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OVERCOMING BARRIERS IN THE IMPLEMENTATION OF ENVIRONMENTAL REMEDIATION PROJECTS

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

IAEA NUCLEAR ENERGY SERIES No. NW-T-3.4

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2013

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email: sales.publications@iaea.org
http://www.iaea.org/books

Printed by the IAEA in Austria
June 2013
STI/PUB/1602

IAEA Library Cataloguing in Publication Data

Overcoming barriers in the implementation of environmental remediation projects. — Vienna : International Atomic Energy Agency, 2013.
p. ; 30 cm. — (IAEA nuclear energy series, ISSN 1995–7807 ; no. NW-T-3.4)
STI/PUB/1602
ISBN 978–92–0–140810–5
Includes bibliographical references.

1. Nuclear facilities — Risk assessment. 2. Hazardous waste site remediation — Management. 3. Radiation — Safety measures. I. International Atomic Energy Agency. II. Series.

IAEAL 13–00819

FOREWORD

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

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

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

The IAEA attaches great importance to the dissemination of information that can assist Member States with the development, implementation, maintenance and continuous improvement of systems, programmes and activities that support the nuclear fuel cycle and nuclear applications, including the legacy of past practices and accidents. The IAEA has initiated a comprehensive programme of work covering all aspects of environmental remediation: technical and non-technical factors, including costs, that influence environmental remediation strategies and pertinent decision making; site characterization techniques and strategies; assessment of remediation technologies; techniques and strategies for post-remediation compliance monitoring; special issues such as the remediation of sites with dispersed radioactive contamination or mixed contamination by hazardous and radioactive substances, as well as monitored natural attenuation; and long term management issues at sites with residual contamination.

It was noted that, although the understanding of the need to address radiological liabilities had gained considerable momentum since the end of the Cold War, in many Member States actual remediation programmes have made little progress beyond the assessment and perhaps the planning phase.

This publication analyses the various drivers for remediation projects, possible obstacles and potential solutions to overcome those obstacles. It is noted that care must be taken when establishing measures that are intended to foster increased protection, for example a very prescriptive regulatory framework, as such measures may turn out to be counterproductive. The main obstacle in most cases is a lack of funding. A number of creative ways to structure projects and to identify sources of funds are discussed in this book.

The IAEA wishes to express its thanks to all those who contributed to this work. The IAEA officers responsible for this publication were W.E. Falck and H. Monken-Fernandes of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

SUMMARY

The main goal of environmental remediation is to reduce the radiation exposure from existing contamination of land areas, through actions applied to the contamination itself (the source) or to the pathways for human exposure. A successful project will be one that can provide for an optimized reduction of the exposure of individuals to ionizing radiation, while complying with the relevant regulatory framework and fulfilling the expectations and demands of the different stakeholders in a reasonable and cost effective way.

It is clear that many obstacles will have to be faced while pursuing these objectives. They have to be identified and analysed, and appropriate solutions must be provided, recognizing that the course of action will always be case specific. However, it is possible to identify some general aspects that will probably be present in the implementation of an environmental remediation project. These aspects, once appropriately described and analysed, can serve as a reference to facilitate the implementation of such projects.

Therefore, the objective of this publication is to highlight the main drivers for remediation projects, and to analyse the possible obstacles to implementation and potential solutions to overcome those obstacles.

The publication is divided into sections that describe:

- — Recent advances in society and their effect on remediation programmes;
- — Factors that affect, or drive, remediation programmes;
- — Model remediation programmes and critical resources and project requirements;
- — Practical guidance on overcoming common obstacles, while offering solution strategies for each one.

Specific examples are provided throughout the book, to highlight the various experiences of Member States.

It is expected that, by taking into account the elements covered in this publication, an implementer of an environmental remediation programme will be in a better position to find appropriate solutions to overcome some of the most common barriers that can delay, or even impede, the implementation of such programmes. The book will also be valuable for regulators, helping them to better understand the problems that implementers generally have to face and thus enabling a more fruitful dialogue between both sides. Finally, it will be also useful for stakeholders involved, or interested, in environmental remediation programmes.

It is anticipated that, with better information and guidance, it will be easier for interested parties to reach consensus and that, as a result, whenever implementation of an environmental remediation programme is necessary, it will become a more straightforward endeavour.

1. INTRODUCTION

1.1. BACKGROUND

Responding to the needs of Member States, the IAEA has initiated an environmental remediation project to address radioactive contamination found in soil and water (i.e. groundwater and surface water). The term ‘remediation’ is used in this publication to mean those measures taken for contaminant removal, containment or monitored non-intervention of a contaminated site to reduce exposure of radiation, in order to improve the environmental and/or economic value of the contaminated site. Remediation of a site does not necessarily imply a restoration of the site to pristine conditions. As part of this effort, the IAEA has been charged by its Member States to develop publications that address various aspects of radioactive contamination. The IAEA has previously prepared several books related to the remediation of radiological contamination, each dedicated to a particular technical or conceptual area (Table 1).

These subjects include: characterization of contaminated sites [7, 13]; technical and non-technical factors relevant for the selection of a preferred remediation strategy and technology [2, 16]; overview of applicable technologies for environmental remediation [4]; options for cleanup of contaminated groundwater [9]; and planning and management issues [21, 22]. In addition, a number of other IAEA publications dealing with related aspects have been compiled under different IAEA projects. These include publications on the remediation of uranium mill tailings [10, 21], remediation of dispersed contamination [17, 22] and of mixed radiological and non-radiological contamination [20], decontamination of buildings and roads, and the characterization of decommissioned sites. Limitations in available funds and difficult and protracted remediation projects are contributing to the increased use of and reliance on (monitored) natural attenuation as a core strategy. The necessary preconditions and limitations of that passive approach have been discussed in a dedicated report [14]. Also, planners and managers may want to look closely at the whole process chain, from shutdown and decommissioning to remediation, to make use of potential synergies [18], with the goal of avoiding future site contamination.

1.2. OBJECTIVES

Environmental remediation has been in existence for decades and a tremendous body of practical and scientific knowledge has developed. However, despite this experience, environmental remediation remains a lengthy and expensive process. Hence, this report aims to provide reasoned decisions for determining whether or not further actions are justified at a given site.

The report provides examples and discusses possible reasons why some remediation programmes have been successful, others have been moderately successful and many have not progressed to a substantive degree. This publication also includes a number of the potential strategies that may provide effective remediation outcomes and have been deemed by other Member States to be cost effective.

It is very important for governments, project managers, communities and the public to recognize the different barriers to implementing remediation programmes and the potential obstacles that could adversely impact them, and to work together to find solutions that are in the best interest of all parties. It is also useful to realize that there may exist differing opinions among the concerned stakeholders over what actually constitutes ‘remediation’. For instance, certain stakeholders may only consider active intervention to be remediation. This report considers that all measures taken to ensure that exposures are below an acceptable level are ‘remediation’, whether they are active or passive.

This report attempts to encompass the major issues related to the remediation of land and water that have been radiologically contaminated as a result of past practices and activities, including:

- The nuclear fuel cycle, starting with uranium mining and milling;
- Other non-uranium mining and milling activities giving rise to radiologically contaminated land (including naturally occurring radioactive material (NORM));
- Research activities, including nuclear power development;
- Military applications of radioactive materials.

TABLE 1. RELATIONSHIP BETWEEN RELEVANT TOPICAL DOCUMENTS PRODUCED OR UNDER DEVELOPMENT

Safety	Management	Databases	Technology	Special topics
Management of Radioactive Waste from the Mining and Milling Ores [1]	Factors for Formulating a Strategy for Environmental Restoration [2]	A Directory of Information Resources on Radioactive Waste Management, Decontamination and Decommissioning, and Environmental Restoration [3]	Technologies for Remediation of Radioactively Contaminated Sites [4]	Extent of Environmental Contamination by Naturally Occurring Radioactive Material (NORM) and Technologies for Mitigation [5]
Monitoring and Surveillance of Residues from the Mining and Milling of Uranium and Thorium [6]	Characterization of Radioactively Contaminated Sites for Remediation Purposes [7]	Design Criteria for a Worldwide Directory of Radioactively Contaminated Sites (DRCS) [8]	Technical Options for the Remediation of Contaminated Groundwater [9]	The Long Term Stabilization and Isolation of Uranium Mill Tailings [10]
Remediation of Areas Contaminated by Past Activities and Accidents [11]	Compliance Monitoring for Remediated Sites [12]		Site Characterization Techniques Used in Environmental Restoration Activities [13]	Applicability of Monitored Natural Attenuation at Radioactively Contaminated Sites [14]
Release of Sites from Regulatory Control Upon the Termination of Practices [15]	Non-technical Factors Impacting on the Decision Making Processes in Environmental Remediation [16]		Remediation of Sites With Dispersed Radioactive Contamination [17]	Integrated Approach to Planning the Remediation of Sites Undergoing Decommissioning [18]
	Management of Long Term Radiological Liabilities: Stewardship Challenges [19]		Remediation of Sites with Mixed Contamination of Radioactive and Other Hazardous Substances [20]	This report

This publication assumes that the intention of remediation is to meet objectives for human health and environmental protection and to reduce risk levels to be consistent with the optimization principle known as ALARA (as low as reasonably achievable). Factors that affect the ALARA level include:

— Protection of humans and the environment;
— Ability to use a resource(s) associated with the land and waters safely;
— Doing the above while meeting regulatory requirements;
— Associated social and economic considerations.

The focus of the IAEA is on issues associated with radiological contamination; however, this book recognizes that other types of contamination may also be present, which also need to be taken into account within the overall risk assessment/risk management process.

There are two basic questions to be considered, and that this report seeks to address. The first question can be stated simply as, Why undertake remediation in the first place? There are several factors or drivers that typically contribute to the undertaking of remediation programmes, and any number of these may apply to a single project. They include:

— Identified risk or hazard;
— Regulatory and legal requirements;
— International conventions and agreements;
— Public concerns and expectations;
— Economic development considerations;
— Political influences.

For those situations where legacy contamination may exist, this report intends to provide guidance for determining the need, timing and nature of the remediation to be undertaken.

The second question, then, is, Why does a remediation programme not occur in many instances, even after a thorough site assessment has been completed? Obviously, where the site assessment has concluded that there was no significant hazard or risk, there may be no technical need for action. However, some action may be warranted, or at least expected, to satisfy public demands. In those cases where a risk or hazard has been identified and remediation planned, there are common obstacles that tend to thwart effective progress. An evaluation of the key features of successful remediation efforts offers insight into strategies for overcoming the commonly encountered obstacles. For cases where remediation programmes are being planned or implemented, this book intends to provide practical guidance on improving the effectiveness of programmes and enabling optimization of constrained resources.

This report is intended for decision makers, regulators and remediation managers who may become involved in an environmental remediation project. Stakeholders of these projects may also find this report beneficial, in that it provides insight into the many challenges faced by these decision makers, regulators and remediation managers.

1.3. STRUCTURE

This book highlights the main drivers for remediation projects, possible obstacles to implementation and potential solutions to overcome those obstacles. It is divided into the following sections: Section 2 describes recent advances in society and their effect on remediation programmes, and presents a vision for the future, where remediation needs to be implemented through optimized planning; Section 3 identifies and describes the factors that affect, or drive, remediation programmes; Section 4 describes model remediation programmes and provides explanations of critical resources and project requirements; and Section 5 provides practical guidance on overcoming common obstacles and offers solution strategies for each one.

2. ADVANCES IN REMEDIATION AND LIFE CYCLE MANAGEMENT

It is widely accepted that human activities have altered the form and function of many ecosystems around the world. Many people believe that if the cause of the change can be identified and removed, then these ecosystems will return to their predisturbance conditions. Unfortunately, this does not hold true for most systems. Ecosystems are the result of complex and interdependent processes. From the point of view of geological timescales, they are metastable, i.e. in a kind of dynamic equilibrium over the lifespan of a human being. Hence, humans tend to consider them 'stable', and when they change, this is often perceived as something negative. From a human perspective, such changes, indeed, are often undesirable, as the local populations have developed strategies to live within the given ecosystem and now need to adapt to new circumstances. Depending on the resources and other factors, these adaptation processes may be painful, or even impossible.

It is important to note that it is virtually impossible to fully 'restore' an ecosystem; therefore, the concept of total restoration is not an achievable goal (from a basic scientific point of view). However, ecosystems or a site within an ecosystem can still be improved or remediated to a reasonable approximation of the area's pre-impact conditions.

In a somewhat similar way to what has been described above, sites containing radioactive materials may give rise to locally elevated levels of exposure. In particular, sites contaminated as a consequence of past activities, which may not have been subject to the authorization and control procedures that currently apply, are more likely to result in local exposure pathways. However, remediation objectives are often poorly articulated, raising unrealistic expectations, and sometimes cannot be evaluated in cost–benefit terms. The goal of remediation is to reduce the existing exposure, if it is judged to be unsatisfactory from the radiological protection perspective. It may take the form of a single set of protective actions that achieve a permanent reduction of components of the existing annual dose (cleaning up of some radioactive residues), or it may also reduce the whole existing annual dose but require continuous protective action to be effective.

Remediation is often the option that is chosen to satisfy the need for sustainable development, which demands that current activities do not impair the ability of future generations to live in a way they choose [23, 24].

In recent years, a slow change in operational paradigms has occurred. Among these changes is a move away from treating environmental problems after they have occurred (reactionary), without positive feedback into the activities that have caused the problem, towards a more integrated management (proactive) approach to human activities. Today's life cycle management approach aims to treat each stage in the life of a facility or site, not as an isolated event, but as one phase in its overall life. Thus, the planning not only covers each stage, but is a continuing activity, taking into account actual and projected developments and feedback mechanisms between different stages in the life cycle. Thus, the remediation decision would be one step of the life cycle in a comprehensive planning process. Long term stewardship, however, must accept the many decisions that have been made earlier in the life cycle, i.e. before a holistic view had been taken, and ensure that impacts on human health and the environment are minimized. Figure 1 illustrates the typical life cycle approach for an industrial installation.

Another change deals with the current investigation paradigm. Some of the current methodologies for site characterization include a multistage investigative process that was intended to provide sufficient understanding of site contamination issues in order to take remedial action. This process has proved to be very expensive and time consuming. When this approach was conceived in the 1980s, there were good reasons to adopt a carefully staged approach to site characterization, ranging from the need to build a base of knowledge in this field to the tremendous complexity involved when predicting contaminant behaviour in natural geologic settings. Analytical methods used for this approach furthermore required the controlled environment of static laboratories for proper implementation and quality control oversight. When these realities were combined with periodic budgeting cycles for government

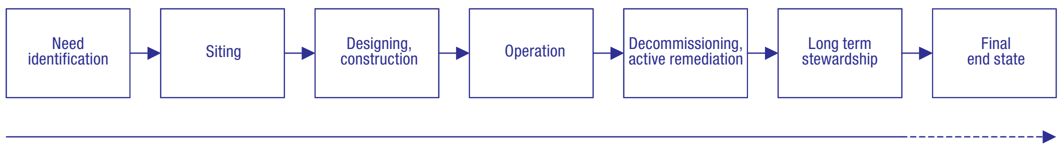

FIG. 1. Life cycle management [19].

funded work, it is not difficult to understand how multiple investigations — each with its own multiyear cycle of workplan preparation, field work and reporting of findings — became the accepted approach.

Associated with the development of the multistage investigation process was the establishment of carefully documented analytical procedures, which have become a standard in the environmental industry. Legal defensibility considerations have led to the widespread opinion that only certain methods are suitable for site decision making. The importance of obtaining contaminant concentration data of known quality cannot be underestimated; however, the exclusive focus on analytical quality alone disregards other equally important considerations. The question then is how to move away from multistage investigations. The fact remains that the complexity of contaminant distribution and geological heterogeneity requires a large number of costly samples, to reduce uncertainty to acceptable levels. However, recent advances in the field of analytical methods, sample collection techniques and geologic definition now offer the opportunity to dramatically improve the effectiveness of investigation. Yet improvements in technology alone are not sufficient, since they must be combined with changes in approach. It is in this context that this publication offers insights and examples that are focused on improving future remediation projects.

The end of the Cold War led to a reduced demand for uranium, which in turn led to the closure of many uranium production facilities around the world that were often operated for national strategic reasons only. Similarly, many defence related research laboratories became obsolete. With the paradigm change from ‘production’ or ‘defence related research’ to ‘closure’ and/or ‘remediation’, the management objectives and management culture also changed. At the same time, the processes for making management decisions changed. For example, other stakeholders (such as the public at large) had to be involved. Efforts to make management decisions more transparent and defensible inevitably also resulted in more paperwork for documentation of the decisions, the processes and their rationale.

Understandably, from a human and psychological point of view, the original managers found these changes in paradigms difficult to follow. This resulted in a loss of power and challenges to their professionalism, founded or not. As already mentioned, radiation safety legislation was virtually non-existent in the early days of the nuclear fuel cycle and NORM industries. This aspect, coupled with the fact that the managers’ original focus was on production, e.g. of uranium, for national security reasons, and not on environmental protection, makes it easy to understand why certain environmentally ‘unfriendly’ decisions were made.

Naturally, the development of a new management culture and the establishment of new processes caused delays in the implementation of remediation projects. The introduction of public consultation processes also caused delays — at least viewed from the perspective of the previous management culture. Public consultation was a necessary first step in repairing damaged trust and building new and more cooperative relationships between project proponents, stakeholders and regulators.

Different management cultures require different skills. Environmental expertise often was or is not available in the organizations concerned. Individuals with this expertise frequently bring with them a different style of working, and it is the task of managers to create a coherent ‘team’ — which may be a challenge for them when they are used to a more consultative style of management. This publication is also intended to provide practical guidance to managers and their teams.

3. DRIVERS OF ENVIRONMENTAL REMEDIATION

The objectives of this section are to identify the typical drivers of considering and potentially undertaking remediation efforts, to investigate various perspectives on the decision, and to identify factors to be considered in ultimately determining whether remedial actions are needed and/or should be undertaken.

There are always a number of drivers or factors to be considered in determining whether or not a particular need is to be fulfilled. This is also true when contemplating the remediation of radiological accident or radiological legacy sites. While many in the technical community argue that remediation projects should be judged solely on the basis of the relative risks posed by an accident or legacy site, it must be remembered that individuals outside of this technical community may have a completely different perspective, and, therefore, may have different needs, fears and desires. The challenge for decision makers is to balance the various technical, legal, social, economic and political drivers in a manner that ensures the protection of workers, the public and the environment in the long term.

A number of the primary drivers that are relevant to the topic of remediation project/programme development are identified in Fig. 2, to aid Member States in assessing their own country specific priorities and challenges. It can be seen from this figure that these drivers include the calculated risks (which should be assessed by means of well established, science based protocols); the regulatory and legal drivers, assuming that a regulatory framework is in place; and the economic aspects that will define the costs of the remediation programme. Political components (in which different conventions and treaties may have to be considered) and the expectations of the stakeholders will also have important roles in the definition of the overall elements of the environmental remediation project. In responding to these drivers, it would benefit a Member State to include the considerations discussed in the following sections when evaluating the need for remediation activities.

3.1. RECOGNIZED RISKS OR HAZARDS

When assessing or evaluating legacy sites, it is appropriate to consider the time period in which a site was operated. In many Member States, environmental legislation either did not exist or was in its infancy when nuclear or radiological site operations began. Sites were operated within the 'rules of the day', with a goal of maximizing production and profitability. As such, they often did not consider the resulting long term impacts of their operations, which were left for future generations to address. The increasing awareness of environmental impacts obtained from the extensive site investigation work undertaken over the past few decades and from the free exchange of information among Member States has shed light on the magnitude of the legacy of past practices in many countries.

Notwithstanding the availability (or otherwise) of regulatory requirements at a given site, a health or environmental risk may become known. Such knowledge may be gained by chance, for instance as a result of investigations at nearby sites. In some instances, site investigations are undertaken by the owners or operators of a site, in order to obtain a better understanding of the liabilities (financial, legal, etc.) that may exist at a particular site. In other instances, it may be a proposed change of land use that triggers an evaluation of the radioactivity present. In the original context, the radioactivity may have been considered un-noteworthy and subject to adequate controls, but a change in circumstance, such as a factory becoming a residence or a childcare facility, may cause a drastic re-evaluation of what is considered an acceptable level of contamination.

A site investigation entails a process of evaluation and assessment, and the process nominally followed may lead to an active remediation of the site or to a 'no further action' remediation. A central feature of the investigation process is characterization. In this context, characterization refers to those investigations, specifically including measurements, undertaken to provide information and data about the contamination (radiological and chemical) and affected site environment. When a long term problem is being addressed, full historical information may sometimes allow a very well planned characterization with no surprises. Alternatively, a sudden public outcry about an unknown site may demand immediate, independent measurements to achieve credible demonstration of acceptability.

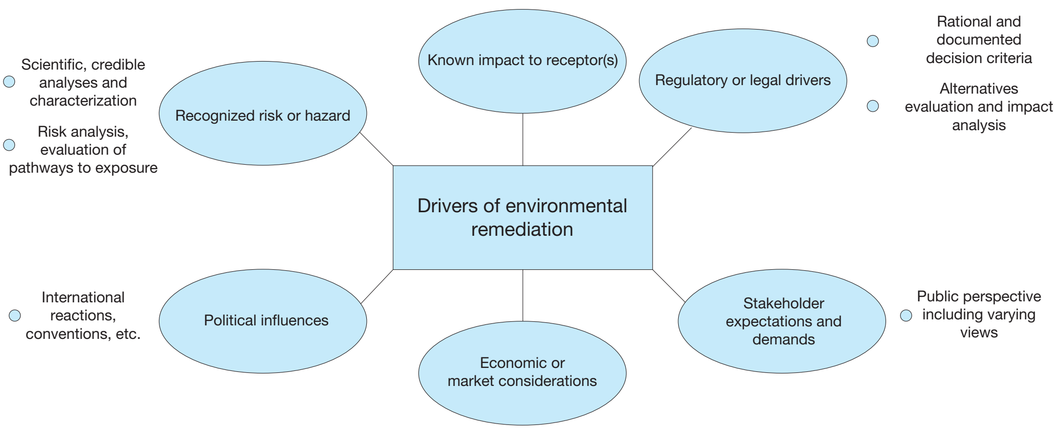

FIG. 2. Drivers for environmental remediation programmes.

The process of investigation entails the following steps:

- — Evaluation of the severity of the problem in terms of radionuclide concentration or dose levels, to determine whether there is a need to remediate;
- — Evaluation of the remediation alternatives, including their feasibility, cost and risk reduction;
- — Design of the selected remediation option;
- — Implementation of the remediation option;
- — Verification and/or monitoring of the remediation performance.

Remediation measures may be undertaken on a voluntary basis, after weighing the benefits and costs against the risks, to eliminate or reduce the associated liabilities.

If a specific radiological, chemical or physical risk becomes known to the public, this can lead to an expectation that the site be remediated, regardless of whether actual risks or hazards exist. It is generally the case that the greater the perceived risk, the greater is the expectation that a company or government will act to address it.

3.1.1. Evaluating the risks

In assessing radiological or chemical risks, a source–pathway–receptor model is usually used, from which, inter alia, a timeframe for the urgency with which to undertake remedial actions, if any, is derived. Of particular interest is the projected timeframe in which impacts to receptors are anticipated. Where impacts to important receptors are identified as having occurred or are predicted to occur in the near future, the project development process to minimize or prevent these impacts is expedited.

It is important to recognize that, in order for there to be a significant risk at a given site, all three factors — source, pathway and receptors — must be present (Fig. 3).

3.1.2. Typical risk scenarios

There are a number of typical conditions that are likely to prompt early action.

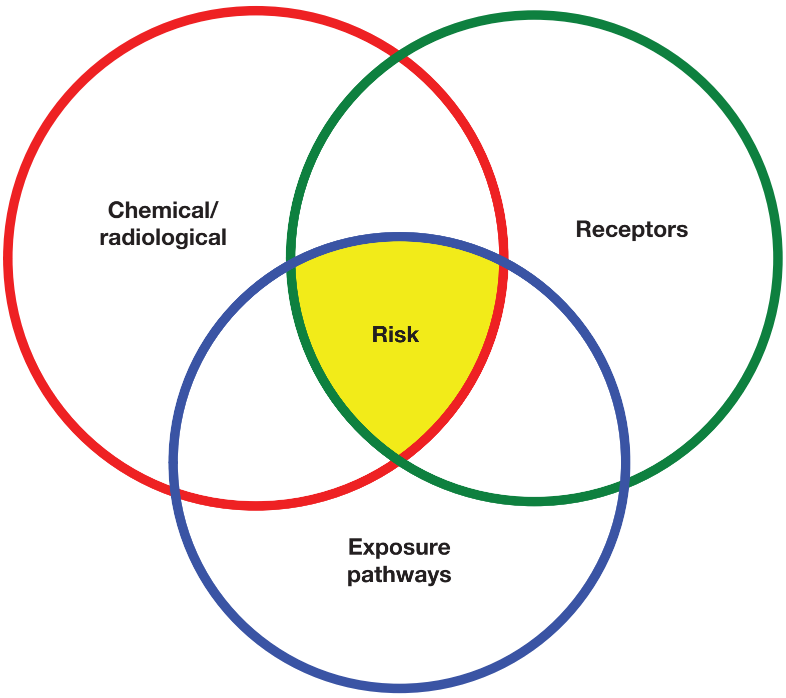

FIG. 3. Three elements of environmental risk.

3.1.2.1. Proximity to densely populated areas

In densely populated areas, the large number of potential human receptors, and the variety and extent of human activities that are difficult to predict and control, may lead to significant exposure pathways. It is likely that where there is a significant population base (e.g. a large city) associated with an elevated level of risk, significant pressure may be placed on local, state and/or federal regulators and politicians to have the remediation carried out in a relatively short timeframe [25].

Certainly, the circumstances contributing to the contamination or hazard have a direct impact on the public's expectations for action. There may be a high degree of complacency regarding contamination resulting over long periods of time, such as during the operation of a mine site over many years or even several generations. Conversely, the perceived need for action is particularly acute in accident scenarios.

Notable examples of where risks were identified adjacent to densely populated areas include:

— Wismut: Königstein, Ronneburg, Helmsdorf (Germany);
— Los Frailas: lead/zinc mine tailings dam failure near Aznalcollar (Spain);
— Andujar uranium mine (Spain): Empresa Nacional de Residuos Radiactivos was the remediation management company for the project;
— French uranium mining sites;
— Rocky Flats (United States of America (USA));
— Tonanwanda: Formerly Utilized Sites Remedial Action Program sites (USA);
— Harwell Southern Storage Area (United Kingdom);
— Sillamae (Estonia);
— Phare (Poland and Hungary Aid for the Reconstruction of the Economy)[1] programme sites.

3.1.2.2. Risk of surface or groundwater contamination

Impacts to water bodies can have a considerable effect on the health and safety of the public and environment, and can place a significant financial burden on those parties tasked with funding remediation. The implications and technical difficulties of remediating surface water and groundwater contaminated with radionuclides can be significant and have been discussed in detail in Refs [9, 17].

3.1.2.3. Risk to ecologically sensitive areas

Ecologically sensitive areas are those in which the ecological balance maintained by the various species is particularly tenuous. In such areas, care must also be exercised to evaluate the expected benefits of carrying out a specific remediation project relative to the collateral damage or impact that the same remediation project could cause. In other words, it would be appropriate to carefully consider whether a remedial activity addressing a relatively low risk would not actually pose a greater threat to the local ecology than simply monitoring the area to ensure that the risks remain at an acceptably low level. The paradigm of 'doing more good than harm' would, therefore, seem to particularly apply to ecologically sensitive areas. Ecological risk due to radiation remains a controversial issue, and one that is being discussed by the scientific community.

3.2. KNOWN IMPACT TO RECEPTORS

When an impact to an important receptor is known to have occurred, measures to mitigate the impact are typically undertaken within a short timeframe; however, this may not always be the case. Remedial actions primarily consist of putting into place mechanisms to remove the contamination source (radiological, chemical) or to eliminate the pathways (through installation of barriers or redirection of the contaminant). In practice, the

[1] The Phare programme of community aid to Central and Eastern European Countries (CEEC) was the main financial instrument of the pre-accession strategy for those CEEC that have applied for membership of the European Union.

various stakeholders within a jurisdiction may differ in their views on the gravity and significance of impacts, and the manner in which these impacts are to be mitigated. This is particularly true in the case of an absence of clear regulatory standards or guidelines on allowable levels of contamination and/or exposure. It may be decided, based on the precautionary principle, to undertake remedial actions in order to limit impacts. In these cases in particular, where there is no clear regulatory guidance, divisions can occur within a community, state or country. One explanation for this is that those persons being impacted expect a higher degree of effort, and by extension financial resources, to be expended to address the impact. Conversely, those not being impacted will tend to see the money being spent on the project as substantially unreasonable.

The impacts on various receptors and environmental compartments are valued differently in different societies. The local population's expectations in this respect need to be taken into consideration when evaluating and deciding on remediation measures.

3.2.1. Impacts to humans

Historically, protection of the public has been the primary issue at contaminated sites. When observable impacts to humans occur, remedial action should be taken to reduce the risk posed to the public. In fact, remediation to reduce the risk to the public is a stipulation in the pertinent legislation of some Member States. Removal of the (human) receptors is considered only a temporary measure [26, 27]. Relocation is very disruptive psychologically, socially and economically, as can be seen in the territories around Chernobyl. When making decisions on what remedial actions should be taken at a site, one also needs to carefully consider potential radiation or chemical exposures to those people working on the remediation activities, as well as other physical hazards that these individuals may encounter. As indicated previously, the benefits of any remedial project should be carefully weighed against the potential risks associated with undertaking the work.

3.2.1.1. Impacts to flora and fauna

Impacts to flora and fauna have historically been viewed as a lower priority when compared with human impacts. However, improved understanding of their role in the overall environment has led to increased attention being paid to them during remediation planning. This is particularly true in areas in which the local population is reliant on regionally available plants and animals for their subsistence. Many Member States now recognize the need for, and value of, the identification of those species that are most important to the survival and cultural needs of the local population. These identified species are often referred to as 'valued ecosystem components'. Determination of which species are most important to the local community needs to be carried out not simply on the basis of scientific knowledge, but also based on the expressed needs of the local community. The issue of bioaccumulation up the food chain has also been identified as an important factor to be considered as part of any monitoring and management strategy and is normally included in radiological impact assessments.

While the problem of radiological and toxic impacts on non-human receptors and ecosystems has generally been recognized and is being discussed by the international community, no agreement has yet been reached on whether and how to evaluate and regulate these impacts. The question one should ask is, Is there solid evidence that radiation at a given site — at least in environmental levels — is harmful to non-human organisms, so that taking it into account would imply a reasonable resource expenditure?

3.3. REGULATORY AND LEGAL DRIVERS

This section provides observations on factors that influence development and implementation of a regulatory framework. Many Member States have a well developed legislative framework that regulates the nuclear fuel cycle. These legislative instruments are intended to prevent undue burdens being placed on future generations by the actions of the present generation. In this regard, and in most instances, the legislation provides criteria for the remediation and release of sites with radiological and chemical contamination. In some cases, however, the criteria are very prescriptive, resulting in the creation of barriers for remediation. It may also be noted that having appropriate legislation in place does not, by itself, prevent environmental impacts. The resources and willingness to implement the actions stipulated in the legislation are indispensable preconditions.

Regulators must evaluate the need for, and appropriate level of, remediation required to address contamination at a contaminated site. This evaluation is typically based on a ‘test of reasonableness’. When judging the need for action, evaluation should be based on a reasoned and scientific assessment. While such an approach would appear to be undertaken easily, it will only be possible if the public perceives that the authorities are taking appropriate precautions to protect their safety and the safety of their environment. For this reason, the role of the stakeholders is particularly relevant. It needs to be recognized that those groups and individuals concerned with a given remediation project should be involved and be given the opportunity to participate in the decision making process. For this involvement to be effective, they should also possess a thorough understanding of the applicable regulations.

In order to understand the impact of regulatory limits and standards on the implementation of remedial actions, it is helpful to analyse the whole process, from problem recognition through to actually addressing the problem.

The first item to consider is how problems are recognized. There may be obvious impacts on humans and/or the environment. In other instances, the impacts may be not so obvious; comparing the state of the environment or human exposure against some reference value (e.g. a ‘standard’) may lead to the conclusion that there is a problem. For instance, environmental concentrations of a radionuclide may exceed a reference value set for the environmental compartment in question, or the annual dose may exceed a certain trigger value.

These reference or target values or standards are set on the basis of what is considered ‘good’ or having ‘no impact’. In radiation protection, this is acknowledged by a distinction being made between a planned situation and the existing situation [28]. If a new activity, a ‘practice’, is introduced, the proponent must demonstrate that exposures and impacts are below certain reference values. Conversely, it is acknowledged that, in some cases, lowering exposures to values as low as stipulated for ‘practices’ may be impractical (e.g. in accident scenarios). However, some recommended values are available, but they are not termed as limits. Some countries have established permissible residual concentration values for certain environmental compartments, e.g. soils [29]. Such values were established on the basis of various assumptions and exposure models. So-called intervention levels were developed for chronic exposures, e.g. to ^{222}Rn in workplaces.

However, the target values stipulated may still be too low to be achieved in circumstances where insufficient funds are available for adequate remediation, or where the relative risks at a site are acceptably low. The consequence, all too often, is that no remediation takes place at all, because the end point required by the regulator cannot be reasonably achieved. In these instances, there is a clear need for all parties involved in determining whether or not to proceed with a remediation project to come to some understanding that it may be in the best interest of all involved to proceed with a limited, or phased, remediation project, rather than abandoning the project altogether.

3.3.1. National rules and regulations

Regulatory requirements tend to be a jurisdiction’s primary driver for remediation projects. However, a variety of factors and considerations drive and shape the remediation project in any case [16]. Although highly diverse in structure and function, legislation, regulations, standards and guidelines have been established by several Member States to help ensure that activities undertaken in support of a remediation project are carried out in a safe and responsible manner. In many Member States, the regulatory authorities will be involved in determining the level of remediation required and/or in approving a specific remediation approach. In most instances, regulatory permits or approvals are required to undertake this work.

In some Member States, legislation tends to be drafted to provide decision makers with the appropriate powers to regulate a particular area of interest or group of activities. The ability to make regulations, to set standards and/or to develop guidelines is generally included in these powers. In some instances, the dominant decision makers may not be regulators. Conversely, they may be politicians or government departments directly or indirectly involved in remediation activities.

The ways in which actions to achieve compliance with legislation are implemented can vary significantly from country to country. In some countries, decisions are made case by case and are based on the discretion of the individual regulators and their advisors. In other countries, subsidiary regulations are developed to set out the details of how specific activities covered by the legislation are to be conducted. Regulations also generally describe the types of information that must be supplied to the regulators in order to receive the requisite permits, approvals or licences to carry out these activities. Some regulations also describe the criteria for compliance with the legislation, such as allowable dose limits, contaminant discharge limits and the reporting requirements for these activities. Many Member States have developed a regulatory framework to address both worker and public safety issues related to radiation and conventional safety. These regulatory instruments set out the various legal requirements that apply in the jurisdiction and may impact the decisions related to the remediation programmes.

Where the responsible party is the State, some jurisdictions have regulatory instruments that clearly indicate that the State is bound by the same requirements as other responsible parties.

Standards are those documents that further detail specific limits and set out operating practices, monitoring and reporting requirements, etc. Guidelines, unlike legislation, regulations and standards, are not strictly legally binding on a party carrying out a specific activity. Guidelines are generally developed, and worded, in a manner that suggests that a particular approach is preferred or recommended by a jurisdiction having authority. Although these guidelines are not legally binding, their development has generally been carried out in a consultative manner and they are expected to be used whenever practicable. It should be noted that failure to adhere to the guidelines might be met with concern by members of the public and by potentially affected stakeholders. For example, if a guideline suggests that a residual ^{226}Ra concentration should be 0.2 Bq/g and the resulting remediation was undertaken to meet only the regulatory limit of 0.5 Bq/g, which is higher than the guideline value, some stakeholders may criticize the remediation as being incomplete, despite the fact that it is compliant with regulations.

It should also be noted that, in some countries, different levels of legislation (e.g. federal, state, provincial, local) may have specific regulatory requirements related to remediation projects that are inconsistent with or contradictory to those at other levels. In instances where various levels of government have inconsistent or contradictory requirements, it is desirable that these governments seek to harmonize their respective regulatory requirements. Confusing and contradictory regulatory requirements pose a significant risk to remediation programmes, as discussed in Section 5.3.

In most instances, a State's regulatory instruments have been drafted with careful consideration of the specific technical, legal, social, political and economic factors in the specific jurisdiction for which they were developed. Adoption of the provisions in other countries requires a careful evaluation of the validity of this context [30].

3.3.2. Environmental legislation

The past few decades of investigation and research have demonstrated that the quality of the environment is inextricably linked to that of human health. For this reason, there has been an increasing focus on developing regulatory instruments that describe a jurisdiction's expectations related to environmental protection [31–34].

As a result of these regulatory instruments, governments are requiring that responsible parties undertake activities to improve the overall quality of the environment. It is in this context that many remediation projects are developed, and, where resources are available, carried out. As in the case of worker and public safety legislation and regulations, environmental legislation and regulations also allow regulators to levy fines against the responsible party and to have the work carried out on behalf of the responsible party. These same instruments may also provide the regulator with the authority to incarcerate the responsible party.

The enforcement of environmental requirements is especially difficult at legacy sites. Various jurisdictions have enacted legislation that allows the government to retroactively assign liability to a company or its successor, even if the activities at a site were undertaken prior to the legislation's coming into force. In cases where a company or its successor can be located, regulators are able to require the company or its successor to remediate the site according to the new regulatory requirements. A continuing activity may be protected by the legal concept that an operator should be able to have trust in the continued validity of the legislative system, and that there is a duty to preserve the status quo. In cases where there is a change in practice or site activity, however, the regulator may introduce regulatory changes.

3.3.3. Legal actions

Where specific laws are in place governing protection of the public or the environment, individuals, organizations, companies or governments may bring a legal action against a party believed to have been responsible for a contamination event. These legal actions may have both a criminal and a civil component. Many Member States have enacted legislation that is based on the 'polluter pays' principle. In the case of an accident scenario, these laws are generally quite effective in ensuring that the responsible party removes the source of contamination and remediates the affected area(s). In the case of legacy sites, these laws may be somewhat less effective, in that the companies (or their successors) and/or individuals responsible for the activities at a legacy site may no longer be viable corporate entities. Where a successor company can be located, it is often difficult, and resource intensive, to prove in court that the corporate linkage is valid from the standpoint of the legal challenge.

It should be noted that some Member States have legislation that allows the government to hold a company responsible for contaminant releases, even if the release occurred prior to the legislation's coming into force [33–35]. These laws were enacted to permit retroactive enforcement regarding releases that occurred in the past, because there were generally very few laws governing environmental impacts during the period in which numerous large scale industrial complexes were operating. As a result, site operators were able to dispose of hazardous wastes in inappropriate ways and locations in most of these Member States. These laws provide those States with the authority needed to address past contamination.

3.3.3.1. Legal challenges in the case of transboundary impacts

Although not common, litigation related to transboundary impacts may occur between countries where there has been a breach of international law. Countries may wish to enter into cooperative agreements rather than pursue a lengthy court challenge.

3.3.3.2. Legal challenges based on 'regulatory failure'

Litigation may also be launched in cases where a government is responsible for ensuring the safety of the environment and the public believes that it has failed in this duty. Such cases represent a recent development. In challenges of this nature, the plaintiff will argue that the regulatory authority/authorities has/have failed to act in a responsible manner in carrying out its/their regulatory mandate with respect to a particular accident or legacy site.

3.3.3.3. Encroachment of contamination onto the property of a third party

Many Member States also have laws that were established to protect innocent third parties from being impacted as a result of the actions or activities of another party. In these instances, the affected party may sue the responsible party for damages resulting from the contamination of his or her property. These types of action are generally civil rather than criminal suits, undertaken by an affected third party. They are distinct from the criminal proceedings that may be undertaken by a government. In many instances, such civil actions follow criminal proceedings.

3.4. STAKEHOLDER EXPECTATIONS AND PRESSURES

Public concerns can be one of the major driving forces behind decisions to remediate and are often independent of the results from any scientific assessments conducted to identify contamination and ensuing risks or hazards at a site. Public concern may be expressed in a number of ways. Individuals may be part of large, well organized and well funded organizations (e.g. certain international non-governmental organizations (NGOs)), or they may be part of a loosely knit group of local individuals who are concerned about the potential impacts from a specific site in their immediate area.

The public is often most concerned in instances in which the contaminated site poses a direct or indirect threat to their lives or property. Proximity to contaminated sites can also lead to depressed property values or difficulties for the owners of adjacent properties when they wish to sell. The public may become concerned if the risks associated with a given site are not openly disclosed. It may be the case that the public's perception of the risk is greater than the actual risk. Regardless of the type of public concern, regulators, operators and politicians are well advised to ensure that the concerns raised are addressed in a manner that is both open and transparent. As with other aspects of daily life, when people feel that they have been dealt with in a fair and open manner, a level of trust is built between the parties. Where that trust is broken, it is extremely difficult to repair. A more detailed discussion of stakeholder involvement can be found in Refs [16, 19].

The extent of stakeholder involvement will also be influenced by the nature of the remediation action. For example, the public's participation in the remediation planning and decisions after an accident will probably differ from what would be deemed 'normal' or acceptable within the context of the remediation objectives. The public is likely to have a more active, and potentially complex, role in cases where the environment was contaminated many decades ago, with insufficient consideration having then been given to impacts of contamination and future remediation requirements. In such cases, public opinion may be divided. The decision maker may face a dilemma: on the one hand, some stakeholders may want to return the site to its original state regardless of radiological protection considerations; on the other hand, some stakeholders may be more concerned with immediately occupying the contaminated lands without any remediation measures. Lack of communication between all the involved parties will tend to increase the costs of remediation of the site(s), which poses a singularly difficult situation for remediation projects being undertaken under constrained resources. Experience has shown that it is imperative that open and honest communication with the public be undertaken in a timely fashion. Where public safety or environmental issues are identified, authorities must be willing to communicate these concerns to the public and must also be willing to demonstrate a commitment to ensuring that these issues are addressed in a timely and responsible manner. In other words, the building, or in certain cases the rebuilding, of trust between the stakeholders is paramount [25–28].

3.4.1. Local residents

Local residents may raise concerns resulting from either real or perceived risks to their safety and/or livelihoods. Where the public perceives authorities to be open and honest about the level of risks, remediation projects tend to receive a higher public approval rating than where the public perceives that the authorities are not telling them the 'whole' story. However, the processes for involving the stakeholders in the decision making process are complex and need to be tailored to the specific sociocultural environment [16, 19].

3.4.2. Special interest groups

Special interest groups, whether they are well organized and funded or not, tend to be highly focused on achieving a specific and often singular goal. These goals can be of a more transcendental nature, or may concern the practical protection of a specific habitat or species. Groups of this nature tend to have a singular purpose — to bring about the cessation of all activities related to the nuclear fuel cycle. In these instances, their ideological views make it difficult, if not impossible, to identify and discuss issues with a view to mediating a compromise.

3.4.3. NGOs

Although not generally directly impacted or affected by a particular radiological liability or legacy, (supraregional) NGOs, are, nevertheless, capable of generating significant public interest and media attention related to a specific site that requires remediation or to multiple sites across a broader geographical area. These organizations tend to be well organized and funded and may be technically able to evaluate the level of risk posed by a site or sites. In some cases, these groups may also be in a position to launch legal challenges to projects that they perceive as being inappropriate.

3.4.4. International and transboundary groups

International and transboundary groups may voice their concern in two distinctly different forms. The first is that of large internationally recognized NGOs. These entities are well organized and funded and many have internationally recognized technical experts that support their cause. The second type of international public concern is that raised by individuals or groups within a country, when it is recognized that potential impacts from another country may impact on their health, safety or livelihoods. As mentioned in Section 3.6, where these concerns can be substantiated, the countries involved may mutually benefit from establishing an agreement to address the identified risk.

Although the above may be true for developed democratic societies in which members of the civil society are fairly organized and will generally vocalize their concerns, in less developed countries there may be a lack of this organized approach to vocalizing public concern about a contaminated site. In these instances, this lack of a public 'voice' may give rise to a situation in which a government feels no pressure to undertake remediation of the site.

3.5. ECONOMIC OR MARKET CONSIDERATIONS

When considering whether or not to undertake a remediation programme, Member States may also want to consider the potential for positive economic opportunities resulting from new development that would be feasible once the legacy site has been successfully remediated.

The economic context of a site can, and will, change over time. The economic value of a site depends on its various properties and any liabilities associated with it. Land may be a valued resource if the site is located near a town or city that requires additional land for development. Clearly, this need for additional land could be a significant driving factor for a proposed remediation project. The actual value of the land will depend on whether or not any land use restrictions will be placed on future developments. For a variety of reasons, a given site may not be able to be remediated for free release, resulting in use restrictions and some sort of stewardship programme to ensure maintenance of institutional controls [19]. However, high pressure for development may not only trigger a remediation programme, but may also define the site end state within the economic boundary conditions. In other words, high pressure for development may result in remediation to free release a site, if technically feasible, to create an economically viable project. Utilizing a partially remediated site for an industrial application may be appropriate, whereas it may not be appropriate to allow residential expansion into this area (Example 1).

EXAMPLE 1. UTILIZING FORMERLY CONTAMINATED MINE LAND FOR DEVELOPMENT IN SOUTH AFRICA

South Africa has a large gold mining industry that has been in existence for more than a century. Gold mines and processing plants are situated over a large area, from the eastern Witwatersrand, Johannesburg and western Witwatersrand areas of the Gauteng Province, to the eastern areas of the North West Province into the southern parts of the Free State Province. Many of these gold mines were established at a time when they were at some distance from residential or other developed areas. Some mines were, however, established within the city limits. Over the past decade, South Africa has been experiencing good economic development, creating a need for land for residential and industrial use. Land belonging to mining companies situated within the developed areas is therefore in high demand. Regulatory standards and criteria have been in place for a number of years and allow for free release of former mining sites after some remediation activities have taken place. Sites that do not conform to criteria for free release for residential use could still conform to the criteria for use as industrial/ commercial sites or other uses. In such instances, approval is provided by the regulator for specific uses.

Land use can be divided into five broad categories according to the potential use, namely agricultural, residential, parkland, commercial and industrial; these in turn can be divided into subcategories with different contamination probability or, conversely, different vulnerability. (As future land use is a significant consideration in planning remediation programmes, additional information on these subcategories is provided in Section 4.)

In Europe, land is highly valued, owing to the relatively high population density. In addition, Europeans tend to value the remaining green spaces that are available in their countries. Therefore, it appears that the current focus when remediating existing mining and industrial facilities is on remediating in a manner consistent with future industrial operations, or, where there are no industrial projects proposed, on returning the land to recreational uses (e.g. parks, spas (Schlema in Germany), historical tourist locations (Seegrotte in Austria), wildlife habitat, golf courses) or agricultural uses [29]. In some Member States, proponents seeking to undertake recovery of secondary minerals at a closed or abandoned mine site may also be required to post a performance bond or other form of financial assurance prior to undertaking the work. In exacting these requirements, several factors are often considered. It may be expedient to carefully weigh the (long term) environmental risks when these mining residues remain in their current state against any risks associated with the recovery operation. In these instances, the responsible authorities may wish to consider whether or not the type of assurance being required is preventing these works from proceeding. As happens with any project, the type and amount of assurance required should be commensurate with the potential risk associated with the proposed activity. When considering whether it is economical to conduct a recovery of other metals or radionuclides by reworking old mining residues, potential operators weigh not only the cost of recovery of these resources but also the tax implications and the cost of obtaining the requisite approvals from the various local, state and federal agencies. Moreover, as mentioned, operators taking over a legacy site must also consider whether or not they may be held liable for the long term management of the site, regardless of whether or not they have improved the chemical, radiological and/or physical stability of the site while they acted as operator.

Some of the benefits of the recovery of resources from old mining residues include, inter alia:

— Removal of a contaminant(s) source term(s);
— An opportunity to change the nature of the residues to a less chemically reactive state;
— An opportunity to construct a more appropriate disposal facility (historical disposal sites typically have few or no engineered controls in place);
— Ongoing monitoring and management (e.g. treatment of contaminated surface water or groundwater bodies, rehabilitation of historically impacted areas) of the facility (in the case of legacy sites, this is of particular interest);
— Reduced long term financial burden on taxpayers (particularly for legacy sites where no owner can be found to be held liable for remediation, monitoring and stewardship costs);
— Reduced need to start resource development in previously undisturbed areas;
— Utilization and possible improvement of existing infrastructure (roads, power, water, etc.);
— Additional revenue to the government through the payment of royalties for the recovered resources;
— Additional jobs and improvements in the local economy through the influx of additional monies to support the activities at the site and through the goods and services required by the workers and their families while remediation activities are undertaken at a site.

The public and NGOs commonly challenge the development of new mine and mill sites, because of the unaddressed legacy of unremediated sites. Where countries actively carry out remediation programmes, it is anticipated that the public and NGOs will tend to be less resistant to new project development. That is, investment in remediation programmes can actually engender support for future economic development and profitability, by enabling new site development.

3.6. POLITICAL INFLUENCES, INCLUDING INTERNATIONAL AGREEMENTS

The international community, through IAEA Member States, has recognized a number of environmental issues that represent a common concern or interest. In order for Member States to address these issues in a thoughtful and consistent manner, conventions and agreements can be put in place. Conventions and agreements can be adopted by the Member States to provide an overarching framework by which to address issues of common interest and/or concern.

The issues of transboundary impacts on neighbouring countries that have occurred as a result of historical operations have led to the necessity for countries to enter into arrangements to address aspects of off-site contaminant migration. These arrangements, often in the form of formal multiparty agreements, are developed to: (i) identify the source of contamination; (ii) remove or reduce the source term; (iii) remove or reduce residual off-site contamination; and (iv) enter into a formal arrangement around funding for the various aspects of the remediation project.

Although not responsible for the activities that have contributed to release of contaminant(s), various countries are, or have been, faced with the difficult decision of either participating financially in site remediation projects in a neighbouring country or continuing to be impacted by the ongoing contaminant discharge and subsequent pollutant transport. In these instances, public pressure may have been brought to bear on local, state and/or federal officials by those individuals or groups that may be potentially impacted by the contamination. Conversely, those in the country that are more interested in the financial implications of the project, and who are not directly impacted by the contamination, are more likely to put pressure on these same politicians to resist signing such a cooperative agreement. Some Member States have put in place legislation that relates to protection of the environment from pollution from one country passing into another [36]. Among the benefits of this type of legislation is that the country responsible for the pollution seeks out internal solutions to the problems, puts mechanisms in place to address the source of pollution, and in certain instances [36] advises the potentially impacted country and may further involve it by seeking input into any proposed solutions.

It is clear that many Member States have placed great importance on the development and implementation of numerous cooperative arrangements to prevent or limit the potential impacts to a neighbouring country. Through these cooperative arrangements, the Member States have taken significant strides toward improving the health of the environment and, by extension, that of the individuals living in these areas. As an added benefit, these arrangements have also acted as mechanisms by which trust can be built between the peoples of neighbouring countries.

3.7. WEIGHING THE DRIVERS

It is important for decision makers, NGOs and the public to recognize that, while a certain type of remedial action is possible, it may not always be necessary or even desirable to undertake that specific action. For example, a remediation solution may exist that is very costly and that can be utilized to rapidly remediate a site, while a lower cost solution may also be available that addresses the same risks at a site, but that takes somewhat longer to implement. This low cost solution would allow consideration of the financial limitations of a country or company, while achieving the desired outcome, albeit that this approach requires a certain amount of patience and understanding on the part of the stakeholders.

It is equally important to recognize that a remediation to residual concentrations as low as technically possible is not always warranted, or desirable, when considering other factors. These extenuating considerations may include:

— Source–pathway–receptor timeframes and anticipated impacts;
— Cost–benefit analysis;
— Availability of technology;
— Human resource skills;
— Proposed end use of the lands to be remediated (i.e. industrial, residential, agricultural, etc.);
— Future advances in remediation techniques;
— Natural background levels versus technologically disturbed areas.

In weighing the drivers and planning the remediation programme, decision makers should consider the following:

— All risks (known and suspected) associated with a remediation project;
— Legal requirements;
— Available resources, including funding;
— Availability of expertise and technology;
— Economic considerations, including plans for future use;
— Stakeholder expectations;
— Political circumstances;
— Possible consequences of the proposed remediation action.

While weighing the pros and cons is often done in an informal way, a more formal decision making procedure is recommended, to make the process more reasoned and transparent [16].

When evaluating remediation strategies, consideration should be given to the potential negative impacts of carrying out a proposed remedial action. In other words, the philosophy of ‘do no harm’ should be applied to the decision making process, to ensure that active remediation does not cause collateral damage to other environmental compartments or pose new risks to the worker or public. A formal alternative evaluation process is recommended, in which the cost, benefit and impact of the proposed remedial action approach (or approaches) are compared with those of a no action alternative, or an alternative other than what the regulations would require. As a result of such evaluations, the potential adverse impacts of the remediation action can be effectively identified and evaluated.

For instance, the relocation of tailings from a local water body to a purpose built impoundment area may result in remobilization of heavy metals or radionuclides during the removal process. Proper controls may be necessary to address the potential impacts, and these could be extensive (e.g. installation of a coffer dam outside the tailings area, draining and treatment of the water removed from the impacted area, removal of the contaminated sediments and re-establishment of the area with clean fill material, establishment of fish habitat areas, eventual removal of the coffer dam with natural infill of water into the area, re-establishment of aquatic vegetation, and reintroduction of benthic macro-invertebrates and fish, as appropriate). The alternative to putting these controls into place is leaving the tailings within the water body, providing an appropriate cover material and then re-establishing the native aquatic flora and fauna.

Remediation may also mobilize other contaminants. For instance, when it is determined that a site has low levels of heavy metals and/or radionuclides leaching from a facility, it seems appropriate to consider the possible negative impacts of trying to further reduce the source term, treating the leachate, etc. It may, in fact, be less harmful, when all factors are considered, to allow this low level of leachate to continue rather than to try and further remediate the area.

Obviously, the two examples described here assume that the risk assessment conducted to allow these options to be implemented has indicated that there is no significant risk to humans in deferring or limiting remediation activities (either because of the remote location of the site or because the anticipated exposures to a local population are acceptably low). These examples simply illustrate the balance between remediation and leaving the site as it is, when the risks can be considered acceptable.

Example 2 shows how an impact evaluation identified potential worker risks, which were avoided through negotiated regulatory exemptions.

EXAMPLE 2. WEIGHING THE RISKS RESULTING IN NOT UNDERTAKING REMEDIAL ACTIONS

In Slovenia, the radiation levels of a mine waste rock pile (low grade ore) resulting from digging exploration tunnels at the Žirovski Vrh mine were investigated and found to be above the regulatory targets. In evaluating remediation options, the mine operator concluded that there would be a significant workplace risk to personnel, owing to extremely steep side slopes, if they were to remediate the area. Discussions between the management of the mine and the regulator reached an understanding that avoiding the real workplace risk to personnel was more important than addressing the (relatively low) risk of potential future radiation exposure; thus, the mine operator was authorized by the inspectorate to leave the material in place.

It is also reasonable to consider the timing of the implementation of remediation activities in the light of available technologies and the likelihood of their effectiveness. Technological advancements continue to be made, and these advancements have led to increasingly effective remediation strategies. It is therefore reasonable to assume that future generations will continue to improve upon current strategies and may, in fact, be in an even better position than the present generation to address some of the existing legacy sites. It is therefore important to ensure that the methodologies used to remediate sites today do not preclude further improvements in the environmental performance of a remediated site by future generations. It is also important to remember that many legacy sites may still require an appropriate monitoring and maintenance programme, to verify that the site is behaving as predicted [14] and to reassure the public.

In summary, the need for remediating a contaminated site may be recognized, and this may be endorsed by both the regulatory authority and the operator. However, the lack of resources may be a constraint. In planning a remediation programme under constrained resources, the drivers for action should be weighed. In addition, even when resources are available, the benefits of remediating the site in the near term should be weighed against the benefits of other applications of the available funding.

3.8. OWNERSHIP ISSUES

Operational management objectives, strategies and practices depend on the type of ownership and the sociopolitical context. Certain owners may be reluctant to undertake a remediation project because of the associated cost. A change in ownership and associated site use may actually bring about remediation.

Site ownership depends on the type of operation and the sociopolitical context in the Member State concerned. Uranium mining and milling sites, for example, have frequently been State owned. In some cases, the government has retained ownership to date, while in other cases the sites have been privatized, following the general trend of the time. Some operations have been transformed into 'commercial' companies, with government remaining the main or only shareholder, sometimes also explicitly changing the objectives, e.g. from uranium 'production' to 'remediation' (notably Wismut GmbH in Germany). In the Central and Eastern European countries (CEEC) and the countries of the Former Soviet Union (FSU), the implementation of remediation projects has frequently been hampered or delayed because of unresolved ownership issues, or the reluctance of new owners to assume responsibility for legacies. In the case of the uranium mining legacies of the former German Democratic Republic, ownership and responsibilities have been laid down in an annex to the German unification treaty, thus clearing the way for action. There, it is also made clear that the goal of the newly formed company is not to "make money", or to mine uranium, but to remediate the mining legacies.

4. REMEDIATION ACTION APPROACHES

Many Member States are faced with the need to undertake remediation activities but have very limited resources to support them. Once a decision has been made that some degree of remediation is required, it is critical that the activity be planned in a manner that optimizes these constrained resources.

Any remediation project follows a certain logical execution pathway. Although some of the aspects may be dealt with at slightly different stages of project execution, the main steps or phases in a remediation project are presented in Table 2.

Although the execution process as presented in Table 2 is the same for most remediation projects, the challenge for the remediation project manager (RPM) is to complete the remediation project on time, and in a cost effective and efficient manner. The objective of this section is to present those 'best practices' and project approaches that should be employed to plan and undertake a remediation project in the most cost effective, timely and effective manner. An evaluation of successful, completed projects revealed that most of these practices were implemented and resulted in an optimized use of limited resources. It is in this context that these strategic approaches are identified and summarized. A more case specific discussion is provided in Section 5, where proposed solutions are offered for the common obstacles that remediation programmes encounter.

4.1. ANALYSING PROJECT CONSTRAINTS

Although the RPM faces numerous project constraints that can jeopardize timely project completion, such constraints can be minimized through effective planning. The basic resource constraints that remediation programmes face involve funding, time/schedule, technology availability, available expertise, regulatory matters, off-site disposal and stakeholder acceptance. The issues an RPM generally faces that can affect project execution and costs are described in the rest of this section. By recognizing potential constraints, the RPM can develop the most effective remediation plan and avoid many of the typical obstacles and barriers.

4.2. EARLY DEFINITION OF SITE ASSESSMENT REQUIREMENTS

Given the limited progress made in remediation activities, despite the degree of site characterization completed during the past two decades, it is reasonable to ask whether the site assessment activities have been, to some degree, too protracted and unproductive. It appears there may be too much focus on sampling in the abstract or without direct consideration of the needed action. The question then is how to move away from multistage

TABLE 2. PHASES OF A REMEDIATION PROJECT

Phase	Main activities	Subactivities
Site characterization	Site identification	
	Preliminary site characterization	
	Problem definition — prioritization: urgent action required or not?	Urgent initial action required — perform remedial actions No urgent action required — perform detailed characterization
	Detailed site characterization	
	Risk analysis	Identify pathways Quantify contaminants Assess risk
Selection of remediation criteria	Decision based on drivers for remediation (goals) as discussed in Section 3	
Identification of remediation options and their optimization	Identify possible options Study of options and selection of preferred option Optimization of selected option	Technologies and equipment Cost–benefit analysis Waste management
Development and approval of remediation plan	Environmental impact assessment Project plan development Regulatory approvals Obtain funding	Radiation protection, quality assurance, monitoring and surveillance, organizational structures, emergency plans, project scheduling, etc. All applicable regulators
Implementation of remediation project	Site establishment Project execution in accordance with project schedule	Personnel appointment Appointment of contractors and subcontractors Plant and equipment hire or procurement Training
Project completion and post-remediation management	Final site characterization Transfer of site (liability) Long term stewardship	Unrestricted or restricted release Long term monitoring plan

investigations. The fact remains that the complexity of contaminant distribution and geological heterogeneity require a large number of costly samples to reduce uncertainty to acceptable levels. However, recent advances in analytical methods, sample collection techniques and geologic definition now offer the opportunity to dramatically improve the effectiveness of investigation. However, improvements in technology alone are not sufficient; they should be combined with changes in approach. Changes in approach include the following:

— Better initial determination of investigation objectives;
— Better use of conceptual site models during planning and project decision making;
— Real time data acquisition management and analysis;
— Use of appropriate techniques to evaluate data uncertainty.

All of these considerations revolve around one central concept — understanding and managing uncertainty. Environmental investigations are truly multidisciplinary endeavours, and this creates a management challenge. The project team should avoid a loss of focus on the specific investigation objectives, while integrating different technical viewpoints. This goal is accomplished by achieving consensus on the investigation objectives before beginning the development of planning documents that support fieldwork. This vital step of systematic planning is central to a successful investigation.

4.3. ENGAGING ALL INVOLVED STAKEHOLDERS

It is critical that the RPM identifies all interested and affected stakeholders that should be involved in the early stages of planning and that must agree with the programme objectives. Early agreement among the project team, regulators and stakeholders on acceptable residual concentrations and remediation end points is critical to the success of the remediation project and can avoid unanticipated delays resulting from late challenges. The stakeholders include not just the public and/or NGOs calling for remediation activities, but also those parties that may be affected by the action, or ultimately involved in future site use and liabilities.

The amount of time required to gain regulatory approval and public acceptance may be largely out of the control of RPMs. There are, however, strategies to improve the communication between stakeholders, as discussed in detail in other IAEA publications [16, 19]. The key issue is building trust and accommodating the various stakeholder requirements, even though the technical experts might consider them unnecessary, and providing assurance that the chosen solution will work. Experience shows that this can appreciably facilitate project execution within the foreseen schedule.

4.4. TRANSPARENCY, ACCOUNTABILITY AND TRUST

It is understandable that the public and stakeholders are often sceptical of certain remediation projects that have been undertaken in the past. Often, little stakeholder consultation was conducted prior to initiating the remediation project. This has led to their distrust in those involved in the project, the regulatory authorities and the project outcomes.

It is now well understood that building trust and giving stakeholders the opportunity to become actively engaged in all aspects of project planning can be vital elements to ensure a project's success. The methods by which this can be achieved depend strongly on the sociocultural context. In certain societies and cultures, it may be difficult, or impossible, to engage stakeholders actively in the process at all, or over extended periods of time [16, 19].

Trust can be characterized as the willingness of a person, group or community to make themselves vulnerable in the expectation (or hope) of a benefit coming from association with others that would not otherwise be forthcoming. The conditions of trust in government, as in science and technology advances more generally, all relate to hopes for benefits, on the one hand, and, on the other hand, to confidence in the capacity and will of society's leaders and innovators, and other potential partners, to ensure the sharing of those benefits. A successful remediation project will arise from effective dialogue leading to confidence in the prospects of a worthwhile common future. Example 3 illustrates this issue.

EXAMPLE 3. STAKEHOLDER DIALOGUE FACILITATING PROJECT EXECUTION

Communication between the management of the Žirovski Vrh mine in Slovenia and the local communities, through the Village Representative Council, has continued to improve over recent years. This improved communication has led to community members feeling free to express their concerns and wishes to mine management, and these concerns and wishes have been, for the most part, accepted by the management of the mine, with appropriate changes being made to address them. This has resulted in an improved level of acceptance by the local communities and has fostered a more cooperative environment in which to discuss issues.

Remediation decisions involve complex judgements about how society will live with or cope with inconveniences and risks that stem from the past. Thus, decisions are often influenced by complex, diverging societal interests and involve negotiations on interests, costs and benefits. This is particularly true for those cases where the funding is derived from public sources. Public benefits derived from investment in health care, education, infrastructure improvements, etc., have to be weighed against the health and environmental benefits to be derived by investment in the remediation project.

In some cases of major misfortunes or accidents, the people most directly concerned, and their descendants, will live with memories, scars and the pain of things lost, and must confront the uncertainties of building a new life. Public policy in such situations must contribute to repairing, revitalizing and rebuilding communities. What are the human factors that permit people, in the face of economic loss, environmental adversity, health damage or other misfortune, to pick up the pieces and again become engaged in society? These challenges of partnership building and rebuilding are important.

Radiology science and engineering address the ways and means of controlling the exposure of present and future generations to radiation, relative to what is considered safe or otherwise satisfactory. Technical expertise (drawing on various aspects of physics, chemistry, biology, epidemiology, etc.) plays a crucial role in advising on what should be considered as adequate safety and protection and on the effectiveness of different engineering and institutional strategies for the present and possible future levels of exposure associated with a site. However, technical expertise on its own cannot answer the societal question as to what ‘should’ be done.

As is the case with most socially mediated risks, the significance — and hence the acceptability or lack of acceptability — to an individual, to members of a community and to a society, of exposure (or a danger of exposure) to a dose depends on how, by whom and why the dose has been produced. To assess to what extent, or on what basis, the members of a society will judge a given strategy for management of high level, long lived radioactive residues acceptable (or not), it is necessary to consider the meanings and relationships (in social, economic, cultural and symbolic terms) that alternative remediation and stewardship strategies might establish between those involved in the site stewardship process, including individuals, classes, interest groups, succeeding generations and whole countries.

Remediation managers are encouraged to ensure that, during the course of the remediation work, qualified and competent individuals are tasked with executing the project plans. In certain instances, remediation managers may be concerned with reducing the costs (by reducing the number of staff at the site) of the project, without considering the detrimental effect that this may have on the quality of the work remaining to be completed. Demonstrating to the stakeholders that the project is being managed and carried out according to the plans and specifications, by qualified and competent people, will help to ensure acceptance of the project outcomes.

It is important for operators of facilities to carefully consider the manner in which they communicate these risks to the public and, in particular, to those living or working in the immediate area of the facility. It should also be noted that, in many cases, it will be necessary to weigh social priorities, in order to achieve the highest benefit for the community. As a consequence of this weighing, remedial actions may be given a lower priority [16].

A fundamental step in ensuring accountability and transparency is to provide access to relevant information. Such information may include [19], for instance:

- (Independent) third party project assessment reports;
- Third party audit reports;
- Project status reports;

— Project monitoring reports;
— Copies of environmental assessment and/or regulatory approvals, licences or permits.

Of the items listed above, probably the most important are the independent third party reports regarding the accounting practices and the effectiveness of the remediation project. The services provided by these third parties in reviewing the remediation plan, and in providing ongoing review and reporting of progress and financial expenditures, are important not only to any parties providing financial support for a project, but also to all other stakeholders who are seeking ways to independently verify the results presented by the company or government.

Securing the services of a third party to review and report on progress to the public is also something that a Member State may wish to consider when undertaking work at a legacy site. The reason for this is that, in those instances in which only (or substantively so) government employees are involved in the planning, execution and regulation of a remediation project, stakeholders may perceive the project as not having an appropriate level of checks and balances. In other words, it may be perceived by stakeholders that the 'fox is looking after the hen house'. It has become the practice in many countries that when large public expenditures are undertaken, independent reviewers are appointed (Example 4).

EXAMPLE 4. REVIEW ARRANGEMENTS FOR MONITORING THE PROGRESS OF THE URANIUM MINE REMEDIATION IN SLOVENIA [37]

The Slovenian government raised a low interest loan from the European Investment Bank (EIB) for undertaking the remediation at the Žirovski Vrh uranium mine. The EIB requested that a European Union consulting company supervise and monitor the technical, economic and safety aspects of the project, to ensure that the funds were used for the intended purpose. During biannual meetings with the Žirovski Vrh mine management, the project monitoring team provides the necessary data and prepares annual reports to the EIB. The consulting firm also provides feedback to the mine management on how to improve the project effectiveness.

One originally unintended benefit of the involvement of the consultants is that the Slovenian Government is able to demonstrate to the Slovenian public that an independent third party has reviewed the work being carried out, as to its effectiveness and appropriateness, and is endorsing this work. As a result, public support for the project has been maintained.

Another way that project accountability and transparency can be maintained is for the company to provide access to information on the project through public meetings, a dedicated web site, newsletters or bulletins, and the media (newspaper, television, radio).

4.5. EARLY IDENTIFICATION OF FUTURE USES OF A SITE

The public's expectations regarding future use of a site impact directly on their degree of interest and involvement in the remediation project. A jurisdiction's regulatory requirements for remediation should address and support the specific land use planned, both to ensure that the remedy is protective of the public and environment, and to avoid establishment of overly conservative cleanup objectives.

In instances where a free release is not possible, Member States need to ensure that appropriate land use restrictions are placed on the property so that inappropriate uses of the land do not occur. It is further suggested that a database be developed identifying the degree to which remediation has been completed and any ongoing monitoring that is being undertaken, as well as providing a description of any restrictions on land use. This approach is consistent with that outlined in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Joint Convention) [38]. Member States may also find Ref. [19] a useful resource in developing a long term stewardship programme. An example of legislation developed based on the tenets set out in the Joint Convention [38] is The Reclaimed Industrial Sites Act [39] from Saskatchewan (Canada).

4.6. THE MONITORED NATURAL ATTENUATION STRATEGY

Monitored natural attenuation (MNA) becomes an important tool when looking into approaches such as risk based remediation end points and staged remediation.

When evaluating the MNA option, it is important to ensure that the rationale for accepting this option is clearly justifiable. The use of MNA as a remedial strategy is not equivalent to ‘no action’, nor is it a ‘walk-away’ option, as it might be seen by some NGOs and other stakeholders; monitoring implies a degree of institutional control. It is therefore incumbent upon the operator or the government to be able to clearly demonstrate why the decision to accept this option has been made. Relying on natural processes does not abrogate responsibility for controlling the source of the contamination, preventing exposures or, ultimately, restoring the site to appropriate beneficial use if this is a requirement of the remediation. A comprehensive characterization programme will invariably be required, in order to develop an understanding of the attenuation processes operating at the site and their sustainability. Regulators are necessarily cautious about approving the application of new technologies or procedures, particularly where the approach is regarded as ‘unproven’. MNA implies a long term commitment to monitoring and the maintenance of institutional controls. There are, however, sites, contaminants and pollution situations where MNA will not be applicable. Physical, chemical, hydrogeological and biological conditions may not allow attenuation to proceed at a sufficient rate to protect human and environmental receptors. Restrictions on land use, and the vulnerability of key receptors, also have to be taken into account. Other potential disadvantages of MNA include longer time frames to achieve remediation objectives when compared with active measures, and the potential for continued contaminant migration and/or cross-media transfer of contaminants. Hydrologic and geochemical conditions may change over time and could result in renewed mobility of previously stabilized contaminants. Should an MNA solution be the preferred option, Member States are encouraged to require that the status of the site be maintained in a registry, to ensure that the status of the site, including the monitoring schedule, is available, and to further ensure that the site is not simply forgotten or ignored in the long term. As mentioned, the IAEA has set out the requirements for maintaining this information, while, strictly speaking, it is not a ‘technology’, but rather a strategy.

4.7. KNOWLEDGE MANAGEMENT AND RETENTION

While the issue of knowledge retention and information transfer is often neglected, it has become increasingly clear to those tasked with gathering information about a site that has not had adequate information retained that remediation projects are difficult, and generally more expensive to develop and implement. The reason for this is that it is critical to understand the issues, conditions and risks at a site prior to developing an appropriate remediation plan. Member States and companies are, therefore, encouraged to support the development of mechanisms by which information about a site is carefully obtained, documented and made available for future remediation managers. In this regard, it is also recommended that this information be shared with other Member States, in order that the experiences, difficulties encountered and solutions developed are made available to others that may have similar situations in their countries. An added advantage of sharing this information with the international community is that it will remain available to a wider audience for a longer period of time than might otherwise be possible if it is retained only within the company’s files. In fact, there are numerous examples of situations in which valuable records have been destroyed when a company has ceased operations.

One novel approach to obtaining and retaining a knowledge base at the local, regional or national level is through establishment of a dedicated liabilities management entity. This entity would be developed either through partnership with existing technical and financial support, or through the development of a company ‘from the ground up’. In the case of a newly formed company, much effort would need to be expended to develop the infrastructure and the degree of expertise required to be a reputable entity to undertake remediation projects, and to secure the necessary projects to maintain the viability of the company. It is easy to see that there may be a significant benefit in two or more partners with complementary skill sets, assets (i.e. infrastructure and corporate history), clients, proven track record, etc., joining together to undertake remediation projects. These partnerships may stand a better chance of early success when compared with the ‘ground up’ scenario.

In cases where a government is responsible for remediation of a number of sites in its jurisdiction, a liabilities management company may be initiated to help not only to retain knowledge within the government, but also to generate funds that may be used to offset the overall costs associated with undertaking the remediation projects. This experience, expertise and infrastructure may be developed over time through the successful undertaking of projects in their own jurisdiction, and, in this way, remediation managers from outside the jurisdiction may be able to evaluate the effectiveness of the remediation projects undertaken by a liabilities management company and determine whether the approaches suggested by the company would be appropriate for their remediation project(s). As mentioned above, any monies gained from the company undertaking remediation projects outside of their jurisdiction could be used by the government to either offset previously incurred costs or initiate future projects. One significant drawback to this approach is that a 'ground up' liabilities management entity may never reach the required level of credibility, or it may be prohibitively costly for it to do so.

When establishing a dedicated liabilities management company, consideration should be given to the utilization of people, equipment and supplies from the communities located near the mine sites being remediated. In this way, the company, its activities and the outcomes of the remediation project may enjoy a greater degree of acceptance than would be the case for a company that simply brings in all of the people, equipment and supplies required to complete the work.

The degree to which this approach may be practical and/or profitable will depend on a number of factors, including:

- The number and types of projects in a given jurisdiction;
- The anticipated timing of project implementation;
- The availability of financial resources;
- Government (local, regional and national) support;
- Technical capacity;
- Infrastructure;
- Public acceptance;
- The success of remediation projects undertaken.

4.8. FORMAL DECISION MAKING PROCESSES

There will typically be two concurrent and interwoven levels of decision making: one is concerned with justification of the remediation action, based mainly on radiological and other risk or impact criteria, and the other concerns the development and implementation of a remediation strategy that is satisfactory overall in the wider social and institutional context. To achieve an integrated remediation strategy, an iterative approach between these two levels of decision making processes is often required. In particular, in order to ensure that local concerns and wider aspects of social demand are addressed, it is important that all relevant stakeholders are engaged or represented in the decision making process. Principle 10 of the Rio 1992 UNCED (United Nations Conference on Environment and Development) Declaration affirms that "environmental issues are best handled with the participation of all concerned citizens, at the relevant level". This presumes that motivation comes with active participation. But participation in its turn requires knowledge, understanding and acceptance of the problems to be addressed.

Efficient application of the limited resources that may be available for a remediation project requires efficient decision making strategies and tools. This is where formal decision aiding tools can be useful, for coming to grips with uncertainties and conflicts inherent in the decision making process, to allow those engaged in the evaluation of options to organize their information and to effectively communicate these options to decision makers and the interested public. To meet these objectives, a formalized decision making technique must:

- Be consistent with the rules of logic;
- Be transparent;

- Take account of the views of all stakeholders;
- Take account of all factors affecting the decision making process;
- Give balanced consideration to possible options for action;
- Provide unambiguous advice.

When these conditions are met, the decision aiding tools clarify the evaluation criteria for a decision, and are important components in the communication between decision makers and stakeholders. For example, it is possible to see how different sorts of information and judgements are used in the analysis, including gaps and uncertainties in the underlying data, and which factors are critical for the choice of actions being proposed. This aids in the understanding of complex issues and their interactions, permitting a more rounded appreciation of 'trade offs' being made or proposed by decision makers, and in the selection of an optimum solution.

Formal tools are not an end in themselves. The methods and degrees of complexity of formalized decision making processes must be adapted to the problem and the resources in hand. Among other things, the cost of implementing decision making tools usually should not exceed a small fraction of the total project costs, and their use should not result in undue delay of the actual action. Careful balancing of costs and benefits is required, to avoid a formalized decision making process becoming counterproductive.

The objective of applying formal decision making procedures is to satisfy or optimize selected criteria within a given reference framework. This reference framework, however, may be limited and controlled by factors external to technological aspects, or indeed separate from the problem at hand. Such limitations on the formal optimization process may originate from many different sources, e.g. fundamental radiation protection criteria, protection of certain habitats or species, and political or social preferences more generally. Within these limitations, evaluation criteria include, inter alia, minimization of the gross amount of resources to be expended, making resource use more uniform over time, minimization of radiation exposure to selected target groups, minimization of the overall environmental impact, minimization of the wastes generated and, perhaps, improvement of employment in the region.

The level of sophistication in the formal decision making methods will depend on the capacities available in the particular Member State. It is particularly important to remember that the expenditure of some capacity building in this area may result in an overall benefit that may also have 'spin off' benefits for other projects. Although it may involve certain modelling tools, the primary focus of formal decision making is on creating a higher degree of transparency of the process and thus increasing the acceptance of the decisions made.

4.9. IDENTIFICATION OF A REGULATORY APPROACH

While some jurisdictions have defined and detailed regulations regarding remediation requirements, other regulatory systems provide greater flexibility with respect to the type of remediation methods that can be applied, with an emphasis placed on the expected performance of the proposed technology. The two types of regulatory system are often referred to as prescriptive and performance driven, respectively. It has been the case over the last decade, and still continues to be so, that some Member States must develop a regulatory framework while addressing actual contamination problems. Much can be learned from countries whose regulatory frameworks are in more advanced stages of development. The basic conceptual framework for prescriptive release criteria and site end point was developed in the late 1960s and 1970s, based on the experience, modelling tools and analytical techniques available at that time. This history, though, can also hamper programmes planned in the current day. Member States with fewer of these legislative legacies can take a more open approach with the benefit of today's technical advances. Tables 3 and 4 outline the advantages and disadvantages of prescriptive and performance based regulatory systems, respectively.

In reviewing projects performed within prescriptive regulatory regimes, a tendency toward unrealistic demands on engineering features (properties of liners, capping, etc.) has been observed, either due to lack of experience or during times of high availability of resources. In reality, neither the necessary know-how nor the required resources have been available, and thus projects have not been executed.

TABLE 3. ADVANTAGES AND DISADVANTAGES OF A PRESCRIPTIVE REGULATORY SYSTEM

Advantages	Disadvantages
• Rules are clearly set out in legislation/regulation. • Operator requirements for internal inspections, audits and monitoring are clearly described in legislation, regulations, standards and guidelines. • Regulatory inspectors have a clear set of rules by which to evaluate an operator's compliance. • Progressive enforcement rules are clearly defined. • The system generally has a formal mechanism for appeal.	• A significant level of operator effort is required to understand requirements. • A significant level of operator effort and funds is required to satisfy requirements. • It often applies 'one rule fits all' criteria that may not be appropriate for all operations. • There is limited flexibility for operators to suggest alternatives to meeting the intent of a legislated requirement. • Regulatory inspectors have limited flexibility when evaluating operator compliance, which can lead to a frustrating and adversarial interaction between the operator and the regulator. • Progressive enforcement escalates quickly and may not allow adequate time for an operator to come into compliance. • Because of the clearly defined rules, appeals are generally not successful.

TABLE 4. ADVANTAGES AND DISADVANTAGES OF A PERFORMANCE BASED REGULATORY SYSTEM

Advantages	Disadvantages
• Rules set out in legislation/regulation are generally less detailed than in a prescriptive system. • Operator requirements for internal inspections, audits, monitoring, etc., can be developed in operation specific licences (permits). • Regulatory inspectors have significant flexibility by which to evaluate an operator's compliance. • There is increased flexibility for operators to suggest alternatives to meeting the intent of a requirement. • Progressive enforcement escalates slowly, which generally allows adequate time for an operator to come into compliance. • There is generally a less formal mechanism for appeal.	• The system requires more understanding on the part of the operator to be able to interpret the intent of the rules. • It may require more effort on the part of the operator to develop the operation specific licences (permits). • Regulatory inspectors may have limited internal guidance by which to ensure consistency of regulatory oversight. • Operators who have multiple facilities may encounter significant differences in how inspectors evaluate compliance. • Progressive enforcement rules are less clearly defined. • Because the rules are often less clearly defined, appeals may be successful where an operator can show that their efforts meet the 'intent' of the rules.

4.9.1. Risk based end state planning

In response to financial resources for remediation becoming increasingly scarce in many Member States, a slow change in the regulatory approaches has also been observed — a move away from a prescriptive to a more performance driven approach. This change is also supported by recent insights into the behaviour of contaminated systems. This improved understanding of the behaviour of contaminated systems leads to more confidence in the performance of a given remediation solution, which in turn allows for a possible reduction in safety margins.

A good understanding of the key processes and reliable predictions are of ultimate importance for decision making. It has to be acknowledged, however, that in most cases the required data are not available or are too expensive to gather. Hence, decisions are almost always made using incomplete information. It is the experts' decision as to what comprises a sufficient dataset, but this will inevitably be constrained by budgetary realities. Care has to be taken not to reduce the data acquisition to below meaningful levels. This may lead to savings in the short term, but, in the long term, expenditures will certainly be higher as a result of necessary emergency measures.

Nevertheless, improved understanding of the behaviour of natural systems and the resulting improvements in predictive models allow better estimation of anticipated risks. In turn, this allows the opportunity to focus remediation decisions on the minimization of identified risks. Thus, individual remediation actions at a given site can be prioritized and sequenced, or a prioritized list of sites within a Member State that need attention can be developed. Cataloguing and documentation of risks among a number of given sites within a single jurisdiction has been undertaken by a number of Member States. Such an approach ensures that sites are only remediated to an end point that is compatible with preset (radiation and other) risk criteria, thus avoiding wasting resources on unnecessary risk reductions.

Determining risk based end points requires some sophistication in the assessment tools and methods. These modelling tools are generally costly and may not be available immediately in any given Member State. Also, predictive models have to be supported by reliable site specific data, which are also costly to gather. Actual remediation measures typically also require a substantial expenditure of (financial) resources. A cost–benefit analysis would help in deciding on the most appropriate approach. It is likely that the approach using risk based end points becomes more efficient with increasing problem size.

The disadvantage of risk based end points is that it is more difficult to demonstrate compliance to the regulator. Regulators may also be reluctant to accept such an approach because the review procedure is more involved and requires active decision making. On the other hand, reviewing the compliance with a prescriptive regulatory system requires little intellectual effort and no personal responsibility in decision making.

When public money is spent on remediation projects, it would be appropriate to look into the amount of risk reduction achieved per unit of money spent, and this could be done across the country. It may be more beneficial to undertake some remediation at more than one site, rather than to spend all of the money on one site with a view to reducing the risk below a certain level. For example, it may be more appropriate to remove the gross source of contamination at a number of sites in a jurisdiction, rather than allocating all of the resources available to the full restoration of a single site.

Member States may also choose to evaluate whether or not there is even a need for immediate action in those cases where the timing of predicted impacts is expected to be far into the future, and, further, whether it is appropriate to allow for natural monitored attenuation as part of a remediation strategy.

4.9.2. Definition of termination criteria

Historically, the execution of remediation projects often had to be undertaken in parallel with development of the pertinent regulatory regimes. This has led to uncertainty over the scope of the work and its desired end point(s). In other words, termination criteria only became clear late in project execution, which led to a huge financial uncertainty and a sometimes disproportionate need to provide for contingencies. Today, the scientific basis, and in many cases the regulatory framework, is available to define remediation end points, and hence project termination criteria, much more clearly. This will enable decision makers to ensure that the anticipated liabilities are well understood prior to, and during, the implementation of a remediation project. It will also provide a clearly identifiable end point for companies, enabling accurate prediction of potential costs.

If remediation criteria are prescribed in regulations, standards or guidelines, efforts should be made to give operators and remediation managers the opportunity to utilize a site specific approach. If this criterion is excessively prescriptive and unrealistic to implement, jurisdictions run the added risk of further delaying remediation efforts, owing to the inability of the operators or remediation managers to fund and implement the remediation.

Site release criteria are the mechanism by which a company may be released from further responsibility for a site. For sites that are physically, chemically and radiologically stable, and where it has been demonstrated that this is the case, jurisdictions may then allow the transfer of responsibility from the operator/remediation manager to the government. Where governments fail to allow opportunities for companies to transfer responsibility for a site back to the government, this may result in an economic and regulatory climate that will discourage future investment, owing to the significant level of uncertainty that exists when a company is not able to accurately predict long term costs.

4.10. DEFINITION OF LONG TERM MONITORING REQUIREMENTS

Where a site has been remediated to acceptable remediation criteria and has been proven to be physically, radiologically and chemically stable, although it may not conform to criteria set for the free release of the site, the site should be placed under institutional control. Institutional controls refer to 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. The government is responsible for sites under institutional control, and it is normally provided for under the laws of the State. Institutional control may be active (monitoring, surveillance, remedial work) or passive (land use control).

Institutional control is needed because the controls are usually required over extended periods of time, possibly even a few centuries. During this time, the safety of the site, physically, chemically and radiologically, must be ensured through the long term management and monitoring of the site. The long term monitoring of the site should ensure that any deviations from historical information on the site are investigated and that remedial actions are performed to ensure the continued safety of the site. The long term monitoring requirements of a site are determined after the initial site remediation has been completed, but have to be reviewed from time to time based on, for example, the results obtained during physical monitoring exercises on the site.

The site should be properly maintained to ensure that it remains in the same condition as it was when it was placed under institutional control. In this regard, it is important to ensure that the information on the site, such as location, previous use and monitoring results, is kept in a proper national site tracking system. This will ensure that the site is not utilized for purposes that will jeopardize the safety of future users of the site, for example, if the site is used as a day care centre.

4.11. DEFINING POST-REMEDIATION OWNERSHIP AND LIABILITY

An important consideration is the need to clearly identify the method by which the liability for a site is transferred between different parties [15]. The responsibilities may rest with different entities during the life cycle of a site and may include:

- Operating facilities — the owner or operator is liable for the site;
- Non-operating facilities — the owner or operator is liable for the site;
- Facilities undergoing remediation — the owner or operator is liable;
- A remediated facility under stewardship — appointed stewards could be the previous owner, a new owner or a government entity [19];
- A site that received free release status — government may assume liability if there is a change in criteria and the site would no longer meet the free release criteria, or if new contamination features are discovered (see detailed discussion in Ref. [19]).

While the post-remediation ownership of a site is usually not a very contentious issue, the long term liability for past activities is normally something that any owner, especially if it is a new owner that wants to redevelop the site, would be very reluctant to accept. In the same light, it is unlikely that any owner of a site, if it is not the government, would be willing to accept long term liability if a site has, for instance, received free release status in order to allow for future changes in criteria, etc. In many instances, the government will assume the long term liability for a remediated site. The post-remediation ownership and liability should, however, be clearly defined and agreed upon between all the relevant stakeholders before the remediation of the site takes place.

4.12. STRATEGIES FOR ACCRUING AND DEPLOYING FUNDS

Funding for remediation projects is usually not freely available and should be addressed at a very early stage of the project. The ideal situation is when, during the operational period, money is placed in a special fund in order to allow for the eventual remediation. In most instances, however, facilities have not done this or the money available from such a remediation fund, if it has been established, is not sufficient to cover the full remediation costs. All funding constraints must therefore be identified early, so that the project may be scoped accordingly. The following aspects related to funding could have an influence on the execution of a remediation project and should be taken into account when planning the project:

- Limited funding may result in only partial remediation. The scope of a remediation project may change significantly as a result of a lack of proper funding. It may result in only certain phases of a project being executed, such as just ensuring the physical, radiological and chemical safety of the site. The extent of these activities will depend on the funding available, but could include aspects such as removal of the inventory, addressing only major exposure pathways or continued monitoring programmes.

— Funding constraints may result in the project being scoped over a longer time period or in phases. A remediation project that was planned to be executed over two years may need to be rescheduled to be executed over five years, owing to limited annual funding. In such instances, the completed project may, however, be more expensive than the shorter project.
— Different stages of a remediation project have different capital requirements. Phase 1 of a project may, for instance, require the dismantling of a plant inside a building, which requires mainly manual labour with relatively low mechanical equipment input. Phase 2 of the project could be the demolition of the building and removal of contaminated soil and material from the site, which will require mechanical equipment and transport vehicles. Phase 2 will obviously require more funding than phase 1, because of the costs involved with heavy machinery and equipment and transport vehicles.
— Some stages of a remediation project may generate revenue. During certain stages of a project, the costs of executing the project may be offset by revenue generated. Plant components that are dismantled can be sold as second hand equipment or as scrap metal. Similarly, some resource material may be recovered from contaminated soil or tailings material, i.e. uranium, gold, copper, etc.

4.12.1. International funding instruments

In addition to domestic financial resources, countries or individual problem holders may look for other sources of funding, as a number have done. Typical sources are international donors through either bilateral or multilateral instruments. Thus, a number of Group of Seven countries have made available considerable amounts of money to deal with nuclear and radiological legacies. Under multilateral instruments, the Phare and TACIS (Technical Aid to the Commonwealth of Independent States) Programmes of the European Community that were aimed at the CEEC and FSU countries, respectively, can be quoted as examples. More regional instruments include NEFCO (the Nordic Environment Finance Corporation) [40]. Example 5 summarizes two cases of international funding instruments.

EXAMPLE 5. INTERNATIONAL FUNDING INSTRUMENTS: PHARE (POLAND, HUNGARY, ALBANIA, ROMANIA AND ESTONIA) “REMEDIATION CONCEPTS FOR THE URANIUM MINING OPERATIONS IN CEEC”

The Phare founding members originally determined that it would be difficult and costly for each individual country to evaluate the relative risks of their former uranium mine sites and to develop appropriate decommissioning and remediation strategies to address these identified risks. It was, therefore, determined by the original members to cooperate at both a financial and a technical level. In order to assist these countries in becoming members of the European Union, the European Commission initiated a multi-annual, multicountry programme whose objectives were to develop a database of uranium liabilities in these countries and to implement appropriate pilot projects to evaluate decommissioning and remediation options. To date, Phare related uranium projects have totalled approximately 5 million euros. It should also be noted that, because of the success of the initial stage of the programme, Phare has increased the number of countries involved, to include Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Lithuania, Montenegro, Slovakia, Slovenia and Serbia.

NEFCO is a risk capital institution financing environmental projects in Central and Eastern Europe. An international finance institution established by the five Nordic countries, NEFCO finances investments and projects in Belarus, Estonia, Latvia, Lithuania, the Russian Federation and Ukraine. Its purpose is to facilitate the implementation of environmentally beneficial projects in the neighbouring region, with transboundary effects that also benefit the Nordic region. NEFCO’s portfolio currently comprises nearly 300 small and medium sized projects spread across different sectors, including: chemical, mineral and metals, food and engineering, agriculture, water treatment, power utilities, municipal services, waste management, nuclear remediation, environmental management and environmental equipment manufacturing.

In addition to those funding instruments, various international financing instruments and banking institutions are available, most notably the European Bank for Reconstruction and Development and the World Bank.

A contaminated site or a contamination event may actually or potentially affect more than one country, for example through transboundary movement of contaminated surface water or groundwater. In fact, some of the international instruments originate in the wish of the donor countries to protect their own environment from impacts arising from contamination in neighbouring countries. If a contaminated site is upstream of a town or city in another country, it is obvious that the country downstream might have an interest in participating in a jointly funded remediation project. There are cases where a source of contamination, a legacy site, straddles two or more countries. In such an instance, the affected countries might decide to pool their resources for addressing the situation. Thus, the international community, in particular the European Union, has been helping to address the Chernobyl related effects. Example 6 illustrates a collaborative effort to prevent transboundary contamination.

EXAMPLE 6. SILLAMAE, ESTONIA: AN EXAMPLE OF INTERNATIONAL EFFORTS TO PREVENT POTENTIAL TRANSBOUNDARY MOVEMENT OF CONTAMINANTS

The Sillamae site in Estonia was established during the era of the FSU and is located on the shore of the Baltic Sea. One of the immediate threats was loss of control, owing to erosion events that would result in (part of) the disposed material being dispersed in the Baltic. Several Baltic coastal states formed a consortium for undertaking remediation measures. A managing board was established that is responsible for approving and scheduling the disbursement of funds and for monitoring programme execution.

It may be noted that such internationally funded projects require a particular transparency on the side of the receiving country. This transparency concerns the financial accounting, as well as the justification of remediation measures. There are examples from the past where audits have shown that some funds provided for specific projects had been used inappropriately, such as for weapons, sometimes even for personal expenses. However, such findings are not unique to remediation projects by any means.

4.12.2. Generating income

A careful assessment of the assets of a contaminated site might reveal opportunities to sell off parts of the site that are not contaminated and are appropriate for free release, thus generating income from the remediation [19]. At the same time, the actual footprint of the contaminated site is reduced. However, this requires careful planning of the remedial activities, in order to identify the land needs of the remediation project, which are typically larger than the actually contaminated parts [18]. Example 7 presents a relevant example.

Assets that could be liquidated in order to fund remediation activities may include not only land but also equipment and infrastructure that are no longer needed and for which a market exists. It is important when considering this option to ensure that any assets to be sold are free of chemical and/or radiological contamination and that any required regulatory approval is obtained prior to the removal of material(s) from the site. This is prudent, as it ensures that those individuals that come into contact with these materials at a later date do not become exposed to chemical and/or radiological hazards.

The remediation process might be designed in such a way that it generates marketable intermediates or products, rather than wastes that need to be disposed of at a cost. This is particularly the case for uranium, where the market is increasingly looking at secondary sources of supply or management of by-products that still contain uranium values. Specifically, as long as the resultant by-products from the uranium feed material being reprocessed in a uranium mill are chemically and radiologically similar to the tailings contained in the facility's tailings ponds or cells, it may be appropriate to consider disposition of these materials via reprocessing through the mill.

EXAMPLE 7. GENERATING INCOME THROUGH REPROCESSING OF URANIUM-BEARING ALTERNATE FEED MATERIAL AT WHITE MESA URANIUM MILL

The benefits of reprocessing various uranium-bearing alternate feed materials through properly managed uranium milling facilities are evident in the case of the White Mesa Uranium Mill near Blanding, Utah (USA). This illustrates optimal reclamation in terms of cost effectiveness for waste disposal, regulatory acceptability and long term stability:

- Through appropriate classification of materials as alternate feeds, the costs of managing uranium-bearing materials that would otherwise be classified as wastes were significantly reduced.
- Large volumes of soils were remediated, at an accelerated schedule, from government owned legacy sites with low levels of uranium contamination, at significantly reduced cost.
- Valuable uranium was recovered and sold to produce electrical power.
- The resultant by-products will be consolidated at one site.
- The by-products will be managed in a disposal cell for which reclamation funds and long term care are ensured through provisions of the US Nuclear Regulatory Commission licence programme and the US Atomic Energy Act.

Coproduction of additional metals and/or conversion for processing other metals may also be considered, provided that the sites can be sufficiently decontaminated. For example, rather than decommissioning a uranium processing facility, it may be worthwhile to consider converting the facility for processing of other metals such as rare earth or base metals. In fact, some mines (e.g. Zvotie Vodi in Ukraine, Olympic Dam in Australia) adapt their processes according to the marketability of the respective metals, while stockpiling ores or process residues until their further processing becomes economical. Keeping a facility commercially viable would provide the means to deal with the contaminated sites.

At sites with ongoing industrial operation, such as mining or ore processing, these operations may be used to generate cash flow for remediation activities. Also, the processing facilities might be used for the actual remediation processes. With rising uranium prices, it might become commercially viable to transport uranium-bearing wastes and residues to other sites or other countries that still have the processing capacities. The proceeds would help finance the remediation activities, with the added benefit of removing (some of) the radioactivity.

Alternatively, in areas where land has a relatively high intrinsic value, developers or communities may consider contributing to reclamation funds, thus facilitating remediation with a view to bringing the land back to a beneficial use from which, in turn, revenues and tax income could be generated.

An additional example of a funding possibility is presented in Example 8.

4.12.3. Finding third party financing

The concept of a ‘good Samaritan’ has also been considered in the context of the remediation of legacy sites. However, our modern complex legal and liability system may backfire on the ‘good Samaritan’, and good intentions may diminish. It is not unusual in certain jurisdictions, or according to common law, that the ‘good Samaritan’ assumes a legal responsibility and liability far exceeding his original intentions, thus making it unreasonable to proceed with the good act. This is illustrated in Example 9.

EXAMPLE 8. NOVEL APPROACH FOR POSSIBLE FUNDING FOR THE POCOS DE CALDAS MINE SITE IN BRAZIL

The uranium mining and milling operation in Pocos de Caldas, Brazil, gave rise to two major piles of waste rock that contain about 60% of the total amount of rocks removed during mining operations. Due to the presence of pyrite in the rocks, acid drainage is observed. The present approach to dealing with the problem consists of collecting and treating the acidic water. However, it has been estimated that it will take more than 500 years for the pollutant concentrations in the drainage to decrease to marginal environmental levels — a timeframe for which it will not be possible to continue the collection/treatment operations. In addition, it is reported that approximately $3.0 million was spent on water treatment from 1984 to 2004.

Different remedial options have been considered for this site. Removal of the source and backfilling the open pit with the material would result in very high costs — approximately $70 million. Capping the piles with a material having an oxygen diffusion coefficient of 10^{-9} m^2/s and a thickness of 0.5 m would be effective; however, this would cost approximately $10 million per pile.

Due to a lack of remediation planning before commencement of operations, the operator is unable to face these very high costs at present, particularly as no more uranium is being produced.

An alternative approach that could be considered would involve the economical recovery of uranium present in the drainage, which may be a possible solution to this problem. It has been estimated that 30 tonnes of ^{238}U are being disposed of as waste per year in the process of acidic water treatment. The challenge will be to establish an efficient way to extract uranium from this wastewater. The use of ionic resins is one way to achieve this goal. It has been estimated that roughly $1.2 million per year can be gained with the recovery of uranium from the acid drainage. The revenue obtained from uranium recovery could be deposited in a fund to be used for site remediation.

EXAMPLE 9. GOOD INTENTIONS DETERRED BY LEGAL AND LIABILITY ISSUES [41]

In Canada, officials from the Government of Saskatchewan had been in discussions with Cameco and Areva (formerly Cogema) regarding the uranium mining industry’s offer to participate in the remediation of a number of legacy sites in Northern Saskatchewan [42]. Although both the Government and the uranium mining industry recognized the mutual benefits of the industry participating in remediation efforts, there remained one primary obstacle to undertaking this work. That unanticipated obstacle was the Federal Fisheries Act. The industry was concerned that, if they undertook any activities at the site, regardless of their good intentions, they could be subject to legal action if it were determined that there was a release to fish-bearing water of a ‘deleterious substance’, as defined by the Federal Fisheries Act. The industry was therefore interested in receiving assurances from both the federal and the provincial governments that it would not be subject to legal action if a release occurred. The industry also wanted assurance that it would not be held liable for future remediation efforts should it be determined at a later date that contaminants were continuing to be released from the site. Due to the wording of the Federal Fisheries Act, and because the industry was unable to accept the legal uncertainty, no remediation efforts were undertaken. The concern raised by the industry was substantiated by way of a legal review that was undertaken to evaluate the barriers to collaboration.

A classic instrument to attract investment into particular business areas is tax reduction or tax exemption, and this could be applied to instances of contamination or their remediation. A favourable taxation regime could attract domestic, as well as international, investors.

4.12.4. Leveraging site resources

Previous sections have discussed that there might be an economic benefit either in the remediation itself or in materials resulting from the remediation activities. It is useful to carefully assess all the resources available and their respective economic potential. In this context, it might be easier to obtain funding from donor agencies, for example, for assessing economic potentials, which in turn would be utilized to fund the remediation project, rather than seeking funds directly for the remediation project itself.

The commercial viability of mining other raw materials at the site in question could be investigated. It may be possible in some instances to partially or fully finance a remediation project from valuable materials still present on the site to be remediated.

An example includes various redundant gold mine tailings dams in South Africa. Some of these tailings dams, which also contain NORM residues in excess of the free release criteria, are situated in urban areas where there is a great need for land for redevelopment purposes. Some of these tailings dams are old and still contain concentrations of gold that make it worthwhile to consider reprocessing them for recovery of the gold. A number of successful operations have already taken place where the tailings materials have been removed from sites for reprocessing, resulting in those sites subsequently being cleaned and remediated.

Overall, an approach that utilizes indigenous resources with a view to providing ‘help to help yourself’ is the preferred option of many donor agencies, rather than to provide funds ‘à fonds perdu’.

Another challenge may also be to find a possible future site use that has added value and generates revenue. This challenge is closely related to similar site reuse challenges discussed in the context of establishing stewardship programmes [19]. A variety of synergies might be explored: thus, a repository for low level radioactive waste may be established at a former (uranium) mine site, provided, for example, that the geological conditions are suitable. The advantage would be, inter alia, that radioactive waste is being disposed of at a site that already has a radiological legacy, rather than utilizing a greenfield site.

The transition from mining to waste disposal can be made part of a seamless life cycle that reutilizes the indigenous resources, including staff experience, in geotechnical engineering projects. However, it should be noted that such a transition may not be met with public acceptance — specifically, if members of the public are already discontent with the fact that they are living in an area where radioactive waste exists, the addition of still more waste may not be acceptable.

There are numerous examples from mining regions around the world where local governments have consciously stood up to the legacies on their territory and turned these areas into tourist attractions. Often, remediation solutions are chosen that help to preserve human-made, mining related landmarks, such as spoil heaps of a characteristic shape, or engineering structures, such as shaft engines. Certain infrastructure features, such as railways, may be developed for tourists’ use — all with a view to generating income to fund step by step environmental remediation programmes.

As has also been discussed in great detail in the context of stewardship issues [19], local communities usually have a time horizon that reaches far beyond the actual remediation project. This is particularly the case when remediation is only one (sometimes short) phase in the life cycle of a site. It can, for instance, greatly enhance the motivation of (local) staff on the project when there are economic prospects after the termination of the project proper. Indeed, it might be in the interest of staff to see project execution being slowed down in order to secure their jobs for a longer period of time. For similar reasons, managers might opt for more elaborate solutions, requiring more resources for a longer period of time.

Project planners may also want to look into the possibility of providing for application of the skills developed in other, possibly nearby, projects or related industries. There are various more or less successful instruments to help the workforce in their transition and life after the project. One example is presented in Example 10.

EXAMPLE 10. DIVERSIFICATION AND NEW EMPLOYMENT OPPORTUNITIES

The Mecsek uranium mine in Hungary employed as many as 8000 employees during its operation. When the decision was made to cease production of uranium, the company determined that this number of employees would not be required to carry out the remediation activities. To help the employees in their transition from their existing jobs to jobs in the external marketplace, the company worked with them to develop alternate employment opportunities. This included the establishment of a new exploration company and a hotel. Where management was not able to help in finding alternate employment through the two new companies, the company provided opportunities for severance packages or early retirement.

4.13. PROJECT SCHEDULING

The development of project schedules and their scope has been discussed from different points of view in a number of recent publications [6, 11, 16, 17, 20]. Project scheduling is an important factor in determining the overall and per annum project costs. It is important that all key aspects of project planning, public consultation and required regulatory approvals are obtained either to coincide with, or prior to, the securing of any required project funding. It is important to recognize that project funding may be granted either in part or in full, and may be dependent on many factors. Key considerations during the programme planning phase and development of the schedule are discussed in the following subsections.

4.13.1. Funding mechanism

The scheduling of remediation activities vis-à-vis the availability of funds is a crucial aspect. Spreading out the operation may facilitate the funding from a tight annual budget; however, doing so will certainly incur higher overall costs, as some costs accrue not by each item undertaken, but rather by time elapsed. In certain circumstances, more than one funding mechanism may be required to ensure completion of a project.

4.13.2. Environmental assessments and regulatory approvals

When undertaking site characterization, a conclusion has to be reached as to when the site has been sufficiently characterized and a remediation decision can be made. There may be legal issues that require time to be resolved. Public hearings and other instruments to involve the public in the decision making process can significantly delay implementation from a purely procedural point of view. In many instances, the amount of information required to prepare an environmental impact assessment and licence application is extensive and may require a significant investment of time and resources, both human and financial, to prepare and present. Requirements for permits may delay the project if they are not addressed in a timely fashion. The formal permitting process must also be completed for any off-site activities. A permits plan is recommended, which lists the permits required and the strategy for complying with permit requirements, including how to address the substantive requirements for the on-site remediation, in advance of project initiation.

4.13.3. Availability and efficiency of technology

The selected technology will be a key factor determining the duration of the remedy.

4.13.4. Worker and safety considerations

Worker and public health and safety issues might affect project completion. For example, the use of levels A or B personal protective equipment for workers may affect productivity and, subsequently, the budget and schedule. There may also be periods when construction is halted at a site to protect the public against safety threats such as a potential increase in air emissions.

4.13.5. Weather

Geographic location and seasonal weather variances at the remediation site should be evaluated. Extreme temperatures, excessive rainfall or high winds may cause delays. Winter construction shutdowns are common in the northern USA. Weather patterns affect design decisions such as whether to use fast tracking. It may not make sense to fast track a remediation action only to have it shut down during winter.

4.13.6. Availability of off-site disposal or other support

The availability of suitable off-site disposal facilities (radiological and/or chemical) should be established during the planning stage of the remediation project, as it could seriously affect the execution of the project. Because the off-site disposal rule can result in lengthy delays in the schedule for remediation action, the RPM should be prepared with an alternative disposal site or other contingency in place, such as requiring the designer/ remediation action constructor to designate backup facilities.

Within a well planned project, a master project schedule containing the major milestones throughout the remediation project will be developed. The scheduling of activities at government owned sites often seems to be influenced by political desires and stakeholder expectations, rather than by specific technical and operational realities and resource availability. The RPM must identify all schedule commitments, to factor them into the contracting and decision making process. The schedule must be updated as the project develops and is executed. It is worth noting, however, that the critical path is determined not only by decisions and activities within the project, but also by outside influences, and managers are advised to factor these in.

4.14. STAGED APPROACH TO REMEDIATION

A staged approach to remediation can be a useful strategy by which to address specific risks at a site, as and when resources become available. The basis for a staged approach would be a risk based prioritization. According to this priority, a schedule for actions would be drawn up, i.e. it will be determined which remedial activities can be scheduled and accomplished in a reasonable amount of time and with the resources available.

While such plans are being developed, it will become clear that there are some items that will require significant investment of human and financial resources and that may also be difficult to address in a short period of time. It will, however, become equally clear that other necessary tasks may require only limited resources and may be very quickly achieved. For example, capping and revegetation of an above ground tailings facility may require significant time and resources when compared with the relocation of a small isolated mine waste pile (such as from exploration adits) back to a central waste repository or its placement as backfill material within the adit. Dealing with the small and simple items quickly and thoroughly may make the overall problem less complex to handle.

The staged approach would be guided by the risk assessment, and it may be possible to achieve a significant (temporary) risk reduction with a few measures early on, which should then be implemented quickly.

4.15. ECONOMIC DEVELOPMENT PROJECTS

In most instances, a remediation project will only provide a short, or maybe medium term, economic benefit to a certain area or community by making use of local labour and services during the remediation process. After completion of the project, there will be no more economic benefit. In some instances, however, it may be possible to establish acceptable alternative uses for remediation sites. Such uses may then also ensure the long term economic sustainability of a local community by the continued provision of services by such a community. Planning such alternative uses should always be done in full consultation with the local communities. Example 11 illustrates an economic development in Germany.

EXAMPLE 11. ECONOMIC DEVELOPMENT PROJECT

In Germany, the former Schlema uranium mining area was remediated and successfully returned to the control of the local community. One of the highlights of this work was the fact that the remediation of the site was done in consultation with local community members and that this consultation allowed the community to have input into proposed project plans. This input resulted in the successful establishment of a radium spa resort in which significant economic value has been realized, both by direct cash influx from visitors to the spa and through secondary economic benefits realized by the activities supporting the spa.

Certain site reuse projects have been specifically developed to ensure institutional control in the context of stewardship programmes [19]. As has been discussed in this report, a stewardship programme will become most viable when it can combine institutional control with economic benefits. Thus, certain agricultural uses, nurseries or tree farms, or recreational use in the form of, for example, golf courses, may generate income for the local community. Although this type of land use is not likely to pay off remediation costs to any significant level, the main purpose is to establish a land use that is compatible with site release criteria.

Some organizations charged with remediation of the uranium mining legacies in certain countries are more advanced than organizations in other countries. Therefore, an obvious way to generate additional income and ensure continued economic benefit is by making this expertise commercially available. An added value from seeking out opportunities in other countries or at other sites is the accumulation of experience that can be brought to bear on the domestic problem. Being able to rely on domestic capabilities rather than having to bring in outside expertise may result in savings. In some countries, government agencies have been set up to encompass the management of all the respective country’s nuclear liabilities, including the decommissioning of radiological sites. The most notable recent example is the Nuclear Decommissioning Authority in the United Kingdom.

4.16. CONTRACTING APPROACHES

After a decision has been taken to continue with a remediation project, the RPM could be faced with a number of challenges with regard to the execution of the work. In many instances, the RPM may not have available all the different types of resources to perform all aspects of the project. Some specialist services may need to be procured from external service providers, such as design work, specialized equipment or even contractors to perform some of the remediation work.

In instances where external services are required, the RPM may use different contracting approaches to obtain such services. He or she may have knowledge of specific service providers with applicable experience or have some preferred service providers. On the other hand, he or she may have no knowledge of preferred service providers. In either case, it is always advisable to follow a fixed, prescribed and well established procurement process that allows transparency and fairness. Procurement processes should be designed to prevent the possibility of corruption or situations where a fair process is not followed, i.e. where a certain service provider is selected over another offering the same service at a substantially lower price. It also follows that the service provider with the lowest offered price is not necessarily always the preferred one. He or she may have quoted incorrectly or may not have enough experience, or may have omitted some aspects that other competitors might have included. Any decision taken should be therefore be defendable and justified. This is normally ensured through a well developed procurement system that allows a systematic approach, ensuring transparency and fairness.

4.17. NOVEL PROJECT IMPLEMENTATION CONCEPTS

Remediation of sites is a very specialized activity and normally something that the former users of the site would not be very comfortable undertaking. It is in the interests of operators of processing plants and mines to generate a product, and therefore income. The back end of an operational process is normally not something a site user is interested in and is also something they do not have experience in. Therefore, environmental remediation is often a problem that has to be addressed by the site owner.

Site operators, who are in many instances government owned entities, normally choose to perform remediation projects on their own, owing to the high costs involved in such projects. They then utilize their own personnel to manage and execute the work and would only consider contracting in some specialized functions.

There are, however, various approaches toward the execution of an environmental remediation project for the site owner. This is of course also dependent on various aspects, such as the income generating potential of the site, current and future use of the site, and current infrastructure of the site. The approaches to a remediation project could include the following novel implementation concepts:

— *Build–own–operate* (BOO): this concept is usually used by governments and, although designed mainly for new infrastructure projects, it could also be used successfully for some remediation projects, especially where there is some income to be generated from such a project. The private sector normally builds the project, owns it and operates it. What distinguishes projects that are called BOO projects is typically that there is some continuing level of government involvement. BOO projects are distinguished from private investment in general by the fact that typically there is an essential service of some kind being provided, in a situation where one cannot simply rely on the existence of a large number of competitive suppliers of that service. So, in one way or another, the government remains involved. The government may, in the case of a remediation project where there may be a continued use for the remediated site such as a spa resort, etc., hand the site over to a successful bidder (private company), who will design, finance and remediate the old site and operate the remediated site. The private company subsequently recovers the costs of the remediation project with the income generated from the continued site use.

— *Build–own–operate–transfer* (BOOT): the principle here is the same as for the BOO concept, but with one change. Here, the contractor builds the project (or remediates the site and prepares it for continued use); it then is allowed to own and operate it for some period of time (such as 20 or 25 years), during which it collects income. At the end of this time, the project is handed back over to the government.

As discussed earlier, site remediation projects are normally very specialized activities requiring specialist inputs, and in some instances specialized equipment, for successful execution. It may therefore not always be easy to find a willing contractor. Governments may therefore also be willing to negotiate with contractors to share some of the remediation costs, in order to make the project more viable.

5. OBSTACLES TO IMPLEMENTATION AND STRATEGIES FOR MITIGATION

The relatively low rate of progress in actual remediation, despite the degree of site characterization completed, is in large part due to the obstacles that remediation programmes often encounter. The type of potential obstacles will vary from Member State to Member State. This section presents a number of the most commonly encountered potential obstacles. These obstacles may relate to, but are not limited to:

— Legal and liability issues;
— Jurisdictional obstacles;
— Regulatory obstacles;
— Social obstacles;
— Technology availability and strategy limitations;
— Financial constraints;
— Organizational and management issues.

Considering these potential obstacles, it is easy to understand why Member States often have difficulty in carrying remediation programmes from the evaluation stage to the implementation stage.

By definition, remediation requires the application of time, money, labour and know-how. These resources must be available in sufficient quantity and quality. The view on what is to be considered ‘sufficient’ may, however, vary between the different stakeholders in the project. In any case, because of the inherent constraint on these resources, remediation efforts need to be focused on options that are likely to yield the greatest results for the resources expended.

Any type of resource is more likely to be available at operating sites than at legacy sites [16]. Operating sites are in the fortunate position of probably having:

- Existing infrastructure during the remediation period;
- The ability to levy remediation costs from the operational proceeds to build up remediation funds during the operation period;
- The institutional knowledge of their staff (this is particularly important when determining where historic contamination has occurred);
- Facility documentation (monitoring records, spill reports, geotechnical reports, maps identifying the location of old waste sites, etc.);
- Existing operators and maintenance personnel who are familiar with the site, its history and any potential hazards, and who thus can contribute significantly to the site assessment or may be more effective in working under the conditions at the site;
- Existing personnel that are familiar with the site as it is, and can be trained to their new role in remediation.

The objective of this section is to identify and discuss the common obstacles and risks encountered during remediation projects, as well as to propose strategies for mitigating or resolving them.

5.1. LEGAL OBSTACLES

The various legal requirements that exist within a given Member State will certainly have an impact on the required remediation programme. In general, however, legislative requirements should not be perceived as obstacles, but rather as a driver for action and the structure within which the action is planned and implemented.

There may, however, be specific legal requirements that present particular challenges to the project schedule. For example, some Member States may have civil requirements related to ‘potentially impacted party approvals’. In many Member States, a proponent wishing to undertake specific works that may potentially have an impact on another party must first receive approval/consent from the owner of that potentially impacted property. This may lead to a significant delay in receiving the necessary approvals, particularly in those instances in which there are a large number of potentially affected parties. In certain other instances, a project may be stopped altogether as a result of not receiving these approvals.

Solution strategy

The RPM should evaluate whether such requirements apply to the site. If so, the potentially impacted third parties should be identified immediately as among the key stakeholders of the planned action. Early interaction and negotiation of approvals should be pursued, and these activities should be incorporated within the master schedule.

5.2. JURISDICTIONAL OBSTACLES

At times, RPMs and decision makers may become confused and frustrated by the lack of clear responsibility for regulating remediation efforts. In many cases, the various levels of government (national, regional, local) are responsible for different areas of mining. In other words, there is no ‘one window’ approach to securing all of the approvals required to conduct all of the activities related to mining (i.e. exploration, construction, operation, decommissioning and reclamation, etc.). It may also be the case that the various levels of government believe that they have responsibility for the same aspects. At times this has caused a direct conflict between the directives issued by one level of government and those issued by another. An example is illustrated in Example 12.

With respect to jurisdictional obstacles, it may also be the case that proponents are required to seek approvals from the various levels of government in a specific sequence. In other words, one may need to secure approval for a project from the local authorities before approaching the regional government agency, etc., until all approvals for a project are obtained. In this case, the length of time required to secure these approvals will be significantly protracted when compared with other jurisdictions in which approvals may be obtained concurrently at the various government levels.

Solution strategy

During the planning phase, the RPM should identify all elements of the government and regulatory agencies that may have (or believe themselves to have) authority over the site and planned activities. Individual representatives from these agencies should be identified as important stakeholders in the project. A formal documentation of their role and interests should be requested and obtained, so that the permit requirements, review processes and approvals may be defined and incorporated within the master schedule for the project. Additionally, a signed agreement (such as a memorandum of agreement) could be proposed, to document the parties' expectations and commitments.

EXAMPLE 12. UNCLEAR REGULATORY AUTHORITIES

In Brazil, the uranium production centre of Pocos de Caldas is regulated by the Nuclear Regulatory Commission (CNEN) and the Ministry of the Environment, through the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). When the production centre received the nuclear licence, the requirement to conduct an environmental impact assessment had not yet been established as it is now; as a result, the site was not licensed according to the current regulatory system. If the operations are analysed under the prevailing system, many aspects will need to be fixed to bring the site into the present regulatory framework. As a result, IBAMA tried to put in place an instrument called a 'term of conduct adjustment'. Under the elements of this term, the production centre would have to adjust its overall situation to a certain number of requirements. The company claimed that it would not make sense to adjust the overall sites to requirements that were created after operations began. Instead, another instrument was put in place, called a 'term of environmental commitment'. Under this term, the industry would have to commit itself to improving several aspects with a view to site remediation. The term was developed by means of the establishment of a multilateral task force, including the Ministry of the Environment, represented by IBAMA; CNEN; the environmental organ at the state level, Fundação Estadual do Meio Ambiente (FEAM); and, obviously, the site operator, Industrias Nucleares do Brasil (INB). The first result of this working group was to establish a list of information that INB would need to provide and the terms of reference for the elaboration of the remediation plan. The assessment of this process is that the coordinated work of the relevant regulatory agencies will produce a more effective outcome and will allow the operator to be aware of the rules and requirements with which it will have to comply. This will save money and time, and will allow for a smoother process.

5.3. REGULATORY OBSTACLES

Regulatory obstacles may come in many forms, and generally depend on the type and structure of the regulatory regime in a given jurisdiction. It may also be the case that the absence or incompleteness of a regulatory regime constitutes a barrier to undertaking remedial actions. Thus, no remediation targets can be set and no compliance can be enforced, though from a scientific point of view a problem may have been recognized.

5.3.1. Lack of defined regulations and standards

A situation characterized by a lack of defined regulations and standards occurred in the early days of the developing environmental consciousness, but more recently has also been the result of fundamental changes in the legislative systems of some countries. Most notably, a regulatory vacuum occurred in many FSU and Eastern European countries after the end of the Cold War (Example 13).

EXAMPLE 13. UNDEFINED REGULATIONS AND STANDARDS

In Bulgaria, where the Government decided to remediate some uranium mine sites, it was realized that, before undertaking this work, there was a need to develop an appropriate legal framework including limits for radionuclides and inorganic/organic contaminants in surface water and groundwater. It took many years to develop these guidelines, which delayed the undertaking of actual remediation measures.

Another example is Kazakhstan, where, upon the establishment of the new Kazakh Government system, all previous Soviet era laws and regulations were removed, effectively resulting in a legislative/regulatory vacuum that lasted for several years.

Solution strategy

In instances where a significant hazard exists that warrants response in the near term, it is recommended that international guidance be used as the basis for the development of a project specific regulatory proposal that would be submitted to the government for review. It is reasonable to expect that a Member State would review the proposed action relative to international standards, to enable the risk or hazard to be addressed.

IAEA standards and guides on radiation safety and best practices are intended to provide guidelines for drafting regulations at a national level where those do not yet exist. There are also examples where these standards and guidelines have been used in lieu of national standards, at least for an interim period.

5.3.2. Unstable regulatory regime

A frequently changing regulatory regime, with changing goals imposed on those responsible for remedial activities, may cause inaction on the part of those responsible. Providing a stable regulatory regime will help those responsible to undertake appropriate financial planning.

Solution strategy

The use of international standards is recommended, such as safety and environmental requirements and conventions set out by agencies such as the IAEA. As these present an international consensus on safety and environmental subjects, they tend to be stable.

5.3.3. Overly stringent requirements

It is also possible that the initial requirements established for a project are miscalculated or technically and scientifically unachievable (Example 14).

EXAMPLE 14. INAPPROPRIATE SELECTION OF REMEDIATION TARGET VALUES

In the context of the Žirovski Vrh (Slovenia) mine remediation project, a review of the dose contribution level was undertaken, prompted by suggestions that the original value was inappropriate. The original dose contribution value was derived by a consultant based at a Slovenian institute and retained by the Government, and was as low as 0.1 mSv/a. This value proved to be extremely conservative and was due to the reviewer's failure to take into consideration that the typical background level at the Žirovski Vrh mine site is around 5.5 mSv/a. Subsequent discussions between the regulator and the company resulted in the application of a more reasonably achievable level of 0.3 mSv/a, which is still extremely low when compared with background values of 5.5 mSv/a. This is an example of a situation where the consultant did not fully understand the concepts of radiation protection. It is assumed that the values of 0.1 or 0.3 mSv/a refer to the additional dose above background. But in this case, if the intervention concept [43] is taken into account, the total dose would need to be considered, which would be 5.5 plus 0.1 or 0.3 mSv. The additional value would probably fall within the range of uncertainty of the local background.

Solution strategy

In instances where specific remediation criteria are set that cannot be achieved, one of the following strategies, or a combination of strategies, could be followed:

- Justification of more suitable remediation criteria by comparing the set criteria with international standards and international best practice: comparing local criteria with international standards provides an indication of whether the local criteria may be too restrictive. Although many countries have their own criteria for remediation, these criteria are, in most instances, in accordance with international standards and guidelines.
- Making use of a background reference site (BRS) to justify more suitable remediation criteria: this methodology is especially useful when remediating land for free release purposes. By using this methodology, another site in the vicinity of the site to be remediated and with similar properties is selected. This site must be free from contamination from the site in question. It is important that the BRS soil is of the same type of horizon material as the site to be remediated. Important considerations for selecting a BRS are past and present land uses, geology, topography, and fauna and flora. The BRS site is then surveyed and sampled, and the results are used to justify to the regulators or decision makers remediation criteria that are more in line with the natural background levels in that area. When performing the final assessment on the site after being remediated, the results should not differ significantly from those found at the BRS.

5.3.4. Changing regulatory requirements

While some may question the notion of allowing government to change the rules after the fact, changing regulatory requirements has helped to ensure that those responsible for the pollution help to pay for the remediation rather than placing the financial burden on the general public. One risk of governments and the courts determining the degree to which remediation should be undertaken is that they may ignore scientific advice, in order to secure public support.

It is also possible that the regulatory requirements will change during the course of a remediation activity, becoming more stringent and requiring more action. This situation may arise when the effectiveness of the remedy falls short of expectations. It may also arise when the public has preconceived ideas about the solution or becomes aware of practices and results at other sites that they expect to be emulated.

Solution strategy

During the planning stages of the remediation project, the RPM should already take into account the fact that regulatory requirements may change. This is especially true for projects that will continue for extended periods of time. The single largest risk factor here is the financial consideration. When regulatory requirements change, they tend to become more restrictive and not more relaxed. It is therefore possible that the remediation project could cost significantly more, in order to comply with the changed requirements. Allowance should therefore be made in the remediation project plan for additional financial support and contract extensions. One of the big problems encountered when changes occur in the regulatory regime is also the fact that it could result in a significant delay in execution of the remediation project. This is mainly caused by uncertainties on the side of the regulator and/or the licensee. The RPM should therefore take note of this possibility and include such eventualities in the overall project plan.

5.3.5. Unexpected regulatory attention

Certain measures that may lead to improvements in the environment may attract regulatory attention, resulting in an undue burden on the programme. Hence, the decision maker may decide to abstain from the otherwise beneficial activity. This is particularly the case in those Member States that have a more prescriptive than performance based regulatory regime. For example, if a proponent was considering revising its milling process to utilize less hazardous chemicals or processes, but is operating under a very prescriptive regulatory regime that would require the company to undertake an extensive and expensive (in terms of cost and time) environmental impact assessment, the company may choose to forgo this improvement to environmental performance, owing to the time and cost intensive process.

In various Member States, the change of ownership or a change in site use may attract regulatory attention to the site. In some Member States, proponents seeking to undertake recovery of secondary minerals at a closed or abandoned mine site may be required to undergo an environmental assessment and regulatory licensing process. As with all risk assessments, Member States will need to weigh the potential environmental benefits of the proposed project with the potential environmental risks.

Solution strategy

Member States are therefore encouraged to develop (or modify existing) legislation, regulations or standards that allow 'screening level' assessment to be undertaken for those projects that are anticipated to have a significant environmental benefit. In simpler terms, Member States should strive to make their regulatory system flexible and supportive of beneficial changes proposed by companies developing industrial operations, including uranium mines and mills.

5.4. SOCIETAL OBSTACLES

While public concern can be an important driving force behind remediation (see Section 3.4), it can also be an obstacle. As has been discussed in detail in previous reports [16, 19], stakeholder acceptance of the proposed remediation plan is essential to ensure its successful implementation.

5.4.1. Public demands for revised end point

One form of a society related obstacle is a change in the determination and evaluation of the remediation end point. This obstacle may occur at any or all stages of the project, and the impacts to the cost and schedule of project could be significant.

Solution strategy

Often, certain sections of the public voice themselves in the form of NGOs. These organizations may represent local interests. Such an organization can be formed by engaged and potentially educated people. To the extent that the demands for revised approaches or end points come from large, well financed multinational organizations, it is recommended that the RPM not expend significant resources to attempt to persuade these parties. In all likelihood, they are entrenched in their position and will continue to both oppose the project and attempt to recruit others to their position. Rather, the RPM should develop a mitigation strategy to respond to this risk, which should include increased involvement of local members of the public and regulators, to secure and bolster their support for the project. An important element of this strategy is providing clear and credible educational materials on the programme plan, risks and benefits.

5.4.2. Legal challenge

Another societal obstacle is potential legal action or an injunction against the project, which may result in a directed suspension of the project and the site owner and operator, incurring significant economic impact. Such cases are often brought by special interest groups, including well known multinational entities.

5.5. PROCEDURAL OBSTACLES

It is possible that an RPM and decision maker may wish to undertake an action or implement a technology for which required operating procedures do not exist. The action or technology may be new and not yet proven and may therefore require comprehensive operational instructions and procedures. Development of these procedures, and the attendant review and approvals that may be required, probably demands significant time and resources.

Solution strategy

To the extent possible, the RPM should evaluate whether other programmes have implemented the same activity and whether existing procedures are available to be tailored to the planned action. The RPM could also make use of specialists to develop the procedures, under contract, and have them reviewed and approved by the appropriate regulators, if applicable.

5.6. ACCEPTABILITY OF STRATEGY AND TECHNOLOGY CHOICES

The successful completion of a remediation project requires techniques and technologies that are, first of all, suitable from a scientific and technical point of view, but that are also acceptable to the regulator(s). Over the years, many regulatory bodies in Member States have developed catalogues of techniques and technologies that are deemed acceptable [17, 20]. The techniques are selected on the basis of experience with their application and proven efficacy [16]. Introduction of novel or innovative approaches may need to be carefully justified and described, in order to get the necessary regulatory approvals, since the approaches may not be familiar to the regulators.

In the CEEC and FSU countries, many regulators and operators were not familiar with techniques and technologies that were considered ‘state of the art’ in other parts of the world. Gaining acceptance for these technologies among all stakeholders required some time.

Even when the regulator is willing to approve a novel or innovative solution, significant delays may result from a lengthy approval process. A clear assessment of the likely benefits (reduced cost, reduced capital expenditure, reduced collateral impacts, increased efficacy, etc.) from employing a novel or innovative technique is likely to facilitate the process, thus surmounting the barrier. It may be, indeed, that only a novel or innovative technique is capable of dealing with the problem in hand.

Solution strategy

The use of any ‘novel’ or ‘innovative’ technologies or approaches should always be well justified to the regulator(s). This will mean a significant effort to build a proper case for justification of the selected methodology. Such a case should include comparisons with similar technologies, cost–benefit analyses, safety considerations such as dose reductions, application potential, and advantages/disadvantages of using the selected methodology. The regulator should be provided with enough information to be able to evaluate the technology in question without leaving any question unanswered. Live demonstration of the selected methodology/technology to the regulator could also assist the regulator in making an informed ruling, and speed up the approval process.

5.7. FINANCIAL CONSTRAINTS

Remediation projects frequently differ from typical commercial operations. In most instances, a certain budget is allocated to the project, with the resources coming, for example, from the proceeds of continuing commercial operations, e.g. mining, or a government budget. This budget is not necessarily allocated according to the needs as perceived by the RPMs, but may be allocated according to the availability of funds at the respective sources.

The resulting lack of control over budgets and possible short term changes in the level of funding pose a particular challenge to RPMs, though this situation is not unique to remediation projects. The challenge here is to project the time execution and to manage and retain the necessary (staff) resources. It has to be recognized at all levels of administration and management that reducing the budget for a remediation project usually results in delays in project execution, unless ways to increase efficiency can be found.

Shrinking budgets because of overall shrinking tax revenues and a corresponding reduction in public spending has been a challenge in many parts of the world. In the former Eastern Bloc countries, this challenge is compounded by the paradigm shift from a planned to a market economy. Many administrators and managers did not, and sometimes still do not, have a comprehensive understanding of all the related implications, and it is usually the RPMs who find themselves at the end of the chain. The scope for gains in technical efficiency may be exhausted quickly, so that the only option to accommodate a lowered budget would be to redefine intermediate and final remediation targets. This, however, requires a negotiation between all stakeholders concerned.

Another issue is that budgets in government administered organizations are not generally transferable from year to year. If the budget has not been fully utilized in one year, this normally results in a loss of the funds for the project. In addition, there is a tendency to reduce the budget allocation in subsequent years. Many government administrations, however, have recognized the problem and are switching from measuring the fraction of funds spent to measuring the results achieved, and allowing funds to be carried over into the next year. As has been discussed in detail in Ref. [19], annual budgeting can make the development of long term programmes a difficult task.

Solution strategy

Development of a resource loaded, multiyear schedule for the project, which identifies the annual costs and funding requirements, is a valuable first step to securing the required financial support. Such tools increase the project's credibility and provide a reference for assessing the adverse impacts of reduced funding.

Also, it is paramount for RPMs to establish an adequate system for monitoring the project's progress. This will help to optimize the utilization of resources and to maximize progress over the year. The monitoring data will help to maintain the confidence of the stakeholders that eventually expectations concerning the project will be met. They will also provide the basis for a reasoned rescheduling of the utilization of funds. Remediation managers may wish to provide these stakeholders with an annual report on the progress made on the project, including project costs, to further demonstrate to these stakeholders that progress made over the course of the year has been appropriate. Depending on the financial arrangements made for the project, this may be a requirement and not simply a suggestion.

It may also happen that the budget for a specific remediation project is suddenly reduced, owing to financial difficulties or other more pressing activities in an organization or government. This may have disastrous effects on a remediation project if not handled properly. A good management practice for the RPM would be to also have a 'risk management plan' in place, listing all potential project risks with actions to address them. Although the extent of budget reductions cannot be foreseen, the RPM should allow in the risk plan for a general strategy to be followed in the event of sudden budget reductions.

5.8. PRESSURES FOR HIGH COST SOPHISTICATED SOLUTIONS

Different strategic choices and technical solutions come with different price tags. 'Sophisticated' solutions may be neither needed nor affordable (Example 15). It may be speculated that many remediation projects are not undertaken because the resources for the proposed solution are not available. Often, remediation strategies are developed by consulting firms (from the western world), who base their proposals on the experience in the western context. However, resources and conditions may be quite different in countries that are less affluent. Funding agencies may insist on the use of proven (in the western world) strategies and techniques. This may result in no action when the resources needed are not available, rather than in an adaptation to the available resources.

In certain instances, the consultants and construction and remediation companies hired to undertake the work may prefer more sophisticated solutions, as the profit margins tend to be higher for these projects. It may also be the case that these higher priced solutions require future involvement by these companies, where proprietary technologies are utilized. In these instances, reliance on the company originally undertaking the work may greatly increase the cost of a remediation project.

Conversely, there may be a benefit in utilizing the services of the original consultant for future projects at the site, where the future project requires knowledge based rather than proprietary technical solutions. The reason for this is that the original consultants:

— Are already familiar with the site, and therefore the project planning phase could be shorter and less costly;
— Have probably accumulated a significant amount of information about the site, which would reduce both the time and the cost of the project;
— May have participated in previous discussions with local, state and/or federal regulators and stakeholders, and therefore have an understanding of the regulator's and stakeholder's expectations;
— Have successfully completed the original project and therefore will probably have a greater level of support from the local community than a previously unproven consultant would.

In other words, the benefits of retaining a consultant have to be balanced against possible higher costs. As indicated elsewhere, some international funding agencies (e.g. the World Bank) require the utilization of credible consulting firms, and therefore utilization of the services of an acceptable consulting firm would be required if any monies were to be requested from these funding agencies.

One of the drawbacks of proposing non-'sophisticated' solutions is that regulators may perceive the remediation project as being less than acceptable, suspecting that the proponent is trying to cut corners at the expense of public safety and the environment. While this may not be true, it is often difficult to convince the regulator to the contrary.

Another drawback of utilizing a non-'sophisticated' solution is that the public may also criticize those responsible for regulating and/or undertaking the remediation project, even when it can be demonstrated that the project has met all of the remediation objectives. One reason for this is that the public, too, may perceive that the project's focus was on keeping the cost as low as possible rather than on protecting people and the environment. Another possible reason that the public may be somewhat reluctant to accept a non-'sophisticated' solution is that there may be a perception that no further remedial work will be undertaken at this site, as the level of risk has been significantly reduced. This second reason may be somewhat more justified, as future decision makers will probably also determine the priority of a given project by carefully evaluating the relative risks at all sites being considered for remediation funding.

Solution strategy

In such cases, a comprehensive process of public consultation, involvement and education is needed that is aimed at creating ownership on the part of as many stakeholders as possible. An important argument could be that, given that two or more solutions are technically feasible but entail different levels of direct project cost, added benefits may arise from a seemingly 'cheap' solution. For instance, a 'low tech' solution may take longer to implement (but not necessarily so, as is demonstrated by many less than efficient 'pump and treat' groundwater remediation projects, unless the treatment method is used for quick contaminant mass reduction or in combination with other technologies), but may have some added benefits, including [16]:

— Enhancement of the local, state or national economy through the utilization of locally available technology and equipment;
— Familiarity of the local workforce with the technology and equipment, thus eliminating the need to bring in an outside workforce;
— Provision of employment for the local workforce.

EXAMPLE 15. DECIDING AGAINST A ‘SOPHISTICATED’ SOLUTION

The strategy currently being proposed by the management of the Žirovski Vrh mine in Slovenia regarding closure of the mill tailings is an example of a case where a ‘sophisticated’ solution may not be practical or cost effective. The mill tailings in question are situated partially on an area subject to landslides, and so an evaluation of possible closure options was deemed by management to be required. It was subsequently determined that it would be extremely expensive to increase the design safety factor to a point that would prevent further landslides. Other factors considered were whether or not the remediation option would be sufficient to guarantee against future slides, as well as the potential downhill impact of a slide involving the tailings. It was determined that, because of the prohibitive cost of the remediation option and the relatively low risk of downhill impacts, the most appropriate course of action was to undertake limited dewatering work beneath the tailings pile, to address the short term stability issue, and for the Slovenian Radioactive Waste Management Agency, through its stewardship programme, to monitor the stability of the tailings pile and undertake any required maintenance in the longer term.

When considering a solution, decision makers also need to consider the overall ‘public good’, e.g. lives saved, that can be achieved with a given amount of money. In other words, the scope of optimization would include alternative projects for different problems, e.g. infrastructure or health care. It may be difficult, however, to communicate these issues to the stakeholders.

5.9. PRESSURES FOR ADDITIONAL REMEDIATION IN THE LIGHT OF ADVANCES IN ANALYTICAL METHODS

As with many advances made by humans, the advancements made to improve analytical detection limits and methods have been both bane and boon to those relying on the analysis. From the positive perspective, the lowering of detection limits has allowed researchers and others to better understand both the physical and the chemical properties of chemicals and materials (through the use of beam lines in synchrotrons, etc.) and through the ability to evaluate the degree to which contaminants exist in the environment. The problem brought about by these advances is that the levels to which contaminants can be measured are often significantly below what would be of concern from the standpoint of adverse effects. However, it is often the case that the press and other media, upon discovering that there is a detectable level of a contaminant in the environment — which is known to be associated with a given industrial activity — raise alarm in the public. The public often does not have an adequate understanding of the risks associated with this contaminant, and so is alarmed that there is ‘any’ of this contaminant in the environment, even though the concentration may be below permissible levels. Owing to the generally increasing mistrust in scientific and technical expertise, it is often difficult, if not impossible, to explain to the public that a given contamination level is not of concern. This is particularly difficult in areas where the measured contaminant is naturally present in the environment, as is the case with the measurement of radiation levels in a given area.

Thus, a lowering of the achievable detection limit may trigger a whole wave of (re-)assessments of contaminated sites and a consequent re-evaluation of the need to remediate.

Solution strategy

As discussed in Section 4, early identification and formalization of the programme end state, including site use and cleanup targets, is critical to minimizing changing expectations and requirements. These aspects should be communicated and agreed with all the relevant stakeholders before the remediation project commences. It will ensure that the stakeholders are aware of, and comfortable with, the requirements and cleanup targets and will subsequently reduce any drive for additional remediation work. It is important, however, that the cleanup targets set for the remediation project are realistic and allow for a remediated site that conforms to international standards and guidelines.

5.10. MULTIPLE, CONFLICTING DECISION MAKING

There are numerous layers of decision makers at the operational, management, regulatory and political level in a country. These layers do not always appear to act after mutual consultation.

Political decisions on the future of uranium mining have, for instance, been made in some countries without consulting major stakeholders in the industry (Bulgaria, Germany and Slovenia). On the other hand, there are examples, such as in Hungary, where the operators were consulted. These decisions were often made without consideration of the operational aspects and without allowing for making proper closure plans. In various instances, this has resulted in the creation of worse environmental problems (e.g. stockpiled ores, contaminated process fluids) and subsequently also the dispersal of staff resources.

Decisions for an unscheduled and unplanned closure are likely to entail higher costs — both direct and indirect (social). There may be disagreement between the different stakeholders and decision makers as to who has to bear the respective costs.

Solution strategy

While it will not be possible to eliminate any chance of unforeseen influences on the programme, the early identification of stakeholders and decision makers, and documentation of their respective authorities and responsibilities, helps to minimize those conflicts that can be anticipated. Also, key decisions required to support implementation of the programme should be identified within the project schedule.

5.11. CHANGE IN PROJECT MANAGER

An RPM may not be the project manager for the entire process, owing to the length of time required for project completion. Remediation projects may take extended periods of time to complete, during which a natural attrition of personnel will take place. This may include the RPM. RPMs are normally highly experienced people within an organization, and there is a likelihood that they may either be reassigned elsewhere in their organization or even be recruited by another organization. Similarly, the RPM may not be able to continue with his or her duties because of illness or other problems. This may result in significant disruption and delays, which could be detrimental to the successful completion of the project.

Solution strategy

To minimize project disruption, records should be organized and kept up to date, so that the replacement RPM can trace the history of the project and the rationale for earlier decisions. This is normally ensured through a well established management system for the remediation project. Such a system ensures the maintenance of records, updating of documents and existence of a good document control system. A new RPM would therefore find it much easier to continue from where the previous RPM has finished.

It is also important that succession plans are in place within an organization, for all senior positions. The RPM should always have a person (on the same level or more junior) available who is fully informed and able to continue, should anything happen to render the RPM unable to continue with the work, or in the event of redeployment or resignation.

5.12. WORKER COMPETENCIES

In many instances, experienced, competent workers are required to execute a remediation project successfully and on time. Certain plants that need to be dismantled as part of a remediation project are technically sophisticated, and especially if the plant is to be reused or sold, it is important that well qualified and experienced personnel perform such work.

It is also important to remember that, in most cases, the remediation of sites involves working with hazardous materials. Although training and awareness courses are normally presented at the commencement of and during the remediation project, it remains important to have suitably qualified and/or experienced workers appointed to perform the work.

Solution strategy

Where possible, workers who have previously been involved on the site during its operational period should receive preference when appointing the workforce. They have a much better understanding of the site and its accompanying hazards. It may, however, be difficult to recruit the previous workforce in instances where there are significant delays in the remediation of a site after termination of operations, although, in most instances, it should be possible to obtain the services of at least some of the former employees.

Furthermore, continuous training and retraining should be undertaken to ensure a competent workforce. Training should also focus strongly on the specific risks of the site and the remediation project, as identified in the respective remediation project safety assessments.

5.13. CONTRACTUAL INCONSISTENCIES

Many remediation projects experience unforeseen problems with various contractual arrangements, as is also the case with many other types of project. This may involve contracts with service providers or personnel, or even the contract with the client for whom the remediation project is performed.

Contractual issues may cause serious delays if not addressed correctly and may ultimately result in significant financial losses. For example, if a contract has some small print that allows the owner of equipment that is rented to the remediation project to use substandard equipment or equipment that is not fully suitable for the work, this may cause serious delays in the project, as it may take much longer to execute the work.

Solution strategy

The RPM should obtain legal advice and inputs for each contract entered into. Although the RPM knows exactly what is required when demanding a specific service, he or she is usually not a legal expert and may overlook some potential pitfalls in the contract. The availability and use of legal experts may save the project considerable expenses in the long run.

6. CONCLUSIONS

This publication discusses the drivers for environmental remediation, as well as the major obstacles that any remediation operation is confronted with, and how to overcome these obstacles. It also discusses some ideal remediation approaches that can be used when dealing with sites that require remediation.

Remediation of sites was not regarded as important or was not taken into account in the design and planning of most of the older operational facilities. In most instances, this resulted in more extensive contamination of facilities and the environment, which presents greater complexity in the remediation of these sites. In recent years, however, a change in operational paradigms has occurred, with remediation being regarded as one of the phases of the total life cycle of an operation. Today’s life cycle management approach aims to treat each stage in the life of a facility or site, not as an isolated event, but as one phase in its overall life. Thus, the planning not only covers each stage, but is a continuing activity, taking into account actual and projected developments and feedback mechanisms between different stages in the life cycle. Thus, the remediation decision would be one step of the life cycle in a comprehensive planning process.

Remediation operations, being one of the very last activities in the total life cycle of an operational facility, normally experience several constraints, among which the financial aspects are the largest, with the need for a competent experienced workforce being second. Proper planning of remediation projects is therefore paramount for the successful completion of such projects. The RPM should, through proper planning of the project, be able to complete the project within the constraints that might be experienced. This may result, for example, in a remediation project being carried out over a longer period, or in phases.

The involvement of all relevant stakeholders is required during each phase of the planning process, especially when certain factors, such as the remediation goals, are being decided upon. It is worthwhile to note that, even with the existence of regulatory frameworks and sound technical considerations, stakeholder views and requirements tend to be the leading drivers that govern the decision making on remediation goals. The stakeholders in this instance are mostly the public, and will focus more on societal considerations such as continued safety of the environment, employment opportunities (short and long term), economic benefits from remediation activities and long term stewardship of the site, etc. This will tend to drive the remediation goals in a direction that will satisfy these considerations.

Performing remediation operations requires careful evaluation and planning, taking all the relevant constraints into consideration. The content of this book provides the information required to enable successful execution of a remediation project, taking all the different stages into account.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Radioactive Waste from the Mining and Milling of Ores, Safety Guide No. WS-G-1.2, IAEA, Vienna (2002).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Factors for Formulating a Strategy for Environmental Restoration, IAEA-TECDOC-1032, IAEA, Vienna (1998).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, A Directory of Information Resources on Radioactive Waste Management, Decontamination and Decommissioning, and Environmental Restoration, Data as of June 1995, IAEA-TECDOC-841, IAEA, Vienna (1995).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Technologies for Remediation of Radioactively Contaminated Sites, IAEA-TECDOC-1086, IAEA, Vienna (1999).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Extent of Environmental Contamination by Naturally Occurring Radioactive Material (NORM) and Technologies for Mitigation, Technical Reports Series No. 419, IAEA, Vienna (2003).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Monitoring and Surveillance of Residues from the Mining and Milling of Uranium and Thorium, Safety Reports Series No. 27, IAEA, Vienna (2002).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Characterization of Radioactively Contaminated Sites for Remediation Purposes, IAEA-TECDOC-1017, IAEA, Vienna (1998).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Design Criteria for a Worldwide Directory of Radioactively Contaminated Sites (DRCS), IAEA-TECDOC-1251, IAEA, Vienna (2001).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical Options for the Remediation of Contaminated Groundwater, IAEA-TECDOC-1088, IAEA, Vienna (1999).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, The Long Term Stabilization of Uranium Mill Tailings: Final Report of a Coo-ordinated Research Project 2000–2004, IAEA-TECDOC-1403, IAEA, Vienna (2004).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation of Areas Contaminated by Past Activities and Accidents, Safety Requirements No. WS-R-3, Vienna (2003).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Compliance Monitoring for Remediated Sites, IAEA-TECDOC-1118, IAEA, Vienna (1999).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Characterization Techniques Used in Environmental Restoration Activities, IAEA-TECDOC-1148, IAEA, Vienna (2000).

[14] INTERNATIOAL ATOMIC ENERGY AGENCY, Applicability of Monitored Natural Attenuation at Radioactively Contaminated Sites, Technical Reports Series No. 445, IAEA, Vienna (2006).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Release of Sites from Regulatory Control on Termination of Practices, Safety Guide WS-G-5.1. (2006).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Non-technical Factors Impacting on the Decision Making Processes in Environmental Remediation, IAEA-TECDOC-1279, IAEA, Vienna (2002).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation of Sites with Dispersed Radioactive Contamination, Technical Reports Series No. 424, IAEA, Vienna (2004).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Integrated Approach to Planning the Remediation of Sites Undergoing Decommissioning. IAEA Nuclear Energy Series No. NW-T-3.3 Vienna (2009).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Long Term Radiological Liabilities: Stewardship Challenges, Technical Reports Series No. 450, IAEA, Vienna (2006).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation of Sites with Mixed Contamination of Radioactive and Other Hazardous Substances, Technical Reports Series No. 442, IAEA, Vienna (2006).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Planning for Environmental Restoration of Uranium Mining and Milling Sites in Central and Eastern Europe, IAEA-TECDOC-982, IAEA, Vienna (1997).

[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Planning for Cleanup of Large Areas Contaminated as a Result of a Nuclear Accident, Technical Reports Series No. 327, STI/DOC/10/327, IAEA, Vienna (1991).

[23] BRUNDTLAND COMMISSION, World Commission on Environment and Development, Our Common Future, Oxford University Press, Oxford (1987).

[24] UNITED NATIONS, Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3–14 June 1992, vol. I, Resolutions Adopted by the Conference, A/CONF.152/26, United Nations, New York (1992).

[25] FERNANDES, H.M., PIRES DO RIO, M.A., FRANKLIN, M.R., L'assainissement des sites contaminés par des substances radioactives au Brésil, Recueil de contributions contamination radioactive: Quelles actions pour les sites pollués? Autorité de sûreté nucléaire and Ministère de L´écologie et du dévelopment, Paris (2004).

[26] INTERNATIONAL ATOMIC ENERGY AGENCY, On-site Habitability in the Event of an Accident at a Nuclear Facility: Guidance for Assessment and Improvement, Safety Series No. 98, IAEA, Vienna (1989).

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Preparedness and Response for a Nuclear or Radiological Emergency (Jointly sponsored by FAO, ILO, OECD/NEA, PAHO, OCHA, WHO), IAEA Safety Standards Series No. GS-R-2, IAEA, Vienna (2002).
[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards — Interim Edition General Safety Requirements Part 3, IAEA Safety Standards Series GSR Part 3 (Interim), IAEA, Vienna (2011).
[29] EIKELBOOM, R.T., VON MEIJENFELDT, H., "The soil clean-up operation in the Netherlands: Further developments after five years of experience", Proc. First Int. TNO Conf. on Contaminated Soil, Utrecht, 1995, Springer, Amsterdam (1985) 255–267.
[30] TACIS Programme, http://europa.eu/legislation_summaries/external_relations/relations_with_third_countries/eastern_europe_and_central_asia/r17003_en.htm
[31] GOVERNMENT OF CANADA, Nuclear Safety and Control Act, S.C. 1997, c. 9, Minister of Justice, Ottawa (1997).
[32] GOVERNMENT OF CANADA, Metal Mining Effluent Regulations, SOR/2002-222, Minister of Justice, Ottawa (2002).
[33] GOVERNMENT OF SASKATCHEWAN, The Environmental Management and Protection Act, 2002, E-10.21, The Queen's Printer, Regina (2002), http://www.publications.gov.sk.ca/details.cfm?p=489
[34] GOVERNMENT OF SASKATCHEWAN, The Mineral Industry Environmental Protection Regulations, 1996, E-10.2 Reg 7, The Queen's Printer, Regina (1996), http://www.publications.gov.sk.ca/details.cfm?p=1060
[35] GOVERNMENT OF CANADA, Canadian Environmental Assessment Act, 2012, S.C. 2012, c. 19, S. 52, Minister of Justice, Ottawa (1992), http://laws-lois.justice.gc.ca/eng/acts/C-15.2/
[36] GOVERNMENT OF CANADA, Canadian Environmental Protection Act, 1999, S.C. 1999, c. 33 Ottawa, Minister of Justice (1999), http://laws-lois.justice.gc.ca/eng/acts/C-15.31/
[37] The Contract between Žirovski Vrh Mine, d.o.o and Wismut, GmbH: Rendering of Professional Monitoring of the Permanent Close-Out of Uranium Mine Žirovski Vrh Liabilities, Todraz, 2003.
[38] INTERNATIONAL ATOMIC ENERGY AGENCY, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997), http://www.iaea.org/Publications/Documents/Infcircs/1997/infcirc546.pdf
[39] GOVERNMENT OF SASKATCHEWAN, The Reclaimed Industrial Sites Act, R-4.21, The Queen's Printer, Regina (2006), http://www.publications.gov.sk.ca/details.cfm?p=23009
[40] NORDIC ENVIRONMENT FINANCE CORPORATION (NEFCO), www.nefco.org/
[41] CASTRILLI, J.F., Barriers to Collaboration: Orphaned/Abandoned Mines in Canada, Joseph F. Castrilli, Toronto (2002), http://www.abandoned-mines.org/pdfs/Castrilli%20Final%20Report.pdf
[42] GOVERNMENT OF SASKATCHEWAN, An Assessment of Abandoned Mines in Northern Saskatchewan, Queen's Printer, Regina, 2001 (Year 1), 2002 (Year 2), 2003 (Year 3), http://www.environment.gov.sk.ca/Default.aspx?DN=52a8a117-332f-4c49-89b9-2f90d79bca5a
[43] INTERNATIONAL COMMISSION ON RADIATION PROTECTION, 1990 Recommendations of the International Commission on Radiation Protection, IRCP Publication 60, Ann. ICRP, **21**(1–3) (1991).

ABBREVIATIONS

ALARA	as low as reasonably achievable
BOO	build–own–operate
BOOT	build–own–operate–transfer
BRS	background reference site
CEEC	Central and Eastern European Countries
CNEN	Nuclear Regulatory Commission (Brazil)
DRCS	directory of radioactively contaminated sites
EIB	European Investment Bank
FEAM	Fundação Estadul do Meio Ambiente
FSU	Former Soviet Union
FUSRAP	Formerly Utilized Sites Remedial Action Program (United States of America)
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources (Brazil)
INB	Industrias Nucleares de Brasil
MNA	monitored natural attenuation
NEFCO	Nordic Environment Finance Corporation
NGO	non-governmental organization
NORM	naturally occurring radioactive material
Phare	Poland and Hungary: Assistance for the Restructuring of the Economy
RPM	remediation project manager
TACIS	Technical Aid to the Commonwealth of Independent States
UNCED	United Nations Conference on Environment and Development

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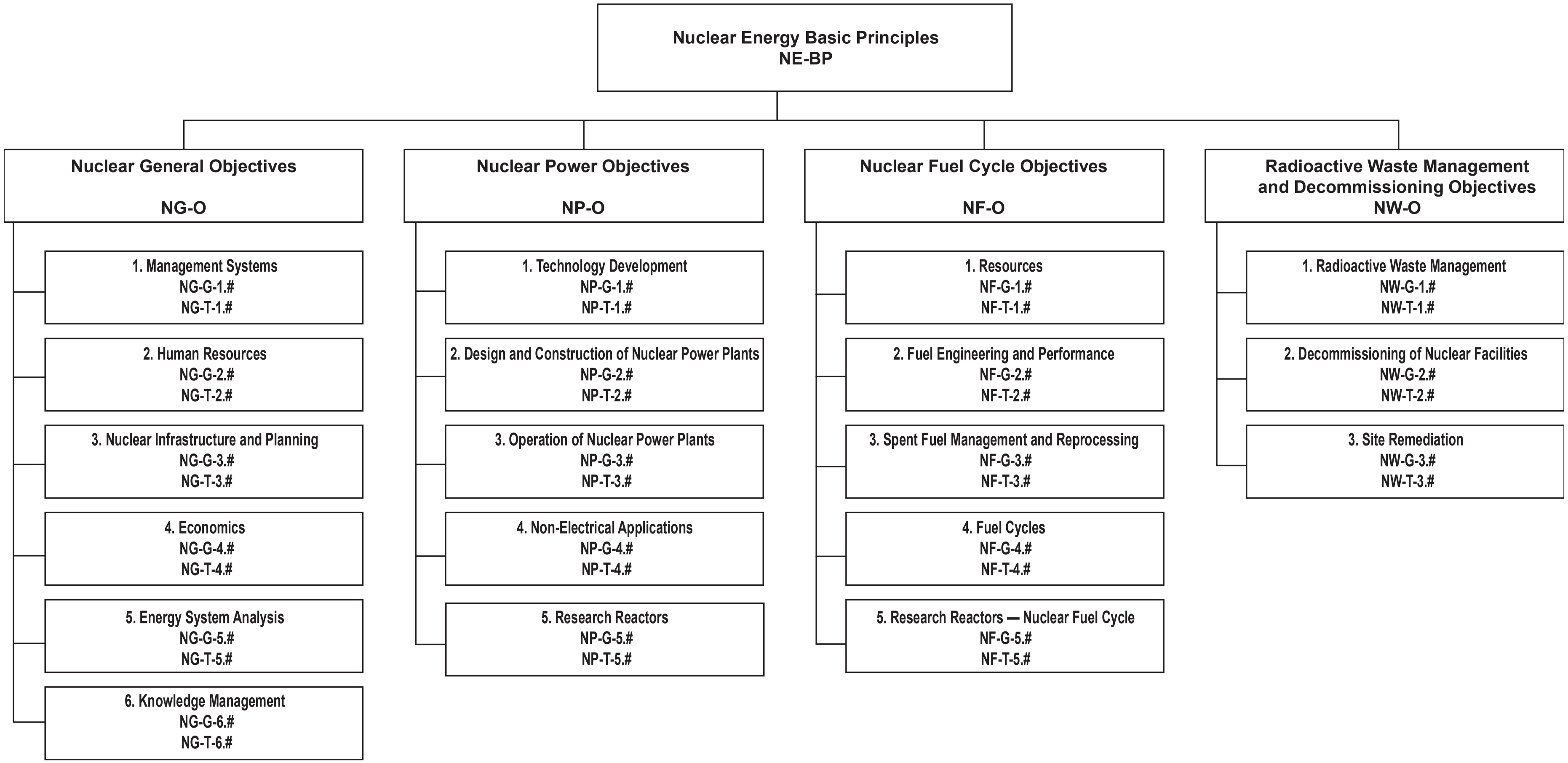

Key

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

Examples

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