise series of activities towards the final end state) if they were identified as part of the end state decision. The content of this plan will be site specific. However, the following elements need to be considered in developing the plan:

(a) Detailed description of the end state (and compatible future uses) with measurable attainment criteria and any interim states (milestones) proposed.
(b) Health and safety aspects.
(c) An adaptive management approach, if needed, to address site challenges and uncertainties.
(d) Roles, responsibilities and funding.
(e) Description of necessary actions.
(f) Schedule.
(g) Administrative and physical controls.
(h) Monitoring plan.
(i) Waste management and disposal plan.
(j) Physical management and maintenance needs.
(k) Administrative management (e.g. records).
(l) Life cycle planning elements:
    (i) Site evolution and potential disruptive events over time that need to be considered;
    (ii) Dose and radiological risks and how these are expected to vary over time;
    (iii) A process to control changes related to any environmental, economic and social variations over time.
(m) The relation between interim states and the final end state, when interim states are used, and management for progression from the interim state to the final end state, including time factors and performance objectives and metrics for the interim state.

4. CONSIDERATIONS FOR IMPLEMENTING THE PROCESS

The process described in Section 3 is a straightforward approach, like those applied for other environmental decision making processes. However, implementation of this process can have specific challenges because of the multiple factors involved in the decisions to be made. The sections below provide some considerations for implementing the decision making process to help address some of the common categories of challenges.

4.1. NATIONAL POLICY AND LEGAL AND REGULATORY REQUIREMENTS

The determination of a site end state is usually based on the formal requirements of the national policy and strategy and the national legal and regulatory framework. National regulatory frameworks can range from very prescriptive to non-prescriptive:

(a) Prescriptive frameworks usually define numerical end state criteria that need to be met by environmental remediation activities, such as maximum allowable radionuclide concentrations in soil or water, maximum allowable dose rates or radon exhalation rates. Prescriptive requirements are relatively easy to communicate, and their attainment is easy to verify by measurements. However, they are not usually based on actual risks and site specific conditions. In prescriptive regulatory frameworks one may claim that the room for optimization is somewhat limited.
(b) Non-prescriptive (objectives based) frameworks start from the site conditions and the actual risks that can arise from a contamination situation. The site end state is usually expressed in terms of site specific risks that are based on realistic use scenarios and other objectives. In this case, the process of determining a site end state inherently includes an element of optimization, as does the development of technical remediation activities to achieve the site end state.

The aspects of justification and optimization of protection and safety are also applicable in the determination of a site end state, as discussed in Sections 2 and 3.

4.2. CONSIDERATION OF RADIOLOGICAL AND NON-RADIOLOGICAL FACTORS AND OTHER SITE CONDITIONS

The framework encompassing the radiation protection aspects is an important element for the scope of remediation and decommissioning associated with a site end state, as discussed above. At former nuclear sites or sites containing radioactive contaminants, risk perception can be driven to a great extent by the presence of radioactive substances in the environment. However, when evaluating a site for determination of an end state, non-radiological risks need to be considered and, at some sites, these may pose greater risks than radiological hazards.

TABLE 1. EXAMPLES OF POTENTIAL HAZARDS AND RISKS TO BE CONSIDERED IN DETERMINING THE SITE END STATE

Potential hazard	Key aspects describing the site end state
Radiation safety	Expected doses to members of the public or the environment and associated impacts
Non-radiological environmental factors	Quality of water, soil, air with respect to non-radioactive pollutants, exceedance of quality standards (e.g. drinking water quality, soil for agricultural use)
Geotechnical stability	Potential failure of containment structures, sudden release of wastes (e.g. tailings). The risk can be exacerbated by natural conditions such as landslides, mudflows, earthquakes, etc.
Erosion	Contaminated material (radioactive, non-radioactive) can be eroded by rivers, heavy rainfall, storm events, or human activities, which may lead to uncontrolled dispersion of contamination
Community safety	People (especially playing children) or livestock can be harmed by insecure infrastructure, mine openings (shafts, adits) or subsidence
Regional development, availability of land	A facility can occupy land that could be used for developmental purposes (property development, agriculture, tourism, etc.)
Visual impact	A facility can cause major visual disturbance
Risk perception	A facility can cause public concerns over perceived risks, even though real risks may be low or negligible

Thus, establishing dose criteria is only part of the end state definition. Determination of a site end state needs to consider all of the hazards and risks at a site and how candidate remediation options alter these hazards. Table 1 provides examples to be considered.

In addition to the planned site end state and related site conditions, it may also be necessary to consider unplanned accident scenarios and evaluate how candidate end states would respond under these conditions.

4.3. LIABILITY FACTORS

One factor that needs to be considered in evaluating end state and associated future use options is any environmental (e.g. residual contamination) or other (e.g. physical) liabilities that remain once the end state is reached. There are many situations where continuing environmental or other liabilities are managed effectively and are suitable to the situation. Thus, it may be acceptable to have remaining liability at a site. However, liabilities need to be identified as something to consider in comparing options. As part of this process, ownership of any continuing liability for an end state option needs to be defined.

4.4. DEALING WITH UNCERTAINTY

Given the time, scale and complexity of many remediation projects, and hence the effort to achieve a desired end state, uncertainties may need to be considered as credible risk factors that have to be actively managed to mitigate their impacts. If not properly addressed, uncertainties can affect the decision making process negatively or impede environmental remediation progress.

Because environmental management of contaminated sites involves environmental factors that cannot always be fully controlled or characterized, the process of end state determination will involve assumptions for some aspects of the site and selection of numerical values for data and parameters that describe the site, for which some degree of uncertainty will exist. Despite these uncertainties, decisions have to be made and ultimately translated into remediation and control actions. It is not realistic to reduce or control all the uncertainties inherent in decisions and the environmental management process. However, it is useful to consider what steps are reasonable to improve the level of confidence in decisions and environmental management with respect to the sources of uncertainty.

The typical sources of uncertainties are knowledge of the spatial distribution of the contaminants, contaminant redistribution through time and space, performance of the technologies to reduce the contamination, quantities and characteristics of wastes to be produced, and costs and time necessary to achieve a potential end state. Several types of information can be applied to address uncertainties, for example, measurement data, theoretical considerations and expert judgements or default values. However, when determining the level of effort to be made to reduce uncertainty it is necessary to consider the potential for diminishing returns; increasing quantities of data may not result in continued reduction in uncertainty. Therefore, site investigations need to be weighed carefully in terms of the information that is expected to be gained for reducing uncertainties. In addition, other approaches, as discussed below, need to be considered.

For decision making processes, dealing with uncertainties is about being informed about them (all parties) and carefully considering choices without full knowledge of the scope and consequences of a proposed action. One way to deal with uncertainty is to use a conservative hypothesis in the process. The process of end state determination could include conservatism to ensure adequate protectiveness for the future use of the site. However, as a balancing factor, over-conservatism can be counterproductive by limiting options or escalating costs beyond financial resources. Thus, the sources of conservatism need to be clearly identified and the degree of conservatism incorporated into evaluation of the benefits, risks and costs of end state options. A useful approach in considering conservatism and uncertainty in the evaluation of options is to conduct a sensitivity analysis to identify how these aspects influence the decision making factors. Discussion of uncertainty and conservatism can also be an opportunity to take the different points of view of the interested parties into account and incorporate them into the decision making process for the end state.

Because all options will have some uncertainty, screening and evaluation of options needs to focus on relative evaluation and relative accuracy for comparative estimates, recognizing that in some cases standardized comparison between options might be difficult. Decisions between options can consider the accuracy of the information and the possibility that information may improve over time during implementation of actions. Evolving information during actions may be a driver for considering interim states to progress towards a final end state. Thus, for there to be confidence in the decision making process, it is necessary to consider the need for preliminary evaluations and decisions that may ultimately be refined during actions.

As a general rule for planning purposes, the selection of a site end state that is robust against uncertainties and external influences that are hard to control would be preferred over a site end state that is sensitive to uncertain factors. End states that require a longer time to achieve may have more sensitivity to uncertainty. In this case, interim states can be considered that do not prevent attainment of the final end state and for which the cost and effort are justifiable as steps towards the final end state.

The following list describes some examples of uncertainties that can cause challenges in the decision making process or for implementation of remediation:

(a) Interested parties: there may be a variety of interested parties with different perspectives and input and new interested parties can be added over time, while others may withdraw.

(b) Regulatory authorities: limitations or changes in national policy or regulations can cause difficulty in interpreting the approach for a site.
(c) Practitioners, site owners or responsible parties: changes in responsibility, ownership, or financial situation for sites can affect the decision or implementation process.
(d) Financial resources: these may need to be secured over a long time period to reach an end state. Funding uncertainty or lack of funding can affect the type of end state that is feasible or require re-evaluation of a previously determined end state.
(e) Limitations of site information or differences in risk perception: available information can affect support for end state decisions.
(f) Site conditions: unknown conditions during end state determination can emerge during implementation.
(g) Future use: vagueness in describing future uses and associated end state requirements can cause uncertainty in implementing remediation and agreement on completion of remediation activities, and could result in a need for future remediation, for example, if the original end state criteria are later found not to be adequate for a newly identified intended future use.

4.5. BUILDING CONFIDENCE IN THE DECISION

It is established that in the legal and regulatory framework, the government shall provide as appropriate, the involvement of interested parties in decisions making regarding the development and implementation of protection strategies [3]. Thus, the process of determining an end state is expected to include appropriate participation of interested parties. The end state determination process needs to be designed to build confidence among all parties involved in the decision making for all the steps leading to achievement of the desired end state. With this end in mind, the following items need to be considered:

(a) The decision making process:
  (i) Adhere to a defined process as presented in Section 3 and communicate it to all involved parties.
(b) Involvement of interested parties:
  (i) Engage interested parties early in the decision making process, with a focus on directly affected interested parties;
  (ii) Engage all the involved organizations simultaneously to build trust.
(c) Legal and regulatory framework:
  (i) Consider the need to include appropriately precise and detailed requirements that provide confidence that there is a clear framework

of standards to be followed, and that make it possible to determine if the standards are being met;
  - (ii) Determine whether there is flexibility in the regulations that allows adaptation to site circumstances;
  - (iii) Define, where needed, verification monitoring for some period of time following completion of the specified activities to show that the site is suitable for the designated future use(s).
- (d) Recognize uncertainties:
  - (i) Use a transparent approach to recognize uncertainties and a documented approach to addressing them;
  - (ii) Reduce uncertainties through stepwise interaction between site investigations and interpretation to improve the site understanding in relation to the decisions.
- (e) Communication, consultation and transparency:
  - (i) Build into the schedule for the end state determination process the time needed for communication and consultation exchanges to enable understanding of the process, information, uncertainties and decision factors;
  - (ii) Manage information, decision factors, resource constraints, challenges and evaluation criteria in a transparent manner to build trust in decisions and enable optimization that accounts for all of the factors required for a sustainable solution.

4.6. SITE COMPLEXITY

In the context of this publication, site complexity and associated site challenges for determining and implementing an end state are increased when the site contains multiple elements (e.g. number and type of facilities or waste disposal features and mixtures of planned and existing exposure situations) and/or the environmental setting or contamination condition includes distinct zones that are substantially different from one another. For instance, increased site complexity may be indicated by a mixture of elements and conditions, such as the presence of a core industrial zone that is heavily contaminated compared to other portions of the site, waste disposal features with substantially different contamination characteristics and a dispersed groundwater plume. Site complexity can also increase for administrative reasons, such as when multiple parties have responsibility for aspects of the site. As site complexity increases, the characteristics that affect selection of an end state for a specific element or within a specific zone of the site may be substantially different from those for other portions of the site.

While this publication is intended to be applied to determine an end state for an entire site, increased complexity could cause portions of the site to have substantially different end state conditions and/or implementation approaches than for other portions of the site. There are several options for handling this situation. Note that in either case, different portions of the site could have different intended future uses and associated end states (e.g. areas of the site could be used for commercial or industrial purposes, while other areas could be used for recreation or nature conservation). The following options can be considered to help address complexities:

(a) Consider the entire site in the process of determining the end state and address the complexities and associated differences in zones during the steps of the process. In this case, the overall end state would describe the target conditions and controls for each zone and how these are collectively considered in the implementation process.
(b) Consider separate end states for selected zones of the site so that the process focuses on important aspects of the end state and its implementation for each different zone.
(c) Recognize the potential interactions between zones when considering each zone selected for separate analysis.
(d) Evaluate whether the end states for individual zones need to be combined or if the situation is best suited by separate implementation and management to obtain individual end states.
(e) Consider the schedule for implementation where attainment of the end state and transition to the selected future use for some zones may occur before implementation within other zones has been completed.
(f) Consider whether interim states may be appropriate:
    (i) Use interim states if the disparity between zones or uncertainty caused by this disparity results in difficulties due to the interactions between zones (e.g. contamination in one zone needs to be reduced below a certain level to mitigate current or future risk in another zone);
    (ii) Use interim states to provide more time to:
        — Reach agreement on a final end state;
        — Address a critical constraint (e.g. lack of funds, need to build an off-site repository);
        — Allow natural attenuation of radionuclides to a level where less costly and safer end state and implementation options are possible.

The composite impacts of each element on overall site risk and implementation approaches need to be considered when determining an end state for a complex site containing multiple elements. For instance, conditions at one element can impact on working conditions at another element. Total waste volume also needs to be considered with respect to implementation approaches, even if phased approaches are used. Similarly, decisions for early actions at less challenging portions of the site need to be considered in the context of setting precedence for later actions at more challenging portions, where these approaches may not be appropriate. However, there may be advantages from early actions to address fewer challenging portions of the site if these actions enable more effective approaches for the remaining more challenging sites. Ultimately, the end state determination, whether done upfront for the whole site or in staged or segmented approaches, needs to consider the composite life cycle costs and benefits for the overall effort.

Site complexity and associated challenges can also affect implementation because of the difficulties in conducting efforts or uncertainties in site conditions that will be encountered as activities proceed. Thus, use of interim states, phased approaches and adaptive management may need to be considered when developing and evaluating the approach to reaching a candidate end state. In some cases, reassessment of the site using the end state process may be advantageous to proceed between phases of implementation or from an interim state to a final end state.

Site characterization and end state implementation challenges are typically increased by site complexity. Increased planning and resources may be needed for efforts to collect information to support the end state decision. When formulating end state options, implementation challenges need to be identified and included for each option. Some implementation options may be better suited than others for addressing the site challenges, and the ability to address these challenges may need to be included as one of the evaluation criteria.

5. CONCLUSIONS

Determining an agreed site end state upfront is important to guide site activities so that the site is transitioned to a condition that meets social and economic expectations, is sustainable and protects people and the environment appropriately. The process needs to be based on IAEA safety fundamentals, principles and guidance, and associated safety standards for radioactive contaminants, and implemented with consideration of national policy and regulations for radioactive and non-radioactive (if present) contaminants. The determination of an appropriate end state includes implications for site future use and associated controls, if needed.

A robust decision making process needs to be conducted in the context of key enablers and site specific inputs. Key enablers to address radioactive contamination include a national policy and regulatory framework, a national waste management strategy and specific regulatory requirements. Another key enabler is incorporation of input from interested parties throughout the process to build confidence in the determination process, associated decisions and the selected end state. Site specific inputs are important to consider the site contaminant and physical conditions appropriately, along with social, economic and environmental factors for the site, in determining an acceptable sustainable end state. A holistic life cycle evaluation of options based on an agreed set of evaluation criteria and an associated evaluation process is needed to promote consideration of candidate end states in terms of an overall balance of risk and benefits within the allowable bounds of the regulatory requirements. The process needs to be applied in a proportionate manner, for example reflecting the potential for harm, the level of uncertainties and the concerns of interested parties. The end state decision making process needs to be conducted in a way that reduces the uncertainties affecting the decision making and builds confidence for all participants, including interested parties. It is important to consider input from site owners or operators, regulators, policy makers, decision makers and interested parties involved in the decision making process needed to determine an appropriate site end state.

It is important to recognize that the end state decision may be driven by 'hard' as well as 'soft' constraints.

Hard constraints include quantitative factors such as radiological and/or non-radiological risks and other site conditions that characterize the site after completion of remediation (or at any interim state that may be defined), or quality parameters (water, soil) that need to be achieved at the site. Hard constraints are often determined by the national legal and regulatory framework and may depend on specific requirements related to future site uses.

Soft constraints are often related to developmental and socioeconomic aspects, perceived risks and public concerns that are expected to be alleviated because of environmental remediation. Soft constraints may be significant factors in reaching decisions for a site end state, depending on the site situation.

The relative importance of either type of constraint depends on the site specific conditions, the radiological and non-radiological risks and the involvement and expectations of the interested parties.

Engagement of interested parties is an important aspect of reaching a viable end state decision. Collectively, site owners, regulators and interested parties will need to be participants in the process of determining an end state.

The end state decision making process will typically require consideration of the following factors:

(a) Radiological and non-radiological risks during the implementation of remediation to achieve the desired end state;
(b) Costs (short and long term) and the availability of funding to sustain long term financial needs;
(c) Available remediation options, including technical, administrative and institutional options;
(d) Master planning aspects and priorities among sub-sites and/or phases associated with interim states;
(e) Sensitivity of the decision with respect to uncertainties;
(f) Sustainability and the need for continued activities to maintain the site in the desired end state.

The decision making process will be most rapid and effective if there is clarity regarding the key benefits being sought (e.g. minimize waste, cost or time; maximize flexibility and future utility). However, if the suggested approach is not demonstrably ‘safe’, then it would be unacceptable irrespective of other arguments. In simple terms, the decision making process is complete when the site owner or responsible parties, regulatory authorities and other interested parties deem the end state as ‘safe enough’ and are satisfied with the benefits obtained from a proposed site end state relative to the costs.

The end state decision making process needs to be well documented, and all relevant records need to be kept, including descriptions of any long term controls and residual hazards, so that the process is highly transparent and can be tracked and reanalysed in the future. A record of the decision may also need to be publicly disseminated.

Given the potential complexity and long timescales of the environmental issues involved, detailed knowledge concerning all aspects of a site relevant to optimization and decision making is unlikely. Therefore, consideration of uncertainties, building confidence in decisions, and use of an iterative and adaptive approach for determination of an end state and implementation of remediation are important for success.

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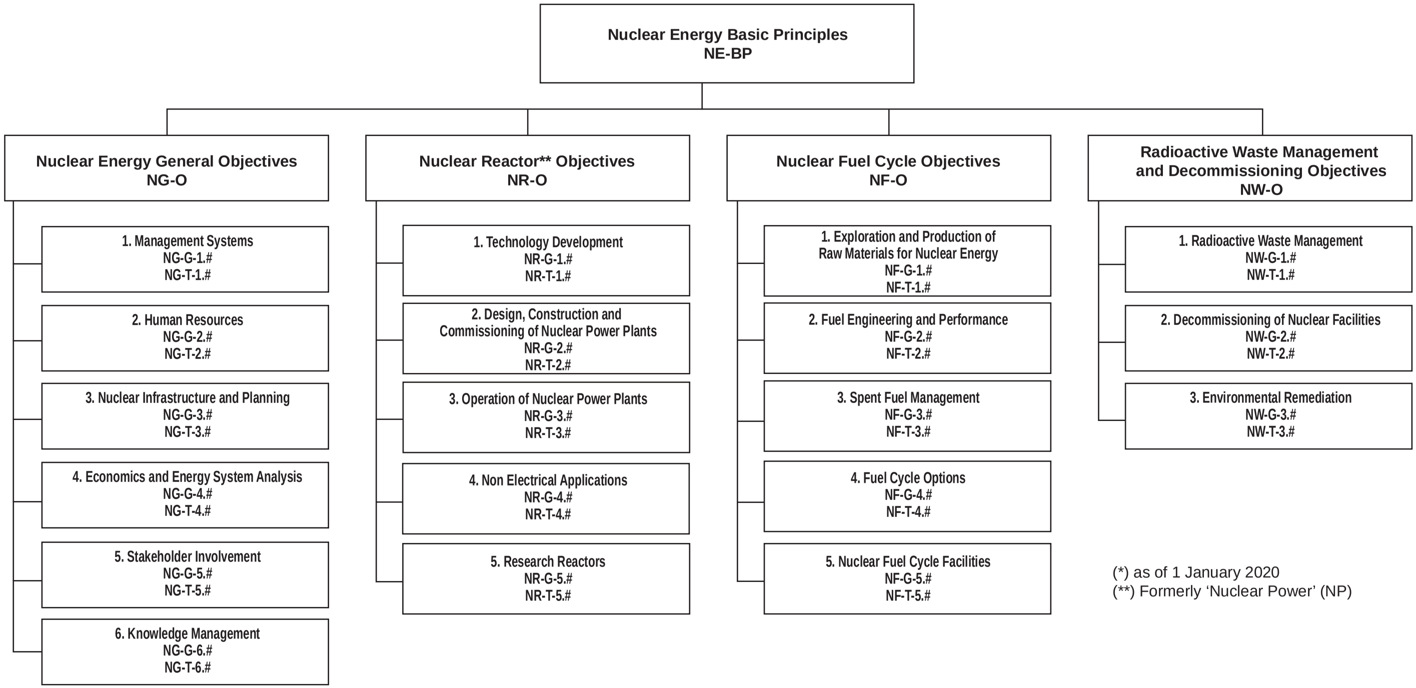

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Key

BP: Basic Principles
O: Objectives
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Sites with radioactive contamination may require action to protect people and the environment and to enable transition to a different future use. To support environmental management of these sites, this publication presents a process to determine the "end state" of the site to be remediated or being remediated and implications for the site future use and necessary controls. The approach is intended to assist those responsible for a site in making an informed and transparent decision on what is the mutually agreed end state. It provides a common basis for all stakeholders involved in the decision-making process, who are working on achieving consensus, so that the potential for misunderstanding is reduced.

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