IAEA-TECDOC-1279

Non-technical factors impacting on the decision making processes in environmental remediation

Influences on the decision making process such as cost, planned land use and public perception

INTERNATIONAL ATOMIC ENERGY AGENCY

April 2002

The originating Section of this publication in the IAEA was:

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International Atomic Energy Agency
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NON-TECHNICAL FACTORS IMPACTING ON THE
DECISION MAKING PROCESSES IN ENVIRONMENTAL REMEDIATION
IAEA, VIENNA, 2002
IAEA-TECDOC-1279
ISSN 1011–4289

Printed by the IAEA in Austria
April 2002

FOREWORD

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

In response to this, the IAEA has initiated a comprehensive programme of work covering all aspects of environmental remediation:

— factors important for formulating a strategy for environmental remediation;
— site characterisation techniques and strategies;
— assessment of remediation technologies;
— assessment of technical options for cleanup of contaminated media;
— post-restoration compliance monitoring;
— assessment of the costs of remediation measures;
— remediation of low-level disperse radioactive contaminations in the environment.

While this project mainly focus on technological aspects, non-technical factors will be influencing the decision making process in remediation decisively. Often their influence is only tacitly accepted and not explicitly acknowledged by the responsible decision makers. This makes it difficult to trace the decision making process in the event that it has to be revisited.

The present publication attempts to make these factors explicit and to present methods to include them consciously into the decision making process. As one such important factor is cost, a database on the cost of environmental remediation measures was developed and is included as an Annex. This database will also form part of the Directory of Radioactively Contaminated Sites currently under development for access via the Internet.

The IAEA wishes to express its thanks to all participants in the work. Special thanks are due to Z. Dlouhy, who under a consultants' service agreement helped to develop the database on costs of environmental remediation, and to A.T. Jakubick, R. Kahnt and F. Pelz, Wismut GmbH, who provided the material for Appendix D.

The IAEA officer responsible for this technical publication was W.E. Falck of the Division of Nuclear Fuel Cycle and Waste Management.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. Background

Responding to the needs of Member States, the IAEA has launched an Environmental Remediation Project dealing with the problems of radioactive contamination world-wide and aimed at collection and dissemination of information by publishing documents on key problems of environmental remediation of contaminated sites.

The term ‘remediation’ is used here to encompass all activities leading to reduced exposure to radiation and to improved environmental and/or economic value of a site. It does not, however, necessarily imply recreation of pristine environmental conditions. The terms ‘rehabilitation’ and ‘restoration’ are often used interchangeably in a similar context, depending on the language and other national peculiarities. In the present context the term ‘remediation’ refers to the management of contamination, that is, removal, fixation, monitoring, and so on.

In addition, the project includes organising and conducting an IAEA Co-ordinated Research Project in the given subject area [1], as well as participation of IAEA experts in concrete remediation projects as requested by individual Member States.

Table I. Relationship between relevant topical reports produced or under development

Safety	Management	Databases	Technology	Special Topics
Cleanup of areas contaminated by past activities and accidents *work in progress*	Factors for formulating Strategies for Environmental Restoration IAEA-TECDOC-1032	Design Criteria for a Worldwide Directory of Radioactively Conta-minated Sites (DRCS) IAEA-TECDOC-1251	Technologies for Remediation of Radioactively Contaminated Sites IAEA-TECDOC-1086	Technologies for long-term stabilization and isolation of uranium mill tailings *work in progress*
Management of radioactive waste from mining and milling of ores *work in progress*	Characterization of Radioactively Contaminated Sites for Remediation Purposes IAEA-TECDOC-1017	A worldwide directory of radioactively contaminated Sites (DRCS) Web-based database *work in progress*	Technical Options for the Remediation of Contaminated Groundwaters IAEA-TECDOC-1088	Environmental contamination by NORMs and relevant abatement measures *work in progress*
Monit. & surveill. for ensuring the radiol. safety of residues from mining and milling of U and Th *work in progress*	Compliance Monitoring for Remediated Sites IAEA-TECDOC-1118		Site Characterization Techniques used in Environmental Restoration IAEA-TECDOC-1148	Remediation of sites contaminated by hazardous and radioactive substances *work in progress*
	this TECDOC		Remediation of sites with low levels of radioactive contamination *work in progress*	

In this context, the IAEA has published several publications, and is carrying out work dedicated to specific technical or conceptual areas (see Table I). These subjects include: characterisation of contaminated sites [2], factors relevant for the selection of the preferred remediation strategy [3], overview of applicable technologies for environmental remediation [4], options for cleanup of contaminated groundwater [5], and planning and management issues [6][7]. In addition, a number of other IAEA publications dealing with related aspects, but compiled under different IAEA projects can be mentioned. These include TECDOCs on the remediation of uranium mill tailings, decontamination of buildings and roads, and the characterisation of decommissioned sites.

Of particular importance is the overall effectiveness of a project within the given legal and institutional framework, under the prevailing socio-economic boundary conditions, and balancing technology performance and risk reduction with the fixed or limited budgetary resources, not simply the result of the technical remediation operation itself (cf. Figure 1). Public perceptions of the remediation process and its results can be of overruling importance. Cost–benefit assessments and constraints on the availability of resources could also have a decisive influence. Underlying rationales and incentives for remediation, which may be of economic nature, such as envisaged future land use, or of more ethical quality, need to be included.

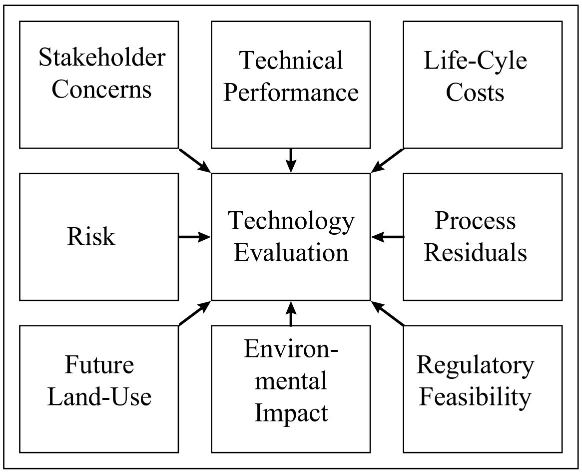

FIG. 1. Technology evaluation framework [8].

The considerations concerning the justification of a remedial action and the criteria for its termination are laid down in the relevant IAEA Safety Standard [9]. However, the subject of non-technological factors needs further enlarging on, because it may be just these, which eventually control the selection of strategies and techniques employed. A further elaboration of these topics, treated rather briefly in the already published document on the selection of environmental remediation strategies [3], appears to be necessary to provide practical illustrations for specific cases. To fulfil this task, the IAEA decided to provide Member States with a more comprehensive overview of these topics in the form of this technical Publication. The decision making processes concerning the justification of remedial action and the selection of an appropriate remediation strategy and technique are intimately interwoven.

1.2. Scope of the Publication

This TECDOC is intended for individuals interested in the design, selection, review, or approval of remediation projects.

It provides an overview of decision aid methods, describes the context of the decision making process, and addresses the factors influencing the selection of appropriate environmental remediation technology as applied to land-based, radioactively contaminated sites. Outside its scope are the engineering and safety aspects and cases of the marine environment being contaminated as a result of nuclear testing, accidents, and former sea dumping practices, as well as regular decommissioning activities. These are or have been the subject of other IAEA projects. Similarly, radiation protection issues at contaminated sites and the overall justification of remediation are dealt with under the umbrella of other projects.

A range of non-technological factors will influence the choice of techniques to be employed in remediation and the strategy for their implementation. Some of these factors are pertinent to the site in question, such as the envisaged or designated future use of the land. Others may not be directly related to the site, but reflect *inter alia*

— regulatory boundary conditions, e.g. standards for radiation exposure of the public and site-workers,
— socio-economic drivers, e.g. the need to create jobs locally and to minimise social, cultural and economic impacts,
— budgetary constraints, e.g. the need to minimise the costs to develop, demonstrate, deploy, and implement techniques.

While it is generally accepted that non-technical aspects have to be included into the decision making process, or that they bring themselves to bear implicitly, there is a considerable divergence of thoughts on the methods for their formal incorporation. The overall objective would be to arrive at an instrument for selecting the most appropriate solution, which is not necessarily the ‘best’ from a mere technical standpoint of view. Such factors and a range of possible mechanism for including them in a quantitative and traceable way with the aim to reduce programmatic risks and improve the public acceptance of environmental remediation projects are the subject of this TECDOC.

The present publication illustrates the non-technical factors influencing remediation decision making. It has to be borne in mind, however, that there are always decisive engineering and scientific considerations. If a technology is not viable or is not expected to perform for the problem in hand, the choice is limited accordingly. For instance, a pump-and-treat or excavation option may appear attractive to the public, as it seems to ‘remove’ the problem, but in a given case its effectiveness or efficiency may be questionable.

Hence, while the societal context certainly exerts a strong influence on the decision making processes — and it may be indeed advisable to actively induce the public to participate, it is important to remember that the implementability of the result is constrained in any case by its technical feasibility and overall safety requirements. These constraints have to communicated to the stakeholders in an unbiased way for all solutions under scrutiny. If technical solutions are suggested from outside the technical community, their technical feasibility has to investigated within the decision making process. The specific properties of selected remediation techniques and their applicability to real problems have been discussed in several technical publications published already by the IAEA, e.g. [4][5][1].

1.3. TECDOC Structure

The TECDOC is structured into six parts. Section 2 introduces remediation as a decision problem and outlines possible conceptual approaches to formal decision aiding for choosing solutions. Section 3 explains how these technology choices for remediation projects are situated in the societal and economic context. Given the methodological background and context, the relevant non-technological factors and methods for their assessment are discussed in Section 4. Section 5 provides a summary and conclusions. A glossary of relevant terms and acronyms is also provided. National examples for implementing conceptual approaches or problems with specific factors are presented as appendices and an annex provides historical cost data on selected remediation technologies.

2. DECISION AIDING METHODS

2.1. Rationale for Using Formal Decision Methods

The primary objective of remediation, whether in an ongoing activity or in dealing with consequences of past practices or accidents, is to remove radiation exposure pathways for human receptors [9]. More recently, attention has also been placed on reduction of wider environmental impacts. These objectives can be met by a variety of technical and management measures, and combinations thereof. However, because of long time frames, the public goods character of many environmental and health services, and the variety of technical, scientific and economic inputs, effective site rehabilitation requires a concerted approach which can identify and select appropriate remediation technologies consistent with radiation protection standards and the demands of society.

An ultimate goal of remediation would often be the unrestricted release of a site or territory. However, particular circumstances and considerations such as budgetary constraints or the disturbance of valuable habitats, may lead to prohibiting access. Such restrictions can be temporary, as may be expedient in the case of contamination with short-lived nuclides, or long-term, as for uranium mill tailings impoundments.

The need for remediation and the judgement about permissible residual contamination levels are often driven by society's demand to bring a site back into use. Depending on the envisaged land use and foreseeable exposure pathways, permissible residual contaminations may be different. Land to be sealed and earmarked for industrial use might be left with a higher residual contamination than land for residential, recreational or agricultural uses. The scope of decision making is illustrated in Figure 2.

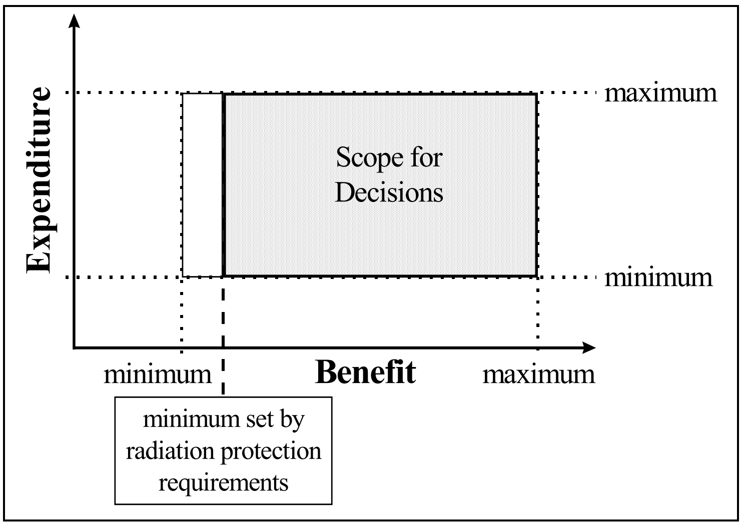

FIG. 2. The scope for decision making.

While in many instances the objective is to restore some or all aspects of the original functionality of a site, a new land use may (need to) be envisaged in cases of past practices and obsolete industrial activities. Depending on the level of socio-economic pressure, different remediation strategies and technologies may be chosen. Where a high demand for land puts a prime price on it, more expensive technologies and/or faster processes might be chosen. It is also true, by corollary, that the choice of remediation technique and strategy may put restrictions on possible future land use. For instance, certain land use types may interfere with containment or *in situ* fixation techniques.

In sum, remediation activities are undertaken to address public health risks for communities living with a legacy of contamination, whether that be from operational or accidental occurrences, in the context of wider development objectives. In this context, the complexity of natural systems, the time gaps that can exist between contamination and response, and the consequent uncertainties concerning management risks and requirements for long-term safety pose special challenges for decision makers.

Typically, there will be two concurrent and interwoven levels of decision making: one which is concerned with the justification of the remediation action, based mainly on radiological and other risk or impact criteria [88], and another one concerning the development and implementation of an overall satisfactory remediation strategy in the wider social and institutional context. To achieve an integrated remediation strategy usually an iterative approach between these two levels of decision making processes is 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 Declaration affirms "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 and acceptance of the problems to be addressed.

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 evaluation of options to organise their information and to communicate about the options to decision makers and the interested public. To be effective in this way, a formalised decision making technique must fulfil the following basic criteria:

— 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 all possible options for action,
— provide unambiguous advice.

When these conditions are met, the decision aiding tools make clearer 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 the understanding of complex issues, and their interactions, permitting a more rounded appreciation of 'trade-offs' being made or proposed by decision makers and aids selection of an optimum solution.

2.2. The nature of Formal Decision Support Analysis

A good decision aiding method or model has a coherent conceptual underpinning that relates well to the problem being addressed. In particular, it needs to be clear to the users, not just the model developers, how the method helps to direct collective action for robust decisions, often in controversial settings.

Formal tools are not an end in themselves. The methods and degrees of complexity of formalised decision making processes must be adapted to the problem in hand. Among other things, the cost of implementation of decision aid tools should not usually 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 formalised decision making process becoming counterproductive.

The objective of applying formal decision making procedures is the satisfaction or optimisation of choice criteria within a given reference framework. This reference framework, however, may be bounded and controlled by factors external to technological aspects, or indeed foreign to the problem at hand, as is discussed in detail in the subsequent chapters. Such bounds on the formal optimisation process may come from many different sources, e.g., fundamental radiation protection criteria, protection of certain habitats or species, and political preferences more generally [10]. Within these bounds, evaluation criteria include, *inter alia*, the minimisation of gross amount of resources to be expended, making resource use more uniform over time, minimisation of radiation exposure to selected target groups, minimising overall environmental impact, minimising wastes generated, and, perhaps, improvement of employment in the region.

When choosing formal decision aid tools, attention should be given to:

- scientific considerations of rigour, coherence, measurement validation and sensitivity testing for the sequences of data transformation, aggregation and modelling;
- user-oriented considerations of relevance for framing a decision problem and for discussing pros and cons.

Practical decision reasoning thus requires the construction of local, problem-specific models in which attention is confined to a restricted universe of propositions [11].

Approaches to decision making vary considerably from Member State to Member State and from organisation to organisation. While some approaches are quite informal, for instance based on personal judgements by experts or administrators, others are much more structured. A range of pertinent decision aiding tools has been developed for the environmental context in recent years, mainly based on the earlier experience with complex management tasks in e.g. the construction sector. Some are outlined below, together with a discussion of their data requirements, potential benefits and short-comings.

Once measurable remediation goals are set, analysis will focus on defining technologies necessary for their achievement. In many situations, remediation goals can be specified in terms of sustainability standards that, taking account of the various forms of contamination, the characteristics of the site or wider ecosystem, define the requirements to meet remediation objectives. For example, in the CRiTiNC method developed for the European Commission during 1998–2000 [12], sustainability standards are set on the basis of an assessment of the requirements necessary to ensure maintenance of key environmental functions.

Given that the approaches may differ between Member States and organisations, this publication provides a general outline consisting of a number of phases. These are not fixed, and are provided for assistance in framing the problem and determining an appropriate selection of tools and techniques to undertake evaluation of options. These phases are summarised in Figure 3 and further considered within the following sections.

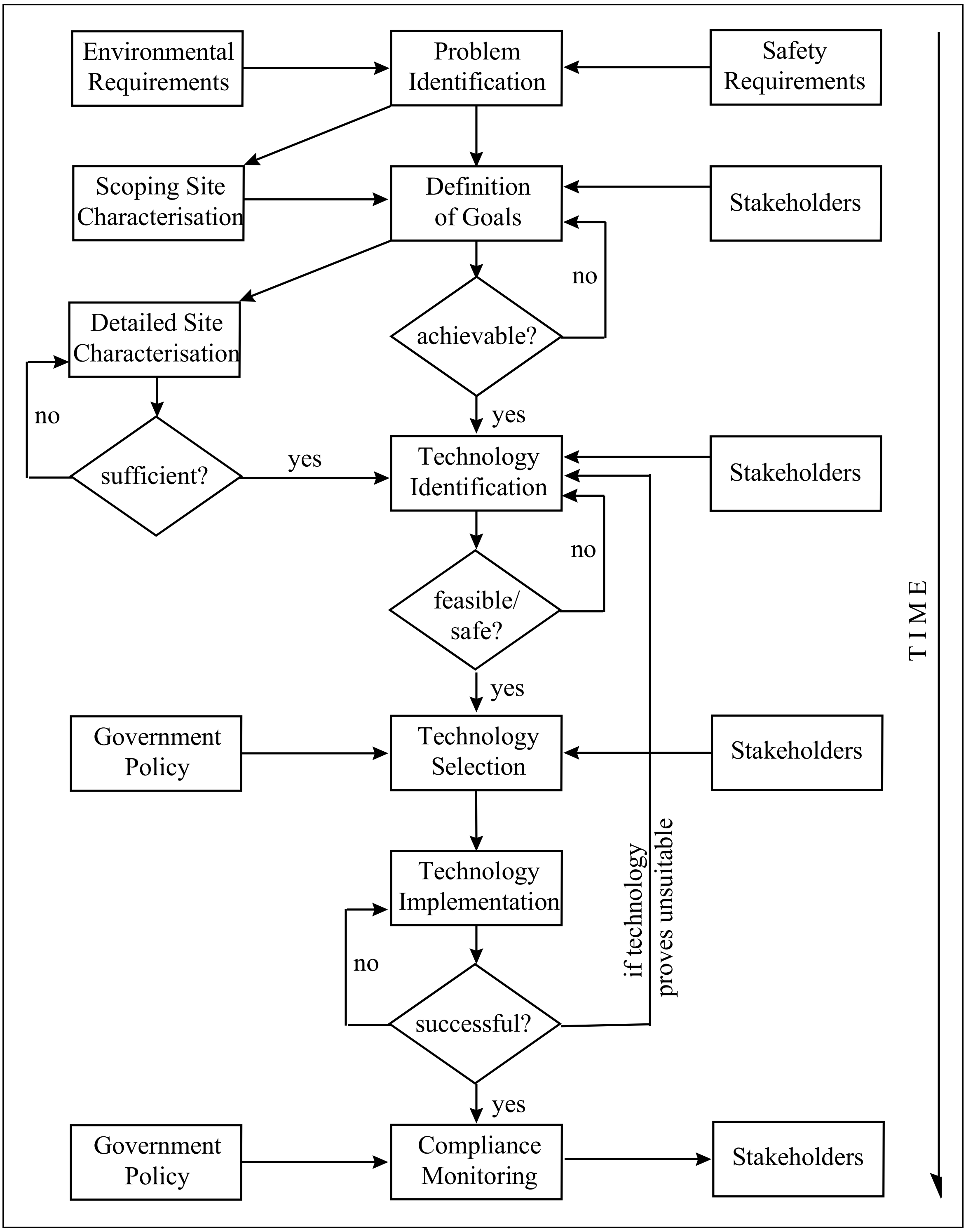

FIG. 3. The phases of decision making in choosing appropriate strategies and technologies.

2.3. Key Dimensions of the Evaluation Process

2.3.1. Building the steps of analysis

The first phase is problem identification. Then, after identifying the the main features of the problem being addressed, comes the step of defining the set of possible actions, or solutions to be considered. This relies on a good understanding of the contamination problem. For example, the technologies for controlling inhalation exposure routes will be different from those related to controlling direct ingestion. Also, as already mentioned, different land use and wider societal goals will influence the options to be assessed. So, as shown in Figure 3, the initial stages of a decision making process involve a number of aspects:

— problem identification;
— identifying options; and
— detailed characterisation of technologies and their consequences.

Having sufficiently identified the problem and available information, data or insights into the issues, it is possible to enter into option generation. This phase incorporates some knowledge of the available solutions, either through having undertaken initial research or through representation by relevant expertise. Initial option generation may be undertaken through 'brainstorming' sessions or workshops, conducted by or for the problem holder. These technical options are likely to be very generic, e.g. 'contain', 'excavate', 'treat', etc.

Once the basic options have been framed, it is then necessary to bring together scientific, technical and wider societal considerations, for a full and detailed characterisation of options and evaluation of their respective advantages and drawbacks.

So, as shown in Figure 3, the subsequent stages of a decision making process involve the following aspects:

- full evaluation of options;
- communication of options to the stakeholders; and
- selection of a solution.

After the an initial solution is selected, an ongoing process of implementation, monitoring, interaction with the stakeholders, and review occurs [13].

To aid the specification of the options, and also the criteria for analysis during decision making, it is necessary to undertake systematic and logical option development. This process, initially carried out in a simple way, ultimately aids comparison of the options within the selected decision framework through ensuring consistency in identification of all relevant or significant issues.

For example, in the context of a contaminated site, a simple process diagram can be used to indicate the inputs and outputs. On development of options for remediation, it would be possible to specify the inputs and outputs associated with the options, and thus permit comparison.

Figures 4 and 5 indicate the development of two options from a basic understanding of the issues associated with a contaminated site. The problem situation is a contamination source in association with groundwater and an agricultural land use, which could be on, or near the contaminated site. From simple consideration of the linkages and issues, it can be seen that the outputs, or effects, are contamination of the soil and groundwater, which due to the land use near the site leads to ingestion of contaminants, dose uptake and associated health effects.

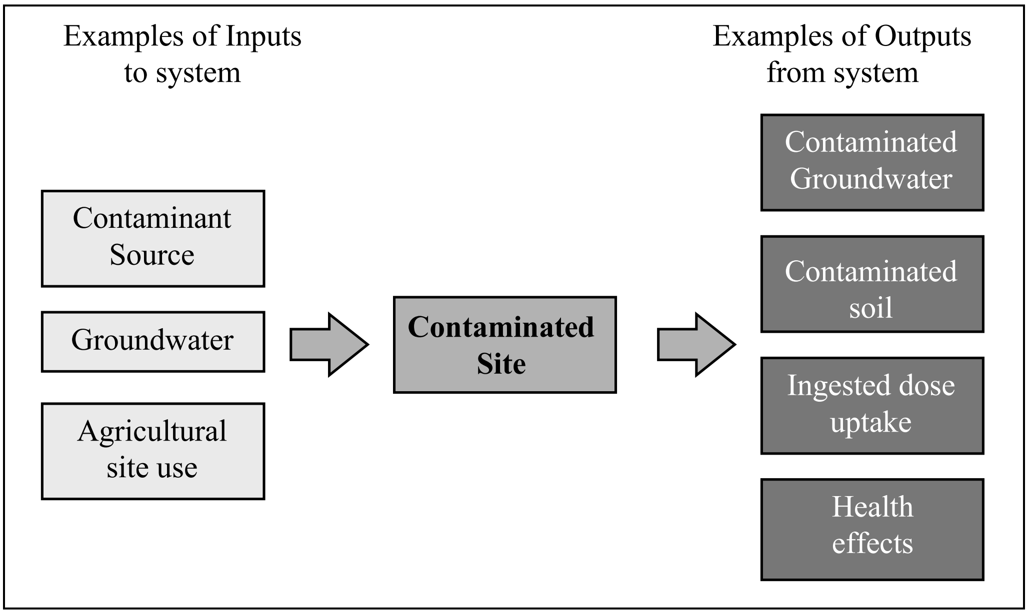

FIG. 4. Initial situation for technology selection.

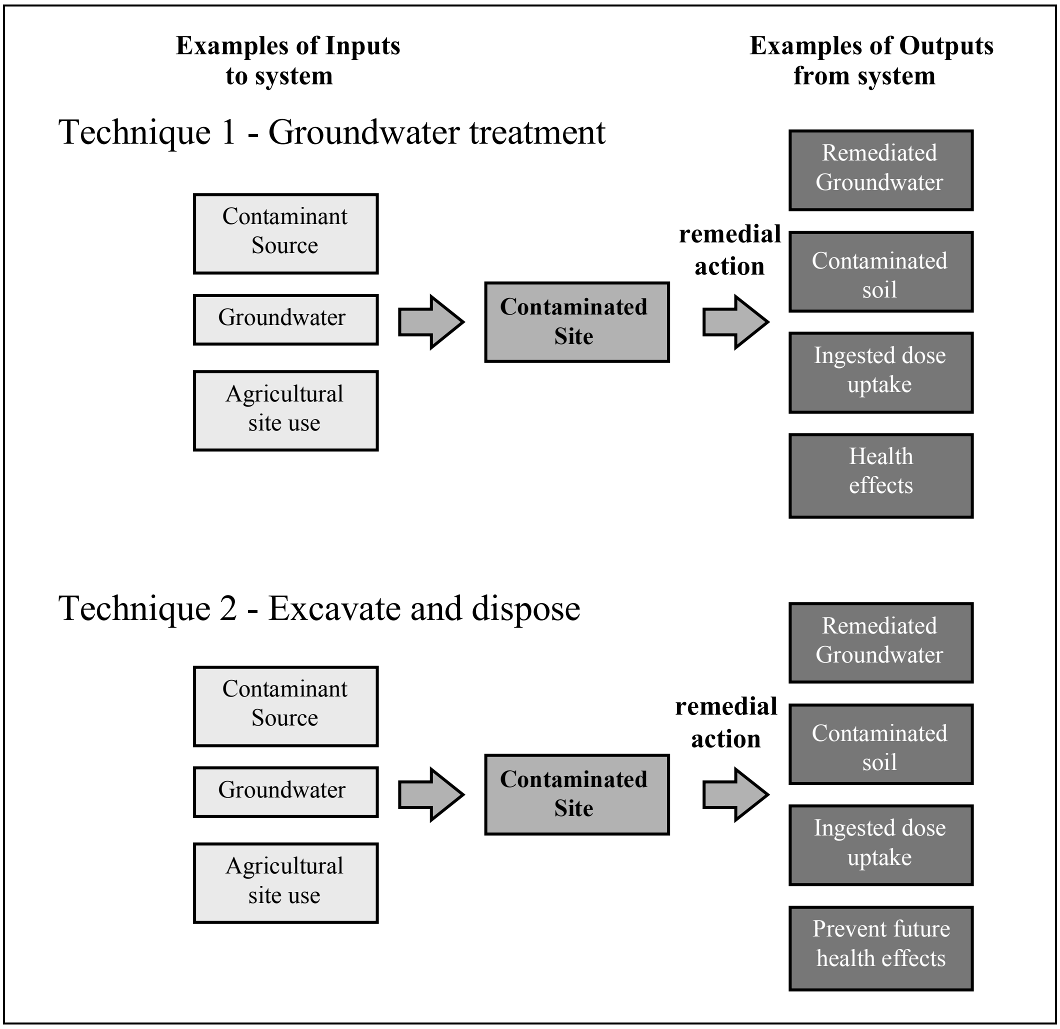

FIG. 5. Simple option representation through basic analysis of inputs, outputs and effects.

For the purposes of this example, Figure 5 considers two techniques: treatment of groundwater, and excavation of the contamination source. Even at this generic level, it can be seen that there are differences emerging between the two options under consideration. Further, these figures begin to develop, or identify the properties of the techniques, which leads on to identification of the assessment criteria. This will also aid identification or selection of the assessment method. Development of relevant assessment criteria may also reveal maximum/ minimum acceptance or target criteria in addition to the radiological protection requirements — it is these that frame the 'Scope for Decision' as indicated in Figure 2.

At this point the process enters the phase of option development or evolution. The generic technologies, of containment for example, must be investigated and developed further. As the options are being developed, it will become obvious that there are information and data requirements, which require parallel development or investigation. This is the phase termed Detailed Characterisation of the Options in Figure 3. This process can be facilitated through the use of formal supporting tools and techniques, such as process flow diagrams, Life Cycle Analysis, scenario models, etc., and through the incorporation of relevant societal concerns through stakeholder participation in successive steps of the process. These aspects will be discussed in the following subsections.

2.3.2. Life Cycle Analysis

LCA is utilised to undertake assessment of both the direct and indirect environmental consequences resulting from any system or process. As such, it seeks to provide an insight into the interactions and a measure of the total effects throughout the entire 'life cycle', often referred to as 'cradle to grave' — from extraction of the raw materials, transport, manufacture, use and eventual disposal and degradation. The SETAC 'Code of Practice' [14] lists the objectives of LCA as:

- to provide as complete a picture as possible of the interactions of an activity with the environment;
- to contribute to the understanding of the overall and interdependent nature of the environmental consequences of human activities; and
- to provide decision makers with information which defines the environmental effects of these activities and identifies opportunities for environmental improvements [15].

Work undertaken for the United Kingdom's Office of Science and Technology Foresight Programme [16] proposes that LCA has four phases, defined as:

- *Goal Definition and Scoping*: defining the purpose, scope, functional unit and data requirements for the study.
- *Inventory Analysis*: quantifying the inputs and outputs of materials, energy, emissions and solid waste (environmental burdens or interventions) in relation to the functional unit;
- *Impact Assessment*: translating the interventions quantified at Inventory Analysis into impacts; and
- *Improvement Analysis/Interpretation*: identifying points for improvement in the system.

Typical issues identified and assessed within a LCA approach are listed in Table II below.

Table II. Typical issues identified and assessed within an LCA approach

POLLUTION	DISTURBANCES	RESOURCE DEPLETION
— radiation	— direct victim	— biotic resources
— ecotoxicity	— physical habitat degradation	— land use
— human toxicity	— landscape degradation	— water use
— acidification	— loss of amenity	
— eutrophication		
— global warming		
— ozone depletion		
— noise		
— odour		

For the purposes of decision making, LCA is not strictly a decision analysis tool, *per se*. Rather, LCA is a process for analysis and representation of a complete system. As such, it can be used to support, or aid decisions, primarily through comparison of options. LCA, through using a common 'functional unit' is able to compare the relative environmental merits for different processes, schemes, scales of operation, etc.

One of the difficulties associated with the development and use of LCA is the need to relate all aspects (inputs, outputs, etc.) of a process into a form which is readily comparable. Typically this 'functional unit' has been rationalised to either a measure of energy or a monetary value.

Initial steps require the preparation of a process flow diagram and development of a complete balance sheet of masses and energy identified within the system or option under consideration. It is then necessary to produce a balance sheet of the effects resulting from these activities. This will generate data for energy usage, land use, secondary waste generation, etc. The difficulties arise when trying to undertake the assessment of these effects and determine/ develop the functional unit. Although often not ideal for consultation/participation exercises, or for situations where public concern is high, one method is to rationalise all environmental effects to a monetary value (Fig. 6). Many of the supporting methods/tools/approaches on valuation methods can be utilised to aid this process.

Effect Category	Category Result	X	Cost Base	=	Cost
Use of energy	x_1GJ		2.80 \$/GJ		y_1\$
Greenhouse effect	$x_2$kg CO_2		0.022 \$kg CO_2		y_2\$
					$\Sigma\, y_1+y_2.....+y_n$ \$

FIG. 6. Example of monetarisation of contamination effects.

One difficulty in working with and presenting LCA is the requirement for, and subjectivity associated with determining the base cost. Although a relatively flexible tool, with respect to detail and development, it is possible for over-simplification to compromise the role of identifying the overall environmental impacts. However, for many decision aiding situations a simplified approach may well be justified.

2.3.3. Constructing Decision Scenarios

Scenarios for site rehabilitation and redevelopment are intended to explore different co-evolutions of the relevant ecological, social and economic systems. Each scenario should specify a set of site remediation and management practices that, depending on circumstances, may assure the maintenance over time of health standards, risk thresholds and specific economic and ecosystem activities, or may put a number of these values at risk.

Typically, the scientific analyses quantify and cross-link two broad types of information:

- economic information — such as systems of accounts and models quantifying volumes of sectoral production, water use and pollutant emissions on a national, regional or local basis;
- geographical/environmental information — such as an aquifer or watershed, or land use patterns and GIS-based representations of risks or of contamination.

Such scenarios do not aim to predict. Nor is it as simple as identifying which is the 'best' remediation or management scenario. The exploration of economic and physical feasibility is interwoven with assessments of the adequacy or not of existing institutional arrangements at different scales of jurisdiction.

2.3.4. Stakeholder involvement in option identification and evaluation

Stakeholder mapping, a type of institutional analysis, can be carried out as a formal research task, through documentary analysis and selected interviews. This aims to identify significant socio-economic groups and their interests, concerns, and *de facto* entitlements in regard to protection from risks, access to benefits from rehabilitated sites, shares of the economic and other costs, and possible health risks, associated with the remediation processes. These stakeholder interests are usually quite diverse. They include the actual or potential future users of the site and the resources linked to it (land, water, wetlands, etc.); they include all sectors who stand to gain, or to lose, as a function of decisions about site remediation; and they include the various agencies presumed (whether in the public eye or by duly constituted authority) to have competence for managing the site and the activities contributing to contamination and to remediation.

Stakeholder consultation can be an efficient (if not indispensable) source of insight and information to analysts and decision-makers on management options. Often, however, the communication process is driven the other way, from pressure groups to policy and decision-makers. In this case the stakeholder mapping does not need to be done as a desk exercise. Rather, it is built up *de facto*, and emerges over time as different persons, sectoral groups and institutions make heard and felt their 'claims' on the process in various ways.

It is often most satisfactory for a stakeholder concertation to be deliberately fostered as part of the technology selection process. Those responsible for defining and evaluating site remediation options then seek deliberately to incorporate stakeholder interests within key stages of decision making, in order to achieve a 'tuning' of the analysis categories and result presentation with the aim of enhancing prospects of legitimacy for the proposals.

2.4. Putting Information and Judgement to Work

2.4.1. Overview of Decision Aiding Methods

Information can be exploited in a variety of forms to appraise technology options. This section of the publication summarises four main groups of techniques that are commonly used to aid decision-makers in selection of remediation technologies.

A simple approach to deciding between options is sorting on the basis of their effectiveness and their costs (or other drawbacks). First, the desired or imposed targets, e.g. cleanup levels, are defined. Remediation options not capable of meeting the target are eliminated. The remaining options are then ordered according to some additional criterion, such as cost. The lowest cost alternative capable of meeting the target is adopted (see also Figure 2).

Sorting may go through several iterations, where ordering according to different variables is employed. Questions that arise are, for example, how to specify the target (there may be several relevant criteria), how to go about aggregation of different categories of costs and benefits, how to decide the weighting or trade-offs between different criteria, how to resolve conflicts over the distribution of costs and benefits, how to cope with uncertainty. These issues can be resolved through informal expert judgement, or else more formally structured methods for aiding decision making as indicated below.

- Economic cost–benefit and cost-effectiveness analyses (Section 2.5.1);
- Multiple criteria decision aid methods (Section 2.5.2);
- Expert and knowledge-based system (Section 2.5.3);
- Deliberative procedures and stakeholder concertation (Section 2.5.4).

2.4.2. Expert Opinion and Judgement

Everyone is capable of making, and makes many decisions in everyday life. In many practical instances, decisions are being made, or their basis is being prepared, by 'experts' — either specialists in their area or field, or more specifically decision analysis. The decision makers may be experts themselves, for instance public administrators may have received technical training in relevant areas, or may consult outside experts. While the use of expert judgement is often an effective way to utilise the experience accumulated in individuals, the actual judging process is not always transparent.

Formal evaluation aims at aiding transparency in planning and decision problems by systematically structuring relevant aspects of choices — for instance, the assessment of health consequences, of site suitability for different uses after remediation, or of (ecological) benefits and impacts resulting from alternative cleanup technologies. Evaluation is usually not a one-off activity, but takes place over time, in all phases of decision making. A systematic support for complex planning and decision problems requires a balanced approach, on the one hand to avoid too much detail, and on the other hand not to end up with too little information. Moreover, policy processes are not static, and judgements regarding the political relevance of items, alternatives or impacts may exhibit sudden changes, particularly over longer time-scales, i.e. a decision may become invalid as the regulatory framework develops. So, the evaluation tools have to be flexible and adaptive in nature.

The critical assessments through expert judgement were mainly developed in the context of (probabilistic) safety assessment for nuclear waste disposal [17], but many of the considerations are equally applicable in the present context. Of particular interest are the considerations concerning bias and conflicting or diverging opinions, both leading to uncertainty in the end-result of decision making and reflecting the uncertain basis on which typically decisions have to be made. The ability to think about uncertainty and, hence, to consider it as part of a decision making process may be strongly culturally determined [18].

Several methods for eliciting experts' opinions are being used. Apart from separately eliciting individual expert's opinions, a number of feedback and group techniques are in use, e.g. Delphi, Nominal Group Techniques (NGT) and brainstorming [17]. Aggregation of experts' opinions poses a number of conceptual and practical challenges. The methods mentioned have been used extensively in the context of probabilistic safety assessment for nuclear waste repositories, but their direct application and usefulness in the context of decision aiding for environmental remediation might be limited.

Nevertheless most decision making processes in environmental remediation exhibit features similar to interactive group techniques and, thus, considerations concerning a structured approach and biases should be valid. Similarly to decision making conferences [17], a reflection on the following points might be helpful to understand the decision problem and its outcome:

- exploration of motivational biases (re. stakeholders);
- definition of the uncertain parameters (e.g. volumes of contaminated material);
- considerations of how the parameters are assessed/measured;
- considerations of the factors that influence the parameters and the assumptions that need to be made in estimating values of parameters;
- consideration of sources of uncertainty;
- exploration of the decision makers' individual and joint range of knowledge to minimise the effects of individual bias, or at least to recognise its potential influence.

2.4.3. Uncertainty and Sensitivity Analysis

Applications of technology, and economic and environmental processes generally, are marked by an inherent incompleteness of scientific knowledge. Simulations and scenarios for conceivable future economic activity can make use of precise categories of economic goods and services, assigning the 'uncertainties' to the quantities in each categories, the rates of technological innovation, and to the space and time specifications of the future commodity production, transportation and use. By contrast, in the case of unplanned 'side-effects' on ecological systems even the categories of systems flows and outcomes are not able to be so precisely represented, and these effects will, in many cases, fully emerge only over long periods of time and across large distances. The affected parties may be extremely diffuse (for example people suffering from ill-understood health problems induced by or aggravated by urban pollution or low levels of radiation), or hypothetical in character (future generations and ecosystems that may be affected by climate change or contaminations).

Sensitivity analysis is used to examine how robust an alternative is to changes in the information used in the original analysis. Sometimes the original information or data set may be limited or not precise in nature. Additionally, the misuse or selection of parts of a data set can lead to the manipulation of the final solution. The application of sensitivity analysis can help to show in a more transparent nature, how varying certain parameters can affect the outcome of a decision making process.

Sensitivity analyses are powerful instruments to guide the decision making process and can help to evaluate the impact numerical values of variables have on the outcome of such a process. Sensitivity analyses will help to distinguish between crucial variables and those less so. In consequence they will help to guide and optimise the data collecting efforts. A prerequisite, therefore, is some form of quantification of the various variables in the decision aiding system.

A variant of this are critical path analyses, which serve to identify those criteria that have to be met in order that the overall process can proceed. The result is a ranking or weighting structure identifying the relative importance of decisions.

Applying Monte-Carlo simulation techniques to the input variables can also give valuable information on the possible outcomes of complex decision making processes and/or the performance of the environmental remediation project under investigation. Sampling and statistical analysis of the various realisations of the underlying model also allows conclusions on the likely outcome of the project.

This has produced a shift from the self-contained use of analytical ‘expert’ procedures such as probabilistic risk analysis and economic cost-effectiveness analysis for exogeneously specified targets, towards interactive processes of working with complexity through deliberation and information sharing.

Various decision analysis software packages, like SEDSS [19], or HIVIEW™ [20], are now on the market that allow the user to change physical values or amend weighting factors in real time, which is especially useful for presentational purposes. Such software can offer, for instance, the following features:

- Value tree visually created and edited. Up to 15 options, 50 criteria per branch, with unlimited branch layers.
- Each node graphically displays the weighted scores for each criteria; bottom up or top down calculation of weights. Option normalisation of weights within mode.
- Map to show the efficiency frontier.
- Sensitivity analysis to test robustness.
- Construction of options by importance of the weighted criteria.

The software package ExpertChoice™ [21] on the other hand can offer the user the following features:

— Uses the analytical hierarchy process.
— Guides you through the process of entering pair-wise assessments of your alternatives and criteria.
— Includes a rating method to rank large numbers of alternatives.
— Results are displayed graphically or in a detailed summary.

2.5. Evaluation Techniques

2.5.1. Economic Evaluation Methods

2.5.1.1. General Concepts of Economic Evaluation

Economic analysis is the widely accepted phrase used to describe those decision aiding methods that involve placing a monetary value on the inputs and, when possible, the outputs of environmental remediation. [22][23]. Monetary estimates of value can be a key part of the information base supporting environmental remediation decisions. As discussed here, cost-effectiveness and cost–benefit analysis are techniques for assisting decision makers in selecting among alternative courses of action. The underlying purpose is to provide an appraisal of the economic implications of investing in remediation [24].

Conducting an economic analysis implicitly assumes that people presented with choices have a sense of what mix of resources they are willing and able to commit and which outcomes they desire. The choices which individuals or groups make as they select less of one thing and substitute more of another reveal something about the values they place on different mixes of inputs and outputs. Sometimes there will be disagreements about the mix or balance to be achieved, and this must also be considered in the decision aiding analysis.

The general procedure used in economic evaluation techniques involves assessing the costs of further environmental improvement (or avoiding further damage) in relation to the benefits obtained. Cost–benefit analysis (CBA) involves the optimisation or maximisation of net benefit, defined as the total benefits minus total costs resulting from some allocation of resources for environmental remediation. This requires monetary estimates of both the benefits and the costs of the remedial action. Cost-effectiveness analysis involves the assessment of costs associated with achieving specified remediation goals. The specification of remediation goals and associated benefits is made in non-monetary terms.

2.5.1.2. Defining and Measuring Costs and Benefits

Costs are the value of all the inputs associated with remediation over a specific time period. Costs also include the possible adverse outputs. Benefits are the improvements compared to existing conditions. The evaluation in money terms of the various benefits and costs associated with different remediation strategies, makes use of a variety of techniques adapted to different categories (e.g. the equipment and human resources used in the remediation activity itself, the environmental improvements, etc.). All remediation technologies will have economic costs, and some may also yield immediate economic benefits (e.g., increasing the value of land by bringing it back into productive use).

Costs typically include direct expenditures for project planning and implementation, capital costs, operations and maintenance, and monitoring. In addition, the various costs for safety at work need to be taken into account (see Section 4.6). Annualised costs are derived by adding the sum of operating costs for the year in question plus amortised capital costs, which include interest and depreciation associated with accumulated capital investment. Amortisation schedules reflect assumptions about the life of capital equipment. Commonly chosen depreciation rates are 3, 7, or 10%. The cost comparison method can be used to examine cost differences [25][26]. Alternative remediation options can differ widely in the duration of the remediation work and in the time horizon after which future uses may become allowable. Taking into account the time dimension can have a significant influence on the evaluation results, (see also Section 2.5.1.3 on distribution of benefits and discounting). Economic costs which may be considered and can be calculated by capital value methods, include loss of interest due to having to pay up-front costs and loss of interest due to absent revenue (non-availability of the site for productive uses).

Varying amounts of revenue are obtained as a consequence of a remediation. Measurement of the revenue in monetary terms is straight-forward when a market exists since information about prices and quantities can be used to measure benefits. In particular, revenue is derived from subsequent use of the remediated site, but also the avoidance of higher remediation costs at a later date, the enhanced image of the landowner or the avoidance of claims for damages put forward by the owners of adjacent land that would be affected by the contamination spreading (see also Section 4.8). The revenue from any subsequent use can then be assessed from a business costing point of view and be compared to the costs of carrying out the remediation.

In many cases, the consequences from remediation are not measured monetarily. Instead, health benefits and, as relevant, wider environmental consequences are identified using impact assessments or other techniques to provide information about types of effects (human health, ecological, or aesthetics), environmental media (air, water, soil), or resources (fishery, forest, wetlands). Those consequences are usually, in the initial description of remediation options and expected outcomes, expressed in the original units of measurement for the outputs such as deaths or illnesses, soil or groundwater quality, or energy streams. For cost effectiveness and multi-criteria analyses, the consequences do not need to be converted into monetary values from their original units of measurement.

For cost–benefit analysis, the consequences need to be assigned monetary values when they are not originally expressed in financial terms such as revenue. Measurement of non-market benefits requires the use of proxies to estimate implicit prices when a market with defined prices does not exist. The estimation of such costs and benefits can in principle be approached from two distinct directions:

- On the ‘supply side’: by estimates of economic costs — that is, the reduction in other opportunities for assuring goods and services provision — that are or might be incurred in avoiding, abating or repairing damage; and
- On the ‘demand side’: by estimates of the monetary value of the benefits that are lost or at risk — that is, the value of the lost or potentially damaged environmental asset, amenity or service itself.

The monetary figures obtained with the supply-side approaches relate to expenditures to achieve improvements in quality or to avoid further degradation in quality. Examples of supply side valuation include remediation costs and avoidance costs. Remediation costs are costs paid by individuals, firms and state institutions in response to contamination events to, for example, maintain or restore buildings, restore rivers and lakes to certain levels of water quality or fishery stock, or to remedy human health problems due to contamination. Avoidance costs are costs incurred by individuals, firms and state authorities to avoid environmental damage. Examples include the costs incurred in introducing traffic calming and noise buffer measures in town, the costs of reducing atmospheric greenhouse gas emissions; costs of installing catalytic converters, costs of improving safety measures against toxic chemical spills in storage, factory use, and transportation, costs of diverting a road out of a site of special environmental value, etc.

Table III. Valuation methods for environmental factors (modified after [27])

OUTPUT BASED METHODS — an example of an output loss is the money value of a reduction in crop, forestry or fishery yield caused by environmental damage. A focus on output effects may disregard other impacts over which people are concerned. In particular, ill health may stop people from working, but may also cause pain, grief and suffering.

PREFERENCE BASED METHODS — seek to take explicit account of the preference, constrained by available income, of those people who will be affected by a particular decision. Broadly speaking, they are of two kinds:

Revealed preference methods

preventative expenditure: the amount paid to prevent or ameliorate unwanted effects, for example, expenditure on insulation and double glazing to keep out noise (sometimes a community valuation can be inferred, as when governments provide grants towards such expenditure)

replacement/remediation cost: the amount individuals spend on, for example, the restoration of damaged buildings or landscapes

property valuation: differences in the market value of similar properties that reflect differences in the local environment, for example the amount by which the price of a house is lower because it is next to a busy road

compensating wage differentials: the premia in wage rates in occupations that are riskier or have above average health hazards, from which money values for preventing fatal and non-fatal health effects can be inferred.

travel-cost method: seeks to estimate a money value on the basis of the amount that people actually pay (in money and time) to gain access to beauty spots, wilderness and so forth, or to avoid various forms of damage and degradation. In effect, the costs that are incurred by visitors to a site are taken as a proxy to calculate the recreation value they place upon that site. This can be the basis for estimate of the significance (in money value terms) of damage or loss of availability of the site.

hedonic pricing: correlates the environmental good or bad with some actual market item such as houses, so that variations in the price of houses from one locality to another can be correlated with the presence or absence of some desirable or undesirable environmental feature. e.g. contamination. How much people are willing to pay is then supposed to reflect their preference for the environmental good in question, or their aversion to the bad.

Expressed preference methods

contingent valuation: asking people to say either how much money they would be willing to accept to compensate for unwanted effects *or* (which tends to produce lower valuations) how much money they would be willing to pay to avoid unwanted effects (but the amount people say they will be willing to pay may differ from the amount they would be willing, or able, to pay in practice)

conjoint analysis: asking people to rate or rank alternative bundles of attributes of good, service or policy option (for example, bundles comprising specified amounts of environmental damage; health effects; effects on wildlife; etc.) and eliciting from their rankings or ratings the implied rates at which they trade off one attribute from another. If one of the attributes is money, implicit money values can be inferred

relative valuation: determining the relative value people place on a good or service by comparing it with other good or service for which a money value has already been established, for example deriving money values for preventing non-fatal road injuries of different severity from the money value previously determined for preventing road fatalities.

Demand-side approaches involve placing a money value on attributes of the system that may change due to remediation action. This requires some way of identifying and describing these benefits and services and changes — in quality and quantity. It is common to distinguish between one-step and two step approaches. One-step approaches supply descriptions of the different changes in environmental quality, usually with the aim of eliciting information on individuals' willingness to pay for improvements or to avoid deterioration. Here the primary difficulty is often with defining the changes (the good or harm) in question. The objects or systems often have many different functions. Soil, for example, may be associated with agricultural production, or may be a site for buildings and transport corridors, or may support vegetation forming attractive landscapes and biodiversity. In the case of water, it is possible to link quality with biological, health or recreational possibilities — is it safe to drink, is it safe to use in food processing, or to bathe? Soil and water as dynamic media in larger ecological cycles may also be important. Two-step, or 'Dose-Response' approaches, by comparison, begin by asking 'what caused the damage?' and develop a description in terms of causes and effects. Frequently, data from the physical and biological sciences are used to link a particular sort of pollution at different levels (the dose) with different levels of physical damage to human, animal and plant communities (the environment's response).

After the benefit and damage categories have been decided, the question is how to attach a monetary figure to them. For resources used as productive inputs, it is possible to specify a 'derived demand', that is, amount that a user would be willing to pay as reflected by the revenue stream that is obtainable, *e.g.* timber products from a forest. For non-commodified environmental services, no such commercial reference point exists and various artifices must be employed. Commonly used methods for quantifying environmental benefits from the demand-side are the Travel Cost Method, Hedonic Pricing, and Contingent Valuation Methods. Table III summarises techniques used for valuing benefits [27][28].

2.5.1.3. Distribution of Benefits and Discounting

The costs and benefits of environmental remediation often occur in different places, for different communities of interest, and distributed over time. For a full economic analysis it is sometimes necessary to aggregate these various categories of costs and benefits. Technology choice and environmental investment decisions can be politically difficult because they involve questions of exposure to and protection from risks such as health damage, genetic integrity and loss of production capacity. Questions of fairness inevitably arise when those who reap the benefits and those who bear the costs are different constituencies, as can be the case for remediation costs that may be imposed on possible future generations. Considerations of fairness are not resolved by economic analysis, and can be brought into decision making in some complementary way.

Questions can arise whether or not to weight monetary costs and benefits differently depending on the time at which they occur. Discounting is an analytical convention in economic analysis that permits aggregation and comparison of costs and benefits across time. The two main arguments usually offered for using discounting are (1) that individuals have positive 'time preferences', viz., they are 'impatient', they prefer benefits now to benefits tomorrow simply in virtue of when they occur, and (2) that future benefits of a remediation programme need to be compared to possible future benefits that might be obtained if, instead of doing the remediation, the resources are invested for other uses with a rate of return defined by (for example) commercial profitability or bank rates of interest. Future benefits and costs should, therefore, be discounted by the rate of return expected to prevail over the period of evaluation. Discounting by a defined percentage on a period by period basis (usually year by year) provides weights that make the aggregated costs and benefits subjectively comparable over time [29]. Present value is the current value of benefits and costs that accrue in future time periods:

$$V_p = V_f / (1 + r)^n$$

Where: V_p = present value; V_f = future value; r = interest rate; n = number years into the future.

Because the denominator gets larger as n increases, costs or benefits appear to become insignificant in the distant future. Discounting has been criticised because, in some cases, it induces a neglect of damages or reductions in welfare that may be felt over the long term since the value placed upon damage felt in the future will be smaller then the same money value of current consumption. This can excite objections on grounds of inter-generational equity.

Discounting in itself does not resolve what might be considered to be fair or unfair between individuals, or between generations. So even when discounting is used, there remains the question of the fairness of the outcomes. One practical way to deal with distribution and discounting questions is to work 'backwards' from a specification of the desirable properties of outcomes. During the problem framing stages, fairness, protection against health risks and inter-generational justice etc. can be specified as performance goals The analysis preserves an important dimension of disaggregation of benefits and costs — through the explicit focus on distribution through time (e.g. scenarios for key variables such as cash flow from future land uses, income distribution for the local population, site soil contamination levels, water resource quality and availability, landscape attributes and so on). In effect, the distributional criteria work as constraints on the CBA, which gives the overall analysis the character of a multiple criteria decision aiding framework (see Section 2.5.2 below).

2.5.1.4. Cost Effectiveness Analysis

Cost-effectiveness analysis measures the relationship between benefits and costs, expressed as monetary costs per unit of benefits, where the benefits are measured in non-monetary terms. These standards define the goals for the cost effectiveness analysis. Once measurable remediation goals are set, analysis may focus on defining opportunity costs associated with the remediation programmes necessary for achievement of specified environmental quality goals.

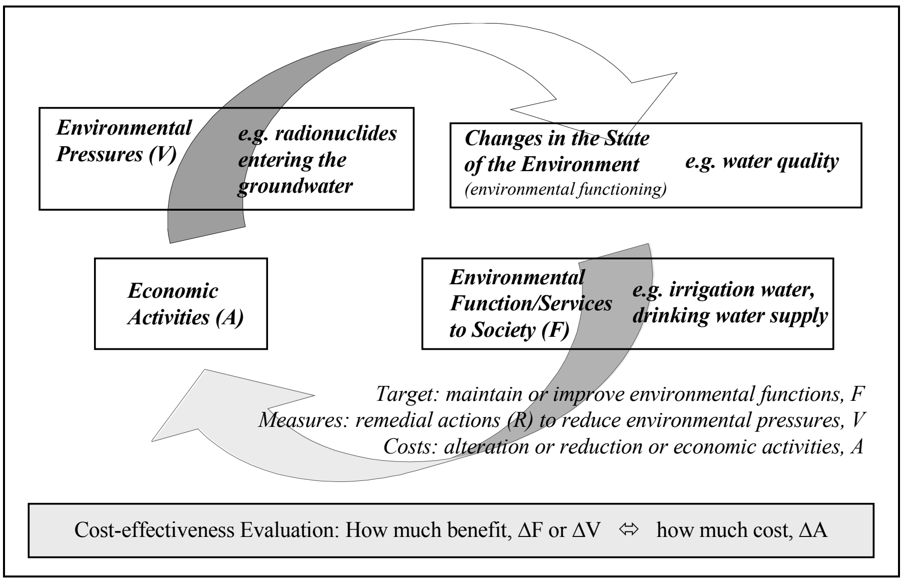

FIG. 7. Basic concepts of a cost effectiveness analysis.

A cost-effectiveness analysis involves the following steps:

(a) Identify the benefit of interest and quantify in its original units of measurement (e.g. reductions in exposure of a population to radiation);

(b) Identify costs and quantify in terms of money (e.g. costs of excavation and disposal of contaminated soil and rock; or costs of treatment of groundwater);

(c) Divide benefits by costs to derive cost per unit of benefit.

The basic concepts of a cost effectiveness analysis of options for environmental improvements are shown in the schematic diagram (Figure 7).

An example involving three technologies for soil remediation is given in Table IV. According to Table IV, technology B has the lowest cost per unit of benefit. Technologies A and C have comparable cost/per unit, although C obtains a greater total benefit. In order to choose, it has to be known how much total soil remediation is sought, and then the technique or techniques can be engaged that achieve the desired result at the lowest unit cost.

Table IV. Hypothetical Cost Effectiveness Analysis of Soil Remediation Technologies

Technology	**Volume of Soil Remediated [m^3]**	**Costs [Million US$]**
A	5000	1.00
B	9000	1.35
C	11000	2.20
Results for the calculation of cost-effectiveness:		
Technology A:	US$ 1 000 000 / 5000 m^3	= US$ 200 m^{-3}
Technology B:	US$ 1 350 000 / 9000 m^3	= US$ 150 m^{-3}
Technology C:	US$ 22 000 000 / 11000 m^3	= US$ 200 m^{-3}

2.5.1.5. Cost–benefit Analysis

Cost–benefit analysis measures the relationship between benefits and costs, with the measurement of both benefits and costs expressed in monetary terms. It involves the following steps:

(a) Identify benefits of interest and quantify in terms of money;

(b) Identify costs and quantify in terms of money;

(c) Subtract total costs from total benefits to derive net benefit.

Once available funds for remediation have been determined, the alternative that has the greatest net benefits should be used instead of benefit-cost ratios. Benefit-cost ratios on their own can produce misleading results in terms of efficiency. A hypothetical example is given in Table V. As can be seen from Table V, alternative A is the most desirable since it provides more net benefits than either B or C. It would be preferred on the basis of the CBA, as long as sufficient resources can be mobilised to carry it out.

Table V. Hypothetical Benefit-Cost Analysis of Risk Reduction Alternatives

Alternative	Benefits [Million US$]	Costs [Million US$]	Benefit/Cost ratio	Net Benefits [Million US$]
A	30	20	1.50	10
B	20	16	1.25	4
C	21	14	1.50	7

Results:		
Alternative A	US$ 30M — US$ 20M	= US$ 10 M net benefits
Alternative B	US$ 20M — US$ 16M	= US$ 4M net benefits
Alternative C	US$ 21M — US$ 14M	= US$ 7M net benefits

Estimates for the cost of achieving remediation goals do not, in themselves, tell us the monetary value of the benefits gained (or the damages avoided) from remediation. This can be for several reasons. First, the goal may be to satisfy a standard specified under law, and depending on circumstances this might be quite easy (low cost) or very difficult (high cost) irrespective of the benefits gained. Also, investments in site remediation will be economically attractive only if returns on investment are comparable in scale to the costs. The remediation benefits of land improvements (such as decontamination, soil stabilisation, and forest replanting) might be much greater than the costs to those immediately responsible (e.g. a landowner), while being felt diffusely — by a large range of other persons over a long period of time. Arguments can arise that sometimes too much, or too little effort, is put into site remediation, relative to the benefits obtainable. For this reason, a lot of effort has gone into devising techniques for putting a money value on benefits gained or risks and damages avoided — that is, the 'demand' for remediation benefits.

2.5.1.6. Limitations to Cost Benefit Analysis

The question often is asked, why try to put money figures on the expected effects? The reason is to provide a common and understandable measure through which different objectives can be traded off so that the loss in relation to one objective can be quantified against the gain in relation to another. However, there are limits to this procedure. Sometimes the social demand for environmental quality, which may include provision for future generations, the desire for protection from uncertain environmental harms, and the maintenance of landscapes and ecosystems as elements of heritage and culture, cannot easily be expressed as values in monetary terms. For many categories of health impact and environmental change, estimations of consequences of human actions (harmful or otherwise) is incomplete and somewhat speculative. The results of monetary valuations will have large sensitivity to underlying assumptions. For this reason it is important to carry out sensitivity analysis (see Section 2.4.3).

Recent years have seen emergence of a wide portfolio of approaches to the economic and scientific analysis of environmental risk and uncertainty. Some are developed as ways for extending the application of the CBA optimisation approach to situations of uncertainty. Others insist on the difficulties of meaningful quantification, and place emphasis on social/political processes for appraising and distributing the burdens of risk. Within the logic of CBA, elements of uncertainty may be incorporated if predicted outcomes are replaced by probability distributions (for all outcomes imagined as possible) and the values associated with outcomes are replaced by 'expected values' (for example expected-utility-maximisation). Two main variants exist. The first arrives at the 'expected value' of some action or effect (good or bad) by taking people's estimates for each conceivable outcome as if it were certain to materialise, then weights this value by the (alleged) actual probability of its occurring. The second admits that defining actual ('objective') probability distributions is often open to doubt, and arrives at the 'expected value' by taking people's own 'subjective' estimates of the probabilities, whether or not these appear justified from some expert point of view. In some applications the expected-value approach to health and environmental uncertainties can be unsatisfactory. Despite progress in science it is impossible to quantify all the roles played by the environment as a source of livelihood and as a site for waste disposal.

The uncertainties associated with environmental change and risks are indeed one of the main reasons why decision making is inevitably controversial. A variety of other reasons also contribute to the difficulty or perceived inappropriateness of monetary valuation. These include distributional concerns (fairness about exposure to risks and access to benefits, mentioned in Section 2.5.1.3). Cultural, ethical and historical factors may bear strongly on individual and collective evaluations, for example, notions of rights to life or property for other people or other species; people's individual and collective senses of the sacred; natural or built features that are paramount matters of local identity.

Often the decision process is an iterative process of analysis, debates, negotiations, trade-offs, exploring the sacrifices and compromises that might be tolerated in a collective solution that is judged satisfactory in terms of economic, social, and ecological imperatives. In such cases there can be a motivation for decision support techniques that do not depend exclusively on monetary valuation, such as multi-criteria and deliberative political and decision making procedures (see Sections 2.5.2 and 2.5.4 below).

2.5.2. Multiple Criteria Decision Aiding Frameworks

2.5.2.1. Basic concepts in Multiple Criteria Decision Analysis

The basic premise of multiple criteria decision support analyses (MCDA) is that the resource requirements and effects of alternative course of action may be comparable in a number of different ways, but that the information cannot easily be brought into a single unit of measure. Assessment explicitly with reference to several distinct criteria allows a balance to be made between these attributes in a quality-assured and transparent manner. This makes multi-criteria evaluation a natural approach for organising information for appraisal of technology and land use alternatives.

A number of different terms exist for multiple criteria decision support analyses, notably multi-criteria decision aid (MCDA) and multi-attribute decision analysis (MADA) methods. These are essentially the same thing and for clarity this publication will refer to MCDA alone. Multi-attribute utility analysis (MAUA) is one branch of MCDA that is particularly useful when some or all factors cannot be expressed in financial terms but where an overall ranking of options is sought. MAUA is based on the concept of 'utility' (welfare or well-being). For each decision option, a total utility is calculated. The decision option with the highest total utility is preferred. An example of a MAUA is presented in Section 2.5.2.3. MAUA can be extended to cases where some or all parameters are uncertain.

It is important to emphasise that MCDA methods do not exclude the use of economic analysis techniques. In fact, cost-effectiveness analysis is a simple form of MCDA. What is distinctive about MCDA is that there is no single unit of measurement — monetary or non-monetary — against which all the economic, environmental, health, aesthetic and cultural values are put on a common scale.

The key issue for decision making concerns the advantages and disadvantages of having sacrificed full commensurability of valuations (widely argued to be one of the chief merits of monetary CBA methods), in favour of ways of presenting information for decision making procedures that do not give a unique ranking but make more explicit the sorts of trade-offs that might be involved. Four degrees of comparability can be distinguished (e.g. [30]) and presented as:

— ***strong commensurability*** (existence of a common measure of the different consequences of an action based on a cardinal scale of measurement);

— ***weak commensurability*** (common measure based on an ordinal scale of measurement);

— ***strong comparability*** (there exists a single principle of comparison by which all different actions can be ranked);

— ***weak comparability*** (one has to accept the existence of conflicts between all different consequences of an action).

Weak comparability can be considered to be the philosophical base of multi-criteria evaluation. Conceived as such, multi-criteria decision aid does not itself provide a unique criterion for choice, rather it helps to frame the problem of arriving at a political decision [31][32].

A great variety of multiple criteria analysis methods have been developed and applied in recent years, in efforts to help organise scientific as well as economic information as a basis for technological appraisal and environmental decision making. Typically, monetary valuation — or cost/benefit — procedures can be incorporated alongside other methods for identifying the nature of the choices and trade-offs in question. Through the production of a matrix, values or scores can be assigned for each option against the various attributes. These values may be determined either qualitatively or quantitatively and, if deemed useful, weighted to indicate the relative importance of one attribute over another.

The incorporation of a MCDA approach establishes transparency through breaking the decisions down into smaller more manageable comparisons. The attributes are thereby available for direct comparison enabling a measure of performance to be made. Numerous methods for displaying this measure of performance exist and are often based upon checklists. These methods include:

Scaling — assignment of algebraic scales;

Ranking — alternatives are ranked from best to worst in terms of their potential impact;

Rating — utilise a predetermined rating scheme.

Weighting-scaling or weighting-rating checklists refer to methodologies that embody the assessment of relative importance weights to attributes. Weighting-ranking checklists involve importance weight assignments and the relative ranking of the options through the application of preference scores.

2.5.2.2. Balancing between analytical complexity and value in deliberative processes

The theoretical and empirical analyses of MCDA can become very technical due to the wide range of information categories that analysts may try to bring together in order to facilitate comparisons between alternatives. (For a recent overview, see [31]). This formal process ensures that all the necessary factors have been considered and that the outcomes of decisions reached are recorded. The formal and auditable nature of the process becomes very useful in the communication of the rationale should the final decision/outcome need to be explained or defended. This is discussed in more detail in Section 2.6 on quality assurance/quality control.

There is inevitably a political judgement component in most decision making, even when information bases and analyses are scrupulously respected. In cases where no course of action fully satisfies all identified criteria applied in an MCDA study, and no 'best' option can be identified on the basis of all criteria taken together, a compromise decision may be identified. Often stakeholder negotiation or deliberation among experts and stakeholders can aid in this compromise identification process. A multi-criteria analysis can also be developed on the basis of the identification of the main interest groups who may be affected. Criteria and technology alternatives are formulated to take into account the conflicting preferences of these groups.

In many ways MCDA seems to be an intuitively obvious and natural form of decision support. It systematises the common-sense awareness of different points of view and different concerns. However, at times MCDA analyses have been criticised in view of their highly technical (essentially mathematical) character which can make them technocratic and inaccessible to lay or policymaker scrutiny. Where weighting of criteria is used (as in some multi-attribute methods), the results can be highly sensitive to conventions about weighting and ranking algorithms. The link between mathematical forms employed by the model, and the social, ecological and economic justifications, seems sometimes obscure. Thus, the challenge for MCDA is two-fold. First, it must really live up to its claims of making more explicit the ways that alternatives are evaluated and compared. Second, the technical aspects of the analysis can be embedded within deliberative decision-support processes so that the ways the mathematical analyses are developed can be made responsive to stakeholders' preoccupation with environmental and socio-economic concerns in structured ways. This requirement has been articulated in a number of recent MCDA studies [33][34]. Decision analysis software can help achieve this by allowing the user to create an interactive decision model. Such a model allows an observation of the effects of altering the weighting values against the attributes under assessment through utilisation of the in-built sensitivity analysis tools.

2.5.2.3. An example of a MCDA with attribute weighting

A simple example of a multiple attribute utility analysis as an instrument for the assessment of complex alternative actions is presented here. For purposes of illustration, consider the two remediation technology alternatives (groundwater treatment *vs.* excavation and disposal of contaminated soil) presented in Figure 5 (Section 2.3.1) for a hypothetical site. The goal of the analysis is to make comparable alternative techniques with a variety of attribues and to show the results as numeric expressions. The process starts at the stage of 'weak comparability' as discussed in Section 2.5.2.1 and moves progressively to 'strong comparability' and 'weak commensurability' through the application of a weighting scheme. The process is illustrated in Figure 8.

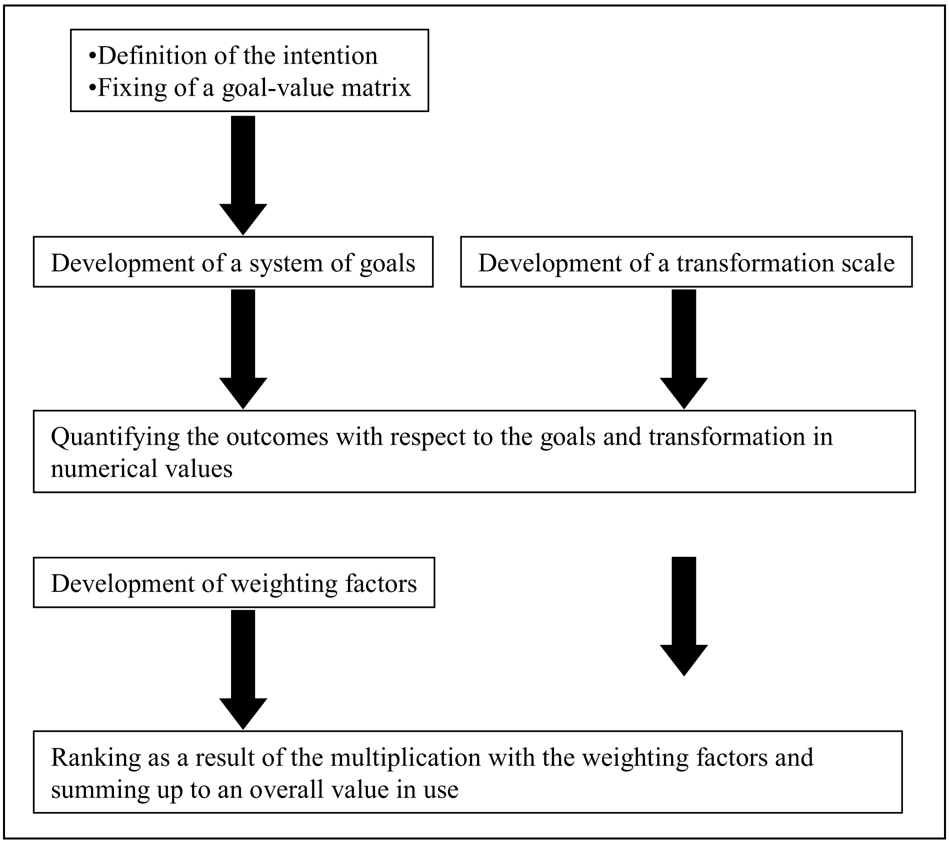

FIG. 8. Flow diagram for utilising the MCDA with attribute weighting.

In conducting the analysis, it is necessary to formulate goals to be achieved and to subdivide the higher level goals into lower level goals. For instance, a high level goal may be formulated as 'minimise adverse impacts from contamination'. Lower level goals corresponding to this could comprise:

(1) Minimisation of exposure to radiation;

(2) Minimisation of generation of secondary wastes;

(3) Minimisation of restrictions on land use.

Either or both the formulation of higher level goals and the subdivision into lower level goals may be carried out internally by the problem holder or may be included in a deliberative process. After formulating the goals, appropriate rules for their assessment must be developed. Such assessment rules may be obtained from, for example, radiological assessments, engineering studies, expert judgement, or (where appropriate) public surveys. The value of a technological option increases with the degree of achieving these goals. In the approach illustrated here, the degree of satisfying the goals is measured on a common assessment scale to provide numeric comparability. This assessment scale then is transformed into numeric values (value-transformation). Figure 9 illustrates the transformation of the lower level goal of minimising land use restrictions to a numerical value between zero and one.

A hypothetical result for the performance of the two techniques mentioned above is presented in Table VI.

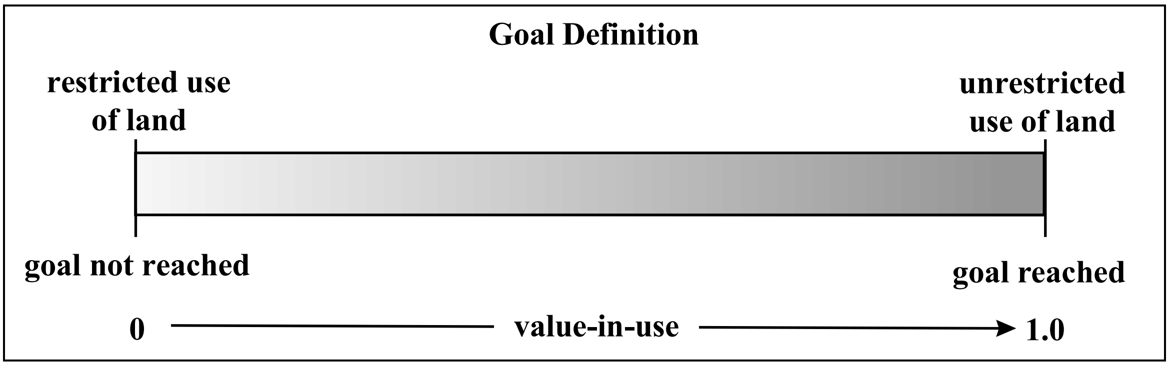

FIG. 9. Valuation of achieving pre-set goals for remediation options.

Table VI. Hypothetical performance scores of two remediation alternatives

Impact	Groundwater Treatment	Excavation and Disposal
Radiation exposure	0.7	0.9
Secondary wastes	0.9	0.1
Land use restrictions	0.7	0.9

In a further step, the attributes are weighted to make the scores for each alternative comparable. The weighting factors can be derived by a process of successive comparison. As in the goal formulation step, this process may either be done by the problem holder or may be included in the deliberative process. An example of a three step process for obtaining the weighting factors is as follows:

(1) Arrange the assessment attributes to make a subjective ranking from most to least important;

(2) Assign numerical weights to each of the criteria, say P_i for each attribute i. With three attributes i= 1,2,3;

(3) Normalise the weightings: $W_i = P_i / \Sigma P_j$ for j= 1,2,3.

These normalised weighting factors express the relative importance of the individual goals within the context of the overall objective (see Table VII).

The weighting factors shown in Table VII illustrate the high importance given to measures that reduce radiation exposure, and identify reduction of secondary wastes as an important secondary priority. The final step is the multiplication of the numerically expressed goals by the weighting factors and summing up to an overall performance score. This is shown in Table VIII. The weighted results in Table VIII clarify the tradeoffs in selection between these two technologies. In this hypothetical case, the extremely large amounts of secondary wastes generated by an excavation and disposal technique offset the slightly improved performance in terms of reducing radiation exposure.

Table VII. Normalised weighting of the main goal 'Minimisation of adverse impacts from contamination'

Attribute, i	**Weighting Factor, P_i**	**Normalisation**	**Normalised Weighting, W_i**
i= 1 Radiation exposure	4.0	4.0 / 7.0	0.57
i= 2 Secondary wastes	2.0	2.0 / 7.0	0.26
i= 3 Land use restrictions	1.0	1.0 / 7.0	0.14
Sum			**1.00**

Table VIII. Hypothetical ranking of two remediation alternatives

Attribute, i	**Weighting Factor, W_i**	**Groundwater Treatment**		**Excavation and Disposal**	
		Performance Score	**Weighted Score**	**Performance Score**	**Weighted Score**
Radiation exposure	0.57	0.7	0.40	0.9	0.51
Secondary wastes	0.26	0.9	0.23	0.1	0.03
Land use restrictions	0.14	0.7	0.10	0.9	0.13
Overall Score (Sum of weighted scores)			***0.73***		***0.67***

The preceding discussion illustrate the application of a single methodology to a relatively simple case. There are a wide variety of techniques available, and the selection of a decision aiding framework thus requires a firm understanding of the problem at hand and must be made based on the usefulness of the selected technique in resolving the relevant issues. Understanding the context of the decision and the goals to be achieved by use of a formal MCDA — such as improving transparency and illustrating tradeoffs in a deliberative process or simply screening alternatives for initial feasibility — will assist in the selection of the appropriate method.

2.5.3. Expert and Knowledge-Based Systems

2.5.3.1. Overview

An expert system is a computer program designed to simulate the problem-solving behaviour of a human, based on a set of structured rules [35]. An expert system provides the decision makers with a framework to organise data and the decision making in a structured form.

The concepts for expert system development come from the field of artificial intelligence (AI). An AI program is made up of a knowledge base and a procedure to infer an answer. Expert systems are capable of delivering quantitative information, much of which has been developed previously through basic and applied research, as well as rules to interpret qualitatively derived values, or where quantitative information is not available.

The development of a computer supported decision aiding system requires the combined efforts of specialists from many fields working in unison to formulate solutions. Expert systems are capable of integrating the perspectives of individual disciplines into a framework that best addresses the type of decision making required in the context of environmental remediation. Expert systems can be one of the most useful tools for accomplishing the task of providing the decision maker with the integrated decision support needed.

2.5.3.2. Components of an Expert System

All expert systems are composed of several basic components:

- a user interface (accepting inputs, generating outputs),
- a database (information),
- a knowledge base (heuristics, rules),
- an inference mechanism (analyses the knowledge base).

Expert system development usually proceeds through several phases including problem selection, knowledge acquisition, knowledge representation, programming, testing and evaluation.

A characteristic of expert systems that distinguishes them from conventional programs is their ability to utilise incomplete or incorrect data. Given only a partial data set, experts are likely to have less than absolute certainty in their conclusions. The degree of certainty can be quantified in relative terms and included in the knowledge base. The certainty values are assigned by the expert during the knowledge acquisition phase of developing the system. By incorporating rules in the knowledge base with different certainty values, the system will be able to offer solutions to problems without a complete set of data. The capacity to deal with uncertainty is available in development software.

The knowledge an expert uses to solve a problem must be represented in a fashion that can be coded into the computer and is then available for decision support by the expert system. There are various formal methods for representing knowledge and usually the characteristics of a particular problem will determine the appropriate representation techniques employed. Knowledge bases can be represented by production rules. These rules consist of a condition or premise followed by an action or conclusion (IF condition...THEN action). Production rules permit the relationships that make up the knowledge base to be broken down into manageable units. When using an expert system, the rule base is searched for conditions that can be satisfied by facts supplied by the user. Once all of the conditions of a rule (i.e. its IF parts) are matched, the rule is executed and the appropriate conclusion is drawn. Based upon the conclusions drawn and the facts obtained during consultation, the inference mechanism determines which questions will be asked and in what order. There are various inferencing methods available to perform the tasks of searching, matching, and execution [36]. Typical analytical methods include *inter alia* Markov chains [37] and influence diagrams [38].

2.5.3.3. Benefits

One of the attractive features of expert systems is the program's ability to provide the user with an explanation for how its conclusion was derived. The explanation function is essentially a record of the reasoning process selected by the user to resolve the problem. It provides for a better understanding of how the conclusion was reached and provides the user with a greater capacity to judge the pertinence of the conclusion and the expert system itself. The accumulation of facts to be presented when an explanation is asked for is usually encompassed within the development shell or software. This audit trail will also be useful in helping to maintain transparency [39][40], quality control and communicating with stakeholders.

As previously mentioned, a feature of expert systems is that they can address imprecise and incomplete data through the assignment of confidence values to inputs and conclusions.

2.5.3.4. Cost of Development

One of the negative aspects of expert systems is that they are expensive to develop from scratch. They require resources, expertise, and time to build. It should be determined if the proposed expert system can be justified in terms of savings or other benefits it produces. Costs include software, hardware, and personnel to do the work. A developer should ask if the problem to be solved justifies the investment of time and money. However, development costs can be reduced if a generic system is available for the problem at hand.

There have been a number of attempts to create generic expert systems for particular problem areas that provide site- and case-independent information such as e.g. performance data and costs of selected remediation technologies. After supplying the problem-specific data, this type of expert system would be readily available for interrogation.

2.5.4. Deliberative Dimensions of the Decision Process

No matter in what way environmental impacts and policy options are identified and measured, decision making may involve choices between divergent interests, and necessarily a process of conflict resolution. In this context, it is helpful to define the relation of the formal decision aiding methods, such as those outlined in the pages above, to the forms of reasoning and deliberation that may characterise the overall decision process and technology choice.

The formal methods aim to identify a best option based on *a priori* ranking. Limits to the application of formal methods include uncertainties, questions of fairness, and divergences of criteria within society. Where uncertainties are quite large and the range of effects of a decision extends to many different ecological, social and economic domains, evaluation techniques that produce a single ranking can become controversial or arbitrary. In such situations, a more pragmatic approach aims at defining thresholds and norms of adequacy or satisfactory performance in relation to the many qualitatively different concerns. Decision makers then will not claim that the choice is absolutely the best one, only that, on the basis of the information available and the several criteria used, it seems a satisfactory one.

It is also important to note that, in practice, decision making criteria are not always formulated or used in an unambiguous way. In some cases, formalisation is used in order to try to provide a reasoned justification for a choice that has already been reached in a more informal way. In other cases, even where formal goals (with one or multiple criteria) have been specified, there may remain unresolved arguments about what the goal really is (or was, or should be), or which thresholds or which criteria are the right ones to use, or what relative weight they should have. When difficulties of this sort arise, deliberative processes and negotiations can sometimes be used as mechanisms for resolving conflict and for exploring possible solutions. The purpose and activity of deliberative procedures and institutions is not to attempt a completely formal or mathematical justification of a decision. It is to determine a ‘good’ and socially acceptable decision through structured argument and practical judgement involving experts, policymakers and stakeholders of the interested communities who bring a range of different arguments to bear [28][41].

Sometimes full agreements are reached through deliberative procedures, on other occasions the disagreements between different points of view are made more plain as decisions are taken. Deliberative processes can be particularly useful for investigating underlying value issues that divide or unite communities of place or interest, and, where interest in finding a compromise or consensus exists, for enabling the stakeholders in question to contribute to conflict resolution processes.

The context in which the decision process takes place and the range of wider non-technical factors impacting on technology choice that must be addressed through the deliberative or political process in its broad sense, are more comprehensively discussed in the following.

2.6. Quality Control/Quality Assurance

Today, quality control (QC) procedures and quality assurance (QA) measures are essential management tools in any public and private expenditure project. Certification according to the ISO 9000 family of standards [42] frequently is a pre-requisite for any contractor before bidding and also increasingly applied to government administrative procedures.

Quality control procedures in particular concern data acquisition and handling, document management, engineering design and execution of construction projects. In recent years such procedures have also been extended to the implementation of environmental remediation technology. The monitoring programmes undertaken during and after a remediation action can be seen as element of a quality control procedure, but themselves have to subject to quality control [13].

Quality assurance measures serve to assure that the objectives and targets of individual project elements and of the project as a whole are being met. This broadly means that appropriate procedures, methods and technologies are selected and that these have to perform efficiently. Basis and benchmark for a successful quality assurance programme are clearly defined quality objectives (e.g. [3][43]).

It is obvious that for some elements in the decision making process it is more difficult than for others to define such quality objectives and devise methods to assess whether they have been met. This is particularly the case for public perception and stakeholder participation [44].

Formalised decision making methods in themselves constitute an important element of both quality control and quality assurance. The formalised process assures that all relevant aspects of the process are covered adequately. At the same time, being formalised, it provides documentation of inputs to and outputs from the process, which is necessary for quality control. Hence, there are obvious advantages to develop QC/QA procedures around a formalised decision making model.

Computer supported quality management and project performance assessment systems consist of software elements that allow quality control functions to be integrated, prioritised, planned and scheduled (e.g. [45]). They are intended to monitor all activities applicable to each functional area of work and encompass quality assurance/quality control, continuous process improvement, and performance measurement and management. This ensures that the planning, performance, measurement, and feedback mechanisms are in place for deficiency prevention, detection, correction and closure. Performance objectives and standards can be quantified and tracked using measurable performance indicators. Responsibility for collecting these data is to be assigned to specific work centres. Responsibility for implementing the programme and achieving the objectives is to be assigned to the appropriate work centre. Progress towards achieving the objectives can be, for instance, displayed graphically, using various graphs and charts for statistical process control, supporting also statistical techniques as mandated in ISO 9002 [45].

3. THE CONTEXT OF THE DECISION MAKING PROCESS

3.1. Introduction

The following chapter discusses the overarching context in which remediation decision making will take place. Certain issues, such as overall social goals, local social and economic conditions, and the desirable level of public participation, are embedded within both a national and local socio-cultural context, and will shape the way in which the process is played out [46]. The context of decision making will shape both the overall objectives of a remediation activity within the framework of competing societal goals, as well as generate constraints on the decision making process. Most decision do not exist in isolation, but are built on decisions that have already been taken and affect the choices that will be available in the future. The timing of a decision may, therefore, also be an important factor, since the circumstances surrounding the decision will determine the external constraints, any other factors to be taken into account, and the people who should be involved.

The measure of a decision is not just, whether it is made efficiently and economically, but whether the decision making process has sufficient legitimacy and the decision sufficient acceptability to permit implementation [47]. In the subsequent sections, the specific non-technical factors which shape the formulation and selection of alternatives for remediation will be identified and discussed.

3.2. Social-Cultural and Economic Context

3.2.1. General Considerations

Environmental decision making will always take place against a backdrop of overall social goals and values. These goals can include, for example, full employment, preservation of the cultural, economic and archaeological resources, traditional patterns of land use, spiritual values, quality of life factors, biological diversity, sustainability (in the environmental sense [48]), and protection of public health. There is a strong link between the overall set of societal goals and the availability of resources, including funding, man-power and skills.

It must be understood that resources spent on remediation activities are typically not available for use in achieving other goals of the society. Their availability, therefore, may be controlled by priority setting within the society:

> "*Society must distinguish between significant and trivial risks. ... When money and resources are wasted on trivial problems, society's wealth and hence health is harmed*" (Bruce Ames, University of California, Berkley as quoted in [49]).

Or even more poignant [50]:

> "*Many radiologists have come to realise that their overreaction to theoretical (actually imaginary) health-harming effects of radiation is unethical in that it leads to the consumption of funds that are desperately needed to deal with real health problems*"

The balancing of the various goals of social policy are often handled in a political context which specifies the level of resources available for remediation.

3.2.2. Social Goals and Values

When environmental remediation strategies are being developed, "decisions must be informed by an understanding of peoples' values. Traditional forms of consultation, while they have provided useful insights, are not an adequate method of articulating values. A more rigorous and wide ranging exploration of peoples values requires discussion and debate to allow a range of viewpoints and perspectives to be considered and individual values developed" [27]. "The decision whether to use one of the new methods for eliciting peoples values in any given context should depend on the nature of the issue under consideration", further that "these new methodologies should be used primarily in connection with issues which are both complex and of broad scope" [27]. No methodology for determining or articulating peoples' values, whether traditional or novel, provides a guaranteed solution. Novel approaches need to be evaluated for their ability to elicit a full spectrum of values on the issue in question from representative participants, so that the (environmental remediation) can be refined in light of experience and their full potential realised [27]

Sustainability, as an overarching social value, is becoming an increasingly significant issue in decision making for all aspects of society. Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [48], although many critics have argued that sustainable development is an unachievable goal. Sustainable development, therefore, requires reconciliation between improving the conditions of life in an equitable way, now and in the future, and in the long-term conservation of the natural environment, which supplies the resources on which development is founded [27]. Radioactive waste management, and by implication also the problem of radiological site contamination, are the subject of Indicators for Sustainable Development currently under development [51].

3.2.3. Ownership and Social Identity

As individual remediation activities take place in a specific geographic location within a country, local communities will play an important role in setting the context of decision making for a specific remediation activity. A community is formed on more than the natural ties of kinship; implicit in the term are: the sense of territory, a considerable degree of interpersonal acquaintance and contact, and some special bases of coherence that separate it from neighbouring groups. In many countries, 'new communities' have emerged in recent years as strong players in the collective bargaining process on decisions affecting society. These new communities are 'communities of place and interest', and have emerged in the pursuit of individual interests. These new communities often endeavour to curtail the power of the state while simultaneously allowing individuals and groups in society to manage their affairs directly. They include all forms of collectivities, associations, non-governmental organisations (NGOs) etc.

Previously, communities affected by contamination instances were generally considered to be restricted to those local to, or directly affected by the site or the implementation of remedial actions. Deliberation and decision analysis therefore was typically restricted to those parties with a recognised claim and vested interests. However, the emergence, and impact, of well-organised and -funded (environmental) NGOs in recent years has been significant. NGOs are not limited to environmental groups; the paralleled increase of industries' (lobbying) associations has also led to significant changes in the number and scope of interest parties potentially involved in decision making.

Local factors — social, cultural, and economic — will form a critical backdrop to the process. The choice of remediation technologies may be tailored to the socio-economic needs of a region or the respective resources available. Thus the overall socio-economic benefit in a region might be improved by choosing a perhaps less sophisticated technique, but involving the local man-power and other resources. Or, drawing out a project over a longer time scale, thus keeping local staff employed for a longer period of time, might be more economic at the bottom line than earlier completion followed by paying unemployment benefits; and it may add a social dividend. Working out such trade-offs typically requires the collaboration of all parties involved, the owner of the contamination, licensing authorities, the funding bodies, the contractor, the operator, and indeed the affected people themselves.

Failure to consider local conditions can derail the remediation process in a variety of ways. For example, a remediation plan may not be accepted by the local community. Particularly when institutional measures are part of the overall remediation strategy, solutions may fail when local behaviours are not considered adequately. Finally, decisions may be considered inappropriate when they interfere with local practices and customs.

The structure of the local economy may be significant in framing the objectives of the remediation activities. Remediation in an industrialised region may focus, for example, on issues such as employment and economic re-use of lands. In a region with a primarily rural traditional economy, emphasis on avoiding disturbances to indigenous cultural conditions may be paramount. A prolonged contamination situation and ensuing remediation measures may have a serious impact on the socio-economic structure of the communities concerned. Such impact may ensue from restrictions on land use or marketing its products, or from perception by the outside world, which finds investing in the area unattractive or shies away from buying the products. Compensations to be paid to the affected people can be a major item of the overall project costs. While some effects may be desirable, such as creating employment, at the same time some kind of dependency on the project itself may develop.

Local land use and land-cover in the region will also affect the remediation decision. For example, decisions on the remediation of a contaminated urban site may be very different from those taken in a wilderness area. In the first case, the local needs for industrial or commercial lands may shape the final end-state and require a different remediation process.

While it is understood that the socio-economic context would be very much site and country specific, it may be helpful for regulators and operators alike to develop a clear understanding of the various factors and their possible interactions.

3.2.4. Culture and Communication

Efficient communication between decision makers and stakeholders has proven to be difficult enough in a homogeneous cultural context. How much more difficult is communication across cultural boundaries, as is frequently necessary in an international corporation context, or where foreign experts are involved. The value placed on scientific reasoning, economic aspects and on material goods varies depending on cultural and societal background. This has obvious implications for risk communication. Cultures that are less individualistic are likely to disagree with decision making based on scientific rationale, which actually may appear irrational in some cultures [52].

3.3. Public/Stakeholder Perception and Participation

3.3.1. Definition of Stakeholder

The definition and delineation of the ‘public’ and the ‘stakeholder’ are neither straightforward nor unequivocally accepted [53]. Indeed, any one individual can be both, member of the public and stakeholder, depending on whether the private, political, or professional aspect of the life is concerned. Typically, the ‘public’ comprises stakeholders such as affected citizens and civic organisations, environmental groups, labour organisations, schools and universities, representatives of business interests (e.g. chambers of commerce), representatives of government (local, regional, state etc.), and the scientific and technical expert community (academia, professionals’ organisations, government departments). However, neither each member of these groups, nor all groups are necessarily directly affected by the contamination in question and the related remedial activities. The question of whether all ‘concerned’ or only those ‘affected’ need to be considered stakeholders in the decision making process remains unresolved to date — not the least because a clear definition of the groups is difficult.

Stakeholders are those individuals or organisations which may have an interest in the results of an environmental decision or be affected by that decision. Although identification of stakeholders is difficult, consideration of the following questions may provide some insight:

— Who has the information and expertise that might be helpful?
— Who has been involved or wanted to be involved in similar risk situations before?
— Who may be affected, with or without their knowledge, by the remediation planning?
— Who may be mobilised to act or angered if they are not included?

The emergence of NGOs — despite their qualitatively mixed appearance — has had a positive effect in many Member States. Acting as a voice for less influential societal groups, they have been playing a mediating role between the communities, on the one hand, and the government on the other. However, it may be stated that most of the NGOs have their own perceptions and agenda, which may often be at variance from those actually affected, largely because of different cultural background of their key leaders and workers. In the process, NGOs may not only impose their own perspectives on locals, but tend to expand their own space and establish their indispensability as mediators [54].

Figure 10 indicates potential actors, or affected parties, within a remediation programme. Their typical interests are outlined in Table IX. It should be noted that the diagram and the table are for illustration only, and are far from comprehensive.

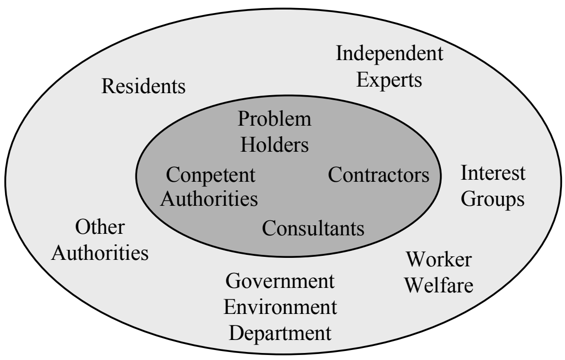

FIG. 10. Stakeholders, after [55].

Table IX. The function of interested parties in the remediation project, after [56]

ACTORS	INTERESTS
Problem holder	cost effectiveness functionality of environmental media efficient decision making
Authorities	multi-functionality of soil minimisation of residual environmental load consistent policy efficient decision making maintain/improve tax revenue through viable economy
Consultant	looking after the interests of the client (problem holder or competent authority) efficient decision making shareholder benefit
Contractor	looking after the interests of the client efficient decision making shareholder benefit
Public	risk reduction minimal limitations of use minimal nuisance efficient decision making maintain/improve socio-economic conditions

Even if all conceivable groups of stakeholders have been identified, individuals may (have to) set for themselves priorities other than to become actively involved in the decision making process. There are sound economic and social reasons for such priority setting, as active involvement commonly has to take place during ‘spare’ time. Most social groups do not have the opportunity to do so during the time they earn their livelihood or follow other social occupations. Active participation and actively seeking involvement commonly is associated with certain kinds of social disposition and cannot be taken for granted. However, the decision making processes, in order to adequately reflect the interest of all groups, have to strife to sample the views of those who cannot or want not actively participate. Respective concepts and methods will be discussed in section 4.5.3.

The development of a ‘this-is-not-my-problem’ attitude among potential stakeholders is often observed in the context of complex decision making problems. This essentially affects all parties concerned with the development of remediation scenarios. It may be due to a relative distance from the problem, or simply related to the fact that the individual/community cannot actually ‘see’ the site. It is most prevalent in situations where the implications or issues associated with a project are too complex for an individual, or a community, to rationalise and comprehend. This effect has obvious implications when communicating and consulting with potential stakeholders.

Loss of interest, even by key activists, along a lengthy decision making and implementation process can also seriously undermine the diversity, effectiveness and credibility of public participation programmes [57].

3.3.2. Perception

Various groups of the public will be affected by both the contamination and the remediation process in various ways, for instance with respect to their social status, personal and group well being, local environmental and economic setting, etc. There will be also a considerable difference between actual effects and risks ensuing and those perceived [58]. Individual or group decision makers dealing with radioactive contamination issues, naturally base their decisions on the problem as they perceive it. In planning for remediation objectives, including future land use, and before taking any step towards remediation, it is important to take the community's perceptions into consideration. Local attitudes, perceptions and values have formed over long years, they are active agents in organizing a system of resources use in practice, and they reflect the raw material from which a future land use could emerge.

A perception approach in environmental remediation planning takes it that for each objective element and relationships there are many perceived elements and relationships as seen and understood by different people and at different times and places [59]. Each decision and action taken is taken so within the framework of perceived sets of elements and links, rather than an externally defined 'objective set'. Within a given time-frame or culture, the scientific knowledge of the day may also be looked upon as formalised and rigorous sets of perceived environmental relationships. While this is usually taken as the 'objective reality', the subjective perceptions/valuations by the individuals and groups concerned may have a much more significant bearing on the decision making process.

Modern decision making is faced with a number of conceptual questions: is environmental perception entirely subjective and individual in quality, or can we find broad similarities in perception of groups? How can we understand the individual's assessment of the environmental characteristics of the present time so that planning measures for the future can be based on them? Are these assessments entirely qualitative or is there a way to quantify them?

The analysis of environmental perception tries to develop a systematic and scientific understanding of the views from inside-out, in order to reconcile it with the more traditional and external scientific approach. The perception approach requires that some ingrained habits of seeing and thinking with respect to decision making processes are broken down.

The result are sometimes considerable differences in reasoning/logic between community and decision makers and between official/scientific estimates of effects and risks ensuing and those perceived by the communities, leading to misunderstandings on the goals and objectives of a given project. It is important to recognise that perceived risks are as tangible as 'real' risks as far as the decision making process is concerned. Those immediately affected and 'concerned' groups, such as environmental pressure groups, frequently have different priorities and agendas. Priorities might also change with time and as remediation progresses. Those immediately affected might be concerned at the beginning with health risks, but later on in the process, economic criteria typically become more dominant. These problems have been, for instance, addressed by a recent OECD-workshop [60], but no simple solution to the problem is available.

Rather than approaching the problem with elaborate data gathering exercises and subsequent modelling, it is probably wise to begin with finding out what people value about the site and its surroundings concerned and what information on the project they would like to have [52].

3.3.3. Trust

Much of the existing work on public perception and public participation is concerned with the development of new projects, e.g. the siting of (industrial) facilities or waste repositories, and general (environmental) policy aspects. The difference to remediation/restoration projects is that there is likely, at a first glance, an inherent bonus in the latter, as they have the inherent aim to improve an existing situation, and, therefore, an 'advance' in trust is not unlikely.

However, there may be an initial lack of trust between the originators of a radiological contamination and other stakeholders when the originator is also responsible for the remediation. This frequently affects governments, and declining confidence in public institutions has led to view the government-citizen relationship with growing concern [61]. (Re-)building of trust often becomes a vital element in the planning and implementation of remediation/restoration projects. The general loss of trust in 'experts' and the loss of confidence in 'technology', observable over the last few decades, particularly in the developed countries, adds an extra dimension to the individual project [62]. Trust can be structured into six components (Table X, [63]). Since it strongly depends on the social-cultural context, no universally applicable approaches to trust-building can be given.

Table X. The six components of 'trust' [63]

COMPONENT	DESCRIPTION
Perceived competence	degree of technical expertise in meeting institutional mandate
Objectivity	lack of biases in information and performance as perceived by others
Fairness	acknowledgement and adequate representation of relevant points of view
Consistency	predictability of arguments and behaviour based on past experience and previous communication efforts
Sincerity	honesty and openness
Faith	perception of 'good will' in performance and communication

Efficient communication on environmental matters, including restoration/remediation, needs to take account of a (Western world) public increasingly becoming pre-conditioned to those values and concepts. "Trust is both the fruit of good communication and its necessary precondition" [64]. Sharing information and creating transparency are essential elements in trust building and new media of communication are increasingly being explored for this purpose [65].

Nevertheless, it has been shown [66] that communication needs to go beyond reconciling expert and lay viewpoints. Hence, the authors of [67], based on their extensive practical experience with public participation in a remediation project, recommend to:

— understand the different 'publics' affected — be sensitive to different informational needs of the people affected by the project;

— be prepared for interactions — use pre-project risk communication training and ‘practice, practice, practice’ before each interaction;
— be proactive with information — saturate the various ‘publics’ with project information as soon as it becomes available;
— develop clear and open relationships — facilitate as much in-person, one-on-one contact as possible with the people affected by the project;
— listen, then always respond — make sure you understand the concerns of the public first, then make sure you respond; and,
— Compare results with known standards — provide the appropriate safety standards along with the project results for comparative purposes
— provide means for the public to independently assess a situation [68].

Conversely, those in charge of remediation projects may have little reason to trust stakeholders. If they had negative experience with stakeholders, they may have no faith that the public can understand technical data and exert a positive influence on the decision making process. Stereotypes of stakeholders as uninformed, irrational, obstructive, etc., and of experts as irresponsible, unresponsive, impassionate, narrow minded etc. can damage communication efforts from the outset. However, such emotional reactions must be acknowledged as being appropriate or at least understandable. Showing empathy and value emotions are useful in building trust [68].

3.3.4. Participation

The underlying principle behind government projects often has been ‘I manage, you participate’ [69], that is, getting people to agree to and go along with a project which has already been designed for them, or to get the support of a few leaders [70]. Governance by meaningful participation, however, involves decision making at various stages, control and management of funds, share in benefits, and ownership of the decisions. In the context of developing countries, participation is “the process by which” those affected “are able to organise themselves and through their organisation, are able to identify their own needs, share in the design, implementation and evaluation of the participatory action” [71].

Public participation can involve either or both, participation in the decision making process, and participation in the implementing process of remediation measures. The objective is to reach a ‘win-win’ situation through the involvement of a range of people who are affected.

In practice the level and form of participation will vary widely between Member States (Appendix A demonstrates a process used in the UK). The Aarhus Convention [72] actually demands facilitating participation. In some regions of the world, extensive public participation in decision making is part of the socio-cultural behavioural pattern and will be a major activity in a remediation effort [57]. Other regions may have less of a tradition of public participation, and the process will be carried out in a very different fashion. In some regions, participation will be initiated by the responsible organisations, while in others, the public will initiate participation on their own accord. In evaluating the design of a participation process, it will be highly important to consider the level of experience of the involved communities in public participation, and tailor the process accordingly. Capacity building in the public thus can become a vital element in the participation process [73].

The discussion of public participation has been influenced by two competing theories. Consensus theory postulates that society is maintained through the sharing of norms and values. Conflict theory, by contrast, postulates that groups or individuals have fundamentally different interests and attempt to impose their values upon others. These competing theories led to fundamentally different points of view about the goals and consequences of public participation [66].

Public participation in the decision making process may be promoted based on commitment to fundamental democratic principles. It may also be promoted to assist in creating ownership in its results. In some Member States, mechanisms for public participation in the decision making on certain types of projects has already been institutionalised and become a statutory requirement. Practical experience has shown that cost savings on direct and indirect project expenditure, e.g. from averted legal actions, and savings in time can be considerable. Operating public monitoring schemes independent of the actual project operational scheme can also enhance trust [68]. It thus may be beneficial to extend public participation on a voluntary basis to projects where no such statutory requirement exists. Including such mechanisms formally into the decision making process makes their effects transparent to the public. However, many Member States do not (yet) have formal means to obtain feedback from impacted communities.

The practical implementation of public participation in a 'fair' way depends on achieving the necessary level of communication, interest, information, and involvement [74][75]. This implies however, that there is enough administrative, public or political pressure to actually implement the remediation programme in question [76][77].

Making the public in general and/or stakeholder participate in the actual implementation of remediation measures can have a variety of benefits as has been discussed above. Participation beyond the decision making process further enhances the sense of ownership and therefore may improve acceptance of implemented remediation measures. There also can be economic considerations which may favour the delegation of some activities to the affected people themselves. An example from Belarus for involving affected stakeholders in the data generation and the decision making process at community level is afforded by the ETHOS-project (Appendix B). This example indicates a conceptual transition zone between (emergency) radiation protection and active remediation.

The 'appropriateness' of stakeholder participation is a notion much open to philosophical debate, including different perspectives about the ethics of inter-generational equity [48][53] [78]. Because various groups of the public will be affected by both the contamination and the remediation process in different ways, sometimes the diverging interests of heterogeneous groups may make it impossible to reach a consensus or even an understanding of each other. In addition, there may be a temptation to 'buy-off' concerns on the side of those responsible. The decision about where the dividing line resides between 'buying-off' and 'justified compensation' may be made differently by the various participants in the decision making process. Those affected may also be caught in a vicious circle of real or perceived economic dependency on those who caused the contamination. Sometimes, individuals or groups use the decision making process for their own ends and constructive decisions or understanding may be never reached. There is also a possibility that broader environmental issues not specific to the problem at hand enter the discussion and that thus the participation programme loses its focus [57], with ensuing loss of efficiency and credibility.

3.4. Legislative and Institutional Context

3.4.1. Legislative Framework

The legislative and regulatory framework will decisively influence the decision making process in environmental remediation, both with respect to the way it is progressing and with respect to end-points to be achieved. The desirable prerequisites of the legislative framework has been discussed in [3]. In some Member States, an extensive legislative basis and regulatory framework to address issues of contaminated site remediation is already in place. In others, due to a lack of prior experience of contaminated site management, or due to transitions in the governmental structures, the legislative basis may be incomplete or even non-existent. Both situations offer potential challenges for the remediation project manager. The legal or regulatory framework will often develop in an evolutionary fashion in response to a particular contamination situation in a Member State. For states with an extensive legislative basis on environmental issues, the historical development of different laws may give rise to conflicting requirements at a given site. Typically, this is due to the historical events leading to adoption of the various laws and regulations. Examples include the situation in which wastes from chemical industrial processes are regulated under one law, and radioactive contamination is addressed by a different law. As co-contamination may be present, the requirements for management may be in conflict. In many cases, the remediation activities may proceed on a legislative basis originally intended to address a different problem or a different aspect of the same problem. For example, laws requiring safe drinking water may provide the basis for remediation of a contaminated aquifer, but do not address the problems associated with soil contamination.

On the other hand, remediation activities may be strongly impeded by the lack of a clear-cut legal framework for managing contaminated lands. In particular, the lack of a mechanism for identifying responsible parties for managing legacy sites may delay or prevent cleanup, even when the need for remediation is widely acknowledged. Some countries have adopted legislation to deal with contaminated sites ‘orphaned’ by the disappearance of their originators, most notably the formerly state-owned enterprises in Central and Eastern Europe.

Side effects of planned remediation measures may also run afoul with legislation in related fields. For instance, changes in land use may have impacts on drainage pattern, on groundwater recharge quality, on the ecology of protected landscapes, they may lead to eutrophication of surface water bodies, and so on. A predictive assessment is needed to ascertain that no such impacts will occur. Where such competition between different legislation exists, some Member States either allow room for negotiation, or assign through an administrative act the leading responsibility to one government department. Thus, in the case of the remediation of the Wismut uranium mining sites in Germany, the radiation protection department in the Saxony Environment Ministry was assigned the leading role and in turn consulted the water authorities and the mining board on the respective matters.

Environmental remediation projects are often multi-annual undertakings. Hence, pertinent legislation and the underlying political thinking may change from the time the justification is developed to the time when the implementation is to be fully achieved.

3.4.2. Institutional Framework

The identity of the governmental body responsible for remediation will influence the way in which remediation is carried out. Two important factors related to the identity of the responsible agency are, whether the agency has the appropriate resources for carrying out remediation activities, and whether the lead agency has been clearly identified. In many cases, the jurisdictions will be overlapping and the responsible agency will be unclear, as has been discussed above. Conflicts, rivalries, or 'passing-the-buck' syndromes between government departments may seriously impede remediation activities. For example, remediation of a radiologically contaminated industrial site containing wetlands may involve an interplay between the atomic energy ministry (radiological contamination), the environment ministry (chemical contamination of water resources), and wildlife protection ministries (protection of wetlands and endangered species), or which ever government departments are responsible for these topical areas in any one Member State.

Furthermore, the responsible entities may be allocated at different levels of the government — for example, radiological protection is often a nationally administered programme, game preservation may be managed at a state or county level, and zoning requirements may fall within the remit of local or municipal government. It is often the case that different levels of resources for carrying out remediation activities are available at different governmental levels.

Environmental remediation decisions are taken within a larger, and usually pre-existing management framework. Of particular importance is the composition of the individuals or the body responsible for developing and implementing a remediation plan, and the functional role of the responsible entity within the decision making framework.

Identification of the responsible body is clearly among the first steps in making decisions about remediation. The decision maker can be either a single individual — for example, a remediation project manager — or a (small) committee of individuals within the responsible organisation. In some cases, particularly for large-scale public projects, the decision maker may be the public as a whole, with decisions taken by referendum.

The functional role of the decision making entity can also affect the process. Conceptually, decisions can be taken by a variety of specialists. These can be technical experts, members of an administrative or bureaucratic body, political officials, or environmental managers acting as mediators/facilitators for stakeholder groups.

There are many instances in which the decision making entity is a technical expert or group of experts charged with responding to a particular environmental problem. Civil engineers or public health specialists, for example, may have responsibility for creating and implementing an environmental remediation programme. Assigning responsibility for remediation to technical experts is a good solution for ensuring that all relevant technical factors are identified and accounted for and that a feasible solution is found. However, when the overall responsibility for identifying, planning, and implementing a remediation option is assigned to a purely technical groups, the resulting solution, while being feasible from an engineering point of view, may run the risk of public resistance (due to lack of participation in the planning and decision making process as discussed above), or may not be adequately balanced against other societal needs.

The difficulties are compounded for the decision makers by the need to develop and implement remediation programmes that are both technically and socially feasible — where there is frequently both, disagreement about the evidence provided by technical experts, and a lack of commonly accepted values and standards [66]. Those in charge of implementing a remediation programme often view their role solely as one of implementing decisions made at policy level in the e.g. national interest, and they define their scope of responsibility as one of ensuring that technical analyses were appropriate. They tend to compartmentalise community concerns into two categories: a technical category and personal/political category. Issues in the technical category are viewed as legitimate and could be addressed through additional studies, while the other issues were deemed illegitimate, i.e. the project would not be able to and should not address them. The task is seen in implementing the 'best available technology' (BAT), usually also 'not entailing excessive cost' (BATNEEC), and then communicate the results to the public. However, a shift of paradigms in the management of public expenditure projects from a top-down/non-participatory/technology-driven to a bottom-up/participatory/ human-oriented, 'mutual trust' paradigm [79] can be observed in response to trust-building needs over the last decade or so, at least in the Western world.

In some cases, remediation options may be identified and implemented by officials of the relevant bureaucracy, who may or may not have the technical background for the problem at hand. Such individuals may simply implement the letter of the law, without adequate concern for either other societal values, economics, or opportunities for technological and procedural innovation.

Scientists and engineers, based on their own mental patterns, are inclined to think that environmental decision making takes place in a 'rational man' context [80]. This is a context in which the decision maker dispassionately — and with unlimited time, resources, and access to information — weighs alternatives to find the technical solution that maximises the benefits. It is well-established, however, that this context seldom exists in reality. Decisions may be taken on a purely political basis, which in fact may overrule most or all other factors. Political officials are in a position to trade off the overall societal values of concern to the government. However, political decision makers usually are faced by serious time constraints due to other public duties, have inadequate resources and information, and may not have the educational background or the necessary experience to arrive at a carefully crafted decision. They are buffeted by special-interest pleading, bureaucratic imperatives, and political forces whose vision sometimes does not extend further than the next election. The likelihood of such impaired decision making typically tends to increase with decrease in the governmental level concerned, mainly due to the availability of specific and personal technical advise decreasing. The average mayor, and this probably holds for both developed and less developed countries, probably has less opportunity to make recourse to advisors than a state's minister. This scenario often makes to seem technical advise irrelevant in the eyes of the stakeholders. On the other hand "rational analysis, carried on in an ignorance of political reality, may well end up so divorced from social reality as to be of little use to anyone" [81].

In some cases, the responsible entity may act simply as a mediator or facilitator for managing the interaction of stakeholder groups which are collectively responsible for the identification, and possibly also the implementation, of a remediation option.

4. NON-TECHNICAL FACTORS INFLUENCING REMEDIATION TECHNOLOGY SELECTION

4.1. General

Following from the context outlined above, a number of specific factors and constraints which will impact more or less directly the decision making process on the remediation programme can be identified. Some of them have to be included explicitly and actively into this process in order to make it most efficient. These factors include:

- remediation objectives, e.g. envisaged land use;
- economic factors, e.g. employment, infrastructure;
- environmental impact;
- public perception/acceptance and public participation;
- risks affecting remediation technologies;
- occupational hazards;
- costs, funding, and availability of resources;
- regulatory aspects, such as cleanup standards and competing legislation.

The sections below will discuss the various factors requiring assessment in terms of what the factor is, why it is important and how it can be assessed. The weighting of these factors can be driven by a variety of considerations, including technological, economic and socio-psychological ones. Thus, following the Chernobyl accident many measures were undertaken on socio-psychological rather than on radiation protection grounds. However, this value judgement will depend on the specific situation. In a non-accidental situation the social factors would probably be given far less weight than in a major accident situation like Chernobyl.

4.2. Economy, Employment and Infrastructure

4.2.1. Economic Background

Depending on the size of the problem, remediation decisions can have wide-ranging economic implications. Those implications may occur over short time-scales or long-time scales. Integrating economic considerations into the decision making process is not a straightforward task [82]. Decisions are often taken on political grounds and are not necessarily related to scientific or technical aspects of the environmental remediation problem. On the other hand, it is probably fair to expect that public benefit from public money is maximised. Therefore, the economic benefits, or detriments for that matter, of decisions on remediation projects need to be evaluated *a priori*.

Economic impacts of contamination events may manifest themselves in a variety of direct and indirect forms, including loss of property value, loss of markets for agricultural produce, job losses, relocation costs, costs of extended commuting to farther workplaces, or higher cost of food-stuffs. Unlike the siting of nuclear installations, including waste management facilities, where often the negative perception of things nuclear prevails [83], there will be a notion of considerable potential for economic benefits for the local community from the remediation activities. The remediation measures may bring with them an influx of money. Education and training opportunities for local inhabitants often increase. Overall, the standard of living increases — at least with respect to a situation without remediation — and sometimes above the pre-contamination level.

Often the decision affecting a region, and therefore also the local perception of a remediation programme, will be made having a detailed knowledge/perception about the individual or community surroundings. However, social groups typically differ in their perception. For example, certain groups of the public may be reluctant to support a given proposal affecting their settlements owing to an inability to move elsewhere — often reflecting a lack of inward investment or regional decline, thus lowering its respective appeal. This is not to say that the individuals actually wish to leave — just that, if they should wish to do so, they are unlikely to find a buyer for their property, or would receive a relatively low price, which curtails their ability to purchase elsewhere. There is, therefore, a perception of inhibited mobility, which may not be felt by other groups, who retain more flexibility/mobility. The affected groups may vary considerably depending on the Member State and its current economic setting. Typical examples include rural poor in developing countries, but urban middle and upper classes in developed countries living in declining regions have found themselves in a similar situation.

Table XI. Societal and infrastructure impacts (after [84])

IMPACT LEVEL	SOCIETAL IMPACTS IN THE AFFECTED AREA
0	No social or economic disruptions occur; no commercial, residential, or agricultural displacement occurs, and no adverse impacts on water resources occur.
1	An in-migrating population of about 10% of the resident persons is dispersed within an area; in-migrant lifestyles match those of current residents, and no major social disruptions result; disruption of existing business patterns is avoided by standard economic planning measures; no adverse impacts on water resources occur, but minimal commercial, residential, or agricultural displacement results.
2	An in-migrating population of approximately 10% of the resident persons is concentrated within a few communities; major upgrading of the public infrastructure is required; 25% of residents have lifestyles and values that are unlikely to match those of in-migrants; major social disruptions do not result; disruption of existing business patterns is avoided by standard economic planning measures; minor diversion of water resources from other activities occurs; half of the land is privately owned, and commercial, residential, or agricultural displacement results.
3	An in-migrating population of approximately 20% of the resident population is concentrated in a few communities; major upgrading of the public infrastructure is required; affected communities have homogeneous lifestyles and values that do not match those of the in-migrants; significant disruption to existing business patterns and substantial economic decline result during or after completion; minor diversion of water resources from other activities occurs; all land is privately owned, and commercial, residential, or agricultural displacement occurs.
4	An in-migrating population of approximately 20% of the resident population is concentrated within a few communities; major upgrading of the public infrastructure is required; affected communities have homogenous lifestyles and values that do not match those of the in-migrants; significant disruption to existing business patterns and substantial economic decline during or after completion occurs; major diversion of area water sources occurs, resulting in impacts on development in the affected area; all land is privately owned, and commercial, residential, or agricultural displacement results.
5	Changes in the level of availability of public infrastructure includes schools; police and fire services; water, sewer, and solid-waste systems; and recreation facilities.

The choice of remediation technologies may be tailored to the economic needs of a region or the respective resources available. Thus the overall economic benefit for a region might be improved by choosing a perhaps less sophisticated technique, but involving more local man-power and other local resources. Or, in former industrial areas, drawing out a project over a longer time-scale, thus keeping local staff employed for a longer period of time, might be more economical at the bottom line than earlier completion followed by paying unemploy-ment benefits; and it may add a social dividend. Working out such trade-offs requires the collaboration of all parties involved, the contractor, the operator, licensing authorities and the funding bodies and the public. Installation of a quantitative decision aiding system allows to make the complex process of decision finding transparent to all stakeholders and parties.

For the purposes of this publication a simplified tabular method for measuring the performance and societal impact of a remediation option is given in Table XI above.

4.2.2. Employment

Employment rates effectively provide a measure of the direct and indirect jobs created through remediation process implementation. Employment is an important socio-economic factor to consider within any decision making process, especially for the communities affected by the contamination or the remediation work. Employment has been in decline owing to large-scale facilities being closed down. Employment creation can be effected in a number of ways, namely:

- directly during the physical implementation process and any required aftercare by creating jobs on these projects;
- indirectly in other economic areas within the local community, for example due to increase in business volume of shops, hotels and other service industries;
- owing to the general socio-economic revitalisation of areas previously in decline.

The effects can be measured with relative ease over both short and long time-scales and can be linked to the local infrastructure. Both positive and negative influences need to be considered. While overall employment may increase, the specific technical expertise required may not be available within the local community.

For assessment purposes, a clear and comprehensive baseline needs to be established, which then allows at least a qualitative comparison with any potential future scenario. Pertinent employment data can be acquired through a number of different methods:

- employment surveys;
- case studies;
- estimates from operational technical requirements.

4.2.3. Skill Base and Education

Depending on the size and nature of the problem, a remediation programme may be both, determined by, and impact the skill base and level of education available in the community or region. Local unavailability of skilled personnel may be a constraint on implementation of an otherwise viable remediation technology. The problem may be overcome by either recruiting staff with the required skills or by training and education, if project resources and time scales permit this. For example, re-training and re-deployment of scientists and engineers from the workforce of the previous operation on a site is a major element of the conversion programmes from nuclear weapons production to civilian activities in the USA and the successor countries of the former USSR.

The effects on the socio-economic context of the communities may be quite varied, again depending on the scale of these measures with the respect to the size of the community. A sizeable influx of outside workers may give rise to social tensions, but also boost the economic situation of the community. Training and education of locals is likely to improve their ‘market value’, but can induce demographic changes later on, for instance by outward migration following the completion of the remediation project. Assessing such effects in detail is probably beyond the means of the average remediation project, but decision makers on the (higher) political level may well be guided by such deliberations.

4.2.4. Infrastructure

The quality and availability of local infrastructure can affect, and in turn may be affected by a remediation programme. Relevant variables include:

- the physical setting of the site;
- local facilities, e.g. transport (road, rail networks), accomodation, etc.;
- regional facilities, e.g. transport (road, rail networks), waste disposal facilities;
- general state of development.

The added value from infrastructure improvement may be an important factor in the decision making process. Due to the numerous and disparate factors which describe an area or community infrastructure, it is not possible to be comprehensive here with respect to methods to be used for the analysis of potential benefits for and impacts on the infrastructure. Specific methods may be utilised for detailed and specific analysis of individual infrastructure components.

4.3. Costs, Funding, and Financing

4.3.1. Life-Cycle Costs

The term 'cost' in the context of this section is meant to cover direct expenditure and not a numerical value coming out of the monetarisation of some non-tangible item, such as detriment to the environment etc. It is clear that all relevant cost items for all options under investigation must be included adequately in the decision making system. These include, *inter alia*, management costs, labour, procurement or renting of equipment, licensing fees for technologies, monitoring costs, and costs of final waste treatment and disposal. The latter can indeed become a major cost factor.

The issue of costs is also linked to the risk that the technique selected for implementation may fail. The more innovative a technique is, the higher the provisions for contingency have to be.

Life-cycle costs consist of the total expenditure required to design, implement, and demobilise a remediation technology for the projected life of the project [85]. Those costs can be divided into capital costs, management and integration (M&I) costs, and operation and maintenance (O&M) costs. Capital costs include direct and indirect capital costs. Direct capital costs include equipment, labour, and materials to deploy the technology. Indirect capital costs include such items as design, construction management, and treatability studies. M&I costs include regulatory compliance management, infrastructure and materials support for the project's operation, and assurance of an adequate workforce. O&M costs include expenses for the start-up and operation, including monitoring activities, of the remediation alternative under consideration.

Because budgetary resources may be fixed or limited, delineating the life-cycle costs can be an important input for the decision making process. A common cost basis permits evaluation of the life-cycle costs of remediation alternatives. While this is typically possible within one country, cost comparisons between countries are notoriously difficult.

Standard engineering cost principles can be applied in a consistent manner to develop life-cycle cost estimates [86][87]. In general, a work breakdown structure (WBS), detailing the activities necessary for implementing the remediation technology is specified. Unit costs are applied to each of the cost elements [88]. Unit costs for the activities can be obtained from prior project experience, vendor quotations, existing databases (e.g. [89]), and unit costing reference books. A historical cost analysis for a range of technologies and strategies is provided in the Annex.

Environmental remediation projects for radioactively contaminated sites have presented managers around the world with a number of properties that are not comparable to the normal cost estimating climate within other commercial projects. These properties include:

- A higher than normal exposure to cost and schedule risk, as compared to most other projects, due to changing regulations, public mistrust, resource shortages, and scope of work;
- A higher than normal percentage of indirect costs relative to the total estimated cost due primarily to record keeping, special training, insurance, liability, and indemnification.

4.3.2. Funding and Availability of Resources

Many Members States today have adopted the ‘polluter pays principle’, meaning that the originator of a contamination is responsible for adequate remediation measures. However, in many cases the originator has ceased to exist, or it is difficult, even impossible, to attribute a contamination, owing for instance to multiple contamination events, thus resulting in ‘orphan’ contamination. Owing to the nature of such radiologically relevant contamination, the responsibility for making safe, cleanup, and monitoring often rests with or, in the wider public interest, is assumed by the government. The government has to fund such activities through (regular) tax revenue and limited income in any one year may hamper and delay remediation. Similar constraints apply to private enterprises, where remediation funds typically need to come out of the annual (gross) profits or from (non-taxable) reserves, if these are permitted under the prevailing legislation.

In some instances alternative funding can be sought, such as through the increase in market value of property following cleanup and re-development. Speculations on the property value may indeed influence the performance of a remediation programme as well as its end-point, for property value is closely linked to foreseen land use. This kind of funding mechanism is more applicable to (former) practices, rather than to accidents, where previous activities typically resume after cleanup. In the private domain and for new practices, or the further extension of licenses for existing practices, insurance cover for environmental liabilities are increasingly required by the licensing authorities in many developed Member States. Depending on the type and size of operation, these may take the form of classical risk-type policies obtainable on the insurance market, or the form of bonds [90]. Environmental liabilities and their financial coverage are also becoming an integral element of corporate business plans and company accounting systems [91], thus minimising the risk of generating new ‘orphan’ contamination.

Resources available for remediation measures are usually limited both in total amount and with respect to the time over which they can be spent. Allocation to the various sub-tasks and supporting activities will be an important aspect of the decision making process. Cost control not only addresses the allocation of resources to individual sub-tasks, but also controls the flow of resources over time. The amount of funds available at any one time might well limit the choice of remediation option. Two possible extremes are i) an option involving a high investment over a short period of time, as opposed to ii) another option involving moderate expenditure of a longer period (Figure 11), both options incurring the same total cost. The second option may be more in line with the general mode for tax money availability, but additional costs from spreading out the task must be taken into account. These typically include interest on loans, rental fees and higher depreciation for equipment, and maintenance costs for the necessary infrastructure. This indicates that a full economic cost assessment and accounting is an essential element of the decision making process.

4.3.3. Financing and Procurement

While the discussion above concerned the ultimate source of funding for a remediation project, various models for financing the remediation activities exist. The method of financing is determined by the nature of the problem owner and the source of funding. Typically the problem owner or his intermediates, be it government or private, would contract out at least individual technical measures, if not the project management. Contracts would be honoured upon the achievement of certain agreed programme milestones, such as achieving a specified level of residual contamination or processing given amounts of wastes. There are also cases where the government may hand over the whole problem to a contractor/management consultant to be delivered with the agreed final solution. In any case, the financial and programmatic risks largely remains with the government for public sector projects.

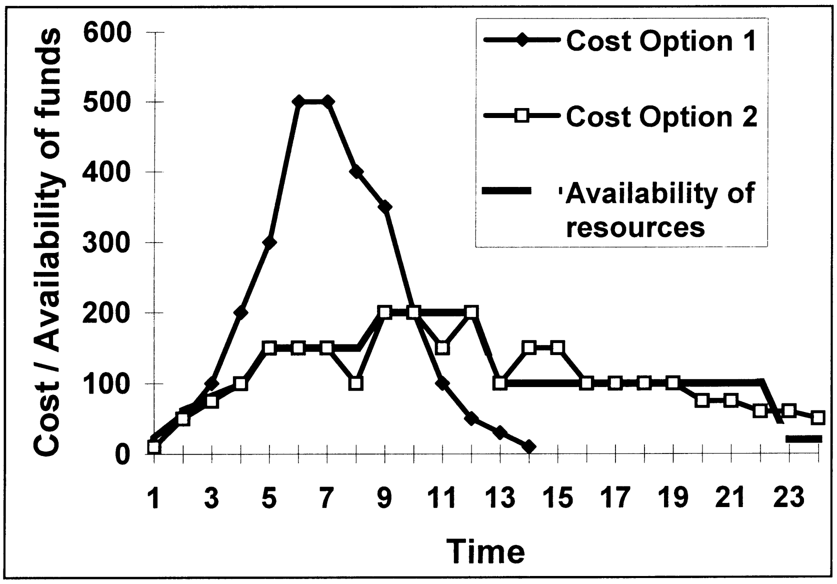

FIG. 11. Viable (Option 2) and not viable (Option 1) cost vs. time functions.

Tight budgets, both in the public and private sector, and higher accountability of resources spent in the public sector have led to increased financial risk awareness and a move away from pure service contracting towards remediation results oriented contracting [92]. The intention is to devolve programmatic, and hence, financial risks upon the contractor, with the aim to complete a project within budget and schedule, and to specification. Following the success in competitive bidding for a project, the economic incentive for a contractor resides in the margin to be obtained, if the project can be completed within or below budget and schedule. In order to be economically attractive, the obtainable profits must be commensurate to the financial risk the contractor is exposing himself to. A pre-requisite, therefore, is a clear description of the project, its objectives, and identification of all risks associated. Parcelling a project into logical, smaller and easy to oversee work packages, however without compromising the overall efficiency, makes contracting and bidding easier.

Financing for the project execution may come from government or private sources, or a combination of both. The relative proportion will depend on how well the project and its associated risks can be defined in order that these risk remain commensurate with the market incentives for the contractor. In the case of public money financing, it may take, for instance, the form of down-payments to the contractor. In the case of private sector financing the contractor may seek funding on a corporate or on a project basis. With 'corporate borrowing', lenders look to the borrowers', i.e. the contracting firms', balance sheets for loan security. With 'project financing' lenders look to the performance of the project for payment rather than the borrower's balance sheet. Hence the lender will analyse the project risks on a stand-alone basis. This analysis involves

- an identification of all transaction risks;
- a determination of whether the risks are manageable;
- an assessment of whether the party accepting the risk is able to do so; and
- an appropriate allocation of otherwise uncovered risks [93].

Computer-supported tools have been developed to assess and analyse the respective project risks [45]. The lender can then use this analysis to determine whether to lend to the project, how much interest to charge and when to expect re-payment of principal and interest [94]. To effect an optimal allocation of risks requires that risks be allocated to the party best able to manage the risks. At the same time, risk allocation directly impacts the financial feasibility of a project. Placing too much risk or unmanageable risk on a contractor, or having unknown or unquantified risks, may jeopardise or void a contractor's ability to secure private financing [94]. To mitigate a lender's concerns regarding project risks, a contractor has several options, including finding alternative sources of financing (additional equity or subordinate debt), obtaining insurance to cover specific risks, or guaranteeing a portion of the debt with his balance sheet. Structuring a contract to achieve practical allocation of risks optimises the economics of a remediation project by ensuring private financing is available, cost savings to the government are effected, and cleanup is achieved [92].

4.3.4. Taxation Aspects

The taxation framework in the Member States, and in particular its flexibility or non-flexibility, can have a decisive influence on the methods of funding and the possible allocation and deployment of funds. Issues of relevance include allowable reserves, fiscal vs. project-oriented accounting, continuity (meaning that a stable tax regime is necessary for planning and implementing long-term remediation projects), etc.

4.4. Regulatory and Institutional Aspects

Establishing a remediation strategy which fits in with the current regulatory framework applicable to the Member State or even specific regions (as in federal states) is required. It is unlikely that any strategy which does not fit into the regulatory framework will be acceptable to either the regulators or the general public, even if the other assessment factors are positive in nature. A clear distinction between legislation and guidance is therefore imperative.

Assessment could take place via establishing a clear understanding of the current regulatory framework in terms of:

- likelihood of regulatory acceptance/favourability;
- sustainability (environmental and socio-economic);

- licence issues (if applicable);
  - ability to meet current regulatory requirements;
  - ability to meet with anticipated future regulatory requirements;
  - continued retention of a site licence.

The data required to underpin this factor can be obtained from

- guidance documents, e.g. [9];
- existing legislation;
- international conventions and standards.

Regulatory aspects will influence the decision making processes at various levels. The initial decision to remediate typically will have been instigated by action levels as described in national regulations and international guidance. The regulatory framework varies considerably from Member State to Member State, leaving the decision makers a degree of freedom in some, while being fairly rigid in other countries. Some countries have adopted a quite flexible approach concerning justification and the targets for remediation; these targets may be adjusted in order to optimise the overall decision making process by minimising e.g. doses/environmental concentrations and costs, and optimising the deployment of resources. In those countries which have adopted a more rigid approach with respect to justification and targets, a decision making system will help to optimise the process within the given set of boundary conditions. There is, however, a dose rate above which remediation in all cases will be justified [9].

Environmental remediation projects are often multi-annual undertakings. Hence, pertinent legislation, both at national and international level, and the underlying political thinking may change from the time the justification is developed to the time when the implementation is to be fully achieved. Changed target values and doses/environmental concentration levels on the basis of which the action was justified may lead to the reappraisal of the whole project.

Side effects of planned remediation measures may also conflict with legislation in related fields. For instance, changes in land use may have impacts on drainage pattern, on groundwater recharge quality, may lead to eutrophication of surface water bodies, on the ecology of protected landscapes, and so on. A predictive assessment may be needed to ascertain that no such impacts will occur [95].

The short term components of a remediation strategy can be tailored to meet current regulatory requirements, while the longer term components can be tailored to have a reasonable chance of success in meeting foreseeable future regulatory requirements.

4.5. Stakeholder Perception and Participation

4.5.1. Introduction

It is now widely recognised that the way that a contamination situation and remediation proposals are perceived by members of stakeholder communities and by the public at large, can have a major bearing on the social acceptability and effectiveness of a remediation strategy. This point is related to the increased emphasis on providing for participation of stakeholders in the decision making process. Communication between decision makers, experts and members of the stakeholder communities can often lead to better knowledge about the issues because each party brings its own knowledge, opinions and preoccupations to bear, thus improving the decision making. Also, as people interact, their perceptions of each other and of the issues can change, which sometimes improves prospects for effective implementation of agreed solutions.

In this context, a wide variety of participatory procedures have been explored over the past 30 years, that place emphasis on improving communication of different points of view and on the search for a widely acceptable solution taking into account the diversity of interests and perceptions. These range from negotiation procedures between sectoral interest groups as a component of policy-making at national and international levels, through mediation processes involving a small number of interested parties in local community settings.

Good awareness of the perceptions of stakeholders and the public at large, is thus important for identification of issues and for evaluation of risks and acceptability of possible solutions. It is also the starting point for building participation processes. The objective of participation, generally speaking, is to look for a consensus, and to avoid an unilateral decision that is imposed whether the parties concerned agree or not. This is a ‘participatory’ ideal, one that can be given only incomplete effect at different levels of decision making. Sometimes different groups of people simply cannot, or do not want to agree. Nonetheless, the shared or ‘public’ character of many health risks and environmental benefits and harms justifies the view that decisions ought best to be made through wide concentration of stakeholders. Judgement is partly a learning process, and participation offers the hope that people can learn from each other and that something more than a straight compromise between fixed positions is possible [96][97][98][99]. By sharing knowledge and exposing participants’ initial perceptions to one another and to reasoned debate, they may change, and in this way be brought together.

4.5.2. Stakeholder Perception

Perception is effectively an expression of individuals opinions about the short and long term acceptability of remediation strategies and political and corporate bodies. This factor encompasses the stakeholders’ views on all aspects of the remediation activities and their possible consequences. The way how the public perceives the approach to remediation will feed back into the decision making process in a variety of ways, including political pressure on the decision makers. A remediation programme thus may be designed, for instance, such that economic benefits for the affected communities are maximised, or that technical measures are highly visible to the public, or that certain expectations concerning the aesthetic appearance of the site are fulfilled.

Including perception issues in the decision making process is important, because any such process revolves around a balance and comparison of all the different assessment factors. The perception of the different stakeholder groups of these factors is of relevance because certain issues may be more important to them than to others. Stakeholder groups usually fit into three main areas, namely:

- political
- social, welfare and regulatory
- non mandated.

Stakeholder viewpoints with any of these groups may vary depending on their geographical location. The assessment process needs to be comprehensive so as not to miss out any stakeholder groups. Stakeholder perception can be broadly split into either environmental or socio-economic issues. For example:

- Environmental
  - Visual impact
  - Occupational radiation dose to workers
  - Disturbance during the project (traffic, noise, vibration)
  - Water/air quality

- Socio-economic
  - Project start
  - Employment and mobility
  - Future land use and property values
  - Cultural resources

Data collection to assess stakeholder perception can take place through a number of different ways, but most, if not all, will reflect the assessment factors highlighted in the previous sections.

- Local liaison groups
- Stakeholder engagement forums (local and national scale) and focus groups
- Public meetings
- Questionnaires
- Visitors Centres (static or mobile)

The subject of risk perception and its accurate communication is an important area within this factor. For example, different remediation technologies may be perceived quite differently with respect to their effectiveness by the public, i.e. the effect of public reassurance may vary considerably [100].

A large variety of methodologies for surveying perception have developed in recent years, reflecting the philosophical standpoint of the person undertaking the survey.

Sampling-based questionnaire methods, adopted for quantitative surveys in the field, are able to generate data which can be evaluated quantitatively. However, their main drawback is that anonymous verbal expression and overt behaviour often have no relationship at all. A person may reply/state one kind of attitude/perception, but may behave/act in reality in a different way. Structured or semi-structured questionnaire-based surveys can remove this ambiguity associated with attitudes and behaviour through careful wording and more personalised treatment. It is possible that linguistic or semantic differences will still continue to remain.

Another method used recently is ‘participant observation’. In this method, the researcher becomes one of the subjects [101]. Some international development agencies, such as The World Bank have sponsored participant observation investigations [102] in an effort to integrate their policies and plans with people’s priorities and perspectives. A methodological problem — well known to ethnology — arises here: the observer continues to remain an outsider, as long as his gaze searches out for environmental perceptions hidden and untold by the subjects under study, but at the same time he tries to identify himself with the subjects and may lose his objectivity. Some form of Heisenberg’s Uncertainty Principle may come to bear here, as the process of observation disturbs the objects being observed.

One more emerging method of measuring subjective assessments is 'group interviews' — both focus group interviews and community interviews. The small, focused group analysis is the most novel and innovative strategy developed in recent years to enable decision makers and group members to explore together [103]. Repeated interviews with focus groups are clearly more likely to produce more information than those groups that meet once only. Again bias due to 'non-participation' is probably unavoidable.

On a more applied level, behavioural sciences have emerged with the 'Delphi method' [104], which aims to develop answers to problems through reaching consensus among experts. A newer form of the conventional Delphi method is the 'Delphi conference', in which a special computer program summarises results and develops new questionnaires for the respondent group, who also gets at least one opportunity to re-evaluate their original answers on the basis of examination of their previous responses [105]. A modification of the Delphi method is called 'Strabo' [106] which depends on the experts' knowledge-base and their ability to draw mental maps of the area of their expertise. Communication is generally conducted through a series of sketch maps, and the final products are maps based on the best available information.

Another type of quick, informal and relatively inexpensive survey, developed particularly for less developed countries, is called rapid rural appraisals (or assessments) — in short RRA. These are semi structured, but systematic surveys providing rapid turnaround, interactive approaches (survey teams meeting with local residents), conceptual rather than statistical clarity, and the flexibility to make continuous in-field refinements in response to new findings. RRA is actually a part of a growing family of approaches and methods known as participatory rural appraisal (PRA) which enables local people to share, enhance and analyse their knowledge of life and conditions with outside decision makers [107]. An exercise in PRA significantly improves local inputs in environmental remediation planning. PRA techniques represent a paradigm shift in environmental planning.

Oral history is another method whereby oral evidence is taken from people who have directly experienced, or are relating accounts that have been personally handed down to them. This listening technique can be used in particular to recreate some past environmental conditions, as well as the meaning of certain environmental attributes.

4.5.3. Bringing about Participation

A great variety of participatory procedures and institutional forms have been proposed. Formally constituted deliberative institutions can be identified in the following broad categories.

- There are deliberative political institutions of representative democracies, ranging from local governments through to the national parliaments (and supra-national entities such as the European Parliament).
- There are deliberative institutions that have their roots in political traditions other than Western democracy, for example tribal forums in many parts of Africa and the South Pacific based on complex protocols of hierarchy, reciprocity and consensus-seeking.
- There are *ad hoc* indirect deliberation institutions. These approaches bring together a group of enquirers who are not directly involved in the issue to consider an issue and recommend a decision to the government or legislature. There are also under this head a

wide range of processes for what we might call a 'group valuation', as distinguished from individualistic valuation approaches such as standardised contingent valuation.

— There are *ad hoc* direct approaches that involve deliberation not by the members of a parliament or by a forum exercising tradition authority, but directly by persons affected by or claiming an interest in a planning decision. Such procedures can be initiated by the participants in a controversy or as an official process bringing together people selected as broadly representative of those interested and affected.

Some of the specific methods and formats of the *ad hoc* direct and indirect deliberative processes are summarised in Table XII. There is a continuum between direct and indirect, and between the various methods.

For a European context, a detailed documentation of how multi-lateral stakeholder negotiation allied with scientific and economic multi-criteria analyses can be effective ways of achieving an 'integrated assessment' of development options was given in [108]. Reference [33] shows how multi-criteria and attitudes survey analyses can be embedded in a community deliberative process.

Table XII. Typology of *ad hoc* deliberative procedures

(a) Indirect methods

— **Focus groups**: focused and facilitated group discussions of particular topics, issues and reactions.

— **Citizens' panels**: small groups selected to input representative citizen views to *decision making* processes, usually at a local level, through moderated discussion of relevant issues.

— **Citizens' juries**: groups much like citizens' panels except that their deliberation is intended to result in a 'verdict' or specific planning recommendation on some relevant question.

— **Consensus conferences**: larger conventions which combine a panel of lay people with expert testimony in an *ad hoc* public forum, typically to consider broader or more fundamental questions and to produce a written report with recommendations.

(b) Direct methods

— **Mediation**: parties to a dispute or controversy seek to identify their differences and design solutions through discussion with the help of a neutral third party.

— **Citizens' juries**: can also deliberate directly when selected to represent an interested and affected community and their verdict given standing within the appropriate jurisdiction.

Such processes can be purely consultative, or the deliberations and opinions expressed could have the status of advice with weight in binding decisions. For a set of examples on deliberative procedures see Appendix D, adapted from [28].

The use of multi-criteria, deliberative and participatory processes for appraisal of technology choice problems is growing in many parts of the world [109]. This is consistent with the idea that different groups of people with their varying life experiences can, together, bring greater wisdom to the problem solving process. It is also a means of seeking scientific, as well as political quality assurance in the face of high-stakes, high uncertainty decision problems [78].

The goal of deliberative methods and institutions is to try to find a satisfactory decision in terms of the public good, one that is fair and respectful of divergent points of view through argument and practical judgement. Just as it is difficult to reject entirely the idea at the heart of cost–benefit analysis (CBA), of assessing the opportunity costs of a policy choice or action, so it is difficult to speak against the deliberative ideals of co-operation, open communication of information, and consensus solutions. Nonetheless, the mediation and other deliberative procedures do run into difficulties that, in many cases, have their roots in the same features of conflicts of interest, divergence of perspectives, and uncertainty that pose problems for monetary CBA as a decision support process.

First, a process may not be inclusive of all parties in society that claim an interest, and parochial interests are not necessarily consistent with larger ecological, social, or long-term sustainability objectives. Even when a process seeks to be inclusive, the asymmetrical distribution of power in society can mean that poorer, less articulate (within the chosen communication forms), or less well organised interests have a lesser say. Second, major health risk, land use and environmental disputes are grounded in differing and deep-rooted principles which may be incompatible, meaning that agreeing to a compromise for one or more of the parties is not really possible [110].

Developing a process for public participation is a complex undertaking, but over time experience has been gained in the characteristics of successful as well as unsuccessful public involvement programmes. Some recommendations (adapted from [111]) for participation are:

— **Selection of participants** in the decision making process needs to conform to four principles: participation needs to be broad, the selection process needs to be perceived as being fair, chosen representatives of interested and affected parties need to be acceptable to those parties, and participants need to have the necessary knowledge, experience, and perspective to contribute to the decision making process.

— **Timing participation** needs to be so that involvement is sought early in the decision making process and continue throughout the remediation programme. Participation is particularly necessary during the problem formulation and scoping stages to ensure that the measures are appropriate at the end to the problem at hand.

— **Establishing objectives** for the participation process early will assist in ensuring that the activities of those participating are focused on results. Care must be taken in this step, as the imposition of overly restrictive objectives on stakeholder groups may be counterproductive. This step will be guided in light of the expectations of the stakeholder groups and the past history of the responsible organisation. However, the determination of the objectives will shape the process. Lack of clear objectives for the participation process can considerably delay the remediation, as well as create confusion and mistrust on the part of the stakeholders.

— **Listening to the participants** is probably the only way to ensure participation. If the stakeholders sense that the decision makers are not actively listening and acting on their input and, if they are only seeking token input to fulfil legal or regulatory requirements — the highly divisive activity often referred to 'creating the illusion of choice' — the involvement programme will not be effective and may increase public mistrust, as it demonstrates continued official unresponsiveness to public concerns. Thus participation has to be a two-way process — not merely dictating to the public or informing the public of the decisions.

— **External constraints** suffered by the decision makers such as budgets, regulations and timing in their decision making must be explicitly addressed and communicated early to the stakeholders to avoid misunderstandings later in the process of participation. Also, public involvement cannot be used to abdicate legal responsibilities to act. Responsibility for environmental remediation planning typically continues to rest with a government body, and both the stakeholders and the responsible body must remember this.

— **Participation** must strive to be fair, though it may be difficult to achieve in the actual practice of decision making. A major concept in fairness is the idea of a level playing field for all stakeholders; in practice this means evaluating the relative power of the different parties to participate. Levelling the playing field may involve providing access to information and resources that some stakeholders normally lack. Determining the appropriate level of support for different stakeholders will be problematic, but it need to be guided by the idea that the discussion among stakeholders need to be balanced. Also, assumptions and value judgements must be formally defined and communicated in the decision making process. In less developed countries special care has to be taken to facilitate involvement of groups which typically have less access to information, such as the poor, women and disadvantaged indigenous populations.

— **Flexibility** and iteration in participation have to be carefully managed to ensure effectiveness. This includes developing timeframes, delegating responsibilities, allocating resources and coordinating efforts. Failure to plan effectively can cripple an environmental remediation programme and foster frustration and lack of trust among the participants.

Comprehensive stakeholder concertation processes that deliberately integrate systems science with deliberation in a recursive cycle can be envisaged as in Figure 12. The iterative loop emphasises the real-time process of 'putting onto the scene' interests, knowledge, justifications, disagreements and possible solutions. Such procedures can often be quite simple. However they are distinctive because they require the bringing together of formal expertise with wider stakeholder negotiation or deliberation procedures.

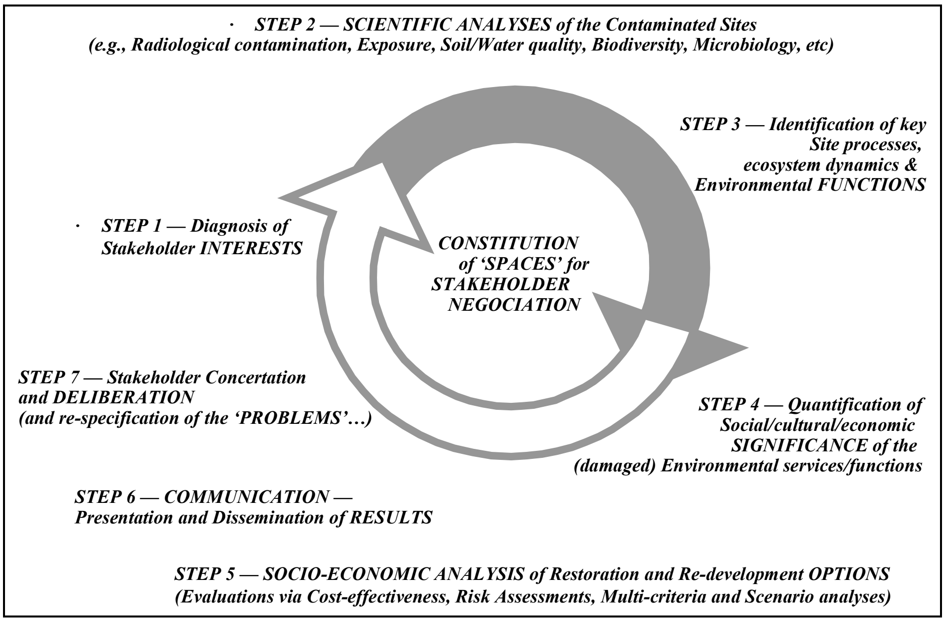

FIG. 12. The iterative process of decision making.

Effecting active participation goes beyond sampling the public's opinion on a particular subject. The USA have extensive experience in the use of citizen advisory boards (CABs) for the large-scale remediation activities at former DOE sites [57][112]. Selecting suitable and representative participants meets with problems similar to those of collecting a representative sample of views. Participants are selected as representing certain groups of the public and expected to report back to their 'constituents' [112]. For this reason a 'representation' model, whereby stakeholder organisations are allotted specific seats on the board is favoured over a non-representative, 'at-large' model, whereby interested individuals are selected on ethnic, gender etc. grounds. An intermediate model allots seats on the CAB to specific demographic categories, such as race, gender, ethnicity etc. Report-back under the representational model is relatively straightforward, since board members understand precisely who their constituencies are. With the at-large model, members represent only themselves and do not presume to speak for any particular segment of the stakeholder population. Members may be representative of identifiable constituencies, but not representative from those constituencies [112]. On the other hand, existing stakeholder organisation may not provide a representative cross-section of the public opinion in general.

The scale-dependency of participation has been noted [54], where participation sometimes is easier to achieve for smaller-scale problems, for instance at community level, than for instance at water-shed level. This is presumably an effect of the increasing heterogeneity in the stakeholder community. Constraints to up-scaling of participation also apply to different agencies, such as government departments, sponsors, NGOs etc. engaged in promoting participation. This is one reason for micro-level realities often conflicting with macro-level perspectives and plans. While conflicts of scales are an inherent obstacle to participation, participation in itself is the means to overcome it.

The most effective medium for enhancing communication will depend very much on a country's or region's infrastructure and socio-cultural context, many of which will not currently have wide-spread access to information technology dependant techniques. Typical media for facilitating the exchange of information include community newsletters, direct mail, local information meetings, one-to-one meetings with community member immediately affected, and increasingly interactive electronic media, such as the Internet (Table XIII) [75][113]. The evaluation given in Table XIII has been obtained from the North American and Western European context. Different results may occur in different cultural contexts. Some of the techniques would not be used as alternatives, but rather consecutively or complementary, i.e. to give presentations to groups or take them on tours would require to develop an initial interest using some other medium. An intrinsic bias need to be kept in mind: that it is only those who are 'concerned' tend to become 'involved', while the majority of the public may not have the interest, resources or the intent to do so, leading to a bias in the sampled opinions. Some of the techniques listed require an active step on the side of the public, such as visiting a reading room or an information centre. A step towards reducing this bias is to make it easy for the public to become involved, thus reducing the amount of resources they have to devote to the case [114]. Using modern sales and marketing techniques, such as prize draws in newsletters to both, attract a wider readership, and to gauge levels of readership by the responses to the draw, has been discussed [68].

Table XIII. Evaluation of Techniques for Public Involvement mainly in a North-American/ Western European context (modified after [75])

PUBLIC COMMUNICATION TECHNOLOGIES	DEVELOP INTEREST	PROVIDE INFORMATION	PROVIDE INVOLVEMENT	AUDIENCE
Briefings	H	H	M	Active citizen and groups
CD-ROMs	H	H	L	Student, reference librarian, active citizen
Fact sheets	L	H	L	Citizen asking for detail
Focus groups	H	H	H	Active citizen
Interactive multi-media	H	H	L	General public
Internet	M	H	L	Citizen seeking information via computer
Internet chat rooms	M	L	H	Internet active citizen
Touch-screen displays	H	M	L	Travellers, shoppers, users of public facilities
Media coverage	M	H	L	Large audiences
Newsletters	L	H	L	Large groups of interested citizen
Newspaper advertisements	L	L	L	Often required by law for the general public
One-to-one interviews	H	H	H	One concerned person at a time
Slide shows	L	M	L	Groups
Posters/story boards	L	M	L	General public
Public meetings	L	M	H	Small to large groups of interested people
Invited lecturers	M	H	L	Groups
Tours	H	H	H	Small to large groups

Note: H= high, M= medium, L= low effectiveness.

Providing for public participation is likely to require a non-negligible amount of financial resources. Means for measuring success, therefore, are justified requirements in a project management context. Measuring success is often complicated by the fact that public participation does not necessarily lead to tangible results. Rather, participation typically results in a reduction of programmatic risks and in savings, i.e. in averted overruns of schedule and budget. The public concerned may apply different measures of success, according to their agenda.

4.6. Project Implementation Related Risks

4.6.1. Framing the Problem

Two types of risk bear on the implementation of environmental remediation projects. The first category consists of the radiation exposure risk [115], which is being treated in the relevant IAEA safety standards [6]. The second category is the risk that a given remediation project may not meet its stated targets and objectives, namely the achievement of cleanup within schedule and budget. Hence, discussions of higher level risk-based decision models, which intend to answer the question of whether and to what level cleanup is justified, are largely excluded from this chapter.

From a 'technocratic' perspective everything potentially impeding the implementation of a project within schedule and budget would be termed a 'risk'. Such view implies (pre-)defined objectives and a justification for the remediation action. Identifying and minimising risks is necessary to ensure efficient project implementation. This becomes even more important, when key benefits associated with third-party financing, including inherent performance incentives and requirements of private lending sources, are to be preserved [92].

Traditionally, those in charge of environmental remediation projects have focused on technical risk only. The practical experience gathered over the last few decades, however, shows that different categories of risks are interrelated, including technical, operational, commercial, and people-related. To devise an effective cleanup strategy using suitable project management and contracting strategies, therefore, requires risk to be addressed in an integrated way [116]. Operational and commercial risks include site conditions, construction issues, programme management and financial risk. People-related risks include legal and procurement issues such as liability and indemnification was well as the stakeholder and associated political dimensions as discussed above.

Another key consideration is that active remedial measures taken to protect possible future individuals from residual contamination could cause considerable adverse effects to existing environmental, cultural, and economic resources, as well as to operators. This raises the question of whether losses incurred in the near term will be offset by any potential future benefits [116].

4.6.2. Technology Related Risks

The application of techniques, in particular new ones, always entails an element of risk and, hence, uncertainty about meeting the stated objectives. This uncertainty can be categorised into a number of different sources of uncertainty:

- The actual and apparent uncertainty or risk is related to the extent of practical experience with the technique in question.
  - Some technologies have been available for a long time and applied in many cases, their effectiveness has been demonstrated, both in the short and the long-term.
  - At the other end of the scale, there may be emerging technologies which appear to be promising, but their effectiveness in a given situation or on the longer-term time-scale has yet to be shown.
- Technology-specific risks, such as occupational health and safety risks to workers [117][118][119], have to be worked-in also.
- Logistics of deployment, e.g. the availability of equipment, staff, licenses etc. may pose additional uncertainties.
- Unwanted/undesirable side effects may occur [120]. Any technical measure constitutes an interference with a natural or man-made system with a potential to disturb the (dynamic) equilibrium of this system. Examples include geochemical measures to reduce uranium solubility in mill tailings which may enhance radium release, or changes

in agricultural land use, which may result in nitrogen release to ground and surface waters.

— Most technical measures will result in wastes which have to be disposed of in an orderly fashion. Availability of disposal facilities and cost (see above) of disposal may become limiting factors.

At the planning stage, there may be also some uncertainty with the respect to the acceptability of certain remediation or waste management techniques by all or some parties concerned, namely the owner, operator, regulator and the public. Some techniques are considered more 'politically correct' than others, for instance, waste incineration is disfavoured in certain countries. Technology acceptance is strongly related to the issue of innovation, innovation acceptance, and stakeholder participation in technology development [121].

Public health risks involve risks to the general public or to specific subgroups of the general public resulting from exposures or accidents that are associated with the deployment of a given remediation technology. This risk is a function of the likelihood of an exposure or accident occurring, coupled with the anticipated severity of the accident, that results in morbidity, injury, or mortality.

Worker safety and health risk refers to the risk to workers involved in implementing a remediation technology. Safety risks may result from (industrial) accidents that are associated with the deployment of a certain remediation technology. Health risks may result from workers being exposed to radionuclides and/or hazardous chemicals.

These risks are an important factor in the choice of a remediation technique because the safety and health impacts may vary substantially among technical alternatives [8]. Information about such risks can be derived from existing sources, such as standard nuclear and industrial engineering references, published health standards for radiologically relevant and toxic substances, medical surveillance, epidemiological studies etc. Data for the safety evaluation can also be obtained from specific hazard analyses or accident risk analyses.

4.6.3. Transportation Risk

Moving cleanup wastes or residues from one site to another site may result in industrial, radiation and traffic accidents that lead to morbidity, injury, or mortality. Transportation may also impact on natural resources or pose an ecological risk. In general, the magnitude of transportation risk depends on the number of kilometres travelled and the specific mode of transportation [122]. The severity of the impact associated with a transportation risk depends on the type of material being transported and the degree to which the material is confined, i.e. the waste form if any.

The potential for transportation risks may influence the choice of a remediation technology because some technologies require off-site transportation of materials for conditioning, or result in residues to be disposed off in designated and licensed facilities. Information about transportation risks can be obtained from hazard analyses or accident risk analyses.

4.6.4. Programmatic Risk

Programmatic risk consists of project uncertainties due to schedule demands, technology availability, logistical factors, and funding profiles.

The application of technology always entails an element of uncertainty. The implementation of a project, especially remediation projects whose life-cycle extend over a long time period, is particularly sensitive to meeting schedule demands and funding priorities. The technical performance may be uncertain, i.e. the effectiveness, readiness, implementability, and availability must be ascertained to reduce risks [8][122]. Logistics of deployment, e.g. the availability of equipment, staff, licenses etc. may pose additional uncertainties. Funding priorities may change over time, being often controlled on a political level, where perceptions and agendas may change.

A clear baseline needs to be established with critical path elements delineated. Information can be obtained from management plans, work breakdown structure analysis, operational technical requirements, and prior experience.

It has been demonstrated for the USA how the availability of technologies to solve a given set of problems can be assessed. Factors taken into account are the financial resources spent in the past and the present on their development and a complex index for their relevance, based on a judgement of needs being addressed [123].

4.6.5. Environmental Risks

The implementation of a remediation project may result in a variety of environmental impacts in addition to those resulting from the contamination itself. Environmental risk involves adverse impacts to ecological receptors located on-site or off-site due to significant disturbance to the site ecosystem and its surroundings as a result of remediation [124]. For instance, certain technologies such as removal of topsoil or soil washing may remove surface contamination at the cost of destroying the soil ecosystem.

Depending on the size of the site, an area larger than the actual contamination may be required for installations, intermediate storage of wastes and so on. Removal, transport and disposal of residual wastes may result in environmental impacts and risks at locations other than of the original contamination. There is, for example, little benefit in removing a contaminant that is well fixed on a low volume of soil, only to produce a high volume of an aqueous waste with the contaminant in a soluble or mobile form. In addition, the remediation techniques chosen may generate large quantities of secondary waste and may pose risks of exposure to the public or operators that exceed the risks of quiescent contamination [125].

Environmental risk may also extend to possible impacts on natural resources such as surface waters, groundwater, air, geological resources, or biological resources [124]. Impacts on biological receptors can be assessed in terms of mortality or diversity. Natural resource damages can be assessed in terms of mitigation of existing damage or prevention of new damage.

The potential for environmental risk may be an important factor in decision making because some remediation technologies are more likely than others to produce adverse impacts on ecological receptors, including habitat disruption, or generate natural resource damage [8].

4.7. Co-contamination Issues

Co-contamination issues offer a good example of where a sound understanding and balancing of technical and non-technical is required. In many practice related contamination situations remediation is complicated by the co-occurrence of contaminants of radiological and toxicological or eco-toxicological relevance. This is frequently the case for mining and milling operations, where heavy metals and arsenic are accessories to the ore, or actually may be its major constituent. In other cases hazardous and low-level radioactive wastes may have been co-disposed (mixed wastes) in a situation now requiring remediation [126]. Complex practices, for instance at large nuclear research centres, have led to co-contamination.

Conflicting cleanup goals associated with different contaminants at a particular site can lead to different cleanup efforts or to an unusual partitioning of a site into different cleanup units. The foreseen remediation technology has to take into account the possibly different geochemical behaviour of the contaminants. In other cases the radiologically relevant components may actually be of lesser importance than the chemo-toxicological ones, and remediation criteria and technologies may need to be tailored to take account of the latter.

The different types of contaminants may also give rise to different types of waste streams and related conditioning and disposal requirements. Disposal facilities for hazardous wastes typically are not licensed to accept radioactive wastes and vice versa. The necessary separation of wastes will add to the operational costs and the cost of treatment and disposal.

The co-occurrence of radiologically and chemo-toxicologically relevant contaminants may also pose particular problems with respect to occupational health and safety. The presence of volatile and/or explosive chemicals requires special protective measures for the work force and equipment suitable for such conditions. Both types of precautions will affect the project schedule and cost, for example working with breathing apparatus reduces efficiency or explosion-safe equipment is more expensive than standard equipment.

The problem of evaluating the co-occurrence of radiological and toxicological risks and the implication for setting standards, action levels etc. has been addressed recently by a project funded by the German Federal government [127], and — in the context of waste disposal — it is also the subject of a forthcoming IAEA publication [128]. Current risk assessments typically use an additive model when dealing with multiple contaminants, but this approach does not take into account any synergistic or antagonistic interactions between the contaminants. Because many sites have the potential for exposure to multiple contaminants this limitation is of great practical concern. Furthermore, the magnitude, or even the general direction of the impact on risk estimates is not known (i.e. whether this limitation would lead to underestimation or overestimation of risks) [115].

4.8. Future Land Use

4.8.1. Objectives and Restrictions

Remediation objectives and the technologies used to achieve those objectives have to be evaluated in terms of their potential impact on future land use. One of the overarching objectives is that the remediation not only improves the radiological situation, but that it also does not result in undue detriments to other properties of the site.

The base-line case for future land use in accident scenarios would be return to its previous use, while for past practices it would be the unrestricted release [9]. In practice, the possible land use depends on the degree of restrictions placed on it due to any residual contamination remaining. Restricted use (industrial or commercial) or unrestricted use (residential or agricultural) as targets influence the kind of technology to be implemented and level to which remediation has to take place [8].

The degree of restrictions to be applied may also vary between areas forming part of a larger contaminated site. Certain parts of a 'site' may not have received any contamination at all, and therefore could be turned to other uses without restriction. For example, it is estimated that only about 6% of the approximately 77 000 km^2 of land associated with US DOE activities are actually contaminated [129]. Much of this land served as buffer zones around the facilities and owing to very restricted human access now supports thriving and valued eco-systems. This in turn may impose restrictions on alternative uses from a nature conservation point of view.

Information on pre-existing plans can be obtained from land management plans, land use decisions, zoning regulations, building regulations, or any other relevant spatial planning instruments that are available in the respective Member State. If future land use is unknown or undecided a common assumption may be made for all remediation options. Land use, however, can also be a variable in itself for the decision making process, allowing for optimisation within certain constraints (for example the criteria justifying remediation) [9].

Release of land for 'restricted use' implies a reliance upon the continuing existence and retention of institutional control. Such 'control' can take the form of signs warning the public against trespassing or other activities, of fencing in and imposing of planning restrictions, usually at local, or even at national level, to prevent and control alternate land use. The applicability, feasibility and efficiency of the respective measures may vary considerably from Member State to Member State, depending on the socio-cultural circumstances, how much respect administrative authorities are drawing and the economic circumstances. There are numerous instances where scarcity of available land, breakdown in governance or lack of communication have led re-occupation of contaminated land. Remediation options relying on institutional control need to be assessed with respect to their realistic sustainability.

Land use after environmental remediation can also be a public participation and community issue. The issue often is part of a broader transition in the local economy. The contaminated site may have been part of the operation of a major local employer, who now has ceased to exist or has changed the market sector, with ensuing changes in employment levels and structures.

Chosen end-points for remediation and hence the amount and form of residual contamination can put restrictions on certain forms of land use. For instance, for a given set of environmental conditions the residual contamination may be stable in the soil column; introducing irrigation, however, may lead to increased mobility of radionuclides. Hence, if such scenarios are foreseen appropriate measures have to be taken.

4.8.2. Land use planning

A vast amount of experience has been accumulated, mainly in the context of revitalisation of former industrial and commercial sites [130][131]. Although planning procedures and requirements and the related legal instruments will vary from Member State to Member State, some common general features and requirements can be observed as indicated in Table XIV.

Table XIV. Land use and re-development planning (modified after [132])

A comprehensive planning strategy for the use or re-development of land need to include an analysis of potential consequences from changes in land use, and strategies for maintenance (and possibly, improvement) of environmental quality. The planning need to be based upon a comprehensive process that involves stakeholder input during which ongoing and emerging site issues are identified.

Questions to Answer

A land use plan need to answer the following questions:

1. What (part of the) property is available for re-use or re-development?
2. What is the most beneficial use of the property?
3. How can the property be transferred to the future user(s)?

Structure of a Land Use Plan

A land use plan need to include three basic components:

- A land use section which identifies local property use characteristics, such as heavy industry, residential, light industry, educational, or historic districts,
- An economic feasibility analysis of the land use plan, which includes both market analysis and fiscal analysis components, and
- An infrastructure section, which evaluates the condition of both the utility and transportation systems on the property, and which projects both the capital improvement and annual operating costs that would be incurred in the course of the plan's implementation period.

A comprehensive land use plan might be structured as follows:

- **Regional Overview:** Provide the general context for governemnt/owner and stakeholder discussions on site issues and influences.
- **Site Conditions:** Address the evolution and general state of the property.
- **Planning Process:** Identify site development goals, the general planning process and methodology.
- **Planning Analysis:** Examine site development concepts in response to current site issues and trends.
- **Strategy:** Present plans for implementation of property transfer initiatives.
- **Master Plan:** A diagrammatic illustration of the planned long range development of a site.

In determining the most beneficial re-use, the plan needs to thoroughly examine possible uses of a property, their benefits, disadvantages and constraints on future use in the context of the property's specific characteristics. Ideally, the plan provides a summary of the site and its facilities, including the estimated operational closure date, total property available for re-development, number of parcels to be released or planned for release; an environmental summary of current and future environmental cleanup and monitoring activities; and a statement of the general environmental condition of the property. Also, depending on site-specific circumstances, the plan needs to cover:

- Marketing of facilities (buildings, transportation, and utilities) to new owners/users;
- Negotiation of property transfer or leases;
- Negotiation of care and custody agreements;
- Environmental remediation to enable the transfer of property;
- Acquisition of funding for continued conversion efforts (planning and implementation);
- Feasibility studies to assist in the successful implementation of specific components of the re-use plan, such as the creation of a heritage district or educational programmes;
- Retraining and re-employment of those who have lost jobs, directly or indirectly, as a result of the contamination;
- Creation of jobs in the community to replace the revenue lost directly through reductions in payroll taxes and property taxes, as well as through indirect impacts, such as lost sales tax revenue;
- Re-use of the facilities on the property so that the local government might generate revenue to cover the costs involved in its newly acquired responsibilities of maintaining and servicing those facilities, such as the provision of police and fire services and municipal utilities such as water service;
- Using the property transfer as an opportunity to revitalise the local community; and
- Mitigating the impacts on the community at large, both from the business and the social service perspectives.

In the interest of the public, a 'most beneficial use' of surplus land in government ownership is to be sought that reflects a balance among various goals, including maximum return to the taxpayer, wise land stewardship, adherence to community values, economic development, environmental protection, cultural and natural resource preservation, and aesthetic value. For some sites, the most beneficial use will be readily evident to all interested and affected parties. For example, if a site is already industrial and can be re-used to create jobs as an industrial area, the re-use determination is likely to be relatively simple. For other sites, where multiple uses are feasible and natural and/or cultural resources are present, determining the most beneficial use may be more complex.

The most beneficial use will depend upon the site's particular traits, strengths and weaknesses, as well as the goals that the site, affected governments and communities, and other interested parties would like to fulfil through re-use. Therefore, the most beneficial use of one property at a site may be industrial re-use, while the most beneficial use of a different parcel of the same site may be as a recreational space or habitat preserve. Establishing the most beneficial use of a site requires a sound understanding of the site's specific features, its legal and environmental status, and the re-use constraints they may impose. Information gathered through site assessments, environmental audits, cultural resource plans, and other research must be considered when evaluating alternative future uses.

A useful way to begin the 'most beneficial use' determination is by conducting a property appraisal to assess a site's financial value. By analysing the property's specific physical and legal features, the area and infrastructure surrounding the facility, zoning, comparable properties, and market needs, the appraisal suggests the highest and best use that would result in the greatest financial value. The market value reflects the expected financial return of the property given its most profitable and allowable use, based on data concerning similar uses in that community.

However, although appraisals are useful tools in determining market value, this financial appraisal does not capture a site's less quantifiable values such as ecological diversity, cultural resources, and recreational opportunity. One must turn to the community and other affected and interested parties to ensure that these less tangible benefits enter into the most beneficial use determination. The instrument of environmental impact assessment (EIA) would also provide valuable insight.

As discussed in previous sections, a number of important facts influence how the site can and may be re-used. For example, the legal status of property and its environmental conditions may clearly limit the range of its future uses. In addition, re-use might be limited due to physical deficiencies of the facility, inadequate supporting infrastructure, or zoning not easily subject to modification.

On the other hand, a site may have attractive characteristics such as ecological diversity or cultural artefacts that need to be considered in the re-use determination. Some members of the public will be interested in preserving these resources, while others will see them as barriers to other types of development and re-use.

Deciding on the best use of a property will be more realistic and efficient, if all affected parties are aware of these constraints and considerations from the beginning. Some property use limitations may be permanent while other restrictions might be lifted in specific time frames. All interested parties need to understand the property's unique features, any constraints that limit re-use, and the rationale behind these limitations.

After the constraints on future use as well as the property's specific characteristics are fully understood, the range of possible uses, their benefits, and disadvantages can be discussed. It may be considered, which re-use alternatives have the greatest feasibility given current market conditions, the property appraisal, public support, and information about prospective users. Affected governments, and the public can be encouraged to express their interests in promoting economic development, preserving habitat or aesthetic value, or serving other goals through re-use. As the interested parties discuss the various uses, it need to be evaluated how each re-use alternative fulfils one or more community values with a view to develop re-use options that potentially satisfy multiple interests. Ideally, this preferred use will strike a balance between various goals, including maximum return to the taxpayer, wise land stewardship, economic development, environmental protection, cultural and natural resource preservation, and aesthetic value. Community support is particularly critical in cases where institutional controls are needed to ensure a specific, limited use. A site may have multiple re-use alternatives with each option satisfying one or more particular values.

4.9. Stewardship Issues

In cases where residual contamination above levels for unrestricted release remains, a system of stewardship for dealing with the site after the remediation action has been completed may be appropriate. Stewardship goes beyond institutional control in that it also encompasses aspects such as public participation and land use planning [133]. Hence, stewardship is concerned with the maintenance and adoption of all activities going beyond the original remediation action. Also to be included into stewardship programmes are provisions for monitoring of compliance with agreed standards [134] and of the performance of any barriers and other engineered structures to contain contamination. Documentation of the site history including remediation activities is an important element of stewardship. The anticipated requirements and availability of resources for stewardship need to be taken into consideration when planning for remediation solutions which call for long-term stewardship as an integral part.

5. SUMMARY AND CONCLUSIONS

A range of non-technical factors will influence the choice of technologies to be employed in remediation and the strategy for their implementation. These factors include:

- economy, employment and infrastructure;
- costs, funding, and financing;
- regulatory and institutional aspects;
- stakeholder perception and participation;
- project implementation related risks;
- co-contamination issues;
- future land use;
- stewardship issues.

These factors, as discussed in the preceding chapters, may have both positive and negative impacts on the decision making process for choosing appropriate remediation technologies and strategies, and on the timeliness with which the chosen technologies and strategies can be implemented. The relevance of any given factor depends on the specific problem and context, which is likely to vary from site to site and across Member States. Some factors may be more subject to ‘control’ than others. The weighting of the different factors in the choice of a solution will therefore be affected by a variety of considerations, including technological, economic and sociological concerns.

This publication provides an illustration of the way in which these factors can be addressed, where significant, for remediation decisions. It outlines the range of formal decision aiding methods that can be useful for organising information and making comparisons between different options. It is emphasised that a formal decision aiding tool is not a substitute for the judgement and deliberation that builds towards a decision. However, formal decision aiding methods can, in themselves, constitute an important element of quality control and quality assurance. The formalised process helps to make transparent whether or not all relevant aspects of the process have been addressed and gives a framework for the documentation of inputs to and outputs from the process.

The way that members of the public perceive the contamination situation and the approach to remediation will influence the decision making process in a variety of ways. Good awareness of the perceptions of stakeholders and the public at large is important for identification of issues and for evaluation of risks and acceptability of possible solutions. It is also the starting point for building participation processes. Through communication between experts, decision makers and members of the stakeholder communities, participatory processes and negotiation

Table XV. Objectives and considerations forming the basis of an integrated assessment for remediation decision making (adapted from [116])

OBJECTIVES	CONSIDERATIONS
Consider a full range of possible effects, across health, environmental, socio-cultural, and economic disciplines.	Combining all effects into a single metric is probably not possible.
Apply a standard approach that reconciles different methodologies, assumptions, and data used previously and anticipated to be used in the future.	Tailor the assessment process to site conditions; no single approach is appropriate for all applications.
Reflect existing environmental, socio-cultural, and economic conditions.	Focus on potential changes in levels rather than on attempting to establish absolute risk/impact levels of existing conditions.
Employ a consistent approach for evaluating the same types of risks/impacts for different population groups.	Do not assume common values for all affected groups; rather, solicit their input.
Consider cumulative effects of multiple sources and interactive effects of multiple contaminants.	Conduct screening analyses and establish cut-off points to exclude minor sources from the full assessment, and incorporate emerging toxicity data.
Evaluate risks/impacts at several geographic scales: local through regional.	Develop different conceptual models to capture local and regional effects.
Evaluate risks/impacts in the near-, intermediate-, and long-term time frames.	Address the near term quantitatively, while addressing the longer term for some risks/impacts qualitatively (at least for now).
Consider the individual and cumulative effects of uncertainties.	Focus on major uncertainties, as determined by sensitivity analyses.

between different interest groups can sometimes be used effectively as mechanisms for exploring solutions. The intention is to ensure a technically sound and also socially acceptable decision that meets norms of adequacy or satisfactory performance in relation to the whole range of different concerns. Stakeholder participation in itself does not always guarantee success. But lack of participation may contribute to difficulties in implementing technically sound remediation solutions.

Table XV lists a range of objectives and considerations that need to be taken into account for remediation decision making.

Although the present publication discusses the non-technical factors influencing remediation decision making, it is to be emphasised that there are always critical engineering and scientific considerations. If a technology is not viable or is not reasonably expected to perform for the problem in hand, the solutions are limited by this. However, failure to include relevant non-technical factors may derail an otherwise technically effective solution. Bringing together technical and non-technical factors is thus a critical element in successful implementation of a remediation solution.

Appendix A

CASE STUDY — AN EXAMPLE OF A STAKEHOLDER DIALOGUE PROCESS IN THE UNITED KINGDOM

This Case Study from the UK highlights a Stakeholder Dialogue Process held within the SAFEGROUNDS Learning Network. SAFEGROUNDS is derived from SAFety and Environmental Guidance for the Remediation Of UK Nuclear and Defence Sites.

The overarching project is focussed on the management of contaminated land on nuclear licensed sites and defence sites. It was set up to identify and disseminate best practice in the health, safety and environmental aspects of managing contaminated land, chemically (non radioactively) contaminated land, and land with mixtures of radioactive and non radioactive contamination.

The project is managed by the Construction Industry Research and Information Association (CIRIA), WS Atkins and The Environment Council on behalf of the main UK nuclear licensed site owners. (BNFL, UKAEA, AWE and British Energy) and the Ministry of Defence. A Steering Group helps provide the programme and subject steer for the project, but in addition to the primary funders, is comprised of personnel from the regulators, consultants and government agencies. The Environment Council, as well as assisting in the management of the project, act as an independent facilitation organisation.

It was recognised that this project provided both industry and government with an opportunity to carry out as wide a consultative process as possible around a subject which previously had encouraged minimal national dialogue. In order to progress this opportunity an initial Workshop was held with the aim of determining which aspects of contaminated land management were deemed to require immediate attention and focus. The Workshop thus allowed a wide range of Stakeholders to identify their concerns and interests, which included technical guidance, advice on effective communication systems and the ability to feed into policy and regulatory decisions. The Workshop was facilitated by the Environment Council, and CIRIA were responsible for producing the list of invitees. In all, over fifty companies, institutes and groups attended with a wide range of Stakeholders being represented including, regulators, Non Governmental Organisations (NGO's), consultants, industry members and academia.

The Workshops themselves had a number of simple ground rules which all participants agreed to at the outset:

- Participants should talk one at a time in group sessions,
- The facilitation team is responsible for the process,
- All participants are responsible for the content, especially accuracy of the records,
- There are no observers only participants,
- Decision making will be by consensus. Voting if used will not be a decision making mechanism,
- Participants should spread the word, especially to their constituents, and
- There should be no confidentiality in the discussions unless specifically stated.

The output of this initial Workshop was developed into a three year programme by the Steering Group. The fundamental subject areas were seen to be health and safety aspects of site characterisation and the formulation of key principles for contaminated land management. In order to further the first theme, an independent contract was raised with a consultancy company to develop a guidance document for site characterisation health and safety best practice. A further Workshop involving the same range of Stakeholder groups was held and the output of this was fed back to the consultancy.

This guidance document has been finalised and can be viewed or downloaded from the SAFEGROUNDS Web site: www.safegrounds.com.

The ability to formulate and agree on key principles for managing contaminated land was viewed as the crux for the entire project, with it's overall success and usefulness essentially being linked into the level of agreement achieved on these key principles. It was important in this instance to attempt to bring together the views of industry and the NGO's which in some instances were known to be different. To progress this process, the Environment Council created and sent a set of questionnaires to Stakeholder participants which could be filled in directly via the web site or in paper form and posted. The questionnaires allowed each participant to express their views on a wide range of contaminated land issues. The overall output was then utilised to structure another Workshop where the themes consistently appearing as being important where proposed as a manageable number of key principles. The key principles proposed through the Stakeholder dialogue process were;

- Protection of people and the environment,
- Stakeholder involvement,
- Use of a BPEO approach for identifying the preferred land management option,
- Timing of identification and implementation of chosen management option,
- Making contaminated sites safe for future use,
- Record keeping, and
- Tolerable levels of residual radioactive contamination.

The Workshop participants were then asked to determine, and where possible, agree on the underlying definitions of these key principles. All comments were documented on flip charts which were subsequently compiled into photo reports to ensure all participants views were captured, and to maintain complete transparency in the process. Five of the key principles were retained after the Workshop with a slight re-phrasing and an agreed underpinning definition, which is highlighted below. These definitions are still provisional and under review as part of the ongoing dialogue process and may therefore still be subject to change.

Principle 1: Protection of People and the Environment. "The fundamental objective of managing contaminated land on nuclear licensed sites and defence sites should be to achieve a high level of protection of people and the environment, now and in the future".

Principle 2: Stakeholder Involvement. "Site owners/operators should develop and use stakeholder involvement strategies in the management of contaminated land. In general, a broad range of stakeholders should be invited to participate in decision making".

Principle 3: Identifying the preferred land management option. "Site owners/operators should identify the preferred management option (or options) for contaminated land by carrying out a comprehensive, systematic and consultative assessment of all possible options. The assessment should include a range of factors that are of concern to stakeholders. At present the best practice is to use a BPEO approach in which health, safety and environmental impacts are considered, together with various technical, social and financial factors".

Principle 4: Immediate Action. "Site owners/operators shall take measures immediately to monitor and control all known (or suspected) contamination and continue such measures until a preferred management option has been identified and implemented".

Principle 5: Record keeping. "Site owners/operators should make comprehensive records of the nature and extent of contamination, the process of deciding on the management option for contaminated land and the findings during the implementation and validation of the option. All records should be kept and updated as necessary".

The Workshop output is currently being fed into a new guidance document on contaminated land management, being produced by a nominated consultancy. Both draft and final versions of the report will be widely distributed amongst the Stakeholder community to ensure their views have been accurately captured and not distorted.

The ultimate aim of this work is to develop a long term learning network. The function of the network is to provide a mechanism through which the impact of the SAFEGROUNDS guidance can be discussed, and improvements suggested and implemented. The members of the network would be broadly similar to those attendees of the previous Workshops but international participation is encouraged. The needs of the members could include, but not be limited to the following:

- To update and improve the SAFEGROUNDS guidance;
- To publicise case studies of managing radioactively contaminated land –both good practice to be emulated and bad practice to be avoided;
- To act as a link between local and national stakeholders;
- To act as a repository for know-how gained through the management of radioactively contaminated land;
- To enable feedback from NGO's on whether the management and remediation of contaminated land is matching expectation;
- To help build trust between stakeholder groups;
- To challenge existing assumptions through dialogue;
- To share best practice;
- To promote research and development;
- To allow non technical parties to understand the issues and to express their opinions.

Although this UK Stakeholder dialogue process is still ongoing, the general consensus is that it has proved to date to be extremely beneficial. Personnel from a wide range of groups have had the opportunity to share views and hear different perspectives. While it is recognized that there may never be total consensus in such contentious subject areas, the fact that a general agreement on some of the issues has been achieved is a positive outcome in itself. Progress within the project, documents and papers emanating from it and stakeholders views on the bulletin board can be found on the SAFEGROUNDS web site.

Appendix B

CASE STUDY: 'PARTICIPATION' AND 'TRUST' — THE ETHOS PROJECT IN BELARUS

The post-accidental situation in the territories affected by the Chernobyl accident is characterised by a high degree of complexity [135][136][137]. In the first place, the inhabitants are confronted with a risk which is omnipresent in every facet of their everyday life, but they do not know how to cope with it. They have the general feeling to be ignorant and to have lost the control over the simple and traditional situations they used to manage in the past. In such a context, the role of authorities and scientific bodies is pre-eminent. Everyone relies on experts to propose relevant countermeasures and on the State to bring in the appropriate resources to implement them.

Facing such a complex situation, how to restore the living conditions in contaminated territories? How to find a balance between the protection of the inhabitants and their quality of life? How to bring back the feeling of safety of the population? How to optimise resources in the long term perspective? The temptation is strong to adopt an analytical approach of the problems and to reduce this complexity by privileging one or two dimensions identified as key to the process of restoration. Because the origin of the problems is in the contamination of the environment, there is a clear inclination to think that a well designed radiological protection programme, based on adequate criteria, is the cornerstone of the process.

The recovery of self confidence and control among the population as well as the restoration of social trust were also key objectives in the ETHOS approach as they were considered as a necessary component in the rebuilding of security. The ETHOS approach was therefore based on a strong involvement of the community and surrounding population. A specific feature of the ETHOS approach was to avoid the dissociation of the social and technical dimensions of the post-accident management. In order to better take into account the observed complexity of the post-accident situation, an interdisciplinary approach was adopted involving a group of experts from the following disciplines: radiological protection, sociology, agronomy, nature and life management, economics, social management of risk, technological safety, communication, social trust.

Since many factors affected the progress in radiological safety, for example the economic recession, another motive for aiming at a global improvement of the quality of life was to achieve sustained progress, but also to facilitate the balancing between radiation protection and other priorities in the local decision making processes. The ETHOS approach dealt with all aspects of the daily life that were affected or threatened by the contamination event: health (especially that of children), food, safety at home, professional life, social life, environmental quality, leisure time activities, economic value of local produce, the future (especially that of the children), individual and collective identities and culture.

The village of Olmany (1265 people) is linked to a collective farm of roughly 1800 hectares the main produce of which is milk, wheat and meat. Problematic contamination levels of privately produced food appeared to be a real concern for both the population (notably the mothers) and the local authorities. Tradition is very deeply rooted in the social organisation. The population, contrary to other districts more severely affected by previous relocation policies, has a large proportion of young people (369 people less than 17 years old).

Humanitarian support was strictly excluded from the project in order to ensure the sustainability of the results to be achieved.

The project focused on four main remediation/radiation protection measures:

— Control of the dietary intake of children;
— Management of the radiological quality of milk;
— Management of the radiological quality of meat;
— Management of contaminated wastes, mainly domestic fuel ashes.

The main results of the ETHOS Project can be summarised as follows: The inhabitants of Olmany have gained a more precise and reliable picture of the radiological situation within and around the village. The production of milk with less than 111 $Bq{\cdot}l^{-1}$ (contamination limit for marketing) has increased from 25 to 55% in winter and from less than 10 to about 80% in summer. The economic circuits with the district and the non-contaminated zones have been restored for milk and meat. The average internal contamination of children has been reduced by at least 30%. Many villagers have regained self confidence and initiative.

By avoiding to keep the population locked up into the technical dimensions of the rehabilitation process, the involvement of stakeholders liberated individual initiatives. It also opened opportunities for affected persons to speak to each others, to interact with experts and authorities, and to act autonomously, which meant finally to maintain human dignity despite all the difficulties.

By the end of the project however, as soon as the concrete outcomes of the groups were obtained, a tendency towards disengagement was noted in the population. As soon as a certain level of confidence was reached, the participants expected relevant collective actors, such as the local authorities, the doctors, the teachers, the kolkhoze to follow up the situation and to maintain the safety levels. While expecting the collective actors to take up the responsibility of maintaining a reasonable level of safety and acceptable living conditions, the local participants also observed that some conditions would guarantee the lasting of the progress achieved. Among those conditions was the existence of an independent certification of the quality of the produce. A second condition was the public availability of the information on the relevant radiological measurements.

The post-accident context of Chernobyl was strongly characterised by the lack of social trust. In many ways, the ETHOS project brought a contribution to the reconstruction of various types of trust among the population. The project contributed to increase the reliability and the credibility of the information on the radiological situation, as well as on the assessment of the associated risks for the population.

The involvement of the local inhabitants remained intense and very demanding. As the economic crisis arose in Belarus, individuals had to develop new economic activities in order to physically survive. The depreciation of salaries together with a serious inflation created a context where, for instance, local teachers or doctors had to develop farm activities in order to provide their families with food. But in a more general way, as explained above, it was considered by the population that the collective actors should assume responsibility for follow-up activities as soon as they felt confident again in the situation. One could observe a switch from social mistrust to confidence, necessitated by the constraints of the day-to-day life, which required to focus social resources. This can also be viewed as a new kind of normality that has been reached within this process of rehabilitation.

Appendix C

EXAMPLES FOR DELIBERATIVE PROCESSES IN CANADA, DENMARK, AND GERMANY

“Round Tables” in Canadian planning and policy processes

The British Columbia Commission on Resources and the Environment (CORE) sets up direct negotiating sessions between the interest groups and communities concerned with land use planning issues. If agreement can be reached through deliberation, the provincial government agrees to abide by the decision. If agreement cannot be reached, the *decision making* power reverts back to the government planning department. While (up to now) mainly concerned with wider strategic policy directions, national, provincial and local “Round Tables” in Canada operate, at national, provincial and local levels, with a similar philosophy and purpose [1,2]. Made up of representatives from interest groups — from industry, the environmental movement, local residents and community organisations, trade unions, first nations (aboriginal groups), academics and so on — the Canadian Round Tables aim to reach consensus on controversial environmental and social issues.

Sources:

[1] DOERING, R., “Canadian Round Tables on the Environment and the Economy: Their History, Form and Function”, National Round Table on the Environment and the Economy, Ottawa (1993).

[2] GORDON, J., Canadian Round Tables and Other Mechanisms for Sustainable Development in Canada, Local Government Management Board, Luton (1994).

Hazardous Land-Fill Mediation in Münchehagen, Germany

The background to the mediation procedure in Münchehagen (Lower Saxony, Germany) was a long controversy over a hazardous waste landfill operation, with accusations of illegal dumping of toxic wastes and scares about soil and water contamination and health risks. A court declared the landfill to be in contravention of the law, and several special investigations were set up. The various local authorities and community pressure groups were deeply divided. A prominent resident of the district organised and chaired a series of discussions in which nearly all parties were involved. This led to the idea of setting up a broader-based mediation procedure, and the Münchehagen Commission was established at the end of 1990 with the mediator appointed officially by the Environment Minister of Lower Saxony. The aim of the procedure was to get the disputing parties to agree on a clean-up method. The role of the mediator was to explore the margins for manoeuvre, identify the principal sources of conflict, and keep dialogue going. In late 1992 an agreement was reached by all parties, covering general clean-up objectives, safety measures, and criteria for evaluating progress. Detailed planning and clean-up action is ongoing.

Source:

[1] WEIDNER, H., “Mediation as a policy Instrument for Resolving Environmental Disputes — with special reference to Germany”, Veröff. Abt. ‘Normbildung und Umwelt’ des Forschungsschwerpunkts Technik, Arbeit, Umwelt des Wissenschaftzentrums Berlin für Sozialforschung, Berlin (1993).

Consensus Conferences — the Danish Experiences

The specific intention of the consensus conferences is to furnish some guidance for political decisions on major technology assessment topics. Several of the topics have important environmental dimensions. Some of the conferences and their recognised political effects have been:

— Gene technology in industry and agriculture (1987). The Danish Parliament decided not to fund animal gene technology projects in the biotechnology research and development programme 1987-1990.

— Food irradiation (1990). Parliament decided on a policy against irradiation of foods, except for dry spices.

— Air pollution (1990). No directly consequent political actions.

— The future of private transport (1993). The Minister for Environment subsequently proposed that petrol prices be raised to 4 times the current price. This was not implemented, but the Association of Danish Motorists has taken up the panel's proposal for a tax policy for transport.

— Integrated agriculture (1994). The Danish Council of Agriculture undertook to prepare a plan for presentation in 1995 in support of the introduction of integrated production as the preferred practice in Danish agriculture.

Source:

[1] KLÜVER, in JOSS, S., DURANT, J., *Public Participation in Science*, Science Museum, London (1995).

Appendix D

CASE STUDY: OPTIMISING THE REMEDIATION OF SITES CONTAMINATED BY THE WISMUT URANIUM MINING OPERATIONS IN GERMANY

Initial Situation and Criteria for Evaluation

The large industrial scale uranium mining operations in densely populated regions resulted in severe impacts on the environment. Radioactive and other contaminants were dispersed in the soils, the groundwater and the atmosphere.

Radiation protection is one of the main motives behind remediation in uranium mining, but by no means the only one. The licensing of measures to ensure mining safety, groundwater protection and further land-use has to consider radiological implications.

The current environmental regulations in Germany have the aim to prevent undue impacts on the basis of precaution. This applies also to measures in planning. In dealing with intervention situations, the planning has to consider not just the current impacts, but also those that might arise due to the remediation measures. It applies both to radiological and to non-radiological impacts. International recommendation, hence, stipulate that any exposure, including those resulting from remediation activities, have to be justified, optimised and limited.

These three principles are applied to practices as well as to intervention situations.

Any individual remediation measure is justified, if the associated benefits exceed any detriment that might be related either to the contamination itself or the remediation measure. Optimising consists in identifying options that maximise benefits while minimising detriments. Hereby the ‘do nothing’-option serves as the benchmark to evaluate benefits. The evaluation has to encompass radiological, environmental, nature conservation and cost aspects and also to consider the acceptability of any proposed solution within the stakeholder community.

Wismut is working towards an efficient progress in remediation. Individual remediation measures have to be integrated in a meaningful way into the overal remediation strategy. Based on a careful site investigation and evaluation of the degree of contamination resulting from uranium mining and milling, the site specific needs for remediation are defined and an optimised remediation strategy is developed, considering achievable remediation goals. The selected remediation option is to be approved by the licensing authorities.

Environmental Impact Assessment

Optimising stands for reducing health risks while minimising the socio-economic cost at the same time. Planning of remedial measures and site investigations are an integral part of a remediation project and expenditure on those has to be carefully balanced against requirements to fulfil the criteria of justification, optimisation and risk reduction.

In many instances of remediation projects those environmental impacts that will be controlled by legislation can be assessed sufficiently on a deterministic basis. In this case, the current state of the site and the effect of the remediation, including any protective and precautionary measures, and the state following remediation are assessed and evaluated. Based on a site specific assessment of exposure pathways the exposure of the public in general and of the workers on the remediation project is estimated. The need for remediation is justified on the basis of action levels for individual doses to reference persons of the general public. Additional exposure of the general public and the workers due to the remedial action is to be limited. In cases where no alternative remediation strategies are feasible or no alternative remediation technology exists, the proof of optimisation is effected by comparing the different protective and precautionary measures.

Evaluation of Remedial Actions

Extensive projects and projects of potentially significant environmental impact are evaluated on the basis of a more detailed catalogue of criteria with respect to the various alternative remediation strategies. This includes a comprehensive assessment of socio-economic implications. In addition to cost and environmental and health risks, remediation options are evaluated with respect to their public acceptance, the use of resources such as soil and water, as well as their impact on the regional development, e.g. stimulation of investment as desirable side-effect of the remediation effort, preservation and creation of job etc.

During the process of optimisation a preferred solution is derived from several technically feasible and regulatory acceptable strategies that have been developed on the basis of predetermined criteria. Transparency and traceability of the decision making path by which the preferred solution has been developed is one important prerequisite for regulatory acceptance. The method used for this purpose are probabilistic cost and risk assessments, and multi-attribute decision making methods.

Probabilistic Cost and Risk Assessment

The cost and risk assessment is performed using an iterative probabilistic 'top-down' model of the remediation project as an integrated system. Initially all relevant processes are captured in a rather abstract and simplistic way. To this end, functional relationship are established between uncertain variables, the value of which are represented by probability distributions. In the course of the model development those variables and processes, to which results have been shown to be sensitive, are described in more detail. In this way resources available for modelling are efficiently deployed without loosing focus and meaningful conclusions can be drawn early in the process, even though some parts of the system may not be known yet in detail. This approach is also useful for identifying any gaps in the knowledge base that have to be filled in the course of the decision making.

In the course of development from the qualitative, conceptual model to the quantitative model, the time-dependent costs and risk are modelled for each envisaged course of remedial action:

1. Collection and evaluation of data on the site and pertinent remediation strategies;

2. Identification of processes and events relevant for the site in question;

3. Identification of the various cost and risk elements (e.g. cost of implementation, major exposure pathways, risk of failure of engineered structures, such as dams or surface covers);

4. Conceptualisation of the relevant processes and events of the various remediation strategies and their effect on costs and risks;

5. Development of the mathematical model to describe the system behaviour (balancing equations, cost functions, concentration-dose and concentration-risk relationships, risks and costs as a result of losing institutional control);

6. Deterministic and probabilistic parameterisation in order to quantify certain and uncertain parameter values;

7. Programming of model using software tools suitable to describe parameter uncertainty;

8. Calculation of time-dependent probability distributions for costs and risks for each remediation option.

9. Identification of the most sensitive variables and assessment of their uncertainty in order to be able to further detail the model in the next step of iteration.

Multi-Attribute Decision Aiding Tools

Multi-attribute decision aiding tools are used to identify a preferred remediation solution taking into account the deterministically and probabilistically derived data on expected costs and health risks. Depending on the complexity of the problem in hand, various methods, ranging from simple pareto- or dominance analysis to probabilistic models are employed.

The requirement for optimisation, also with respect to socio-economic impacts, is met by including other variables in addition to costs and health risks. A typical catalogue of criteria is given in Table 1.

Table 1: Catalogue of criteria in multi-attribute analyses

Costs	**Health Risks**	**Acceptance**
implementation of remedial action	radiation, chemical toxicity, accidents	socio-economic aspects (employment)
water treatment	during and after remediation	quality of life factors
maintenance, monitoring	workers and general public	institutional factors
additional land required		ecological aspects, management of scarce resources

The various criteria influencing the assessment and the optimising are partly in competition with each other. For instance, a certain option that might be preferred on the grounds that it minimises health risks could turn out to be the most expensive and would be rejected in favour of a less expensive solution that might entail higher health risks, if cost were an overriding criterion. Similar mutual relations can be observed for other sets of criteria.

For this reason, trade-offs have to be found by weighing the criteria in a way that is acceptable to society.

The relative weight of the criteria can only be determined satisfactorily on the basis of a uniform measure (e.g. a rating). Monetarisation of criteria has been used in the past, but did not find universal acceptance in society. For instance, the assumed numerical value for the monetary value of loss of one year of collective life expectancy varies in the published literature between US$ 17000 and US$ 450000.

However, a solution based on a cost–benefit assessment and trade-offs can only be considered robust, if it remains stable upon changes in the relative weights of criteria and parameter values. For this reason a test of robustness has to follow the identification of parameters that are relevant to the final decision.

Multi-attribute analysis tools have the advantage over other, more subjective, decision making methods that they

- allow decisions on a rational basis;
- allow to trace decisions made and criteria employed;
- allow to document the weight given of single criteria.

These properties facilitate the communication between problem holders, licensing authorities, consultants and the public and thus facilitate consensus formation on complex decision making problems.

GLOSSARY

Aggregation Equation	An equation specifying the rules used by a RBP system to combine value judgements and measures to yield an overall measure of the value and decision options.
AI	Artificial intelligence
Benefit	The change in the baseline value of each decision objective as a result of implementing a decision option.
CBA	Cost–benefit analysis
Characteristic	Common elements desired for selection, development, or comparison of risk-based prioritisation systems.
Cost	Monetary burdens of implementing a decision option. Cost of implementation should not be confused with monetarised equivalents of benefits.
Concertation	A process of reaching concensus between the various stakeholders.
Decision Option	Alternative activities or sets of activities that are evaluated and prioritised by risk-based prioritisation systems.
Decision Objective	An explicit statement of the desired goal of implementing decision options.
Deliberation	A process of (stakeholder) discussions and consultation.
Monetarisation	The association of the qualitative numbers used in a prioritisation model with specific dollar amounts.
Market Value	The amount at which the seller would be willing to sell and a buyer would be willing to buy, with both being interested but not forced to sell or buy.
MADA	Multi-attribute decision analysis
MCDA	Multi-criteria decision aid
MAUA	Multi-attribute utility Analysis (MAUA) is a decision analysis technique that provides rigorous, sound, and demonstrated ways to combine dissimilar measures of costs, risks, and benefits, along with individual preferences, into high-level, aggregated measures that can be used to evaluate alternatives.
Opportunity cost	The cost of forgoing other options when selecting one particular option.
Performance Measure	A quantitative measure for determining the effect of performing an activity on risk or benefit.
Performance Result	A numerical value (score) of the outcome of performing an activity, which results from applying a risk-based prioritisation system.
QA	Quality assurance
QC	Quality control

Risk	The probability of an adverse event multiplied by the measured effect (consequence) of that event.
RBP	Risk-Based Prioritization is a process that uses quantification of risks, costs, and benefits to evaluate and compare activities competing for limited resources.
RBP System	The collection of procedures, models, and other components used to conduct risk-based prioritisation.
Scaling Function	A functional relationship that translates a level of performance, as expressed by a performance measure, into a number that indicates the value or desirability of performance.
Scoring	The process of determining the input parameter values required by the risk-based prioritisation model to yield the performance result for each activity.
Stakeholder	Any individual or organisation interested in and/or impacted by the decision made by the risk-based prioritisation process.
Value Model	The basis for translating all of the qualitative and quantitative measures and associated scales/values into a single equivalent quantitative scale.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Characterization Techniques Used in Environmental Restoration Activities, Final Report of a co-ordinated research project 1995-1999, IAEA-TECDOC-1148, Vienna (2000).

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

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

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

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

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of radiation protection principles to the cleanup of contaminated areas — Interim report for comment, IAEA-TECDOC-987, Vienna (1998).

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

[8] REGENS, J.L., et al., "An integrated framework for evaluating subsurface contamination remediation technologies", Environmental Geosciences (1999) 82–89.

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Rehabilitation of Contaminated Areas from Past Activities and Accidents (in press).

[10] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, http://www.icrp.org/.

[11] BLACKMOND LASKEY, K., LEHNER, P.E., "Meta Reasoning and the Problem of Small Worlds", IEEE Transactions on Systems, Man, and Cybernetics, 24(11) (1994) 1643-1652. http://nac.gmu.edu/c3i/PubAbstracts/CommdSupport.html.

[12] CRiTiNC, Critical Natural Capital and the Implications af a Strong Sustainability Criterion, http://www.keele.ac.uk/depts/ge/CRITINC/critinchome.htm (2001).

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

[14] SOCIETY OF ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY, "Guidelines for Life Cycle Assessment: A 'Code of Practice', Edition 1", SETAC Workshop, Sesimbra, Portugal, 31 March–3 April 1993. Brussels, Belgium, and Pensacola, Florida, USA (1993).

[15] CONSOLI F., et al. (Eds.), "Guidelines for Life-cycle assessment: A 'Code of practice'". Society of Environmental Toxicology and Chemistry (SETAC), SETAC Workshop, Sesimbra, Portugal, 31 March–3 April (1993) 69 pp.

[16] UK OFFICE OF SCIENCE AND TECHNOLOGY FORESIGHT PROGRAMME, http://www.foresight.gov.uk/default1024ns.htm (2001).

[17] THORNE, M.C., WILLIAMS, M.M.R., A review of expert judgement techniques with reference to nuclear safety, Progr. Nucl. Energy **27**(2/3) (1992) 83–254.

[18] WRIGHT, G.N., PHILLIPS, L.D., "Cultural variation in probabilistic thinking: alternative ways of dealing with uncertainty", Judgement and Decision Making: An Interdisciplinary Reader (ARKES, H.R., HAMMOND, K.R., Eds), Cambridge University Press (1986) 417–431.

[19] SANDIA ENVIRONMENTAL DECISION SUPPORT SYSTEM (SEDSS), http://www.nwer.sandia.gov/sedss/ (2001).

[20] HIVIEW, product homepage, http://www.enterprise-lse.co.uk/hiview.htm (2001).
[21] EXPERT CHOICE INC., http://www.expertchoice.com/ (2001).
[22] GRAMLICH, E.M., A Guide to Benefit-Cost Analysis, 2nd ed., Englewood Cliffs, NJ: Prentice Hall (1990).
[23] BENTKOVER, J.D., COVELLO, V.T., MUNPOWER, J., Eds, Benefit Assessment, Reidel, Dordrecht, Netherlands (1986).
[24] NATIONAL RESEARCH COUNCIL, Ranking Hazardous-Waste Sites, National Academy Press Washington, DC (1994).
[25] WETH, D., "Case study: Cost benefit analysis/multi-criteria analyses for a remediation project", Proc. NATO/CCMS Pilot Study, Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Land an Groundwater (Phase III), Special Session: Decision Support Tools, Wiesbaden, EPA 542-C-01-002 (2000).
[26] GEHRKE, D., "Die Entwicklung von Sanierungskonzepten für Altstandorte", Fortschritt-Berichte VDI, Reihe 4: Bauingenieurwesen, Nr. 122, Diss. Düsseldorf (1993).
[27] ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION, Setting Environmental Standards, 21st Report, Cm 4053, London (1998).
[28] HOLLAND, A., O'CONNOR, M., O'NEILL, J., Costing Environmental Damage: A Critical Survey of Current Theory and Practice, and Recommendations for Policy Implementations, European Parliament/STOA Report PE165 946/2, Luxembourg (1996) 77 p.
[29] KRUTILLA, J., FISHER, A., The Economics of Natural Environments, Johns Hopkins University Press, Baltimore, MD (1975).
[30] MARTINEZ-ALIER, J., MUNDA, G., O'NEILL, J., "Commensurability and compensability in ecological economics", Valuation and the Environment: Theory, Method and Practice, O'CONNOR, M., SPASH, C., Eds, Edward Elgar, Cheltenham. (1999) Chapter 2.
[31] MUNDA, G., Multicriteria Evaluation in a Fuzzy Environment. Theory and Applications in Ecological Economics, Physica-Verlag, Berlin (1995).
[32] ROY, B., BOUYSSOU, D., Aide multicritère à la décision. Methodes et cas, Economica, Paris (1993).
[33] DE MARCHI, B., FUNTOWICZ, S., LO CASCIO, S., MUNDA, G., Combining participative and institutional approaches with multicriteria evaluation. An empirical study for water issues, Transdisciplinary J. of the Int. Soc. for Ecological Economics **34** 2 (2000) 267–282.
[34] JOUBERT, A., LEIMAN, A., DE KLERK, H., KATUA, S., AGGENBACH, J., Fynbos (fine bush) vegetation and the supply of water: A comparison of multi-criteria decision analysis and cost-enefit analysis, Transdisciplinary J. of the Int. Soc. for Ecological Economics **22** (1997) 123–140.
[35] PENNSTATE EXPERT SYSTEMS DEVELOPMENT GROUP, What is an Expert System, http://www.cas.psu.edu/docs/CASDEPT/Expertsystems/ESDG/expsystm.htm (2001).
[36] ADELMAN, L., RIEDEL, S., "Using the multi-multimethod matrix to evaluate knowledg-based systems", Evaluation of Knowledge-Based Systems, Communication and Cognition — Artificial Intelligence, Special Vol. (1993) http://nac.gmu.edu/c3i/PubAbstracts/ CommdSupport.html.
[37] MARKOV CHAIN, http://pespmc1.vub.ac.be/asc/Markov_chain.html (2001).
[38] WALSH, T., DAY, R., Environmental Restoration Project Risk Management, Proceedings WM'97, March 2–6, 1997, http://www.wmsym.org/wm97proceedings/sess37/37-03.htm, Tucson, AR (1997).

[39] HAYES-ROTH, F., The knowledge based expert system: A tutorial, IEEE Computer **17** 9 (1984) 11–28.

[40] IGNIZIO, J.P., Introduction to Expert Systems: The Development and Implementation of Rule-Based Expert Systems, McGraw-Hill (1991) 402 p.

[41] O'CONNOR, M., Pathways for environmental evaluation: A Walk in the (Hanging) Gardens of Babylon", Ecological Economics **34** (2000) 175–193.

[42] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Selection and use of ISO 9000, http://www.bsi.org.uk/iso-tc176-sc2/Selusee.pdf (2001).

[43] US ENVIRONMENTAL PROTECTION AGENCY, "Guidance for the data quality objectives process: Final", Quality Assurance Management Staff, Office of Research and Development, Washington, DC, Rep. EPA QA/G-4 (1994).

[44] FUNTOWICZ, S., RAVETZ, J., Uncertainty and Quality in Science for Policy, Kluwer Academic Press, Dordrecht (1990).

[45] NACHTSHEIM III, H. LandTREK: A Web based tool for land transfer and reuse, Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www. wmsym.org/wm2000/ pdf/11/11-29.pdf (2000).

[46] BIAN, W.-Q., KELLER, L.R., Chinese and Americans agree on what is fair, but disagree on what is best in societal decisions affecting health and safety risks, Risk Analysis **19** 3 (1999) 433–446.

[47] CREIGHTON, J., Final Keynote Address in "Public Involvement: The Critical Path in Siting Controversial Facilities", US Department of Energy, Washington, DC (1986) 98.

[48] WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT, Our Common Future (also known as The Brundtland Report), Oxford University Press (1987).

[49] GOSH, M.M., COX, C.D., Editorial: Towards realistic remedial action plans, Water Environment Research **67** (1995) 891.

[50] JAWOROWSKI, Z., Radiation risk and ethics, Physics Today **52** 9 (1999) 24–29.

[51] UNITED NATIONS INTER-AGENCY COMMITTEE ON SUSTAINABLE DEVELOPMENT, http://www.un.org/esa/sustdev/iacsd.htm.

[52] EDELSON, M.C., SVATOS, M., "Why don't they understand?", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/ pdf/45/45-2.pdf (2000).

[53] ENGLISH, M.R., "Who are the stakeholders in environmental risk decisions?", NEA, Stakeholder Confidence and Radioactive Waste Disposal, OECD-Nuclear Energy Agency (2000) 99–102.

[54] JODHA, N.S., 0Waste lands management in India: Myths, motives and mechanisms, Economic and Political Weekly, XXXV(6) (2000) 466–473.

[55] KOLKMANN, X.I., Besluitsvorming rond saneringsalternatieven — een analyse van het beslisproces, TAUW report No. R0076686.1/XIK, Netherlands (1997).

[56] BEINAT, E., et el., The REC decision support system for comparing soil remediation options — A methodology based on risk reduction, environmental merit and costs, CUR/NOBIS (1997) and http://www.bouwweb.nl/CUR/NOBIS/ (2001)

[57] KEENER, W., et al., "New model for public participation at Sandia National Laboratories: What comes after environmental restoration?", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/53/53-5.pdf (2000).

[58] THOMPSON, P.B., Risk objectivism and risk subjectivism: When are risks real?", RISK, J. Ris0k Assessment & Policy Association **1**, http://www.fplc.edu/risk/vol1/winter/thompson.htm (2001).
[59] WHYTE, A.V.T, Guidelines for Field Studies in Environmental Perception, MAB Technical Notes, UNESCO, Paris (1977).
[60] OECD NUCLEAR ENERGY AGENCY, The Societal Aspects of Decision Making in Complex Radiological Situation, Rep. OECD-NEA, Paris (1998).
[61] CADDY, J. "Legal and institutional frameworks for government relations with citizens", NEA, Stakeholder Confidence and Radioactive Waste Disposal, OECD-Nuclear Energy Agency (2000) 85–87.
[62] LUHMANN, N., "Familiarity, confidence, trust: problems and alternatives", Trust: Making and Breaking Cooperative Relations (GAMBETTA, D. (Ed.), Basil Blackwell, Oxford (1988).
[63] RENN, O., "The role of the media in the coverage of risks associated with nuclear waste", The Societal Aspects of Decision Making in Complex Radiological Situations (O0ECD, Ed.), OECD Proceedings, Paris (1998).
[64] MISZTAL, B.A., Trust in Modern Societies, Polity Press, Oxford (1996).
[65] SCHOENEMAN, B., HOFER, D.A. "Transparency Demonstration of Underground Radiation and Environmental Monitoring", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/31/31-29.pdf (2000).
[66] BRADBURY, J.A., RANCH, K.M., "The acceptability diamond: Essential elements of legitimacy and social trust", WM'97, www.wmsym.org/wm97 proceedings/sess31/31-07.htm, Tucson, AR (1997).
[67] ATTRIDGE, T., "Knock, knock! who's there? The government. A case study in proactive public involvement and risk communication", WM'97, www.wmsym.org/wm97proceedings/sess31/31-02, Tucson, AR (1997).
[68] CONLEY, M.,et al., "Public access to environmental monitoring at waste sites — an experiment00 in progress", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/45/45-2.pdf (2000).
[69] SHINGI, P.M. et al., Development of Social Forestry in India, Oxford and IBH Publ., New Delhi (1986).
[70] MAHONY, D., "Forestry extension training in Somalia", Overseas Development Institute, Social Forestry Network Paper, 4b, June, London (1987).
[71] KUPERUS, S., Participation in Forestry, Paper presented at a workshop in October 1987, FAO, Rome (1987).
[72] UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, Convention on Access to Information, Public Participation in Decision making and Access to Justice in Environmental Matters, UNECE, ECE/CEP/43 (1998).
[73] IAP2 — INTERNATIONAL ASSOCIATION FOR PUBLIC PARTICIPATION, http://www.iap2.org/
[74] EARLE, T.C., CVETKOVICH, G.T., Social Trust: Towards a Cosmopolitan Society, Praeger, Wesport, CT. (1995).
[75] HUTTERMAN, L., SMITH, R., "Where has the public gone and will communications technology bring them back?", WM'97, www.wmsym.org/wm97proceedings/sess31/31-01.htm, Tucson, AR (1997).
[76] KWEIT, R.W., KWEIT, M.G., Bureaucratic decision-making: impediment to citizen participation, Polity **12** 4 (1980) 478–487.
[77] MELILO, J., EVANS, G., "The Environmental Management Advisory Board and the Department of Energy: A partnership that works", WM'97, www.wmsym.org/wm97proceedings/sess_05/05-01.htm, Tucson, AR (1997).

[78] O'CONNOR, M., VAN DEN HOVE, S., Prospects for Public Participation on Nuclear Risks and Policy Options: Innovations in Governance Practices for Sustainable Development in the European Union, J. Hazardous Mat., Special issue on Risks and Governance (2001).
[79] EUROPEAN COMMISSION, The TRUSTNET Framework: A New Perspective on Risk Governance", Commission of the European Communities, Rep. EUR19150EN, Luxembourg (2000) 45 p.
[80] BARKENBUS, J., Expertise and the Policy Cycle, National Center for Environmental Decision Making, http://www.ncedr.org/pdf/policy.pdf (1998).
[81] ROSENBAUM, W., "Why institutions matter in program evaluation: the case of epa's pollution prevention program", Environmental Program Evaluation: A Primer (KNAAP, G.J., KING, T.J., Eds, Univ. of Illinois Press, Urbana, Ill. (1998).
[82] SALT, C.A., et al., Integrating Environmental and Socio-Economic Impacts into Countermeasure Decision Making, IUR Topical Meeting, 1-5 June 1998, Mol, Belgium (1998).
[83] INTERNATIONAL ATOMIC ENERGY AGENCY, Review of the Factors Affecting the Selection and Implementation of Waste Management Technologies, IAEA-TECDOC-1096, Vienna (1999).
[84] MERKHOFER, M.W.A., KEENEY, R.L., A multiattribute utility analysis of alternate sites for the disposal of nuclear waste, Risk Analysis **7** 2) (1987) 173–194.
[85] REGENS, J.L., et al., Integrated framework for assessment of site remediation options, Federal Facilities Environmental J. (1999) 81–93.
[86] US DEPARTMENT OF ENERGY, Documenting Cost and Performance for Environmental Remediation Projects, US Department of Energy report DOE/EM-0302, Washington, DC (1996).
[87] US ENVIRONMENTAL PROTECTION AGENCY, US DEPARTMENT OF DEFENSE, US DEPARTMENT OF ENERGY, US DEPARTMENT OF THE INTERIOR, Guide to Documenting Cost and Performance for Remediation Projects, Federal Remediation Technologies Roundtable Rep. EPA-542-B-95-002, Washington, DC (1995).
[88] US ARMY CORPS OF ENGINEERS, US NAVY, US AIR FORCE, US ENVIRONMENTAL PROTECTION AGENCY, US DEPARTMENT OF ENERGY, "HTRW — ICEG Remedial Action Work Breakdown Structure", US Army Corps of Engineers, Washington, DC (1996) http://www.frtr.gov/cost/ec2/ wbs1.html.
[89] ENVIRONMENTAL COST ENGINEERING COMMITTEE, http://globe.lmi.org/ lmi_hcas/ (1999).
[90] DA ROSA, C., Financial assurance", Mining Environmental Management, 7(2), (1999) 10-13.
[91] BELFIELD, D., "Environmental Accounting, Mining Environmental Management, **7** 2 (1999) 7-8.
[92] HOWES, W.S., BOYD, G.G., SINK, C.H., LYNN, D.A., "coupling environmental contracting using risk allocation with US Department of Energy remediation marketplace", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/57/57-3.pdf (2000).
[93] WEIMAR, M.R., OAKLEY, B.T., DIPRINZIPIO, R., PAANANEN, O.H., "Impact of technical uncertainty on private financing of federal waste clean-up projects", Proc. Spectrum '98, September 13–18, Denver, CO (1998).
[94] OAKLEY, B.T., et al., Privatization Financing Alternatives: Blending Private Capital and Public Resources for a Successful Project, Pacific Northwest National Laboratory, Rep. PNNL-11916 (1998).

[95] DESMET, G., et al., Techniques and Management Strategies for Environmental Restoration, Mid-Term Report of the EURATOM-CIEMAT Association Contract, CIEMAT, Madrid (1998) 215 p.

[96] DRYZEK, J., Discursive Democracy, Cambridge, Cambridge University Press (1990).

[97] FISHKIN, J., Democracy and Deliberation: New Directions for Democratic Reform, New Haven, Conn: Yale University Press (1991).

[98] MILLER, D., Deliberative democracy and social choice, Political Studies **40** (1992) 54–67.

[99] STEWART, J., Further Innovation in Democratic Practice, Birmingham: School of Public Policy, Birmingham University (1996).

[100] VANDENHOVE, H., et al., Investigation of a Possible Basis for a Common Approach with Regard to the Restoration of Areas Affected by Lasting Radiation Exposure as a Result of Past or Old Practice or Work Activity — CARE, Final Report to the European Commission, Contract 96-ET-006, Radiation Protection 115 (2000) 285 p.

[101] CAMPBELL, I.L., Participant observation in outdoor recreation, J. Leisure Research **2** (1970) 226–236.

[102] SALMEN, L., Listen to the People: Participant Observer Evaluation of Development Projects, Oxford University Press (1987).

[103] BURGESS, J., LIMB, M., HARRISON, C.M., "Exploring Environmental Values Through the Medium of Small Groups: 1. Theory and Practice", Environment and Planning A., 20 (1988) 309–326; BURGESS, J., LIMB, M., HARRISON, C.M., "Exploring Environmental Values Through the Medium of Small Groups: 2. Illustrations of Group Work", Environment and Planning A., 20 (1988) 457–476.

[104] LUSCOMBE, B.W., Spatial Data Handling in Data-Poor Environments, PhD Thesis, Simon Fraser University, Burnaby, B.C., Canada (1986) 300 p.

[105] SMITH, K.E., Delphi methods and rural development, South-eastern Geographer **18** (1974) 54–76.

[106] HASSAN, H., HUTCHINSON, C., Natural Resources and Environmental Information for Decision making, The World Bank, Washington, DC (1992).

[107] CHAMBERS, R., Participatory Rural Appraisal (PRA): Challenges, Potential and Paradigm, Repor, Institute of Development Studies, Brighton/Sussex, UK (1993).

[108] SIMOS, J., Evaluer l'impact sur l'environnement. Une approche originale par l'analyse multicritère et la négociation, Presses Polytechniques et Universitaires Romandes, Collection META (1990).

[109] FAUCHEUX S., HUE, C., "Politique environnementale et politique technologique: vers une prospective concertative", Natures, Sciences, Sociétés, 8 (2000) 31-44.

[110] FAUCHEUX S., O'CONNOR M., "Technosphère vs écosphère. Choix technologiques et menaces environnementales: signaux faibles, controverses et décisions", Futuribles, n°251 (2000) 29-59.

[111] US NATIONAL ACADEMY OF SCIENCES, Understanding Risk: Informing Decisions in a Democratic Society, National Academy Press, Washington, DC (1996).

[112] KOPP, S., HEISKELL, M., JENKINS, C., "Taking the report-back function seriously: The Oak Ridge SSAB's public outreach program", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/53/53-1.pdf (2000).

[113] DOWNING, M., WEIGLER, N., MURPHY, B., “Providing communities with electronic access: Building capacity for public participation”, Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/45/45-6.pdf (2000).
[114] MEARES, D., Innovative Techniques in Public Participation and Information, WM’97, www.wmsym.org/wm97proceedings/sess31/31-04.htm. Tucson, AR (1997).
[115] GUIKEMA, S., BOLLINGER, M., “The role of risk in doe environmental cleanup decision-making: the regulatory requirements”, Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/57/57-2.pdf (2000).
[116] MACDONELL, M., HABEGGER, L., NIEVES, L., SCHREIBER, Z., TRAVIS, C., Integrating risks at contaminated sites”, Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/35/35-4.pdf (2000).
[117] TRAVIS, C.C., SCOFIELD, P.A., BLAYLOCK, B.P., Evaluation of remediation worker risk at radioactively contaminated waste sites”, J. Hazardous Materials **35** (1993) 387–401.
[118] BOYD, M., “Development of a Comprehensive Radiation Safety and Health Protection Program for Site Restoration Workers”, Proc. Waste Management’93, 28 February–4 March 1993, Tucson, AZ (1993) 609–612.
[119] US ENVIRONMENTAL PROTECTION AGENCY, Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives), Rep. EPA/540/R-92/004 Interim (1991) 65 p.
[120] SALT, C.A., et al., Impact Assessment Methodology for Side-Effects of Countermeasures against Radioactive Contamination — A Handbook, Nord-Trondelag College, Research Rep. No. 1, Steinkjer, Norway (in press).
[121] TURI, J.A., COLEMAN, J.A., RIZKALLA, E.I. “Fostering technological innovation and the role of users”, Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/10/10-1.pdf (2000).
[122] REGENS, J.L., et al., Screening Technologies for Soil and Groundwater Remediation, Soil & Groundwater Cleanup (1999) 24–27.
[123] REGENS, J.L., et al., “A triage approach to prioritizing environmental management technology review”, Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/ pdf/35/35-2.pdf (2000).
[124] US ENVIRONMENTAL PROTECTION AGENCY, Risk Assessment Guidance for Superfund (RAGS), Volume I -- Human Health Evaluation Manual, Part C, Appendix A, Selected Remediation Technologies and Associated Potential Releases, http://www.epa.gov/superfund/programs/risk/ragsc/appa.pdf, and Appendix D, Radiation Remediation Technologies, …/appd.pdf (1991)
[125] BOARDMAN, C., HOLMES, R., ROBBINS, R., FOX, R., MINCHER, B., “Remediation of soil at nuclear sites”, Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/38/38-5.pdf (2000).
[126] US DOE OFFICE OF ENVIRONMENTAL MANAGEMENT, The State of Development of Waste Forms for Mixed Wastes, National Academy Press, Washington, DC (1999) 129 p.
[127] BRENK SYSTEMPLANUNG, Integrierte Verfahren zur Bewertung radiologischer und nicht-radiologischer Belastungen (Altlasten des Uranerzbergbaues, Draft Report to the Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Aachen (1998).
[128] INTERNATIONAL ATOMIC ENERGY AGENCY, The Chemical Toxicity of Low and Intermediate Level Radioactive Waste Facilities, IAEA, Vienna (in press).

[129] UNITED STATES DEPARTMENT OF ENERGY, The 1996 Baseline Environmental Management Report, Office of Environmental Management, Washington DC (1996).
[130] COMMITTEE OF THE REGIONS, http://www.cor.eu.int/home.htm
[131] US ENVIRONMANTAL PROTECTION AGENCY, Brownfields, http://www.epa.gov/brownfields/ (2000).
[132] LandTREK, Land Reuse Plans, http://www.landtrek.org/LandTrek/DOEroadmap/Planning/Typical_Land_Reuse_Plan/typical_land_reuse_plan.html (2000).
[133] SIGAL, L.L., SARNO, D.J., "Next steps for stewardship — Results of the doe site specific advisory board's workshop on stewardship", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/65/65-2.pdf (2000).
[134] INTERNATIONAL ATOMIC ENERGY AGENCY, Compliance Monitoring for Remediated Sites, IAEA TECDOC-1118, IAEA, Vienna (1999).
[135] DUBREUIL, G.H., et al., "The ETHOS Project in Belarus 1996–1998", Commission of the European Communities, Rep. ETHOS(99)-RP(1) (1999).
[136] LOCHARD, J., "Stakeholder involvement in the rehabilitation of living conditions in contaminated territories affected by the chernobyl accident: The ETHOS project in Belarus", IAEA, Paper SM-395/5.1, Arlington, 1999, Vienna (1999).
[137] SCHNEIDER, T., "Rehabilitation of living conditions in contaminated territories: The ETHOS approach", IRPA-10, 10th Int. Conf. of the Int. Rad. Prot. Assoc., 18 May 2000, Hiroshima, Japan (2000) www.oita-nhs.ac.jp/~irpa10/EO/E11.pdf.
[138] GOUGH, J., Environmental decision making and risk management for groundwater systems, RISK, J. of the Risk Assessment & Policy Association **8**, http://www.fplc.edu/ RISK/vol8/spring/gough.htm (2001).
[139] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Optimization and Decision Making in Radiological Protection, ICRP Publication 55 (1989).
[140] O'SULLIVAN, P., ATHERTON, E., BUSSELL, M., WEBSTER, S., "Staged decision making and public participation for geologic repositories", Waste Management 2000, 27 Feb.–02 Mar., Tucson, AR, http://www.wmsym.org/wm2000/pdf/45/45-1.pdf (2000).
[141] PHILLIPS, L., A theory of requisite decision models, Acta Psychologica **56** (1984) 29–48.
[142] TVERSKY, A., KAHNEMAN, D., Judgement under uncertainty: Heuristics and biases, Science 185 (1974) 1124–1131.
[143] ERIKSEN, S., KELLER, L.R., "Decision trees", Encyclopedia of Operations Research and Management Science (GASS, S.I., HARRIS, C.M., Eds.), Kluwer Academic Publishers, Hingham, MA (1996) 159–161.
[144] MAXWELL, D.T., BUEDE, D.M., "Composing and constructing value focused influence diagrams: a specification for decision model formulation", Operations Research (1994) http://nac.gmu.edu/c3i/PubAbstracts/CommdSupport.html (2001).
[145] EDWARDS, W., NEWMAN, J.R., Multi-attribute Evaluation., Beverly Hills, CA, Sage Publications (1982).
[146] CULLIGAN-DUNSMORE, M., SALT, C.A., "A GIS-based spatial decision support system using multicriteria decision making methodology for radiological countermeasure suitability assessments", Proc. 1st Intern. Conf. Geospatial Information in Agriculture and Forestry, 1-3 June 1998, Florida (1998) 645–652.

[147] OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE, Use of Risk-Based Decision-Making in UST Corrective Action Programs, OSWER Directive 9610.17 (1996) http://www.epa.gov/swerust1/directiv/od961017.htm (2001).

[148] CENTER FOR RISK EXCELLENCE, Glossary of Terms, http://risk.lsd.ornl.gov/CRE/CRE_prior_glossary.html (2001).

[149] PEARCE, D.W., TURNER, K., Benefits, Estimates and Environmental Decision-Making, OECD, Paris (1992) 59 p.

[150] PEARCE, D.W., MARKANDYA, A., Environmental Policy Benefits: Monetary Valuation, OECD, Paris (1989) 83 p.

[151] GALLEGOS, D., Risk-Based Decision Making - A Framework and Automation Tool for Guiding Site Characterization, http://www.sandia.gov/E&E/risk/envir7.html (1996).

[152] KEENEY, R.L, REIFFA, H., Decisions with Multiple Objectives: Preferences and Value Tradeoffs, New York: John Wiley & Sons (1976).

[153] NATIONAL CENTER FOR ENVIRONMENTAL DECISION MAKING ANALYSIS, http://www.ncedr.org/tools/tools/info_analysis.htm (2001).

Annex

THE COSTS OF ENVIRONMENTAL REMEDIATION MEASURES

The cost of environmental remediation measures and of the associated deployment of technologies is an important factor influencing the choice of technical option and, indeed, the question whether any action can be taken and if so, on which time scale. Since environmental restoration and remediation of sites with radiological contamination still is an emerging field, very few comparative assessments of associated costs have been undertaken to date, in particular outside the US. However, many remediation techniques, or elements thereof, are already well developed in principle, and standard procedures have been established in the area of non-radiological contamination. If not in the field of radioactive contamination, at least for treating sites with 'conventional' contamination, many techniques are available commercially.

Environmental remediation projects for radioactively contaminated sites have presented managers around the world with a number of features that are not comparable to the normal cost estimating climate within other commercial projects. These features include:

- A higher than normal exposure to cost and schedule risk, as compared to most other projects, due to changing regulations, public involvement, resource shortages, and scope of work;
- A higher than normal percentage of indirect costs to the total estimated cost due primarily to record keeping, special training, insurance, liability, and indemnification;
- More than one estimate for a project, particularly in the assessment phase, in order to provide input into the evaluation of alternatives for the *cleanup* action.

Comparing costs and prices between countries is notoriously difficult and often unreliable. However, it was felt that by breaking down costs into individual cost elements a limited comparison may become possible. For instance, it would be interesting to see the variation from Member State to Member State in the relative proportion of labour and capital costs. For a given case, substituting e.g. the labour cost from one example with the actual labour costs in the country concerned may then allow a rough estimate of the relative overall costs of applying a specific technology to be made.

The cost data review, hence, specifically addressed the costs of applying certain technologies for restoration and remediation measures. The overall costs of remediation projects typically can be broken down, *inter alia*, into the following cost elements:

- management costs including cost of management of regulatory compliance;
- labour;
- provision of infrastructure;
- procurement or renting of equipment;
- maintenance of equipment and infrastructure;
- development cost for technologies;
- licensing fees for technologies,
- monitoring costs, and
- costs of final waste treatment and disposal.

The review, however, revealed that only in a very few cases a breakdown of cost to such level of detail is readily available. The reasons are be manifold, but commercial confidentiality may be one important reason.

The review was extended to the treatment of organic contamination, because sometimes the joint occurrence of radiological and organic contamination may be encountered. Breaking down certain organic compounds and contaminants in the soils can also release radionuclides for further removal and treatment.

In the following tables an overview over the various techniques are given. Typically a combination of techniques has to be applied, e.g. to first remove the contaminant and then to condition the resulting wastes. The destinction between physical and chemical methods in some cases is rather arbitrary, since a method may act in both ways. Some of the methods listed below, might also be rather classified as waste conditioning methods, than as remediation techniques, but are retained for the sake of completeness.

The majority of cost data available in the literature concern cases of organic contamination. There are two likely reasons for this: one is that this type of contaminant is much more frequent and widespread than radiological contamination, the other may be that the originator, and hence the one financially responsible, often is a commercial company as opposed to some governmental or semi-governmental organisation in the case of radionuclides.

For the USA, more detailed cost data are compiled in the Historical Cost Assessment System (HCAS) [1], an excerpt of which is shown in Table VI.

Table I. Chemical treatment techniques

Technology	**Medium**	**Contaminant**	**Brief characterization**
in situ solidification	soil, sludge	radionuclides, heavy metals	Aims at lowering the mobility of contaminants by injecting binding materials (cement, organic or inorganic polymers) that react with the contaminant, the water and/or the soil to produce a low solubility solid.
ex situ solidification	soil, sludge	radionuclides, heavy metals, (organic compounds)	A low-solubility solid is produced from the contaminated soil etc. by mixing it with a reactive binder (cement, gypsum, organic or inorganic polymer). The solid material may be disposed off *in situ* or at a designated repository.
ex situ chemical treatment	groundwater	radionuclides, heavy metals, (organic compounds)	Ion exchange, precipitation, reverse osmosis, etc. are applied to concentrate contaminants for further conditioning.
Reactive barriers	groundwater	organic compounds, heavy metals, radionuclides	In situ method of funnelling the natural or enhanced groundwater flow through a physical barrier containing reactive chemicals (oxidation, precipitation), metal catalysts (redox reactions), bacteria (biodegradation), or adsorbents.
dehalogenation (*ex situ*)	soil	halogenated VOCs	Contaminants in excavated soils are dehalogenated using one of two processes. Base-catalyzed dehalogenation involves mixing the soils with sodium hydroxide (NaOH) and a catalyst in a rotary kiln. In glycolate dehalogenation, an alkaline polyethylene glycol (APEG) reagent dehalogenates the VOCs in a batch reactor. The resulting compound from either reaction is non-hazardous or less toxic.
ex situ oxidation	groundwater	organic compounds	Organic contaminants are oxidatively destroyed in extracted groundwater by UV irradiation, ozone (O_3) sparging and/or hydrogen peroxide (H_2O_2). Off-gases are generally treated by ozonation.
in situ chemical oxidation	soil, groundwater	organic compounds, (heavy metals, radionuclides)	The injection of ozone (O_3), hydrogen peroxide (H_2O_2), or chlorine compounds induces a redox reaction that chemically converts contaminants into less toxic compounds. This may reduce the mobility of contaminants throughout a plume.

Table II. Physical treatment techniques

Technique	Medium	Contaminants	Brief characterization
Excavation	soil, sludges	all types	Contaminated materials are removed from the site and transferred to a designated disposal site. Conditioning may be required before disposal.
Pump-and-treat	groundwater	all types	Groundwater is pumped to the surface and treated by a variety of methods. The efficiency depends on the type of contaminant and concentrations.
Funnel-and-gate systems	groundwater	all types	The pump-and-treat methods and reactive barriers can be improved by constructing impervious walls, funnelling the water flow towards the well or the reactive barrier.
Isolation	soil	all types	Installation of physical barriers, such as slurry walls or sheet piling to prevent movement of contaminants
Physical segregation	soil	radionuclides, heavy metals	Often contaminants (including radionuclides) adsorb to fine grain size fractions in the soil. Size fractionation by sieving or flotation thus may result in a much smaller volume of contaminated material to be treated.
in situ soil washing	soil	all types	Consists of flushing contaminated *in situ*. Entails the injection and extraction of acidic or basic solutions, with added surfactants, chelates etc., to dissolve, desorb and remove contaminants
ex situ soil washing	soil	all types	This *ex situ* technique uses pH-controlled solutions with the addition of acid or base, surfactants, or chelates to dissolve, desorb and remove contaminants. Organic solvents may be used for organic contaminants. Preceding size fractionation improves the efficiency and reduces the volumes of material to be treated.
ex situ filtration	groundwater	radionuclides, heavy metals	Contaminated ground or surface water is passed through a filter column to remove contaminated suspended solids. The resulting filter cake requires further treatment and disposal.
Membrane separation	groundwater	volatile organic compounds (VOC)	A vapor/air separation involving the diffusion of VOCs through a non-porous gas separation membrane.
Air sparging	groundwater, soil	VOCs, organic compounds	Promoting volatisation of organics by air injection into the saturated zone. Promotes also natural aerobic biodegradation.
ex situ air stripping	groundwater	VOCs, organic compounds	Removes volatiles in pumped surface or groundwater. Stripping towers (e.g. packed columns) have a concurrent flow of gas and liquid. The waste air stream may undergoes further treatment by activated carbon, incineration, etc.
Vapour-phase carbon adsorption	off-gases	VOCs, organic compounds,	Off-gases collected from *ex situ* or *in situ* stripping methods are routed through canisters containing granular activated carbon (GAC).
Soil vapour extraction	soil	VOCs	Removes VOCs from the unsaturated zone by creating a zone of low vapor pressure. SVE is most effective in highly permeable soils
Vacuum extraction	groundwater	VOCs	A vacuum created inside a well forces the groundwater to rise up, allowing additional groundwater to flow in. Once in the well, the air flow causes some of the trapped volatile contaminants to vaporize, thus enabling the capture of VOCs through vapor extraction
Free product recovery:	groundwater	organic compounds	Remove a non-miscible, liquid-phase organic compound, either lighter or heavier than the groundwater by pumping from a defined horizon.

Table III. Themal treatment techniques

Technology	Medium	Contaminant	Brief characterization
Vitirification	soil, sludge	radionuclides, heavy metals	The contaminated material is mixed with glass-forming constituents and fluxes to give solid glass blocks or slag-like products.
in situ vitirification	soil, sludge	radionuclides, heavy metals	Soil is vitrified *in situ* to immobilise contaminants by applying electrical resistance or inductive melting.
Thermally-enhanced soil vapour extraction	soil	VOCs, organic compounds	Contaminated soil is heated by the injection of hot air or steam, or by electrical resistance or microwave heating, thereby volatilizing contaminants. Off-gases are captured for further treatment.
Thermal desorption (*ex situ*)	soils and sludge	VOCs, organic compounds	Excavated soils and sludges are heated to approximately 800°F (high-temperature thermal desorption) or to approximately 400°F (low-temperature thermal desorption) in an effort to volatilize organic contaminants. An off-gas treatment system is attached to capture and treat vapor-phase contaminants
Catalytic oxidation	soil	organic compounds	The use of a catalyst helps to lower the reaction temperature for thermal treatment methods, and thus the energy input.
Incineration	soil, sludge	organic compounds	The combustion of excavated soils and sludges in e.g. rotary kilns or fluidized bed incinerators to thermally destroy contaminants. Often conducted off-site, but also on-site in mobile facilities.
Pyrolysis	soils, sludge	organic compounds	Anaerobic thermal decomposition of organic contaminants in excavated soils or sludges.

Table IV. Biological treatment techniques

Technique	Medium	Contaminant	Brief characterization
Biosorption	surface and groundwaters	radionuclides, heavy metals	Certain micororganisms take up metal ions in their cell walls or on their surface, which process can be used to concentrate these contaminants. Plants can be designed as bioreactors or like sewage treatment plants (organic stationary phase).
Constructed wetlands	surface and groundwaters	radionuclides, heavy metals	Contaminated waters are routed into artficial ‘swamps’, where the metals are taken up by plant tissue. The plants are harvested and incinerated. The resulting ashes are disposed off.
biological waste water treatment	surface and goundwaters	organic compounds, (radionuclides, heavy metals)	Biological sewage treatment plants will destroy also certain organic contaminants. Bacterial populations specialised for certain contaminants may be used. The resulting sludge will also contain the majority of radionuclides and heavy metals and can be collected for further treatment.
Bio-degradation	soil	organic compounds	The generic process utilised in composting, landfarming and other bioremediation processes.
Composting	soil	organic compounds	Contaminated soil is excavated and placed in specialised facilities. Cellulose, biomass, nutrients, and sometimes additional indigenous microbes are added to promote degradation. Specialized bacteria may be added to break down a particular compound.
Bioventing	soil	organic compounds	*In situ* process of injecting air into contaminated soil at an optimal rate, increasing soil O_2 concentration and thereby stimulating the growth of indigenous aerobic bacteria. Low injection rates keep volatilization to a minimum.
in situ bio-remediation	soil	organic compounds	Enzyme activity of natural soil microbes to break down contaminants is stimulated by the injection of nutrients, oxygen (for aerobic microbes), surfactant etc. containing solutions.
ex situ bio-remediation	soil	organic compounds	Enzyme activity of natural soil microbes to break down contaminants is stimulated in bioreactors, treatment beds, lagoons etc. by the addition of nutrients, oxygen (for aerobic microbes), surfactant etc. to soils or surface and groundwaters. Similar to composting or sewage treatment.
Landfarming	soil	organic compounds	Once excavated, contaminated soils are spread over a clean area. The soil is aerated by regular turning or tilling to promote biodegradation.
Slurry-phase bio-remedia-tion:	soils, sludge	organic compounds	An engineered process for treating contaminated soils or sludge that relies upon the mobilisation of contaminants to the aqueous phase, where they are susceptible to microbial degradation.

Table V. Summary of available cost data for various remediation and treatment techniques (all figures are given in US $)

Technique	Medium	Unit Cost				Total Cost		
		Unit	25 perc.	Median	75 perc.	Range	Capital	O+M
bioventing	soil	m^3	14	17	19		28350-758000	24000-177060/a
biological treatment	soil	m^3		430			1.84 M	527000/a
bio-remediation	soil, sludge, gw	m^3	21	111	181	91700-4.21M		
bio-remediation	gw, sludge	m^3		341				
land treatment	soil. sludge, sediment	m^3		262		60000-25M	104250-12.7M	18460-7.4M
bio-degradation	soil, sludge	m^3	39	128	198	1.16-23.5M		
bioreactors	soil, sludge, sediment	m^3	167	291	428	0.93-49.0M		
bioreactors	gw, sludge	m^3		297		3.5-15.0M		
soil-vapor extraction	soil	m^3	47	353	394	183650-12.64M	156950-1.95M	132000-1.8M
solidification/ stabilization	soil	t		120				
chemical treatment	soil, sediment, gw	m^3	225	695	1300	10000-34.0M	1993	
vitrification	soil, sludge, sediment	t	400	888	1020			
thermally enhanced soil vapour extr.	soil, landfill, sand, gw	t	18	58	71	1.95M	4.3M	0.63M/a
incineration	soil, sludge, sediment	t	180	315	355	3.1-47.5M	29-42M	60000-0.5M/a
thermal desorption	soil, sediment	t	132	276	370	2.9-11.6M		
thermal destruction	soil	t		520		2.4M		
pyrolysis	soil	t		290				
cyclone furnace	soil	t		590				
molten salt oxidation	liquid waste, solids	t		550				
gw sparging	gw						70000-100000	
gw stripping	gw					267000-10.4M	4.3M	0.63M/a
barrier techniques	gw						250000-720000	
evap.and catal.oxid.	gw	m^3		29				
filtration	gw	m^3		0.46			150000	213000-1.2M
membrane separation	gw	m^3		60-460				
pump and treat	gw	m^3		0.67			0.57-8.03M	129400-1.24M

Abbreviations: gw = groundwater; M = million; O+M = operation and maintenance.

Table VI. Unit costs of various technologies according to HCAS [1] (all figures in US $)

Activity	Unit	25th percentile	median	75th percentile
Biological tretatment				
Activated sludge	m^3	0.83	3.40	3.71
Land treatment	m^3		11	
Chemical treatment				
Oxidation/reduction	m^3		2.54	
Chlorination	m^3		10.82	
Ion exchange	m^3		7.56	
Neutralization	m^3	0.02	1.60	2.76
Physical treatment				
Filtration	m^3	0.18	0.33	1.61
Straining	m^3		0.09	
Coagulation	m^3	0.55	0.77	14
Equalization	m^3		0.27	
Air stripping	m^3	0.50	1.60	15
Soil flushing	m^3		0.74	
Solids dewatering	m^3	2.98	73	416
Oil/water separation	m^3	5.13	24	134
Carbon adsorption - gases	m^3		181	
Carbon adsorption - liquids	m^3	0.16	0.47	0.67
Soil vapor extraction	m^3	43	43	43
Filter presses	m^3	0.76	2.06	37
Thermal treatment				
Incineration	m^3	51	94	108
Low temperature desorption	m^3	49	188	342
Solidification				
In situ pozzolan process	m^3		426	
Pozzolan process	m^3	12	43	83
Sludge stabilization	m^3		58	
Disposal (non-commercial)				
Landfill	m^3		116	
Underground vault	m^3	7.77	9.41	24
Pads	m^3		13	
Site restoration				
Earthwork	m^3	8.94	17	35
Rock excavation	m^3		36	
Backfill	m^3	6.01	16	23
Burrow	m^3	6.34	19	33
Spreading	m^3		63	
Grading	m^2		2.99	
Compaction	m^3		87	
Stockpiling	m^3		23	
Topsoil	m^3		41	
Revegetation and planting	ha	6011	12671	39083
Demobilization				
Removal of facilities	EA	1425	5268	10837
Decontamination facilities	EA		7466	
Removal of utilities	EA	350	2574	4903
Final decontamination	EA	8629	21715	75926
Demobilization of construction	EA	3654	8570	20573
Other services				
First aid, fire protection, etc.	month		4348	
Watchmen and guards	month		4347	

Note: EA = each at.

Table VII. Continued unit costs of various technologies according to HCAS [1] (all figures in US $)

Activity	Unit	25th percentile	median	75th percentile
Monitoring, sampling, testing and analysis				
Meteorological station	EA		15436	
Radiation monitoring	EA		22575	
Air monitoring and sampling	EA	196	7110	10064
Monitoring wells	EA	2066	4354	20931
Sampling ground water	EA		72	
Sampling liquid waste	EA		167	
Sampling process effluents	EA		401	
Sampling surface soil	EA	29	272	510
Sampling subsurface soil	EA	46	162	253
Sampling sediment/sludge	EA		72	
Sample shipping and handling	EA		20	
Sampling radioactive media	EA		17614	
Laboratory chemical analysis	EA	165	285	1192
Hazardous waste analysis	EA		1042	
Miscellaneous waste analysis	EA		69391	
Soil and sediment analysis	EA		312157	
Radioactive waste analysis	EA		106117	
Geotechnical testing	EA	15	153	230
Geotechnical instrumentation	EA		8570	
On-site laboratory facilities	EA		192868	
Off-site laboratory facilities	EA		34722	
Sitework				
Demolition	m^2	5.83	25	44
Cleaning and grubbing	ha	6869	12231	47556
Rock excavation	m^3		38	
Excavation/fill	m^3	5.60	13	15
Backfill	m^3	6.63	9.84	17
Burrow	m^3	8.94	19	92
Grading	m^3	3.24	3.41	6.32
Compaction	m^3		2.39	
Topsoil moving	m^3		6.76	
Other				
Roads	m^2	11	25	35
Fencing	m	26	81	131
Gates	EA		1885	
Electrical distribution	m	59	76	309
Telephone distribution	m		25	
Water distribution	m		192	
Sewage distribution	m		1935	
Fuel line distribution	m		91	
Storm drainage	m	50	101	339
Selected activities during remedial action				
Pumping, draining, collection	m^3	4.40	5.94	8.46
Excavation	m^3		62	
Erosion control	ha	6654	29164	77916
Extraction and injection wells	EA	11156	26052	70183
Subsurface drainage/collection	m	224	234	634
Sheeting and shorting trench	m^2		124	
Drain piping, fittings	m		110	
Slurry walls	m^2		65	
Sheet piling	m^2		477	

Note: EA = each at.

The following tables provide some data on selected case studies, most of them again in the US context.

Table VIII. Remediation of uranium contaminated soil and associated disposal cost estimate (all figures in US $) [2]

	Cost element	Unit cost	Unit
Conventional disposal costs (dig and haul)	Excavation /screening	130	m^3
	Transportation	390	m^3
	Stabilization/solidification	260	m^3
	Disposal (Envirocare)	293	m^3
	Total unit costs	**1073**	m^3
Disposal costs using segmented gate system (SGS) and containerized vat leaching techniques	Excavation	130	m^3
	Soil processing via SGS	78	m^3
	Well chemistry	325	m^3
	Disposal + transport (Envirocare)	293	m^3
	Total unit costs	**826**	m^3

Table IX. Estimation of attributable costs for various land types in the US (all figures in million US $\$\cdot km^{-2}$) [3]

Process	Western rangeland	Midwest farmland	Forest
site characterization	0.3	0.3	1.4
acquisition	0.1	1.0	0.3
access control	0.3	0.3	0.3
Emergency actions	0.2	0.2	0.3
decontamination	0.7	0.9	6.1
Waste disposal	31.8	32.1	66.9
restoration	3.7	3.6	5.3
certification	0.3	0.3	0.3
Total	**37.4**	**38.7**	**80.9**

The cost incurred in restoring former and operational uranium mining sites has received particular attention in recent years as the price of uranium has dropped and the commercial viability of facilities depends on it. Also, governments are interested in these data, as they often have to take over responsibility for orphan sites or they are the ones with ultimate responsibility for state owned companies.

Table X. Restoration costs of shutdown uranium production facilities in Canada [5]

Site	Production [t of U]	Total cost [M US $]	Tailings [t]	Unit costs [US $\$\cdot t^{-1}$ tailings]
Beaverlodge	17500	10.55	$5.8\cdot10^6$	0.75
Agnew Lake	750	2.14	37500	na
Madawaska	3670	na	$4.46\cdot10^6$	0.04
Quirke	43700	29.87	$46\cdot10^6$	0.35
Panel Mine	9200	16.23	$15\cdot10^6$	0.65
Stanrock	10400	10.39	$5.7\cdot10^6$	1.71
Denison	56100	15.58	$63.3\cdot10^6$	0.65
Rabbit Lake	58900	18.51	$14.1\cdot10^6$	0.46
Key Lake	74400	20.39	$4.7\cdot10^6$	0.92

Note: cost data are given in US $ 1993.

Table XI. Unit costs for the restoration of manufactured gas plant sites [4]

Activity	Details		Unit cost [US $]	Unit
Excavation	0-5.5m (unsaturated zone)		9.1	m^3
	5.5-12m (saturated zone0		18.2	m^3
	sheet piles		150	m^2
	cofferdam		150	m^2
	hydraulic dredging		5.2	m^3
Materials handling	stabilization		140	t
	Screening		0.71	m^3
	Drum filling		25.0	drum
	Tar pumping (from holder)		20	m^3
	Water pumping (from holder)		1.32	m^3
	Tar recovery (3 wells + 1 pump)		20000	total
	Groundwater recovery	capital	50000	total
		operational	10000	year
Transportation	hazardous transport		2.5	km
	Non-hazardous transport		1.75	km
	Truck tank cleaning		500	event
Treatment	Sand filtration	capital	220000	total
		operational	0.55	m^3
	Carbon adsorption	capital	100000	total
		operational	0.07	m^3
	Chemical oxidation	capital	100000	total
		operational	0.53	m^3
Disposal	hazardous waste landfill		220	t
	Non-hazardous landfill		55	t
Offsite incineration			550	t
On-site isolation	slurry wall		216	m^2
	Surface cap		36	m^2
Discharge fee			0.27	m^3

Table XII. Restoration costs of shutdown U production facilities in Australia [5]

Site	Production [tU]	Area [ha]	Tailings [$\times 10^6$ t]	Total costs [M US?]	Unit costs [US $$\cdot ha^{-1}$]	Unit costs [US $$\cdot t^{-1}$ tailings]
Rum Jungle	5193	200	2.20	16.48	65920	7,52
Mary Kathleen	7531	200	7.70	15.20	60800	2,00
Nabarlek	9203	80	0.66	9.60	96000	14,56
Ranger	30000	500	8.16	33.20	53120	4,08
Olympic Dam	5700	1185	80.00	25.60	17283	0,32

Note: cost data are given in US $ 1993.

Table XIII. Restoration costs of shutdown U production facilities in W-Germany [5]

Site	Production [t of U_3O_8]	Total cost [M US $]	Tailings [t]	Unit costs [US $·$t^{-1}$ tailings]
Menzenschwand mine	687.2	0.88		
Wäldel mine	1.36	3.48		
Höhenstein mine	10.8	0.54		
Grosschloppen mine	35.7	1.02		
Total	**735.06**	**5.92**	**200000**	**73.47**

Note: cost data are given in US $ 1993.

Table XIV. Restoration costs of shutdown U production facilities in the Czech Republic [5]

	No. of Sites	Total [$\times 10^6$ m^3]	Tailings [$\times 10^6$ m^3]	Heaps [$\times 10^6$ m^3]	Preparation [M US $]	Rehabilitation [M US $]	Total [M US $]	Unit costs [$·$m^{-3}$]
Mills	8	7.7	6.61		1.08	261.43	262.51	34.10
Mines+expl. sites	224	12.04		6.04	0.98	79.08	80.06	13.26
Total	1	19.74			0.98	78.04	79.02	40.03
(Costs in US $ 1994)					3.04	157.12	421.59	21.36

Note: cost data are given in US $ 1993.

Table XV. Restoration costs of shutdown U production facilities in Spain [5]

		Total costs [M US $]	Unit cost [US $·$t^{-1}$ tailings]
total rehabilitation		14	
plant demolition	hydrometalurgical building	2.2	
tailings rehabilitation	in situ rehabilitation of tailings pond	11	9.44
building demolition	decontamination	0.20	158
	dismantling	0.70	555
	cutting up	0.66	522
	loading in 400 containers	0.4532	361
	container transport	0.0704	56
	embedding in concrete	0.1254	100
	total	2.20	1752

Note: cost data are given in US $ 1993.

Table XVI. Unit costs (in US $ unless noted otherwise) of restoring U production facilities in Bulgaria [5]

Type of activity	Activity	Details	Unit costs	Unit
Rehabilitation work	Demolition	Foundation/site stabilization	112	m^2
		Buildings	224	m^3
		Pipework, cables (10 man-months)	750	plant
	Mechanical cleaning	scrap cleaning (0,5t/man/shift)	7.5-18.6	t
	Land rehabilitation	soil neutralization	0.007-0.011	m^2
		revegetation	0.026-0.037	m^2
Mines	Filling shafts	shaft 7 m^2 section	93	m
	Filling tunnels and galleries	6-10 m^2 section	18.7	m
	Contouring spoil heaps		13.0	m^2
	Removing leaching heaps		7.5	m^3
	Demolition	winding towers	750t	shaft
		pithead buildings	30000	shaft
		plant and machinery	7500t	shaft
Ore processing plants	Demolition	Buildings	300	m^3
	Removal	debris	37.3	t
		scrap steel	112	t
	Rehabilitation	of buildings for re-use	30	m^3
	Scrapping	of plant and machinery	37	t
Workshops	Demolition		11200	plant
	Debris removal		50000 Leva	plant
	Equipment scrapping		187	plant
Offices	Demolition	buildings	300000 Leva	plant
	Cleaning of structures		18680	plant
	Access road repair		7500	plant

Note: cost data are given in US $ 1993.

Table XVII. Bulgarian programme of restoring U extraction facilities [5]

Site	Restoration activity	Total costs [US $]
Mines	Preparatory work	466941
	Closure of 50 open galleries	3736
	Closure of 20 open shafts	186776
	Demolishing of 20 buildings and dumps	224131
	Removal of 20 debris and scrap heaps	1569
	studies, approval, certificates	186776
	other expenditures	37355
Mills	dam stability studies	26149
	engineering plans for emergency measures	74710
	engineering plans of rehabilitation	112066
	site cleanup, access roads	186776
	cleaning building	37355
	other expenditures	37355
ISL sites	cleanup 170 ha of land	5080
	demolishing of 12 adsorption towers	336197
	pumping and neutralization (2 years)	44826
	other expenditures	37355
Total		**2005155**

Note: cost data are converted from Bulgarian Lewa and given in US $ 1993.

Table XVIII. Restoration costs of U production facilities in the USA [5]

Site	Production [×10^6 m^3 ore]	Tailings [×10^6 t]	Tailings [ha]	Total costs [M US $]	Unit costs [$·t^{-1} of ore]	Unit costs [M US $·ha^{-1}]
Monument Valley, AZ	1	0.998	4.5	28.6	29	5.98
Tuba City, AZ	0.8	0.726	8.9	27.7	38	3.11
Durango, CO	1.6	1.361	4	61.8	45	15.27
Grand Junction, CO	2.3	1.996	24.7	445.4	223	18.04
Gunnison, CO	0.54	0.49	14.2	72.8	149	5.14
Maybell, CO	2.6	2.359	17	45.6	19	2.68
Natunta, CO	0.704	0.312	20.2	44.7	143	2.21
Rifle, CO	0.761	2.787	18.6	136.5	49	7.33
Slick Rock, CO	0.037	0.351	24.3	35.3	101	1.45
Lowman, ID	0.2	0.082	3.5	18.4	225	5.29
Bowman/Betheld, ND		0.153	16.6	27.2	177	1.64
Ambrosia Lake, NM	3	2.631	42.5	42.6	16	1
Shiprock, NM	3.7	1.452	29.1	22	15	0.75
Lakeview, OR	0.13	0.118	12.1	30.1	255	2.48
Canonsburg, PA	0.3	0.268	7.5	43.4	162	5.77
Edgemont, SD	0.4	2.087	49.8	5.1	2.44	0.1
Falls City, TX	2.5	2.268	59.1	52.2	23	0.88
Green River, UT	0.183	0.128	3.2	18.9	155	6.12
Mexican Hat, UT	2.2	1.905	27.9	56.7	30	2.03
Salt Lake City, UT	1.7	1.633	48.6	83.7	51	1.72
Riverton, WY	0.9	0.816	29.1	43.1	53	1.48
Spook, WY	0.187	0.17	2	10.1	60	4.99
Canon City, CO		2.1	66.8	10.5	5	0.157
Uravan, CO	12.5	9.5	34.4	35	3.68	1.017
Ambrosia, NM	41.67	30.1	132.7	18.84	0.63	0.142
Bluewater, NM	36.11	21.7	138	43	1.98	0.311
Church Rock, NM	3.43	3.2	40.5	8.35	2.61	0.206
Grants, NM	20.9	20.3	55	22.63	1.11	0.411
L-Bar, NM	7.5	1.9	46.5	2.07	1.09	0.044
Edgemont, SD	1.33	1.8	49.8	4.88	2.71	0.098
Conquista, Fall City, TX	9.92	10.5	101.2	8	0.76	0.079
Felder, Three Rivers, TX		0.4	18.2	0.8	2	0.044
Panna Maria, Hobson, TX	6.51	9.82	65	15.2	1.55	0.233
Lisbon, UT		3.5	14.2	3.47	0.99	0.245
Moab, UT	21.45	9.6	51.8	6.5	0.68	0.125
Shootering Canyon, UT		2.08	28.3	2.3	1.1	0.081
White Mesa, Blanding, UT		3.2	134.8	5.47	1.71	0.04
Ford, WA		2.8	53.8	1	0.36	0.018
Sherwood, WA		2.6	17	6	2.31	0.353
Bear Creek, WY	4.47	4.3	60.7	12.42	2.89	0.205
FAP Gas Hills, WY	9.17	5.3	47.3	3.06	0.58	0.065
Gas Hills (Lucky Mc), WY	16.07	10.6	100.4	9.36	0.88	0.093
Gas Hills (UMETCO), WY	11.91	7.3	59.1	18.57	2.27	0.28
Highland, WY	7.69	10.3	117.1	20	1.94	0.17
Shirley Bsn Mill (Pathfind), WY	3.47	7.3	106.4	5.76	0.79	0.054
Shirley Bsn Mill (Ptrfmcs), WY	3.25	6.3	56.7	4.87	0.77	0.086
Split Rock, Jeffry City, WY		7	67.6	18	2.57	0.266
Sweetwater, WY	2.27	2.1	121.4	4.9	2.34	0.04

Note: cost data are given in US $ 1993.

REFERENCES TO THE ANNEX

[1] ENVIRONMENTAL COST ENGINEERING COMMITTEE, Historial Cost Assessment System (HCAS), Remedial Action Breakdown Structure (33 series), Fourth Level, Burdened Cost Ranges.

[2] CUMMINGS, M., BOOTH, S.R., Remediation of uranium contaminated soil using segmented gate system and containerized vat leaching techniques; a cost effectiveness study, Report LA-UR-96-2663 (1996) http://lib-www.lanl.gov/la-pubs/00323601.pdf.

[3] CHANIN, D.I., MURFIN, W.B., Site restoration: Estimation of attributable costs, Report SAND-96-0957 (1996).

[4] U.S. DEPARTMENT OF COMMERCE, NATIONAL TECHNICAL INFORMATION SERVICE, Remediation Technologies, Remediation alternative and costs for the restoration of MGP sites, Report PB91-220129, Springfield, VA (1990).

[5] URANERZBERGBAU GMBH, International comparison of the costs of decommissioning and restoring Uranium production faicilities, Final report for research contract 37/93, Commissioned by the Federal Ministry of Economics, Germany (October 1994).

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