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Management of Long Term Radiological Liabilities: Stewardship Challenges

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MANAGEMENT OF LONG TERM RADIOLOGICAL LIABILITIES: STEWARDSHIP CHALLENGES

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FOREWORD

The IAEA attaches great importance to the dissemination of information that can assist Member States with the development, implementation, maintenance and continuous improvement of systems, programmes and activities that support the nuclear fuel cycle and nuclear applications, including management of the legacy of past practices and accidents. In this connection, the IAEA has initiated a comprehensive programme of work covering all aspects of environmental remediation:

— Technical and non-technical factors, including costs, that influence environmental remediation strategies and pertinent decision making;
— Site characterization techniques and strategies;
— Assessment of remediation technologies;
— Techniques and strategies for post-remediation compliance monitoring;
— Special issues such as the remediation of sites with dispersed radioactive contamination or mixed contamination by hazardous and radioactive substances.

Experience in Member States has shown that sites with radiation legacies and liabilities often cannot be remediated to residual levels of radioactivity that are below concern. As a result, they cannot be released for unrestricted use. Residual contamination, buried wastes and other hazards may remain after cleanup has been completed, for several reasons: technical limitations, economic feasibility, worker health and safety issues, prevention of collateral environmental impacts, or because they are, in fact, engineered near surface repositories. An optimization between social and economic costs on the one hand and level of protection on the other has to be found. With long lived radionuclides present, maintenance of institutional control will probably be required for nearly unlimited periods of time.

The present publication describes the relevant issues in various Member States and attempts by them to tackle the conceptual, management and technical problems associated with maintenance of institutional control over hundreds or even thousands of years. This collection of provisions and processes for maintaining institutional control over prolonged periods of time and for managing radiological liabilities is often referred to as ‘stewardship’.

The IAEA wishes to thank all the participants in, and contributors to, the work described in this publication.

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

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Responding to the needs of Member States, the IAEA has launched a long term project addressing the problems of managing a wide variety of radioactive liabilities and legacies that has resulted in guidance on technical [1–15] as well as safety related issues [16–19]. The project's aim is to collate and disseminate information concerning the key problems affecting the safe management of these liabilities.

In many instances radioactive materials remain at sites, thus not allowing their release for unrestricted use. Hence, these sites are likely to need some form of institutional control for prolonged periods of time. There are various reasons for not removing the radioactive materials to the levels required for free release:

— Lack of technical feasibility;
— High and uneconomic cost;
— Insufficient resources available at the time;
— Presence of unacceptable risks to the health of remediation workers;
— Inaccessibility of contamination without unacceptable disturbance of infrastructure;
— The collateral damage that would be caused to the environment by the remediation action;
— A site actually being a repository for low level radioactive wastes [1] or other radioactive residues such as mill tailings or processing residues containing naturally occurring radioactive materials (NORM) [2].

An optimization between social and economic costs on the one hand and level of protection on the other has to be found. With long lived radionuclides present, maintenance of institutional control is likely to be required for nearly unlimited periods of time. The present publication discusses the relevant issues and attempts in various Member States to tackle the conceptual, management and technical problems of maintaining institutional control over possibly hundreds or even thousands of years. This collection of provisions and processes for maintaining institutional control over prolonged periods of time and to manage the radiological liabilities is often referred to as 'stewardship'. The term stewardship in essence refers to the mode of implementing and ensuring institutional control, which inter alia ensures the effectiveness of physical protection measures. These measures are intended to prevent or mitigate the hazards indicated in Fig. 1.

1.2. SCOPE

A large body of work specifically on long term stewardship has been developed in the last few decades. A series of long term stewardship approaches in selected Member States is presented in the annexes. This report reviews the management, societal, economic and technical aspects associated with long term stewardship. The management aspects (Section 5) include elements such as restrictions on land and resources use, record keeping and archiving of information about the site, its contamination and remedial actions in place, as well as compliance with the regulatory framework. The societal issues (Section 6) include elements such as public values, beliefs and perceptions, stakeholder involvement mechanisms and means of communication. The economic issues (Section 7) mainly concern the long term funding of a stewardship programme. The technical aspects (Section 8) include elements such as surveillance and care of the site and remedial actions already in place, prediction of site behaviour, or corrective measures in the case of failure of remedial actions. The treatment of these subjects is placed in perspective by putting stewardship into the grander context of life cycle management (Section 2) and reviewing the conceptual basis of remedial actions (Section 3) and of risk management in general (Section 4).

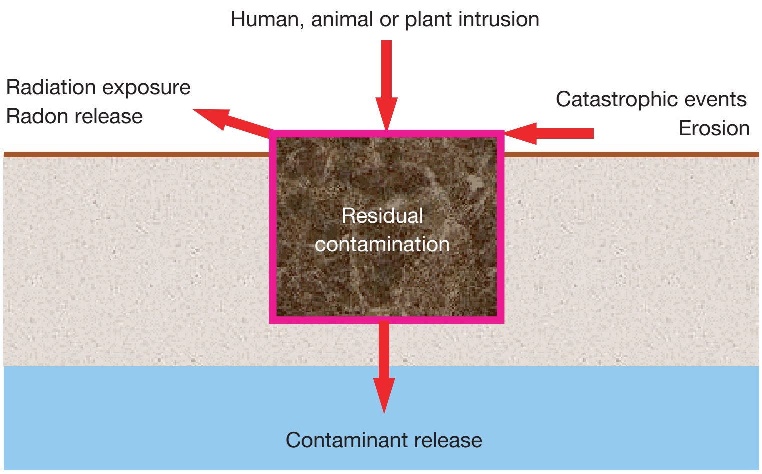

FIG. 1. Stewardship challenges.

The management, societal, economic and technical aspects of long term stewardship are complex yet intertwined. The decision making often involves conflicting and competing goals, large uncertainties, conflicting values among affected parties and a potentially significant investment of society's resources.

The issues discussed in this report may be of concern at the following types of nuclear sites after decommissioning:

— Power reactors and other nuclear industrial non-power applications;
— Nuclear defence sites (e.g. weapons research, development, production and testing);
— Uranium or thorium mining and milling sites;
— Other mining and minerals processing sites containing NORM;
— Nuclear materials facilities (e.g. isotope production, irradiation, medical and industrial facilities);
— Nuclear fuel cycle facilities (e.g. fuel fabrication, conditioning and reprocessing);
— Facilities for storing and processing non-reactor waste (e.g. sealed sources);
— Nuclear research and test reactors;
— Industrial nuclear explosion sites;
— Sites contaminated by nuclear accidents.

Although they are not the main focus of this report, most issues (and proposed approaches to resolve them) discussed here also apply to engineered near surface or deep geological repositories for radioactive waste as well as sites containing residual hazardous chemical materials.

2. LIFE CYCLE MANAGEMENT AND STEWARDSHIP

2.1. A CHANGE IN PARADIGMS

In recent years a slow change in paradigms has occurred: awakening awareness of long term ecological problems has led to a move away from treating environmental problems only after they have occurred. The goal is to avoid environmental impacts from the beginning in the life cycle of a human activity. This life cycle management aims to treat each stage in the life of a facility or site not as an isolated event but as one phase in its overall life. Thus, the planning does not only cover each stage but is also a continuing activity, taking into account actual and projected developments.

As a consequence, a more forward looking integrated management of human activities was introduced into the legislation in many Member States.

2.2. DEFINITIONS OF STEWARDSHIP

The long term and life cycle management of radiological liabilities requires certain provisions and institutions. In recent years the term stewardship has been coined to describe the various activities associated with the long term management of sites with radiological liabilities [3, 4]. In general, 'long term stewardship' indicates the technical, societal and management measures needed to ensure the long term protection of humans and the environment at sites characterized by residual hazards after active remediation or assessment has been completed.

Different audiences have used the term 'long term stewardship' with different meanings. According to the Oxford English Dictionary, a steward is a person entrusted with the management of another's property. In this sense, stewardship in the present context means taking care of sites or land with radioactivity in the ground. More specifically, it refers to those instances or phases of such sites, where, for instance, active remediation has been completed, but residual radioactivity is left, not allowing the free release of the site or land. Accordingly, the United States Department of Energy (USDOE) defines stewardship as:

> "the physical controls, institutions, information and other mechanisms needed to ensure protection of people and the environment at sites where DOE has completed or plans to complete 'cleanup' (e.g. landfill closures, remedial actions, removal actions, and facility stabilization). This concept of long-term stewardship includes, inter alia, land-use controls, monitoring, maintenance and information management" (see Refs [5, 6]).

There are several challenges, both technical and institutional, associated with long term stewardship. A recent report by the National Research Council of the United States National Academies defined the roles of a long term steward of a site with long lived hazards as [7]:

— A *guardian*, stopping activities that could be dangerous;

— A *watchman* for problems as they arise, via monitoring that is effective in design and practice, activating responses and notifying responsible parties as needed;
— A *land manager*, facilitating ecological processes and human use;
— A *repairer* of engineered and ecological structures as failures occur and are discovered, as unexpected problems are found, and as re-remediation is needed;
— An *archivist* of knowledge and data, to inform future generations;
— An *educator* to affected communities, renewing memory of the site's history, hazards and burdens;
— A *trustee*, assuring the financial resources to accomplish all of the other functions.

Nevertheless, it would always be the objective of life cycle management to minimize the need for stewardship within an overall optimizing management approach.

2.3. WHEN DOES LONG TERM STEWARDSHIP BEGIN?

Figure 2 shows the generic life cycle of a nuclear facility. The early stages of the life cycle consist of identifying the need for an activity site and selecting the site as well as designing, constructing and operating the nuclear facility.

At the end of the operational phase, the site undergoes decommissioning and active remediation. Decommissioning involves actions such as decontamination, demolition and dismantling of buildings and equipment, and waste conditioning. During active remediation, engineered, physical and chemical measures (e.g. caps, liners, reactive barriers and microorganisms) are put into place to protect human health and the environment. In some countries, decommissioning and active remediation are considered as an integrated process. In these countries, the boundary between decommissioning and the onset of site remediation is blurred, and there might be different cycles of decommissioning and site remediation. In some countries, these cycles may last for decades to allow the decay of short lived radioactivity and this process is called 'safestore'.

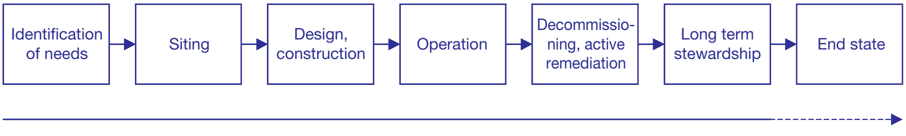

FIG. 2. Life cycle management.

In these cases, there may be interim ‘fit for purpose’ land uses at the end of each cycle. In contrast, in other countries, decommissioning is completed before site remediation begins, so that the boundaries are clearly defined. A site may also be split into sub-sites that are fit for free release and others that require institutional control. A suitable split may greatly facilitate a subsequent stewardship programme [8].

Long term stewardship begins after the end of decommissioning and active remediation. The intermediate guarantee phase of several years that is sometimes imposed for engineered structures, etc., might be viewed as part of the active phase or already be part of the stewardship phase. Long term stewardship fundamentally does not encompass any active remediation. Hazards on the site will have been removed or been contained by engineered systems put into place during the active remediation phase, or natural processes, such as attenuation, dispersion or radioactive decay, will have been used to keep exposures below levels of concern. Long term stewardship primarily involves the care and maintenance of the site and any structures built as part of the remediation solution. Monitoring activities ensure that the remediation solution behaves as predicted and that any land use restrictions are complied with. In some cases, a permanent solution may have been deferred until a (more) suitable remediation technology has been developed, and the site has been put into a stewardship-like state in the interim period.

A long term stewardship programme is being developed during the active remediation and decommissioning phase, and addresses monitoring and maintenance as well as including provisions for corrective actions in case of deviation from the predicted behaviour of the site. The final end state is ideally the unrestricted release of the site. However, if any control measures remain necessary, long term stewardship needs to be put into place. If unrestricted release is not possible, the site can still be used for specific purposes (e.g. industrial use) but the steward needs to ensure that the restrictions are complied with.

2.4. WHEN DOES LONG TERM STEWARDSHIP END?

The length of the long term stewardship phase depends on the half-lives of the residual radionuclides of concern. For some sites, where relatively short lived radionuclides such as ^{137}Cs and ^{90}Sr are the problem, the period of stewardship can be of the order of hundreds of years. Where long lived radionuclides, such as many of the isotopes of uranium, thorium and plutonium, are the problem, the stewardship period may have to last effectively for ever.

It can be noted that these considerations also become more and more important and receive increasing public attention in the case of ‘conventional contaminants’ such as heavy metals, persistent organic pollutants and other toxic or hazardous substances.

The term ‘long term’ is interpreted differently in different Member States. Administrations in various Member States have adopted for practical reasons certain time spans; thus a 1000 year basis may have been selected for engineering designs in this context.

3. REMEDIAL ACTIONS: OBJECTIVES AND OUTCOMES

3.1. REGULATORY FRAMEWORK

The objectives and outcomes of remedial actions have a direct and lasting effect on the level of long term stewardship required at a site. The International Commission on Radiological Protection (ICRP) stipulates that:

> “remediation measures shall be justified by means of a decision aiding process requiring a positive balance of all relevant attributes relating to the contamination. In addition to the avertable annual doses, both individual and collective, other relevant attributes shall be assessed” (see Ref. [9]).

The prime objectives for remediation actions are the abatement of environmental impacts and the reduction of risks to human and other receptors. According to Ref. [10]:

> “remediation shall (a) reduce the doses to individuals or groups of individuals being exposed; (b) avert doses to individuals or groups of individuals that are likely to arise in the future; (c) prevent and reduce environmental impacts from the radionuclides present in the contaminated area.”

The criteria for the release of sites from regulatory control upon the termination of practices have been formulated recently in an IAEA Safety Guide [11]. Though strictly speaking this Guide applies only to the decommissioning of authorized practices, sites where past practices or accidents have led to contamination in the ground would have to comply with most of the criteria set out there. The preferred option, according to Ref. [11], is unrestricted release, provided the site meets the appropriate release criteria developed for a reasonable set of possible future uses (see also Section 7.6). In the case of restricted use,

> "the restrictions should be designed and implemented to provide reasonable assurance of compliance with the dose constraint for as long as they are necessary… Therefore, existing regulatory limits on the institutional control time frames should be taken into consideration in deciding whether to release a site for restricted use."

The scope of a stewardship programme is outlined implicitly in Ref. [11]:

> "The type, extent and duration of the restrictions and controls for site release can range from monitoring and surveillance to restriction of access to the site. They should be proposed by the operator on the basis of a graded approach and in consideration of factors such as the type and level of residual contamination after completion of cleanup; relevant dose constraints and release criteria; and the human and financial resources necessary for the implementation of the restrictions and controls. The restrictions proposed by the operator should be enforceable by the regulatory body and the cleanup plan should specify which entity will ensure that the restrictions are maintained."

The actual regulatory framework will vary from Member State to Member State. Even after free release, a site may become the source of contamination, hence:

> "consideration should be given to the potential circulation of material coming from future modification of the buildings, including demolition after site release. Materials originating from the site, after the site is released from regulatory control, need to comply with the national requirements for radiation protection... This should be an integral part of the optimization analysis of the cleanup process. Scenarios for exposure to sites released for unrestricted use should be realistic and consider the potential uses of the materials from the released site" (see Ref. [11]).

3.2. REMEDIATION OPTIONS

Decision makers are faced with a fundamental choice with respect to the intended remedial action. They must decide whether they will [12]:

(a) *Leave the site undisturbed*, while establishing a monitoring scheme for determining the evolution of the site. This option relies on natural processes to prevent significant exposure. The entire process needs to be carefully monitored so that an alternative option can be initiated if required.
(b) *Contain or restrict the mobility* of the radioactive contaminants. Such technologies aim to immobilize the contaminants inside the area where they already exist, reducing the potential for further migration or entry onto active pathways for exposure.
(c) *Remove* the radioactive contaminants from the site, implementing an appropriate treatment and disposal scheme. Such treatment technologies aim to extract, concentrate and then safely dispose of the contaminants at another location.

While removal is obviously a permanent solution for the site in question itself, the chosen disposal site may have to be subject to a stewardship programme. Any engineered solution to contain contaminants or to reduce exposures, whether on-site or at the chosen disposal facility, will only have a limited period of useful life. Natural forces will gradually degrade structures such as liners, barriers or cappings. Modelling predictions, based on historical experience and observed parameter values, allow an estimate to be made of how long an engineered near surface structure is likely to perform according to intentions. However, experience in recent times with floodwater defences has shown that our events database extending some 100 years into the past may be insufficient to capture the whole parameter range required for, say, a 1000 year lifetime.

This uncertainty over the long term effectiveness of remediation solutions requires provisions for monitoring [13], periodic performance assessment, and, if required, maintenance; hence the establishment of a stewardship programme. It is this uncertainty that creates the need for long term stewardship. While making remediation decisions, it is important to consider long term stewardship issues and obligations explicitly when comparing remedial alternatives and implementing a final remedy [14].

Stewardship, and by inference the steward's responsibilities, must be defined at a practical implementing level, that is from the bottom up. For stewardship to be understandable and affordable, a narrow definition of stewardship is recommendable [15].

Stewardship plans cannot be static but have to be adapted to the development of a site, with respect to both its physical state and its use. Periodic revision of the stewardship plans will be necessary.

3.3. MEASURING SUCCESS

The USDOE's Long-Term Strategic Plan [5] noted that:

> "cleanup at most DOE sites is proceeding in an iterative fashion. End states appear at present to be emerging as the de facto result of multiple interim actions. These interim actions are being applied in a serial fashion via regulatory definition, often at relatively small and relatively dispersed former operational areas within the larger site, of facilities or disposal areas within operational units. Although individual cleanup actions are usually directed at relatively well defined end states (e.g. meeting regulatory standards), the ultimate end state for the site as a whole may be uncertain or unknown."

This is almost certainly also true for other countries.

The measurement of remediation success is still a developing science [16, 17], and research sponsored jointly by the mining industry and government is currently being undertaken, for instance in Australia, to identify and apply ecosystem indicators for this purpose [18]. In the Northern Territory (NT), a company's liability for a mine site ends upon issuance of a Revegetation Certificate by the NT Minister for Mines, and objective information is required to advise the minister accordingly. Thus, the goal and objectives for remediation of the site at Nabarlek are, like those for the site at Ranger, conceptual and value driven, recognizing the absence of sufficient information to enable quantitative targets to be set, such as values for biomass, tree canopy cover and successive colonization of flora or fauna.

The determination of estimation of the time when remediation is complete and long term stewardship begins may differ between Member States and may well vary for different types of sites within a Member State. Many times the determination of when remediation is complete is based on when the regulator certifies or by some means designates that the remedial actions taken have met the originally established remedial objectives. Groundwater remediation in some cases tends to have very long remedial durations, which creates a unique timing issue over when remediation is complete and long term stewardship begins. The duration depends on the time needed for active water treatment. This is a critical issue to consider early in the remediation phase, especially if the parties responsible for remediation and long term stewardship are not the same entity or may change over time.

4. CONCEPTUALIZING RISK

4.1. INTRODUCTION

Long term stewardship is based on the following three elements: risk assessment, risk management and risk communication [19]. Risk assessment is used to determine the risk to human health and the environment, risk management efforts are directed towards control and mitigation of the potential long term risks of residual contamination, and risk communication actions are used to convey information to affected current and future stakeholders [20].

4.2. ENVIRONMENTAL RISK ASSESSMENT

Environmental risk assessment is based on the source–pathway–receptor relationship and allows a prediction of the effects on the environment and human health over time to be made. Environmental risk assessment usually takes place prior to any remedial action in order to determine the levels and types of remediation required. The process needs to be rerun following the remediation phase so that the longer term risks of any remaining contamination can be assessed and appropriately managed during the stewardship years.

4.3. RISK MANAGEMENT

Three major traditions in sociological analysis of risk have been identified [21, 22]:

(1) A positivist/realist theory of knowledge, with a bureaucratic rationalistic policy orientation, whereby risk can be measured and mapped, and thus

controlled (within limits), and where failures in risk management are understood as being due to inadequate knowledge or competence, or to a failure of political will;

(2) A social constructivist theory of knowledge, with a liberal pluralistic approach to integrating knowledge and action, whereby the understanding of risks is shaped by history, politics and culture, and risk management requires negotiation and dialogue to enable the inclusion of different perspectives;

(3) A constructivist theory of knowledge, focusing on the mediation of knowledge and power (among others), which makes risk analysis a particular discourse, and which empowers some groups and excludes others.

Reference [21] states that: "Judgements about the nature and severity of environmental risk inevitably incorporate tacit understandings concerning causality, agency, and uncertainty, and these are by no means universally shared even in similarly situated western societies." However, it is obvious that current (radiological) risk management strategies as promoted by the ICRP and the IAEA fall under model (1) listed above.

An extensive discussion of risk perception and its impact on decision making strategies and acceptance of remediation measures is beyond the scope of this report. A more detailed discussion is found in Ref. [23] and a concise, very readable overview of these issues is given in Ref. [22].

The acceptability of residual risks in general is a function of a wide variety of sociological, economic and political factors. It may vary over time for individuals or certain groups of individuals. This acceptability typically evolves as a balance between perceived risk and actual inconvenience imposed by institutional control measures. Inconvenience here is understood to encompass the restrictions on, for example, site use imposed. The higher the perceived risk, the more acceptable become institutional controls.

The definition of what constitutes a residual risk is subject to scientific developments and subsequent changes in the regulatory systems. A stewardship programme may have to include provisions for accommodating such changes in the regulatory system. While the legal framework usually ensures that the 'goalposts' do not change, the regulator may deem it necessary to reassess risks. Such reassessment may result in changes to the institutional control measures that in turn require changes in the stewardship arrangements. A mechanism must be available for providing (additional) resources.

The need for remediation and the judgement about acceptable residual contamination levels are usually driven by society's perception of the balance between the costs of measures and the benefits obtained. As has been discussed previously [23], there is a certain ‘window’ for decision making, bound by minimum required benefits and maximum allowable expenditure. Expenditures for lowering residual risks typically increase in an exponential or similar way. This is captured in the requirement to optimize radiation protection measures [24].

The conceptual framework for long term stewardship can be represented on a scale (Fig. 3). On the left hand side of the scale, a series of weights represent the hazard associated with residual contamination. On the right hand side of the scale, a series of weights represent technical, institutional and societal factors.

Technical factors include, inter alia:

— Monitoring and surveillance;

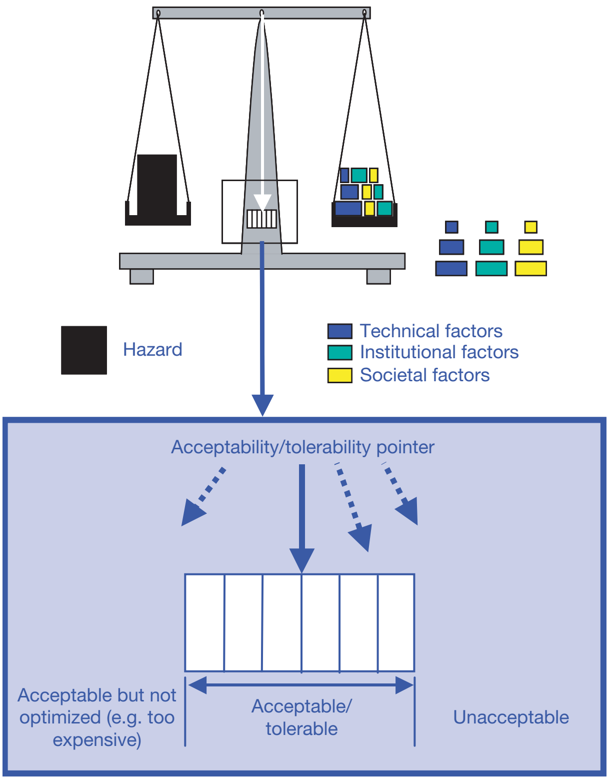

FIG. 3. Conceptual framework for long term stewardship.

— Verification and validation of predictive models for the fate and transport of contamination;
— Development of durable engineered protective measures.

Institutional factors include, inter alia:

— Safety assessments;
— Development of an action plan with contingencies;
— Development of durable institutional controls;
— Reliable funding mechanisms;
— Records and information management.

Societal issues include, inter alia:

— Risk perceptions;
— Public values;
— Stakeholder involvement.

When the scale is in balance then human health and the environment are considered to be protected to a level agreed by the stakeholders — for the present and in the future. The aim of long term stewardship is to ensure that the scale is kept in balance. Thus with time, if the level of hazard falls due to radioactive decay or natural attenuation, then less weight may need to be added to the right hand side of the scale in Fig. 3. This may allow the site to reach an interim end state such that less restrictive land uses may be allowed while still maintaining protection of human health and the environment.

Conversely, if the hazard remains the same but there is a partial failure of, for example, a containment system, then further 'weights' need to be added to the right hand side in order to maintain protection of human health and the environment. These additional weights are likely to involve a technical or institutional solution — for the former this could be an engineering intervention to restore the required level of containment, whilst for the latter this might involve further restrictions on land use.

Each of the weights on the right hand side inevitably has an associated cost. Optimization of a long term stewardship programme involves balancing these costs against the benefits of the actions required to contain the hazard and to retain an appropriate level of protection of human health and the environment.

4.4. RISK COMMUNICATION

Environmental risk assessment is sometimes viewed by the non-scientific community with suspicion, and terms such as black box syndrome are quite often used. It is important, therefore, for scientists to be able to communicate the rationale and benefits behind undertaking environmental risk assessments as well as the results themselves. There has been much research on risk communication, especially in the USA [20].

5. MANAGEMENT CHALLENGES

5.1. FRAMING THE MANAGEMENT CHALLENGES WITHIN MULTIPLE TIME FRAMES

Stewardship for radiological liabilities must be framed for very long time horizons. Given the long half-lives of many relevant radionuclides, and compared with the average human life, 'long term' in essence means eternity. However, it is also clear that, during the life cycle of site management, the stewardship will encompass an extremely broad range of issues and activities. Some of these may be relatively transient in character (e.g. a time frame of a few years), others will specifically envisage engagements for several decades (e.g. leasehold agreements for land uses and liability for defects in engineered system components) and others again will envisage timescales of centuries or even millennia (e.g. performance hopes for containment under the prevailing environmental conditions).

Some studies propose separating 'nearer term' and 'longer term' challenges as a pragmatic way of developing a comprehensible and affordable long term stewardship programme [15]. However, expressions such as nearer term (or short term) and longer term (or long term, etc.) can be and are given a wide spectrum of usages. It may be helpful to distinguish between different strategic planning horizons on the basis of the actors involved (viz. present versus future generations) and on the basis of hypotheses about system stability and change.

Regarding the actors involved, it is useful to follow the sustainability literature, where it is now commonplace to distinguish between present and future generations. This distinction is not associated with a specific period (is a generation 15, 25 or 35 years?), rather it is based on a question of agency:

of actions by some people, on behalf of or for others. In reality, it is the responsibility of the present generation of policy makers and stakeholders to determine the ways in which the interests of future generations (and, by extension, of other species and ecosystems) are to be provided for. Provision for the needs of future generations can be assured only through principled choices of resource use (investment and protection decisions) whose stewardship intent is to maintain and enhance the opportunities and security of future generations. Stewardship actions must be viable and acceptable to the present day stakeholders, at the same time as being motivated with respect to future generations.

Regarding system durability, there are important time horizons related to the stability and finiteness of stewardship strategies. This applies to institutional matters and also to engineering solutions.

Institutional arrangements, including financial conditions, workforce and legal frameworks, can change quite quickly (on a scale of a few years) even when clear and 'binding' agreements have been made. The prevailing frameworks of government and of governance can also change rapidly (the rise and fall of political regimes) but in a deeper sense change more slowly (the rise and fall of civilizations). Therefore, the durability of stewardship for the longer term will depend on rooting the stewardship function in cultural values, purposes and understanding. This may be referred to as the archeological time frame.

Technological solutions (such as near surface containment), when put in place with attention to environmental and geological conditions and with a view to durability, can be proposed reliably for time horizons ranging from decades to hundreds of years. The longer the time horizon, the greater the extent to which performance is associated with the properties of natural systems and is, therefore, dependent on these. Therefore, in the longer term, a scientific characterization of natural processes is the determinant, and there is inevitably an element of indeterminacy associated with the long term evolution of natural processes. This may be referred to as the geological time frame.

These various considerations lead to the recognition of three time frames as being complementary for stewardship functions:

- One generation (approximately 30 years);
- Archaeological spans (of the order of 100–1000+ years);
- Geological spans (e.g. 1000–10 000+ years).

The main challenges for stewardship relate to the transitions in the planning horizon between one generation (the present period of activity) and the archaeological and geological horizons.

The ‘nearer term’ stewardship challenges are more likely to gain support from stakeholders, because they will probably be based upon existing and proven methodologies. These challenges may be economic (discussed further in Section 7), technical or institutional ones, or may involve ownership or measurability of success. While there is always the likelihood that technology will advance over time, there will be less confidence in institutional or financial stability, as the recent past shows only too well.

Convincing stakeholders to accept a stewardship programme when the longer term issues are less developed will be a challenge in itself. The way in which the longer term challenges (responsibilities and obligations, etc.) are framed may have a substantial bearing on the acceptance, or non-acceptance, of the immediate ‘steps’ (or nearer term solutions). The mechanisms of involving stakeholders are very country and culture specific (e.g. see Ref. [23] and references therein).

It will, therefore, be important to incorporate within the longer term process a mechanism that will allow a reappraisal of the control measures and financial provision on a regular basis (this may be a 25 or 50 year period, for example).

For the longer term issues, although very real and significant, satisfactory answers may not be attainable. The pursuit of those answers will probably be very expensive, and demonstrating progress on an annual basis might be difficult. A lack of demonstrable progress for the resources expended can undermine a programme’s credibility in general. Therefore, it was suggested [15] to pursue the longer term issues by a different means. The very act of continuing nearer term activities is likely to clarify actual longer term needs. It must be noted, however, that with this approach, while circumventing the possible paralysing effect of having to design for millennia, there may be no guarantee that the nearer term activities are continued for any length of time beyond, say, one generation.

Such a separation allows, at least, a definition of stewardship to be made from the bottom or from an implementation viewpoint. The danger in defining stewardship from the top down and building a stewardship programme in this way is that the definition and resultant programme to fulfil the responsibilities of a top-down definition must be excessively broad and all-encompassing to be capable of handling every conceivable eventuality.

While there may be no direct solutions to maintaining the ability to manage long term stewardship for thousands of years, focusing on shorter term (100 years or so) solutions will keep people involved at the site, which will allow for evaluation of the changes required over time. If too much energy is spent on trying to solve the problems of 2214 with today’s knowledge, opportunities may be lost to take the best decisions for the short term and unreasonable or unrealistic solutions may be recommended for the long term.

5.2. DECISION MAKING IN THE PRESENCE OF LARGE UNCERTAINTIES

There are several management questions arising specifically from the long term character of stewardship. These include, on the one hand, the presence of large uncertainties about physical system stability and change and, on the other hand, the impossibility of resolving in advance the socioeconomic and institutional dimensions, such as identification of stakeholders, funding mechanisms, communication, and retention and management of records, over very long time periods.

The conclusions for decisions taken in the present are usually based on monitoring and/or observations. However, for the future, decisions are model based and bound to a range of uncertainties [25]. The potential failures resulting from uncertainties may imply or result in a range of 'active decisions' by the steward.

Two main types of uncertainty can be distinguished according to the time frame:

(1) Uncertainties about the result of the assessment after remediation under normal conditions, leading to the decision in the present (e.g. data gaps in the inventory, insufficient site characterization or insufficient engineering quality).
(2) Uncertainties about the future. These cover both the nature and the range of natural phenomena/'events' in the future and the influence of the passage of time on the internal evolution of the designed structures/processes.

All models are back-calibrated to observations made of phenomena during the past few centuries or even just decades, which is a limited period of time compared with the long term for which predictions are to be made. This problem has become obvious in recent years when, for example, predictions of 200 or 1000 year flood events in Central Europe naturally failed because the underlying database only spans 150 years at most.

Some of these uncertainties in our knowledge of a site's properties and behaviour are discussed in more detail in Section 8.

5.3. TRUST, CONSTANCY AND LEARNING

Three significant management challenges for long term stewardship are the following:

(1) Obtaining and maintaining public trust;
(2) Achieving institutional constancy or ensuring continuity of long term stewardship activities over many generations;
(3) Learning from past and ongoing experience as technological and management means for implementing long term stewardship are developed.

These are significant challenges, but there is some relevant experience in the operation of high reliability organizations as well as in the management of natural resources. Organizational tasks requiring high reliability, such as air traffic control, require high levels of trust, both within the operating organization and in its social environment. A central finding of studies of organizations that need to demonstrate high reliability is that public confidence in them reflects the way in which the operations of the organization are carried out. Not only is the substance of long term stewardship affected by choices made in the cleanup process but so also is the social setting in which long term stewardship will be conducted. That setting is critically important to the ability of stewards to discharge their responsibilities. The US National Research Council recognized the importance of trust, constancy and learning in long term stewardship in a recent report [7], which contains advice about means for maintaining and enhancing public trust, characteristics associated with institutional constancy and recommendations on institutional learning. These elements are reproduced in Annex VII.

5.4. IDENTIFICATION OF POSSIBLE STEWARDS

A stewardship organization must be a long lived entity. This increases the probability that the steward will exist long enough to perform their stewardship responsibilities during the mandated institutional control period. On the basis of this premise, a corporate entity may not be an appropriate long term steward because site integrity could be jeopardized by profit driven decisions to transfer title and responsibility for a site, or by dissolution of the corporation.

In the USA the majority of projects on establishing stewardship programmes tacitly assume that the Federal State continues to exist indefinitely as an entity. A similar situation exists for a large number of other countries. Therefore, in the case of failure of institutional control, it is assumed that there is always a higher level organization that is capable of taking corrective action. Thus, stewardship is reduced to providing for the necessary mechanism of making these ‘higher’ authorities aware of any violation. If the past is an indication of future development, this might be a correct assumption for the next two hundred years or so. However, many places in the world have seen substantial changes in governance since the late 1700s and such assumptions may not be valid at all. It is for these types of concern that designs that minimize the need for long term stewardship and that are likely to function whether governmental structures are available or not are preferred.

5.5. FACTORS PROMOTING LONGEVITY OF INSTITUTIONS

A number of institutions have survived a considerable length of time and are still functioning more or less in the same way. Examples include the papacy/Vatican (around 2000 years), Mecca (close to 1400 years), the Royal Society and Academie Française (about 350 years) and the British Museum (270 years). In addition, there are various monuments and other examples of civil engineering that are know to have been in operation (or are still in operation) for hundreds of years, including Roman public baths and water supply systems, the Forbidden City in Beijing (about 600 years) and the Taj Mahal (about 350 years). Some States have survived for remarkable periods of time, if not in territorial integrity, at least as a concept, including the Kingdom of Egypt, the Chinese Empire, the Roman Empire, the Holy Roman Empire and some modern States such as Russia or the USA.

At some stage museums were claimed to be candidate institutions, see for example Ref. [26], but they must be active and ‘living’ museums, such as the British Museum. However, the Second World War and recent events in, for example, Iraq show that museums are by no means safe.

It may be worthwhile to review the properties that made these institutions survive 200+ years. Retaining momentum in public interest appears to be one of the properties required, and is particularly associated with religious institutions. There must be a sustained interest in the services of or values represented by an institution. Thus, longevity is linked to cultural or spiritual values. Conversely, there are many institutions or civil engineering structures that were intended for eternity but that have not survived or which do not fulfil their function any more, for example, the Egyptian pyramids, where the societal context ceased to exist. Some civil engineering structures, on the other hand, seem to have attained a new spiritual value, for example certain megalithic structures, that ensures their continued preservation.

In essence, the longevity of institutions appears to be linked to the relationship built between them and the society, or succession of societies, to which they belong. Similarly, the fact that certain human-made structures have survived in a well preserved and maintained state appears to be linked to society maintaining an active interest in them.

It should be noted that such interest can be both positive and negative, that it can be something that is sought after or something that is to be avoided.

5.6. MAINTAINING INSTITUTIONAL CONTROL

Long term stewardship is an outcome of maintaining institutional control at a site. Institutional controls or institutional provisions are required for sites that cannot or are not remediated to unrestricted use. The IAEA defines institutional control as 'control of a waste site by an authority or institution designated under the laws of a country'. This control may be active or passive and may be a factor in the design of a nuclear facility (e.g. a near surface repository) [27]. Active institutional control measures include:

— Monitoring;
— Surveillance;
— Guarding the site.

Passive institutional control measures include [28]:

— Proprietary controls;
— Governmental controls;
— Engineering controls.

The institutional controls that are required to meet the identified requirements of the remedial action will need to be documented and understood by the steward, as one of the tasks of the steward will be maintaining these controls over time. It is helpful if these controls are developed as an integrated planning effort over the life cycle. The monitoring and inspection requirements needed to maintain institutional controls as established by the remediation process would usually be identified as noted in Section 10. In most cases the stewardship requirements to ensure that these controls remain functional will call for an appropriate monitoring regime themselves.

The following paragraphs contain a discussion of some institutional controls that are currently active and the ideas to maintain them that have arisen in some Member States.

Proprietary controls are often placed on deeds. They involve restricting the use of land through an ownership interest in the property.

(a) Provisions under institutional control may preclude the construction of a building on a specific property. This restriction could be placed on the deed of a property to ensure that future owners will also be restricted from building a house on the property.
(b) To maintain this restriction, the steward has to periodically inspect the property management location (e.g. land register or cadastre) to verify that the restriction is still in force. In addition, the steward (if not the previous proprietor) has to make any new owner aware of such restrictions and if necessary take action to enforce them.

Governmental controls are generally applied through the traditional powers invested in the police by the government and enforced on its citizens. Governmental controls are essentially regulatory in nature. Examples of these would be zoning, permits and ordinances, for example, groundwater use permits:

(a) Special zoning, for instance, may be established to prevent contaminated groundwater from being extracted.
(b) Enforcing certain types of land use can provide a degree of control if the user of the land is likely to be an entity that will continue in existence. In addition, if the land use is very site specific (e.g. a golf course or a horse race course) then changes to land use are unlikely to be brought about without being brought to the attention of the steward.
(c) To maintain this restriction, an inspector would check the site and determine, for example, whether water is being extracted. A review of developments around the site to consider pressures that will probably affect changes in usage over time may be useful.

Engineered controls are physical controls intended to limit or prevent access or exposure to contaminants at a site or at parts thereof, for example buried waste. Typically, engineered controls are an instrument of institutional control aimed at minimizing the need for active control measures. However, they require regular surveillance and maintenance, for instance:

(a) The integrity of the cap of a disposal cell must be ensured.
(b) The annual inspections would include visual reviews as well as other more detailed surveys that will assist in verifying that the cell integrity has not been compromised [13].

Amongst the major issues facing regulators is how institutional control can be maintained over times exceeding a few decades, i.e. the question of how the ‘rules’ can be enforced. Acceptability of, and compliance with, institutional controls is a sociocultural question.

Strategies aimed at ensuring institutional control face two challenges: unintentional and intentional breaches of institutional control. There seems to be general agreement that little can be done about intentional breaches. Experience in many Member States shows that warning signs are ignored, fences are ripped down, sites are misused and impounded material is taken away without authorization. However, education of stakeholders and building a relationship (Section 6) might work towards reducing such incidences. Regulators have to be aware, however, that from a stakeholder perspective the cost–benefit balance may be tipped in favour of a breach; there may be, for instance, pressing economic reasons to reuse fencing and other materials or to occupy restricted sites. It may be expedient to address the underlying reasons for such possible breaches rather than the breaches themselves.

Stakeholders may advocate the complete removal of contamination in order to achieve free release of a site or to have a problem removed from their ‘backyard’. However, it is important to remember that a disposal site for the radioactive residues has to be found or newly constructed. In particular, in the latter case, a reasonable balance between the stewardship needs for the site with residual contamination remaining and the stewardship needs for the site receiving the removed contaminants has to be found.

Institutional control is a broader concept than regulatory control (i.e. institutional control may be thought of as a form of regulatory control applied after the completion of remediation). In particular, institutional control measures may be passive, they may be imposed for reasons not entirely related to protection or safety, they may be applied by organizations that do not meet the definition of a regulatory body, and they may apply in situations that do not fall within the scope of facilities and activities. As a result, some form of institutional control may be considered more likely to endure further into the future than regulatory control.

5.7. INTEGRATION OF PLANNING FOR STEWARDSHIP INTO THE REMEDIATION PLAN

Although the general consensus appears to be that remediation decisions and long term stewardship decisions are best made conjointly, this has not always been followed in practice. This bifurcation can result in stewardship plans that are difficult to implement and enforce, and disproportionately costly for the benefit they provide [29]. Ideally the remediation decision would be one step of the life cycle planning process, with the preference for a comprehensive plan that provides the greatest benefit-to-cost ratio over the life of the facility. To complete a detailed remediation plan before operation is nearing completion is recommended, but review and adjustment are likely to be necessary for practical reasons.

Whatever stage in the process the site has reached, integration of the remaining steps into a life cycle management approach could improve short term decisions for long term benefits. For example, design decisions about the site layout can minimize both site disturbance and environmental impacts, while still providing operational efficiencies. If the site is in the remediation phase, considering the remaining life cycle in immediate decisions may indicate to decision makers, for instance, that slight increases in short term costs or worker risks may significantly reduce stewardship costs and minimize overall impacts.

In long term stewardship, the many decisions intended to minimize human health hazards and the environmental impacts that have been incurred earlier in the life cycle must be accepted (Section 3.3).

The integration of planning for stewardship during the operational and remediation phases is not limited to physical actions. Other considerations may include the building up of trust funds for long term stewardship [30, 31] (Section 7), avoiding foreclosing future options and taking contingencies into account when making decisions.

5.8. TRANSITION TO THE STEWARDSHIP PHASE

When an extended period of institutional control is the selected management option for the site, the active remediation period will be followed by a period where control might be transferred to the steward, who might be another party. This would require appropriate planning and regulatory control [32]. The major milestone in this process is the decision that cleanup has been achieved [33] (as noted in Section 3.3).

Provisions need to be made for a scheduled and smooth transition period in order to ensure (also see Table 1) that:

(a) All the necessary responsibilities have been transferred and there are no uncertainties over which responsibilities belong to which party.
(b) All necessary records have been preserved.
(c) There is continuity of the post-remediation and compliance monitoring activities as well as maintenance of the necessary infrastructure.

(d) The engineered containments for the residual contamination continue to be maintained.
(e) There is uninterrupted compliance with site use restrictions and other controls to ensure the integrity of any engineered containments.

In reality, it may be a question of definition when the active remediation period ends and when a site is actually transferred into the long term stewardship phase. This may also occur at different times for different environmental compartments. For instance, at a given site a groundwater treatment scheme may continue long after the surface soil remediation has been completed. Thus, while the site use may be controlled under a stewardship programme, the underlying aquifers may still be actively remediated. If the groundwater remediation is carried out by the steward, it could be claimed, however, that this is part of the stewardship programme.

Several stewards may be involved for a given period of time with the same site: one could be a user of the surface area, while another organization is responsible for the monitoring of the groundwater and possibly its remediation.

The range of activities, decisions and related records for the transition of a USDOE site from closure to long term stewardship is discussed, for example, in Ref. [34]. Experiences with the closure of parts of the Idaho National Laboratory (USA) are reported in Ref. [35] (Table 1). The slow progress of remediation and towards stewardship has been a major concern at many USDOE sites, and strategies have been developed to accelerate this transition [36–38].

5.9. PROVISION OF A SKILL BASE AND RETENTION OF KNOWLEDGE

Successful execution of stewardship requires a range of special skills and knowledge frequently akin to that required for the original operations at the site in question. However, closing down the original operations typically leads to key qualified staff seeking employment elsewhere. Assigned stewards have to develop strategies to retain qualified staff or a roster of qualified consultants and contractors.

The maturing market for environmental services from the mid-1990s onwards raises concerns over the availability of a suitable workforce to implement remediation and the early stages of stewardship programmes [39]. If the nuclear industry itself has ceased to evolve or even exist in the future, there will also be the possibility that the qualified workforce will become depleted. It

TABLE 1. CRITERIA FOR THE TRANSITION FROM CLOSURE TO LONG TERM STEWARDSHIP [35]

Regulatory based transition criteria	Results of the periodic review indicate that the results of the remediation actions meet the plans.
	For sites where residues remain a post-closure plan has been approved, a survey plan recorded and the competent authorities notified of the volumes and types of residues present.
	Performance assessment has been made and analysis requirements have been met.
	Title, deeds, property transfer documentation and any deed restrictions or covenants have been put into place prior to the transition.
	The long term stewardship plan has been approved by the competent authorities.
Infrastructure transition needs	All required physical and administrative institutional controls are in good condition.
	All accesses and utilities required for the site have been maintained.
	Monitoring wells, monitoring equipment and ancillary equipment are in good condition. Monitoring data and maintenance records have been reviewed to determine the condition of the wells, and procedures are in place for maintaining and monitoring the performance of the equipment.
	Any leachate collection system, related monitoring equipment and ancillary equipment are in good condition.
	Groundwater remediation equipment is operational, maintained and monitored.
	Engineered caps or covers are in good condition. Monitoring data or the results of periodic reviews indicate that the cap is performing in accordance with closure requirements.
	Physical site boundaries have been located and are consistent with the legal description recorded with the appropriate authorities and any deed restrictions.

TABLE 1. CRITERIA FOR THE TRANSITION FROM CLOSURE TO LONG TERM STEWARDSHIP [35] (cont.)

Record keeping	The project file contains management plans, i.e. sampling, quality assurance and quality control (QA/QC) and monitoring plans, and final decontamination and decommissioning reports.
	Monitoring data and maintenance records have been reviewed to determine the condition of the wells, and procedures are in place for conducting maintenance and monitoring performance of the equipment.
	Data necessary for long term stewardship have been identified and documented, and the data types have been defined.
	Institutional control requirements have, if required, been incorporated into the land use plan.
	Site documentation and project files contain the residual contaminant source term, contaminant concentration and location, and potential risks to human health and the environment.
	Site documentation and project files contain current as-built drawings of surface and subsurface site features, residue locations, engineered features, monitoring wells, access and physical institutional controls.
	Required land use restrictions have been properly recorded with the competent authorities.
	Historical and archaeological resources at or near the site have been located and documented.
	Ecological concerns that may require modification of long term stewardship activities have been documented.
	Safety analysis reports, emergency preparedness documents and management plans are all in existence.
Scope, schedule and budget	There is a transition schedule that includes adequate review periods for documentation, site inspections and development of additional documentation.
	The basis for the transition is included in the description of the proposed site.
	The resources and personnel that are critical to accomplishing the tasks that are required in the transition phase have been identified.
	There is a listing of baseline changes that have been approved or of any new contracts or modifications necessary before the transition can take place.

TABLE 1. CRITERIA FOR THE TRANSITION FROM CLOSURE TO LONG TERM STEWARDSHIP [35] (cont.)

Scope, schedule and budget (cont.)	The expectation that the site will continue to perform as designed over the design life period is inherent in the long term stewardship process.
	The proposed site scope has to be consistent with regulatory requirements.
Special conditions	Any special historical or cultural/archaeological resources are identified and documented as well as reviews required of the condition of historical or cultural resources under stewardship.
	Any special ecological concerns such as the management of threatened or endangered species are included in the scope and cost estimates.
	Special management conditions for sites exposed to natural hazards, such as flooding or earthquakes, are documented and incorporated into the management plans. Storm water requirements are incorporated into the long term stewardship plans.

is important, therefore, that a small skill base be somehow retained for both the short and longer terms. As the land use will undoubtedly have changed, the skill base itself will need to change in an appropriate manner in order to manage the new facets of the site.

The shorter term aspects are again easier to cover. Reorientation programmes, such as that of the International Science & Technology Center (ISTC) [40] that aims to redirect Russian weapons scientists to civilian projects including environmental ones, may be useful. Similar activities are taking place in support of the redirection of the major US national laboratories [41]. In USDOE complexes a range of strategic measures and incentives for employees are used [42]:

(a) Establishing a database for all the activities covered by the US Office of Environmental Management for critical questions and initiating mechanisms to foster temporary assignments;
(b) Offering incentives to employees eligible for retirement to delay their departure so as to work at closure sites;
(c) Removing salary offsets for retirees and offering other incentives to re-employ retirees at closure sites.

5.10. RESEARCH NEEDS

5.10.1. Meeting the management challenges

The most significant challenges from the management point of view are: decision making in the presence of large uncertainties, achievement of public trust, consistency, and ensuring learning, record keeping and information management, as well as establishment of a sustainable funding system.

Research needs for strategies that can improve institutional trust, achieve consistency and ensure organizational learning include investigations on the following:

(a) Characteristics of high reliability organizations;
(b) Institutions that have been successful in achieving sustainable organizational learning;
(c) Monitoring techniques to detect losses in, or maintenance of, institutional memory;
(d) Mechanisms to improve the transparency of long term stewardship programmes and communication strategies;

(e) Economic planning to better integrate the site into the overall economic development and to guide its redevelopment and reuse.

Research needs to help address the challenge of decision making in the presence of uncertainty include investigations on the following:

(a) Improvements of risk assessment models;
(b) Parameterization of cost–benefit analyses;
(c) Methodologies for the economic evaluation of environmental and social impacts of contaminated sites;
(d) Social discount rates to reflect intrageneration preferences and intergeneration equity issues;
(e) Development of a framework for life cycle analysis of nuclear installations or installations subject to radioactive contamination;
(f) Actuarial analysis as applied to the constitution of funds to cover long term environmental liabilities.

5.10.2. Development of management tools

The fact that there are always alternative approaches to set up long term stewardship programmes necessitates quantitative comparisons of the various alternatives at both the planning and operational stages. A variety of such tools, including cost–benefit analysis, decision analysis and prioritization processes, are available but few of these are tailored to the specific needs of a long term stewardship programme.

In order to foster trust and ensure traceability of decisions on remediation work and other activities leading towards stewardship, all work should be carried out to internationally recognized standards, such as ISO 14 000 [43], for which specific guidance would still need to be developed.

6. SOCIETAL CHALLENGES

6.1. INTRODUCTION

The societal aspects of long term stewardship present several important challenges, such as building trust, communicating the nature of the risks and of the remediation and stewardship options, reconciling economic, management and technical issues with considerations of public values and beliefs, resolving ethical questions and engaging stakeholders in the decision making process, and thereafter retaining stakeholder commitment.

Stakeholder involvement in the decision making process on long term management strategies has gained importance in many Member States. Many of these aspects have been addressed in the IAEA report on non-technical factors impacting on the decision making processes in environmental remediation [23]. The OECD Nuclear Energy Agency (OECD/NEA) has documented a wide range of case studies associated with radioactive waste management, notably through the activities of the Forum on Stakeholder Confidence [44–47].

In the USA, for example, a range of different mechanisms for stakeholder participation has been used in the context of siting geological repositories. Thus, the US Congress set up the Environmental Evaluation Group as a technical group to oversee the USDOE's transuranic waste repository, the Waste Isolation Pilot Plant (WIPP) in New Mexico. This group provided independent advice to the USDOE, the Environmental Protection Agency (EPA) and the State regulator. Stakeholder advisory boards consisting of representatives from institutional stakeholders and other stakeholder groups such as local institutions, and local and affected governing bodies, have been recommended as effective methods of stakeholder participation in the case of the USDOE's Yucca Mountain project, the proposed repository for spent fuel and high level waste in Nevada [48].

One of the key elements in stakeholder involvement is the provision of and use of information as the basis for decision making. For example, at USDOE sites a variety of strategies and instruments have been applied to make records available to the public during long term stewardship (see, for example, Ref. [49]). The decisions in question range from initial choices of remediation and stewardship strategy, to all the related issues of financial resource management (Section 7), of record keeping and management (Section 9), and of monitoring (Section 10) to assess the requirements for stewardship or intervention as time goes on.

Contaminated site stewardship decisions involve complex judgements about how people will live with, cope with or get along with inconveniences and risks that have their origins in the past. In some cases of major misfortunes or accidents, the people most directly concerned, or their descendants, will live with memories, scars and the pain of things lost, and must confront the uncertainties of building a new life. Public policy in such situations must contribute to repairing, revitalizing and rebuilding communities. What are the human factors that permit people, in the face of economic loss, environmental adversity, damage to their health or other misfortunes, to recover and again become purposeful and enthused in their efforts in society?

These challenges of partnership building and rebuilding are important even when — as with the majority of mining and industrial exploitation activities — site stewardship is not associated with past accidents or traumas. First, there are the requirements of memory associated with the requirements of monitoring and eventual intervention at different types of contaminated sites whose risks extend decades, centuries or, in some cases, even millennia into the future. Second, there is the problem of community and partnership building in the face of adversity. This is partly an economic resources problem but it is also a cultural and political problem of purposes and meanings.

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

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

6.2. PARTNERSHIP BUILDING AND PURPOSE

One can characterize trust as the willingness of a person, group or community to make themselves vulnerable in the expectation (or hope) of a benefit coming from association with others that would not otherwise be forthcoming. The conditions of trust in government, as in a commercial enterprise, as in scientific and technological advances more generally, all relate, on the one hand, to hopes of benefits and, on the other hand, to confidence in the capacity and will of society's leaders and innovators, and other potential partners, to ensure the sharing of those benefits. Successful stewardship, like successful diplomacy, will arise from effective dialogue leading to confidence in the prospects for a worthwhile common future.

As an example, the OECD/NEA's workshop 'Forum on Stakeholder Confidence' held in Ottawa, Canada, in October 2002, highlighted the experience of the communities of Port Hope, on the shores of Lake Ontario (Canada), whose townships have been contaminated with (mostly low level) long lived radioactive wastes due to past industrial activities involving radium and uranium refining [50]. As made clear by key stakeholders and reinforced by multimedia presentations, the Port Hope (and neighbouring) communities have, purposefully, set about to build a social — and societal — relationship with the wastes. After more than 20 years of discussions, suggestions and deliberations, the Port Hope community has insisted on its ownership of the contamination problem, accepting it as a historical liability that the community adopts as a part of its identity. The community's favoured stewardship solution concept, formalized in terms of the Port Hope Area Initiative, is to accommodate the radioactive wastes as modern-day burial mounds. The radioactive wastes, piled together and suitably 'capped', will become landscape features integrated into the everyday life of the community. The managed wastes thus become features in a kind of theme park, which becomes (it is hoped) a tourist attraction rather than a reason to avoid the area.

An interesting feature of this example is that the host community has refused alternative solutions for long term waste management, such as deep underground disposal, that would — in the community's view — depend on expertise and knowledge that they feel is not sufficiently accessible to them. Rather than a solution that would place the problem 'out of their hands' (and out of their control), they prefer a solution that they can see and understand (and, hence, that remains within their control).

No doubt this solution for Port Hope has been facilitated by the fact that the radioactive waste in question is due to industrial activities (radium and uranium refining) that engaged many of the past generations of the town's inhabitants and, thus, contributed fundamentally to the building of the local economy and community. An objection might be made that, even if the 'theme park' concept might work for Port Hope, it is not necessarily an appropriate concept for other contaminated sites or for the long term management of large quantities of high level radioactive waste. This is a valid objection. The key point is that, whatever the details of the site contamination or wastes, relationships of stakeholders in society must and will be built and maintained. Thought will need to be given to the forms of these relationships, and to the conventions and mechanisms (e.g., economic, political, legal and sharing of information) by which they are established and maintained.

Examples such as Port Hope suggest that the 'appropriation' of the problem by local stakeholders, and their identification of a concept for a solution that is acceptable to them, may be among the key ingredients for the economic, social and political viability of a solution. Equally necessary, of course, is the engagement of the relevant national authorities, establishing a political and economic partnership that will unite the complementary local and national resources and forms of authority. This suggests, from a societal point of view, the identification of three key components for a viable solution to a contaminated site stewardship problem:

(1) *Technical and scientific expertise*: The development, application and maintenance of scientific knowledge and technical competence to measure and to control the present and eventual exposure of living beings to radioactivity;
(2) *Building social/societal relationships with the site*: The envisaging and invention, in social and symbolic terms, of how the relevant community (or communities) will relate to and interact with the sites, the risks, the residues and the records.
(3) *Political and economic partnership*: A means to permit mobilization of the relevant knowledge and resources for the implementation of an agreed societal strategy for stewardship.

The societal challenges addressed in this section relate principally to the second and third of these components which, in various ways, underlie the operational considerations such as management (Section 5), economics and financing (Section 7), and records and information systems (Section 9). It should also be emphasized that the societal components are interdependent with the effectiveness of technical and scientific expertise. As highlighted already in Section 5.5, the building and maintenance of the necessary political and economic partnerships depend basically on the relationships that the different stakeholders develop and maintain amongst themselves and with the site. Without these ongoing partnerships, the relevant knowledge for stewardship will not be mobilized or renewed, and the motivation for long term engagement will be fragile. Therefore, it is important to consider stakeholder participation for designing the stewardship solution, or for formulating and evaluating options, as well as for roles in the operational stages. No individual or institution holds a complete knowledge base for 'what should be done'. The participation of stakeholders is necessary for the mobilization of existing wisdom and purposefulness, and for the regular renewal of this.

6.3. SOCIETAL CRITERIA FOR DEFINING AND IMPLEMENTING STEWARDSHIP STRATEGIES

Since the 1980s, partnership building (the third component identified above) has emerged worldwide as a pragmatic response by public authorities (and, sometimes, by nuclear industry exponents themselves) confronted by the ineffectiveness of the standard technical expertise model for viable waste management decisions. In many of those countries directly concerned with an obligation for radioactive waste management, there is an incontestable deficit of stakeholder confidence regarding the decisions proposed by the established expert and government bodies for the long term disposal of radioactive waste. For example, in each of the UK, Germany, France, Canada and Australia, public outcry and dispute has forced the abandonment of envisaged programmes and/or a major reconstruction of the institutional and policy framework. Confronted by public disquiet about the risks, and the very long time frames involved in monitoring sites, the authorities have turned to various forms of stakeholder consultation.

Attention to the question of the nature of the relationships to be established and maintained by society with the sites and the radioactive materials (the second component, as identified above) is less in evidence. The reason for this is that this issue has been treated more implicitly than explicitly. A specific answer to the question of what type of ‘relationship’ is envisaged has dominated in the technical and regulatory literature, without really being made the subject of a focused discussion. In effect, the concepts of containment and of provisional and permanent ‘disposal’ of wastes through the competent action of an authority are based on a clear principle that we can summarize as ‘out of the public’s sight, out of the public’s mind’. The comfort and safety of the public are to be assured by technological means, implemented by a delegated authority, to achieve the segregation of the noxious elements outside the main part of society. Because the waste or contaminated site is placed ‘off limits’ the general public no longer has any relationship to it, and so the problem has disappeared.

Much of the current controversy about radioactive waste disposal and site stewardship arises because this solution concept — based on the principle of containment and segregation, ‘out of the public’s sight, out of the public’s mind’ — does not have widespread social acceptance. The historical record of controversies since the 1970s shows that many people are not willing to believe that wastes will remain where they are (for thousands and thousands of years), and many people are also not willing to trust experts when they say that, suitably contained, wastes will indeed remain where they are.

This lack of confidence undoubtedly arises from many factors, some of which are related to technical factors and some of which are related to non-technical factors. One relevant factor may be the accumulation of experience with nuclear energy, radiation and spent nuclear fuel, revealing the meticulous and costly character of achieving long term and secure containment. Another factor may be the growing general awareness about the problems of waste management in modern societies (extending far beyond radioactive wastes) and about the spectrum of side effects, often unpredictable and sometimes long lasting, of contemporary technologies. Another, certainly, is the heritage of suspicion about official cover-ups of accidents and risks, and hence perceptions of the unreliability of government agencies in risk management matters.

Whatever the reasons that might be identified, it is by now clear that the 'containment and segregation model' of the relation to be established between the society and the risk (the waste disposal or contaminated sites) does not inspire wide public trust. This does not necessarily mean that people are generally irrational about radioactivity. Rather, it suggests that certain features of the model 'out of the public's sight, out of the public's mind' are felt to be inappropriate — and hence unacceptable — for some classes of contaminated site problem. The challenge is to identify the factors that might affect a solution's acceptability, in order that an appropriate strategy can be explored for the underlying problem.

The Port Hope example shows a situation where there is a consensus that the enduring presence of the hazardous wastes is troublesome and requires a societal response, but, precisely because this potential risk is not easily forgotten, a solution that inspires confidence must engage a permanent process of vigilance in which concerned stakeholders are directly involved. This may involve stewardship procedures whereby an economically active community, in partnership with overall regulatory authorities, is living close to (or even within) and maintaining a watch over the site. This is an example of a social (rather than a technical) criterion for acceptability.

Generalizing from this example, the following set of questions might be useful for identifying broad social criteria for the acceptability of stewardship strategies proposed for a given site. The questions (Q1–Q6) are first formulated in descriptive language (namely what the current situation is or features of the proposed solution). As a function of circumstance, and of stakeholder point of view, the questions can be modified with normative or prescriptive language (i.e. to function as criteria for acceptability, as suggested in italics).

Q1. Is there official recognition of a waste, residual risk or contamination problem at the site? (*Should there be official recognition of a waste, residual risk or contamination problem?*)

Q2. If yes, is there, or is there planned to be, active stewardship of the site? (*Should there be active stewardship of the site?*)

Q3. Is there, or is there planned to be, an ongoing public interaction with the site as a dimension of the stewardship process? (*Should there be an ongoing public interaction with the site?*)

Q4. If yes, is the 'historical liability' made a feature of the site's new public identity or use? (*Should the historical liability be made into a feature of the site's new identity and use?*)

Q5. If yes, what types of activity are mainly associated with the contamination features, for example, activities for the public good such as education, training and research, or private benefit activities such as recreation and tourism? (*What types of activities should be associated with the contamination or waste features?*)

Q6. What type of socioeconomic status and prestige should be accorded to the stewardship process? (*What type of socioeconomic profile, prestige or importance should be associated with the stewardship process?*)

Examples of the stewardship concepts that can emerge from different sequences or combinations of Yes/No answers to the above questions are the following:

(1) The response to Q1 might be No, with an ongoing controversy about whether or not there is a significant danger associated with a site.
(2) The sequence Q1 Yes/Q2 No would imply identification of an 'orphan' site, and therefore lead to the question of the acceptability of this orphan status.
(3) The sequence Q1 Yes/Q2 Yes/Q3 No would lead to concepts of a segregated or isolated site, with restricted access. Appropriate analogies might be a dangerous natural site, a rubbish dump, a warehouse for storing dangerous goods, a mausoleum or a nursing home. Answers to Q6 would permit a characterization of the socioeconomic status of the stewardship activity for the site.
(4) The sequence Q1 Yes/Q2 Yes/ Q3 Yes/Q4 No leads to suggestions for 'ordinary' uses of the site, for example, industrial or forestry production, or recreational activities (such as a golf course) that do not in any way rely on or 'exploit' the stewardship status of the site. These activities will,

however, be under regulatory control, and answers to Q5 and Q6 would highlight whether or not a stigma is associated with the site.

(5) The sequence Q1 Yes/Q2 Yes/Q3 Yes/Q4 Yes leads, by contrast, to suggestions for uses of the site that specifically rely on or 'exploit' the historical liability as a distinctive feature of the site. This could include ordinary commercial uses of the site, such as tourist and recreational activities, and ones that specifically make use of the identity of the site or installations such as a shrines or temples, museums and educational facilities.

The purpose of this typology process is to highlight the qualitative range of different models that can be, and have been, envisaged for stewardship of contaminated sites. Each category of solution has its appropriate analogies and metaphors, and thus highlights different aspects of social life, different types of prestige and status, different communities or different relationships. Specific technical, financial, management, record keeping, monitoring and communication procedures (as discussed in other sections) must all be framed with recognition of these qualitative societal and institutional choices.

Suppose, for example, that there are jobs attached to the long term site stewardship activity and salaries to be paid. In what terms will the job of site wardens be advertised? Who will be recruited (the question of job opportunities for locals)? What types of skill will be required? What will the salary scale be? What will be the relation of the site wardens to others in the local community (if there is a local community), and the perception of their role by the rest of society?

(a) In the context of high level radioactive waste disposal, variations of the shrine/temple concept have been offered for some years by many commentators. The concept has appeal partly because it evokes the 'eternal' character of the guardianship task. It might also have appeal because, by the establishment of a high prestige guardian task, the stewardship roles could offer reasonable prospects for highly trained nuclear engineers. Generation after generation of guardians could be imagined, each generation handing down, by algorithm, ceremony and song, a unique competence to those that follow, maintaining an eternal vigil.

(b) The contrasting nursing home concept brings a quite different set of connotations: patience, compassion, meticulous care, weariness, perhaps even mourning, anger and sadness with the pain of a long condemnation to watch over the ageing residents of the nursing home.

(c) The theme park option already illustrated by the Port Hope (Ontario) case, brings once again a distinct set of job profiles and social relations.

6.4. WHO ARE THE STAKEHOLDERS?

It has been suggested above that identification of an appropriate stewardship strategy will depend partly on technical considerations and partly on societal concerns. However, who speaks for society and who are the key stakeholders for stewardship decisions?

Typically, stakeholders are those individuals or organizations that may have an interest in stewardship being executed properly or who are affected by programmes. 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 has 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 mobilized to act or angered if they are not included?

There is no single delineation of the public and the stakeholder that is straightforward and applicable to all situations, and so no definition is universally accepted [51]. Many analyses start from distinctions between public and private sectors of economic activity, for example, government and business, and then refer also to civil society. Some typologies include research and technical experts as a distinct category. In some contexts, tribal, ethnic or local community membership may be more significant than field of economic activity. Any individual can be both a member of the general public and a stakeholder with a business, government or other specific identity, depending on the private, political or professional aspects of their life that are touched upon.

Thus, typically, the public is everybody and also includes all stakeholders such as affected citizens and civic organizations, environmental groups, labour organizations, schools and universities, representatives of business interests (e.g. chambers of commerce), representatives of government (e.g. local, regional and national government), and the scientific and technical expert community (e.g. academia, professionals' organizations and government departments).

Whichever the groupings retained, neither each member of these groups nor all groups are necessarily affected in a direct way by the contamination in question and the related remedial and stewardship activities. The question of whether all concerned citizens or only those directly affected should be given standing as stakeholders in the context of stewardship remains unresolved to date and is probably irresolvable — because different answers refer to distinct models and beliefs about justice, knowledge and political processes.

For example, the question of the roles and legitimacy of non-government organizations (NGOs) has often been a matter of debate. NGOs (citizens' associations, incorporated societies, networks, etc.) can vary tremendously in type and style of activities. There is no doubt that in some cases their activities have had a positive effect on the quality of decision making and site management in many Member States. Acting as voices for the local community, environmental quality and the interests of less influential societal groups, they often play mediating roles between the public, local communities and regulatory agencies (the government). However, it is also noted that NGOs develop distinctive profiles, with their own perceptions and agendas that may be at variance with the perceptions of those actually affected and whom the NGOs claim to represent. The activists within NGOs may, by design or effect, work to impose their own perspectives on locals (and also on regulatory agencies), as they seek to expand their influence and to establish their indispensability as mediators [52].

Figure 4 indicates potential actors, or affected parties, as identified within a remediation programme. Their typical interests are outlined in Table 2. It

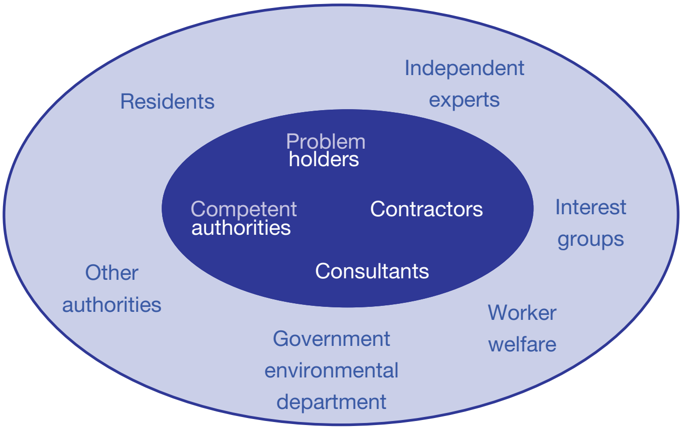

FIG. 4. Typical stakeholders involved in remediation programmes.

TABLE 2. FUNCTIONS OF INTERESTED PARTIES IN REMEDIATION PROJECTS (after Ref. [53])

Parties	Interests
Problem holders	Cost effectiveness Functionality of environmental media Efficient decision making
Authorities	Multifunctionality of soil Minimization of residual environmental load Consistent policy Efficient decision making Maintenance/improvement of tax revenues through viable economy
Consultants	Interests of their clients (problem holders or competent authorities) Efficient decision making Shareholder benefits
Contractors	Interests of their clients Efficient decision making Shareholder benefits
Public	Risk reduction Minimal limitations of use Minimal nuisance Efficient decision making Maintenance/improvement of socioeconomic conditions

should be noted that the diagram and the table are for purposes of illustration only, and are by no means comprehensive.

6.5. PROCEDURES FOR STAKEHOLDER BASED DECISIONS

Stakeholder participation can contribute to all aspects of stewardship activities, including record keeping, monitoring, communication, investment and site maintenance. In this section the focus is on the idea of stakeholders as partners with regulatory agencies and technical experts, through looking at the basis for decisions made about stewardship strategies.

A standard economics approach to decision making is to seek to establish a 'rational' justification for a choice between actions A, B, C, etc., on the basis of relations of preference. If action C is preferred over B, and B is preferred over A (etc.), then C is the highest valued action. However, whenever the span of choices involves and will have consequences for more than one person, judgements typically differ as to which is preferable. Each option for site management will produce distinct types and differing distributions of benefits, costs and risks that will be looked at differently by each of the individuals or sectors of society concerned. Not only will the different protagonists concerned have divergent views about what is their interest, their right or their due; they may also propose quite different principles for resolving this problem of social choice.

The particular difficulties of contaminated site stewardship as a problem of social choice can be summarized by the following four points:

(1) The choices relate to complex entities, processes or outcomes (involving geological, biological and social systems), each option being characterized by a range of attributes. Comparison of stewardship options means comparing a vector of attributes with a wide variety of concepts, units of measure and criteria. It is not always easy to pass from a multiple criteria appraisal to a ranking of alternatives along a single scale.
(2) The consequences of decisions are distributed in time (Section 5.1), and often different aspects of outcomes (good and bad, as perceived by different constituencies) will have distinctive time profiles, for example: vegetation cover; diffusion or dilution of dangerous substances in water, rock and soil; financial costs of monitoring; financial benefit streams including stewardship salaries and eventual site use.
(3) There are various degrees of uncertainty due partly to the complexity of natural systems and partly to social indeterminacies such as decisions not yet made or the consequences of which are not yet known, or future interest in the site.
(4) Many reasons or principles can be put forward as justifications for the acceptability, or not, of different outcomes (including perceived uncertainties and risks, distribution of benefits and costs across different constituencies within society, or across generations through time, see Section 6.6). It may not be possible to respect all principles simultaneously (this may be the case for the judgements offered by a single person, or for the judgements offered by a range of sectors). Because the principles may be 'irreducible' (i.e. incomparable, in the sense of being grounded in qualitatively different considerations), choice can be characterized by dilemmas and the need to make sacrifices of principle, rather than mere trade-offs on quantitative terms.

These complexities account for the importance of consultations with stakeholders, for example through processes of dialogue and of structured deliberations about site management issues and options. Stakeholder dialogues can be used to help build up a clear picture about the merits and demerits of site stewardship alternatives that present themselves to the relevant authorities and stakeholders in the society. In general, three points must be addressed in order to build a structured stakeholder dialogue process:

(1) There must be an explicit identification of the relevant stakeholders, and the establishment of an institutional framework within which exchange of information and opinions can take place.
(2) There must be a clear picture of the relevant site management options. For example, remediation and long term site stewardship issues and options can be explored in terms of a small number of scenarios each of which expresses distinct technological, economic and governance features. Stakeholders can sometimes be solicited to contribute to the framing of these scenarios.
(3) There must be a clear expression of the criteria for selection of the stewardship strategies, with a variety of different criteria reflecting the full diversity of societal concerns.

If these conditions are met, then stakeholder dialogue can be organized as an evaluation of the different stewardship solutions or scenarios, within a multiple criteria framework that covers a full range of governance issues. The distinct stakeholder perspectives become visible through the contrasting judgements made in relation to each option or scenario. As systems analyst Rittel has remarked [54]:

> "A policy maker or analyst in this sort of situation needs to be more like a 'midwife of problems' than a provider of determinate and uncontroversial solutions. Decision making has to be understood as an argumentative or deliberative process, one of raising questions and issues towards which you can assume different positions, and with the evidence gathered and arguments built for and against these different positions."

Quite often, a constructive stakeholder interaction can permit the emergence of novel ideas for solutions, including compromises between different performance criteria. These processes of information sharing and debate can also be effective in building goodwill, respect and trust. Differences of view are not to be feared. Commitment to a stewardship role, or to cooperating with site stewards, can emerge alongside and partly through misunderstandings, disputes and conflicts.

There is already some experience with processes of this type. In the UK, a stakeholder dialogue process has involved NGOs within the SAFEGROUNDS

Learning Network [55]. Although the NGOs and problem holders often have differing perspectives, the process has been very successful in that many areas of common ground have been established. Well structured participatory processes can help with:

(a) Identification and development of elements of common problem definition and common language for all the parties concerned;
(b) Understanding of the assumptions underlying expert solution proposals and evaluation techniques, of the terms in which these techniques can contribute to reasoned decisions, and limitations to their application;
(c) Sharing of the reasons and justifications brought by the different social groups to the deliberation process;
(d) Status and respect given to participation by both professionals and lay persons in the deliberation processes.

Multistakeholder deliberation requires information, and may certainly be aided by good inputs from experts and by systems of indicators at appropriate scales. However, stakeholders do not just receive and exchange information. They interact in a variety of formal and informal ways, sometimes being in conflict and sometimes cooperating. Working together to produce a well structured and transparent evaluation of stewardship options, with inputs from different sectors of the affected communities, can contribute significantly to the confidence and shared understanding needed to build a common future together.

6.6. WHAT ARE THE ISSUES? (MANAGING ETHICAL QUESTIONS)

The prime objectives for remediation actions are the abatement of actual health risks and environmental impacts and the reduction of risks to human and other receptors in the longer term. Site stewardship is a prolongation of these goals.

A key reference point in recent years has been adherence to sustainability principles. Full life cycle management emerges as a natural viewpoint in the perspective of sustainable development as formulated by the Brundtland Commission [56] and in the Rio Declaration [57]. The Brundtland report formulation of sustainable development seeks to reconcile present day needs with the requirements of future generations. Other definitions of sustainability put to the fore the maintenance of biosphere life support systems, species diversity, economic justice between developed and developing nations, political self-determination, and tolerance of diversity in cultural and political conventions.

However, application of sustainability principles is not always straightforward. The management of long term radiological liabilities is associated with scientific uncertainties and also, as has been implicit in preceding discussions, with moral, political and economic dilemmas. What principles should be applied to the distribution of inconveniences and risks that are the ‘downstream’ legacy of benefits gained? What is, and what should be, our attitude about the possibly adverse consequences imposed on others (elsewhere or in the future) by present day production and consumption decisions?

Some sectors of the public may effectively demand a reduction to zero impact and zero risk. This is in contrast to the fact that society in general has received benefits from the site activities resulting in these impacts and risks. Perceptions, however, may be shaped by the fact that the groups of society affected are not necessarily identical to those receiving the benefits. It may be pointed out that in almost all cases the demand for zero impact and zero risk will only result in a transfer of risk from one community to another. For instance, removal of radioactive residues to an engineered repository off-site will result in a net reduction of risk, but at the same time move the risk from one community to another.

The acceptability of residual risks is in general a function of a wide variety of sociological, economic and political factors. It may vary over time for individuals or certain groups of individuals. The acceptability typically evolves, inter alia, as a balance between the perceived risk and the actual inconvenience imposed by institutional control measures. Inconvenience here is understood to encompass, for example, the restrictions on site use imposed. The higher the perceived risk, the more acceptable become institutional controls.

What does the current generation owe future generations in terms of the legacy wastes from nuclear materials and weapons production? One answer is nothing, arguing that future generations are likely to have more knowledge and capability than exists now, and will be quite able to look after themselves, so that attempts at help from the current generation would be considered, from a far vantage point, as merely quaint. However, it is advisable if possible to prevent their stumbling, through ignorance or accident, on what may be harmful to them. Surprise is the greatest enemy of risk and accident management [58].

It is undesirable to leave unresolved problems for future generations, although it is also undesirable to deprive future generations of certain options because of actions taken by the present generation. Some moral philosophers, however, claim that this argument would quickly lead to a justification of no action being taken by the current generation on many issues, and that pre-emption of future options is acceptable ethically, provided that the current action is well motivated and reasonable in the light of current knowledge [59].

An example of these dilemmas is the controversy about the principle of precaution as a guideline in regulatory policy. The spectrum of attitudes within our societies towards technological progress can be highlighted by two contrasting positions around the question of the 'burden of proof' associated with innovations or engineering exercises whose outcomes are uncertain. Those evoking the traditional discourses of progress will argue that 'the future can look after itself'. Those evoking a precautionary attitude will argue that absence of proof of danger is not the same as proof of absence of danger and that, where great uncertainty and possibly grave dangers reside, risks should not be taken. In the Rio Declaration, for instance, it is stated that: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation" (Rio Declaration, Principle 15 [57]).

This precautionary principle can be justified by a variety of arguments in terms of duty or responsibility, respect or esteem for others (notably future generations) as members of an extended community. The idea is that actions carrying a possible (but as yet undemonstrated) risk of serious and long lasting damage to future human interests should not be permitted. It is clear that the principle is founded on specific ethical considerations that gain force where science and technological progress are no longer regarded as ordinarily beneficial and where outcomes cannot be determined fully (or at all) in advance, i.e. where powerful forces of natural and technological change are being engaged under conditions of inability to exercise mastery over eventual outcomes.

How far should the precautionary attitude be taken? Answers to such questions hinge on notions of responsibility, including the definition of inter-generational equity. The controversy around precaution as a principle for orientating social choices thus highlights the dilemmas of action and decision in risky domains. It is interesting to note the peculiarity of the ethical notions of holding ourselves responsible for the detriments caused by past generations, relative to the ethical premises that have guided industrial and scientific developments in the past. It can also be affirmed that, despite some inconveniences from contamination and long lived wastes, future generations will nonetheless enjoy accumulated benefits from previous generations. It can therefore be argued that each generation should also carry some of the burden incurred by their predecessors. Hence, we could ask ourselves, whether we really need to find 'permanent' solutions, or whether we should not be able to leave some legacy to future generations, as these will profit from our technological developments.

The definition of what constitutes a residual risk is subject to scientific developments and subsequent changes in regulatory systems. A stewardship programme may need to have provisions for accommodating such changes in the regulatory system. While the legal framework usually ensures that the criteria do not change, the regulator may deem it necessary to reassess risks. Such reassessment may result in changes to the institutional control measures that in turn require changes in the stewardship arrangements. A mechanism must be available to furnish (additional) resources.

Engineering interventions within complex systems cannot overcome all risks and cannot avoid contributing to uncertainties that have been called virtual or hypothetical risks, i.e. conceivable (and undesirable) outcomes characterized by complex causation networks, time lags and severity of impacts (e.g., a nuclear meltdown or a toxic waste containment system failure caused by an earthquake), whose investigation by any kind of laboratory testing is logically impossible or involves costs that are prohibitive. These 'virtual' risks are often unproven — or unquantified — until they materialize, but at that point they cannot be managed — they can be accommodated in various ways, but only at significant economic and social costs. For those upon whom the misfortune falls, the perceived uneven, unfair and unnegotiated imposition of disadvantages, damage and burdens (including future cleanup costs or enduring health problems) is likely to be resented and unforgiven — and hence of much greater social and political weight than any notion of a net benefit to society.

There are also risks of an essentially human character. One example is the potential that if significant concentrations of contamination are left in the ground at any particular site, the extraction of such material could prove to be an enticement for extremists wishing to create chaos or terror in the world. This type of material, while not in a suitable form to construct nuclear weapons, could nonetheless in theory be used to make so-called dirty bombs or similar devices. It is therefore important to ensure that any stewardship programme takes the security question into consideration. A similar issue will clearly be prevalent for radioactive waste disposal sites.

These scientific, moral and political dilemmas cannot be eliminated; decision making and stewardship must accept them. What remains is that it is the responsibility of the present generation's policy makers and articulate members of the public to affirm, by proxy, the 'entitlements' (if any) of, for example, future generations, vulnerable persons, endangered species and ecosystems. In effect, provision for the needs of future generations (as for all other forms of diversity) can be assured only through generous choices of resource use (investment and protection decisions) with the intent to maintain and enhance the opportunities and environmental security of others, including future generations.

Stewardship is a commitment towards future generations that is given practical effect through communal and political choices for the investment of time, labour and economic resources in environmental remediation and monitoring. The stewardship activity is thus interwoven with many other features of economic life, including:

(a) Investment in infrastructure and durable public assets;
(b) Provision for extensive and ongoing community involvement in decision making processes;
(c) Educational investments aimed at fostering an ethics of care and environmental interest;
(d) Investments in research and technological development intended to furnish understanding, information and practical know-how that may simultaneously enhance the economic opportunities and environmental security of future generations.

In practice, there must be an evaluation of options with reference to multiple criteria. The ethical dimension of management consists, in fact, of the articulation of the different principles that may underlie operational criteria. The spectrum of stewardship strategies can be considered as being, from some perspectives, ethically principled actions, i.e. actions that satisfy or respond to particular criteria of good or sound practice that are suggested by members of the community. For the domain of radioactivity stewardship, current examples of ethical criteria include:

(a) Have the responsibilities of existing parties been appropriately assigned? For example:
    (i) Has the principle of national autonomy/responsibility (for countries to take care of their own wastes at the national level) been applied?
    (ii) Has the principle that ‘the polluter pays’ been applied?
    (iii) Is due respect shown for local, national and international regulatory conditions?
(b) Have responsibilities towards other parties been adequately addressed in the short term? For example:
    (i) Have measures been taken to ensure the health security of workers and the public on or close to the site?
    (ii) Is there security against attack from external or internal sources of aggression?

(c) Have responsibilities towards other parties been adequately addressed in the longer term? For example:
   (i) Has the sustainability principle for intergenerational responsibility (not passing on problems to future generations that cannot be coped with in the present) been applied?
   (ii) Has some version of the principle of precaution been applied?
   (iii) Is the necessary knowledge base for competent stewardship stable in the long term?

(d) Have available technical know-how and systems science been used? For example, are standards of best practice (technical reliability, simplicity, etc.) being applied?

(e) Is the solution economically viable? For example:
   (i) Are the immediate costs of stewardship affordable with the available resources?
   (ii) Are there major financial costs postponed to the future?
   (iii) Are there reasonable prospects of acquiring resources for the forecast stewardship costs in the longer term?

(f) Does the solution enhance the prestige of the host communities or other stakeholder groups closely associated with the residue/waste site?

Each distinct stakeholder group will bring a different balance of preconceptions to the evaluation process. The general idea is that a comparative evaluation of the stewardship scenarios should take place from a variety of different points of view corresponding to distinct preconceptions. Each stakeholder group may express different criteria of adequacy or quality in relation to each of the governance issues. Where tensions, conflicts of interest, uncertainties and dissent emerge (e.g. amongst scientists as well as decision makers, administrators and stakeholders from different areas of commercial activity and civil society), these can be documented. The reasons for dissent can then be discussed in a transparent way, which sometimes opens up prospects for consensus or novel strategies.

6.7. KEEPING STAKEHOLDERS INVOLVED

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 people’s leisure time. Most social groups do not have the opportunity to become involved during the time they earn their livelihood or follow other social activities. Active participation and actively seeking involvement is commonly 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 sample the views of those who cannot, or do not want to, actively participate.

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 stewardship plans. It may be due to a relative distance from the problem, or simply related to the fact that the site is not actually visible to the individual/community. 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 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 [60].

Maintaining and enhancing transparency in the long term stewardship programme and traceability of records and decisions are factors that can influence the level of interest of stakeholders in the programme. Transparency implies that the decision making process be well documented (including a clear and comprehensive synthesis of the bases for decisions) and available to all stakeholders in the programme. In addition, all documents are readily retrievable and can be easily understood by all interested parties. Policy and technical considerations must be clearly differentiated; for instance, a statement of intent and rationale behind each stage and decision needs to be developed and tested for understandability and then broadly publicized to stakeholders. To improve transparency (and auditing), it is also valuable to ensure that key information is not buried in a surfeit of less relevant information. Transparency creates the basis for a dialogue among the implementer, regulator, external review bodies and stakeholders.

Responsiveness to stakeholder feedback is a further incentive to maintain stakeholder involvement. Responsiveness requires that the agency implementing the long term stewardship programme seeks, acknowledges and acts on new information and on inputs from other stakeholders in a timely fashion. Schedules need to be planned to allow timely integration of new knowledge into decision making and to include the time to implement changes responding to newly acquired information. This phased approach to stewardship allows the implementing agency to integrate lessons learned from prior stages and stakeholder feedback, and to plan for future stages.

Finally, trust in the institution implementing long term stewardship is essential to involve and maintain the interest of stakeholders. Trust in the institution implies integrity, for example, carrying out agreed actions. For all decisions, all uncertainties, assumptions and indeterminacies are identified and labelled as such. Technical results are accurately and objectively reported and placed in context at each stage. The applicability and limitations of data remain openly acknowledged. All relevant results, including those offered by external parties, are also incorporated into the decision making process [48].

From the point of view of stakeholders, the success of a long term stewardship programme is measured in terms of public participation. The participants in a workshop on long term stewardship some years ago identified the following seven items as the basis for successful stewardship programmes [61]:

(1) Acceptance of the responsibility for long term stewardship of contaminated areas;
(2) Development of a (national) policy on stewardship;
(3) Establishment of a legal mandate for funding stewardship activities separate from remediation funding;
(4) Development of a better understanding of the trade-offs and relationship between cleanup and stewardship;
(5) Development of guidance for site specific stewardship plans;
(6) Involvement of stakeholders in stewardship planning, oversight and review;
(7) Establishment of information systems (e.g. databases and permanent markers) designed for use by future generations.

While some of these items simply reflect the demand for good practice and the call for a decisive political will to take on long term commitments, others pose a serious technological challenge.

6.8. RESEARCH NEEDS

The main societal challenges related to long term stewardship can be summarized as:

- Balancing management and technical issues with public values and beliefs;
- Involving stakeholders in the decision making process effectively;

— Retaining the interest of stakeholders;
— Communicating risks in an effective way.

However, predicting the future development of society has long been a subject for research (and speculation). Research to address these challenges could include items such as:

(a) Long lived societal structures in order to learn more about the properties that have helped to maintain them, and make predictions about future developments;
(b) Techniques for societal monitoring to detect changes in stakeholder attitudes or confidence in the performance of long term stewardship programmes, as well as monitoring trends in public acceptability and in stakeholder participation mechanisms;
(c) Mechanisms for stakeholder involvement and for monitoring their effectiveness;
(d) Mechanisms for effective public communications and their impact on programmes;
(e) Mechanisms for incorporating stakeholder feedback into long term stewardship programmes;
(f) Mechanisms for improving the transparency of long term stewardship programmes and for monitoring public perception of the programmes;
(g) Improvement of empowerment processes (e.g. the education of young people) as to how society could deal with problems;
(h) Ideological balance, and work towards resolution of ethical questions/issues.

7. ECONOMIC CONTEXT

7.1. OVERVIEW

In terms of the economic context, the implementation of a stewardship programme will probably also best follow the split time frame concept discussed above. While in the near term each country will have its own existing and proven institutional and financial mechanisms, there is no guarantee that these will continue in the longer term. Priorities are likely to be vastly different from current ones; and even though public interest may call for significant stewardship programmes, there may be economic constraints to achieving this.

It is important, therefore, to reappraise the mechanisms for financial provision on a relatively regular basis. The following section highlights some areas worthy of further consideration for developing the protocols that future generations may demand.

7.2. FUNDING MECHANISMS

While the need for long term stewardship has become more widely accepted, major issues remain about how to best fund (or pay for) the required activities and in many cases about who will be responsible to ensure these activities are funded and implemented.

In response to the question of who is responsible, many Member States today have adopted the principle that the polluter pays. This means that the originator of a contamination is responsible for covering the cost of adequate remediation measures as well as the long term stewardship of the site in question. The thus defined responsible party may be the company that is implementing/operating the installation and profiting from it or it may be the final consumer who is benefiting from the goods or services rendered by it. In many cases the originator of the damage has ceased to exist, or it is difficult, even impossible, to attribute a contamination to a certain agent, owing to multiple contamination events, thus resulting in ‘orphan’ contamination with no identifiable responsible party. Even when the responsible party is clearly identifiable, it may not have set options to ensure adequate funding to meet long term stewardship requirements, in which case an alternative funding mechanism has to be put in place. Often contaminated areas are located in zones that are in need of economic revitalization for other reasons [62–65].

Assuming that long term stewardship will require funding for an unprecedented length of time (hundreds or thousands of years), innovative (or innovative adaptations of familiar) financial solutions will be required.

The funding options for nearer term challenges may be different from those for the longer term. Bauer and Probst [30] identified five basic criteria to consider when financing long term stewardship:

(1) Financial security;
(2) Clear rules, roles and responsibilities;
(3) Public information;
(4) Enforceability;
(5) Permanence.

These criteria can also be used to consider the strengths and weaknesses of other funding approaches. It should be emphasized that the raising of funds is only one of the issues to be contemplated when dealing with long term liabilities. The adequate treatment of these will require the implementation of a system capable of integrating in a coordinated way the technical, legal, financial and managerial (decision making and follow-up) aspects towards addressing long term liability issues in their broader dimensions.

7.3. LIFE CYCLE COSTING

Traditional costing approaches normally take into consideration the so-called conventional costs, i.e. direct and indirect cost items that cannot be avoided by the organization undertaking a certain project: capital costs, equipment, energy, utilities and supplies [23].

Life cycle management [43] requires the adoption of broader costing concepts in which all costs involved in the implantation of the project, from the initial planning phase to the decommissioning and stewardship phases, have to be taken into account (Fig. 5). This life cycle costing concept is a key issue when developing financial instruments to cover long term liabilities including stewardship.

In the case of a privately owned installation aimed at generating profit, the fact has to be taken into account that the installation will produce revenues for only a certain period of time. However, the costs involved in the correct management of environmental and societal issues may extend in time far beyond the operational period of the installation. As a consequence, a concept similar to that of a pension plan needs to be developed to cover the costs that will be incurred after the installation ceases operation. The concept is similar to that of a personal pension fund in the way in which provisions are made during the period in which a person is generating income to cover the final period of life. In fact, the same concept can be applied to all kinds of installations, whether private or public.

Lists of the distribution of life cycle costs in addition to conventional costs and of the most commonly used cost category items are provided in Fig. 5 and in Annex VIII (see also Ref. [66]).

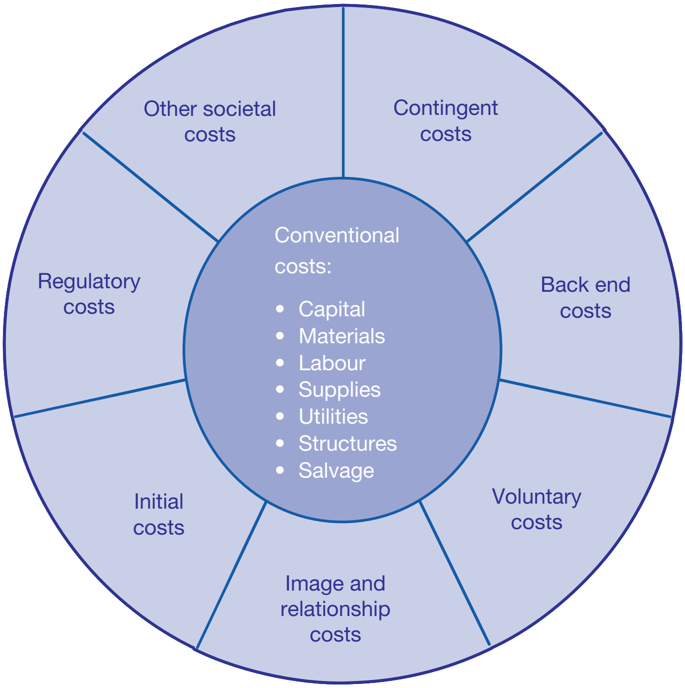

FIG. 5. Life cycle costs.

7.4. PLANNING FOR NEW AND OPERATIONAL INSTALLATIONS

7.4.1. Sources of funds

New installations are best planned to follow the concept of life cycle costing from their very early phases, in order to provide adequate financial coverage to meet future liabilities and to promote the identification of the actual environmental costs, encouraging greater efficiency in the use of resources.

In the case of installations already in their operational phase, it would be beneficial to carry out life cycle cost planning for their residual life, not only because that necessitates a thorough environmental audit and risk assessment of the installation but also because it allows for planning of the financial and technical requirements to meet all future liabilities, including those previously unrecognized.

In both cases there is the possibility to set up funds on the basis of current income streams. The provision of funds for long term liabilities needs to be planned in such a way that when the installation stops operating and income generation ceases, the present value of the funds accumulated to that date is equivalent to the present value of the cost to be incurred until the end of the life of the installation (including the stewardship phase) under a life cycle costing perspective. Many Member States now make long term liability funds a prerequisite for the issuance of licences for new installations.

7.4.2. Fund structuring

Da Rosa [67] quotes six principles that should be observed when structuring a financial guarantee vehicle to cover long term liabilities (Table 3).

One of the methods that have been identified as a useful approach to ensure funds are available is known as a trust fund [30, 31]. A trust can provide a mechanism to ensure that the funds necessary to fulfil long term responsibilities are available.

TABLE 3. FINANCIAL GUARANTEE PRINCIPLES
(adapted from Ref. [67])

Principle	Requirements
Life cycle costs after operations cease	Financial guarantees must cover all the installation's costs, including those incurred after the end of operations.
Liquidity	All forms of financial guarantee should be reasonably liquid.
Accessibility	Financial assurance should be readily accessible, dedicated and only released with the specific assent of the regulatory authority or other decision making body.
Financially robust guarantors	Regulators must carefully screen the financial health of guarantors before accepting any form of assurance.
Public involvement	The public should be given notice and an opportunity to comment both before the setting up of the fund and before any decision on whether to release resources from the fund.
Lack of a substitute	Any financial guarantee should not be regarded as a surrogate for the company's legal environmental liability.

7.4.3. Management of funds

In addition to the fund raising process, appropriate management of funds is a key issue for the effectiveness of the long term management strategy. A number of roles have to be accomplished by various agents in this management process. The main roles to be accomplished in any system designed to correctly manage environmental liabilities are:

(a) Identification of environmental liabilities (life cycle costs that have to be covered by the fund to be put in place);
(b) Provision of resources to cover the environmental liabilities (which typically is the task of the 'problem holder');
(c) Administration of funds in order to ensure their soundness in the long term (a typical asset management function);
(d) Making of decisions about the use of funds for environmental remediation actions, and follow-up on the efficacy of these actions;
(e) Implementation of remedial and stewardship activities (actions to reduce environmental liabilities);
(f) Regulation and auditing of the system (to ensure its overall efficacy and effectiveness).

These roles can be carried out by the different agents potentially involved in the process. Typical agents that may be involved in one or more roles are:

— Owners of installations;
— Governments;
— Final site users;
— Financial management companies;
— Fund management boards;
— Contractors (companies responsible for remediation actions).

Different systems may be devised to combine the roles to be performed by the potential agents involved. It is important to note that although the roles listed above must be performed in any conceptual system, not all the agents actually have to be involved. According to these conditions various systems may be devised, from simpler ones (in which many roles are played by each agent) to more complex ones (in which responsibility is distributed among several independent agents). Figures 6–8 illustrate three potentially feasible systems for the administration of funds for liabilities.

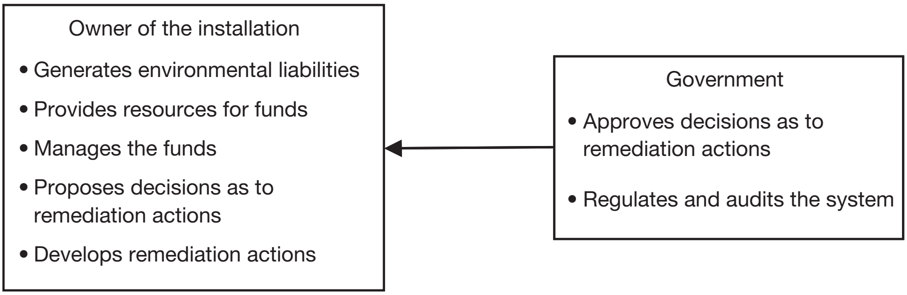

FIG. 6. A liability management system with two agents.

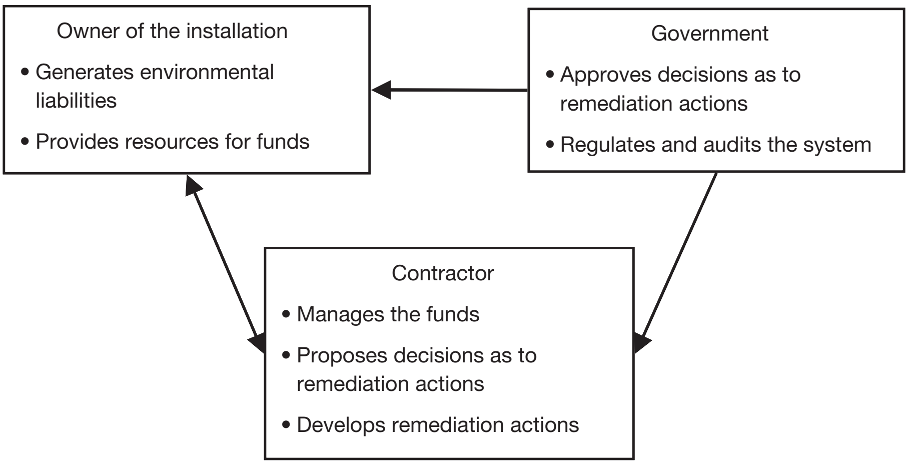

FIG. 7. A liability management system with three agents.

7.5. MANAGEMENT OF LEGACY SITES

In the case of closed installations and legacy sites, the funds cannot normally be raised from the revenue streams of the operations. Governments might be presumed to be the first candidates as a source of funds for these cases. However, unless the liability was originated directly by governmental activities at the site, in which case the government is the actual holder of the liability, the government may not be prepared to assume this role.

In general, all those that could potentially be held liable would be investigated, such as current site owners/operators, former site owners/operators, owners/operators of neighbouring sites that might have (had) an influence on

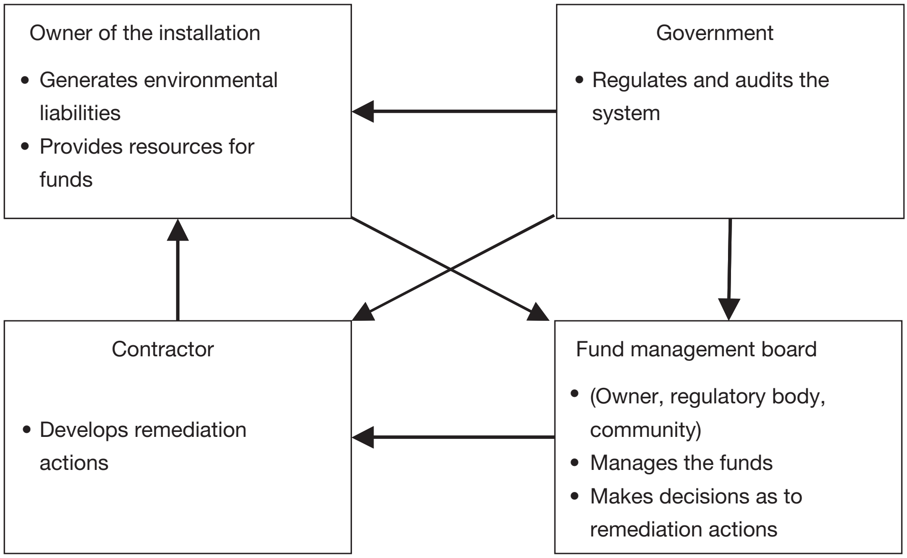

FIG. 8. A liability management system with four agents.

the site in question and local/regional government bodies. In these cases, it is possible to compel the potentially liable party to respond to the damage in question. However, this normally has to follow a three stage process:

(1) The first stage involves identification and characterization of the potential liability holder(s);
(2) The second stage comprises the demonstration of the legal obligation of this(ese) party(ies) for the liability;
(3) Finally, the third stage involves the enforcement of the liability holder's duty to pay for the necessary environmental recovery actions or to conduct them according to a plan approved by the regulatory authority.

For many instances of uranium mining, the responsible party is in fact the government or the responsibility has been accepted by the government since the operation has been in the national interest. In circumstances where it is impossible to make the original owner undertake the remediation, it is likely that the government will be required to manage the situation. It is not rare, however, that the needs in terms of resources for site remediation exceed by far the (annual) budget available. Some form of prioritization of activities will be unavoidable [23]. A particular problem inherent to government budgeting is the usual short cycle of a few years at best, which makes it difficult to provide for long term commitments such as stewardship needs.

In some cases, it is possible for the government to recover part of the costs incurred through an increase in land value after site remediation by selling the site for reuse. A variant on this, but applicable mostly in urban areas with an active property market, is to transfer the land to private investors with a binding obligation to remediate the land according to prescribed standards and, if needed, to provide for long term stewardship. The financial incentive for the investors is the difference between their expenditure for remedial and stewardship activities and the resulting land value. Various combinations of taxpayer and privately funded remediation and stewardship plans (public–private partnerships) can be imagined provided they are adapted to the situation in hand.

7.6. FUTURE LAND USE

In some Member States, there is an ever increasing tendency towards avoiding further exploitation of greenfield sites and restricting new developments to sites with a previous industrial history [68, 69]. Redevelopment potential can be a key factor in ensuring the viability of a remediated site and the associated long term stewardship programme [70, 71]. Redevelopment of the land, however, requires that the land has been remediated to residual levels of contamination that are compatible with its intended use. It is likely that in many non-accident scenarios only restricted releases will be feasible and that the stewardship process will need to cover the management of the future land use. Controlled reuse of a site may generate sufficient revenue to finance the cost of the necessary institutional control and may also prevent or minimize misuse that might jeopardize the institutional controls [72].

Reuse may come in a number of guises, for example, housing, new industries, recreational facilities, museums or even authorized disposal facilities. Monitoring of the site will need to be an ongoing process and may at a later date find that a breach of the containment system has occurred. A mechanism, therefore, needs to be in place that will allow a re-evaluation of the site's status, because the original judgement will have been made on the basis of environmental risk assessment work at that time.

If the individuals who are actually benefiting from the reuse within the stewardship process are involved, this may increase the probability of continuity and orderly records management, as they may have a vested interest in the process. The objective is to create a sense of ownership in the use scenarios that are compatible with the stewardship requirements.

Experience from the mining industry suggests that the development potential of a redundant site is often dependent on one or two key assets left over from the operating life of these sites. These assets can provide an important catalyst to a particular kind of development or serve to improve the attractiveness of the site as an investment proposition for developers. In one example, the key asset was a high quality sports and social club built in traditional style and with excellent facilities. It was originally provided for employees and their families on the edge of the production site but served as the basis for redeveloping the site as a leisure park, also making use of the mine water lake as the focal point of a new golf course [73].

The (re)drawing of site boundaries and the disposition of certain features, such as impoundments for contaminated residues, will have a strong influence on the usability and the redevelopment potential of a site. It is of great advantage if these factors can already be considered during the decommissioning and remediation phase (Section 1.1), or even better when worked into the original operational plan. Features to consider include ease of access, convenient shape of plots, as well as connections to services and other infrastructure such as roads, railways, sewerage systems, drinking water supply and the electric grid.

An important step in exploring the redevelopment potential of a site is to identify these potential key assets and assess their relevance to future development scenarios. Once identified these assets need to be protected from deterioration during the transition from the previous use to the new use with stewardship requirements. A particular threat is the paradigm shift from operation to remediation and reuse that often results in neglect of infrastructure by previous owners or their agents.

There may also be certain protected uses that could be explored, for example cemeteries. In some cultures, certain persons (e.g. priests or medicine men) may impose taboos on sites or particular uses of sites. However, the longevity of such restrictions is difficult to predict. In the western world and the Christian context, many such restrictions have become more or less irrelevant since the Enlightenment. On the other hand, sociocultural development in some parts of the world may make these societies more conducive to the earlier instruments of institutional control.

7.7. RESEARCH NEEDS

The long term aspects of financial management pose a particular challenge to financial managers who are increasingly concerned only with short term goals. Particularly challenging problems remain around putting a monetary value on non-quantifiable issues such as:

(a) Intergeneration equity issues by assessment and guidance on the use of social discount rates in the economic analysis;
(b) Environmental and social assets by improving the economic techniques at present available to perform monetary evaluations.

Certain accounting methods also need further development to accommodate long term requirements:

(1) Specialized actuarial planning as required for the development of long term financial instruments to cover liabilities;
(2) Review/quantification of life cycle cost elements to show the ratio of stewardship costs to revenues and conventional costs.

Innovative ideas are also needed for cost recovery models for the remediation of lands of little value and where the originator of a contamination cannot be held liable (any more).

The international pooling of resources for research into areas relevant to stewardship might be of value, as well as the development of a clearing house for information on international stewardship practices. It may be noted that the Directory of Radioactively Contaminated Sites [74] already goes some way in this direction, as it is intended to provide a comprehensive set of data on such sites.

8. TECHNOLOGICAL CHALLENGES

8.1. CONTEXT

Many of the concepts applied to the assessment and remediation of contaminated sites were developed in the 1970s, and were built on established traditions of applied science and engineering. Implicit and often tacit assumptions prevalent at that time included that:

(a) Cleanup can be effected to near zero residual concentrations.
(b) Cleanup can be performed against a fixed set of standards/parameters.

(c) Permanent solutions can be applied, and the change over time of both the site itself and the engineered structures, such as barriers, can be largely ignored.
(d) Generic solutions can be site independent, and are also independent of the particular economic and social context.
(e) The systems in question can be captured by deterministic parameters.

In recent years the validity of these assumptions and their efficiency is being questioned. Emerging new concepts include acceptance of fundamental uncertainties and the appropriateness of risk based cleanup criteria, comprehensive multicriteria analyses incorporating social as well as technical performance criteria, and acknowledgement of the fact that any engineered structure has only a finite lifetime, that a site interacts with its surrounding environment, and hence insistence on an open ended or evolutionary perspective on stewardship. Advances in knowledge permit more and more sophisticated interventions in the functioning of environmental systems. Going far beyond macroscopic intervention in materials (such as building a dam), it is now possible to intervene on the scales of atoms (nuclear fission and fusion), molecules and cellular structures. However, these forms in which matter is organized are dynamic (e.g. change in ecosystems, hydrological cycles and atmospheric circulation), and some of the components introduced into the environment have long lifetimes (toxic organic compounds and radionuclides).

Science and technology applications can sometimes solve, or at least mitigate, the emerging problems inherited from the (recent or distant) past. However, given that the systems in question are complex and will naturally continue to change, there is always the possibility that undetermined changes (including unintended side effects of engineering interventions) can come to dominate design goals.

Best available techniques (BATs) in general and the specific remediation techniques applied to (radioactively) contaminated sites in particular are described, inter alia, in Refs [12, 75–78]. While they have been implemented worldwide with varying degrees of success, it will be important to assess and ultimately prove their potential against the specific characteristics of the site or sites considered.

Taking into consideration the discussion above, a number of technological challenges for long term management of sites emerge. These technological challenges are within and complementary to the societal framework highlighted in this and other sections. Table 4 highlights some examples of long term stewardship activities and technical uncertainties.

TABLE 4. EXAMPLES OF LONG TERM STEWARDSHIP ACTIVITIES AND TECHNICAL UNCERTAINTIES *(modified after Ref. [79])*

Media potentially subject to stewardship	Possible stewardship activities	Examples of technical uncertainties
Water All contaminated groundwater and surface water sediments that cannot or have not been remediated to levels appropriate for unrestricted release	Verification and/or performance monitoring. Use restriction, access controls (comprehensive site land use plan). Periodic review requirements. Resources management to minimize potential for exposure.	What is the likelihood that residual contaminants will move towards or reach a current or potential potable water resource? Are dense non-aqueous phase liquids (DNAPLs), heavy metals or long lived radionuclides present in concentrations and/or locations different from those identified? Will treatment, containment and monitoring remain effective and adequate? Will ambient conditions change significantly enough to diminish the effectiveness of the selected remediation strategy?
Soils All surface and subsurface soils where residual contamination remains, or where wastes remain under engineered caps	Institutional controls to limit direct contact or food chain exposure. Maintenance of engineered controls or markers. Periodic review requirements.	What is the likelihood of future contaminant migration if ambient conditions change? How will changes in land use affect the barriers in place to prevent contaminant migration and potential exposure? What is the likelihood of cap failure occurring sooner than expected? What is the effect of contaminant caused degradation of remediation strategy components?
Engineered structures All land based disposal units with engineered controls	Monitoring and inspections, by agreements, orders or permits. Institutional controls, including restricted land use. Maintenance, including repairing caps. Periodic review requirements. Land and resources use planning to minimize the potential for exposure.	What is the effect of contaminant caused degradation of remediation strategy components? At what point in time will the remediation solution require significant repair or reconstruction? Is the monitoring system robust enough to detect remediation failure?

8.2. RISK BASED VERSUS DETERMINISTIC PERFORMANCE ASSESSMENT

Risk based performance assessment and modelling, generally associated with waste disposal sites, are finding increased application to contaminated land [80]. The main impetus behind this development is to assist decision making through understanding better the consequences of leaving contaminated material in the ground and communicating this strategy to stakeholders. It can be observed that deterministic solutions often tend to be overengineered and hence expensive. Conversely, certain risks for and challenges to a given engineering structure may not be featured in the generic design specifications. A risk based approach will allow resources to be focused where they are needed.

A point in case are current capping design guidelines in many Member States that are not risk based and do not take into account site specific influences, such as climate, vegetation and soil. Hence, these design guidelines may not address important features, events and processes at the site that may contribute to the long term risk. Traditional design guidelines for cappings often rely on design parameters or deterministic models of flow and transport that do not represent the uncertainty inherent in actual system processes. An alternative is risk based performance assessment, considering regulatory requirements, site specific parameters, engineering design parameters, and long term verification and monitoring requirements. Uncertainty and variability in important site specific parameters, including environmental characteristics, over prolonged periods of time (>100 years) can be incorporated through stochastic simulation and by learning from natural processes.

8.3. CONSIDERATION OF NON-RADIOLOGICAL HAZARDS

While this report is concerned with residual contamination from activities involving radioactivity, most, if not all, radiologically contaminated sites will also exhibit some level of non-radiological contamination. This comes primarily from the fact that many sites will have had a number of different processes occurring on them historically. Practices that would not be acceptable today may have led to chemicals and hazardous materials entering the soil, surface water and groundwater, for example due to inadequate containment, poor disposal practices or accidents. In the case of mining, for instance, operators may have not been aware of the hazard posed by certain constituents in the geological material they have been using.

There are a number of potential problems with sites exhibiting co-contamination [77]. For example, in many countries the legislation dealing with radiological and non-radiological contaminants may differ considerably, both in terms of environmental risk assessment and in authorization for disposal. The environmental risk from non-radiological contaminants may in some cases be greater than that from the radiological species present, but this is often ignored due to the general perception of increased risk from radioactivity.

The presence of other contaminants alongside radionuclides may result in the latter's mobilization or attenuation through changes in chemistry [81]. It is only through a comprehensive knowledge of all contaminant species present that predictions of remediation success and engineering integrity can be made.

8.4. UNDERSTANDING THE SITE AND ITS ENVIRONMENT

From the above it is clear that a comprehensive understanding of a given site's environmental setting is a prerequisite for the design of any containment strategy. Site characterization must be undertaken with the objective of building up a thorough understanding of both the below ground and surface conditions and the various complex interactions that may take place. A good understanding of the geology, hydrogeology and contamination, coupled with the geomorphological and climatological history, is a prerequisite. Alteration of the residual contamination itself, for example by diagenetic processes, can be an important factor and should be included in studies as well (see Ref. [81] for a more detailed discussion of this aspect).

The site characterization data then can be used to construct potential future source–pathway–receptor linkages for exposure of humans and the environment. In turn, a conceptual model describing the system and highlighting the effects and benefits of the remediation can be constructed for use in further decision making.

8.5. LONG TERM BEHAVIOUR OF ENGINEERING SOLUTIONS

8.5.1. Design goals and boundary conditions

Many opportunities exist to reduce long term stewardship costs, reduce environmental impacts and enhance the longevity of engineered features. Consideration of long term stewardship in engineering at the design stage, with periodic updating if and when required, is one of the critical areas to achieve this integration. A mentality of the minimally acceptable with the least short term cost could cloud good decision making over the whole life cycle of the site. Likewise the notion to remediate to background levels everywhere can also limit good decision making by spending too much without gaining adequate benefit in performance or protection, while having an impact on the environment and potentially on worker safety.

While the ‘useful service’ or ‘design’ life of engineering solutions are certainly concepts that all design engineers are familiar with, the timescales are generally orders of magnitude shorter than those of interest in the present context. For most civil engineering structures, continuous or periodic maintenance is also implicitly assumed. Methods and concepts to predict the long term behaviour of near surface structures are still in their infancy, while the problem itself has been explicitly recognized in the context of the performance assessment for radioactive waste repositories [48].

Thus, the erosion resistance features can be modelled on the basis of short term data, but methods to assess the long term performance need to be developed on the basis of insight into geomorphological processes. Basin scale, statistical studies, rather than discrete mechanistic studies, might provide the necessary insight.

The long term stability of engineering structures has also to be assessed in view of the probability of major accidents such as seismic events. Over the last few decades, highly engineered capping designs have been developed, which are also commonly required by regulators with the intention of reducing radon emanations and external exposures to gamma radiation, as well as minimizing water infiltration. However, these designs are likely to retain their high sealing performance for only a limited period of time. Signs of deterioration in performance (an increase of permeability in the sealing layer) are usually already observable 5–10 years after emplacement. A good way forward to ensure long term stability of the capping appears to be an emulation of the natural soil structure as found in the vicinity of the remediated site. Although such ‘natural’ capping designs (with the use of long lasting natural materials and structures mimicking as far as possible the natural soil profile) are likely to have a lower immediate sealing performance than plastic liners, for instance, this will be outweighed by their long term stability.

Recent flooding events in various parts of the world often seem to indicate, inter alia, that the design base, in particular with respect to the magnitude of infrequent events, is insufficient. Precise flood water level records only go back some 100 years, while anecdotal evidence may extend this to a few hundred years. Thus, a design base may not capture an event that occurs, on average, every 1000 years. Similar effects may occur in areas other than flood defences.

8.5.2. Design for long term stability

In order to select and implement the most efficient design from the point of view of self-sustainability over the long term, learning from natural processes and environmental behaviour may be a valuable strategy. The paradigm is engineering with nature and not against it.

The natural evolution of soils and diagenesis also give valuable insights into the development of long term management plans. The contaminated material will not remain unchanged in the long term, and assessment of its evolution will give confidence in the project if diagenesis improves the retention of contaminants.

Limiting infiltration will reduce the need for seepage control downstream. Long term management of the quality of drainage or seepage from the site is best provided for by some form of passive water treatment. Active water treatment plants are labour and maintenance intensive, and there are no guarantees that the resources will be available over the longer term. Passive forms of treatment may include, for instance, either a limestone layer to prevent the formation of acid drainage or a wetland to polish seepage water before release to surface water courses [12].

Cappings and similar features are also intended to prevent biointrusion. The structure of the cover, as heavily engineered as it may be, may not be able to prevent root intrusion in the long term if it has not been designed to be compatible with the natural vegetation cover and plant succession typical of the surrounding environment.

The ecosystem around a remediated site is the result of a process lasting for centuries or millennia and is shaped by a wide variety of initial conditions and contributing factors, such as the initial rock type, climatic evolution, and surrounding flora and fauna. The result is a (dynamic) equilibrium between soil type, vegetation cover and climatic conditions. Any attempts to reconstitute an ecosystem at the site, such as revegetation, need to be as compatible as possible with the surrounding ecosystem(s).

The final use of the site needs to be compatible with the ecosystem in order to minimize pressure on the site due to human use.

Any environmental impact study is intended to assess the potential of a site to be integrated into the surrounding environment. Indeed, the best shape for a remediated site is achieved when it is compatible with the surrounding geomorphology. This concerns in particular slope stability. From a geomechanical point of view, gentle slopes contribute to achieving low relief energy. Natural geological processes achieve this over millennia, and engineered structures may benefit from observation of the evolving geomorphology and slopes around the environment of a site.

While completing engineering for remediation, consideration of the stewardship requirements on a site by site basis is recommended. In general, when considering stewardship the following points should be kept in mind:

(a) Designs with low inherent (potential) energy are preferred to designs with higher energies. This applies in particular to geomorphological relief energy: all above ground structures are subject to the forces of erosion and will eventually disappear, starting, of course, with any engineered capping. In addition, the surrounding environment may have a high relief energy, although the actual engineered structure may be below the surface (Fig. 9).

(b) Designs with a low likelihood of failure and limited effect if failure occurs are preferred to those that are less reliable: for example, self-sustaining systems and approaches such as waste rock or tailings cemented by geochemically stable secondary minerals or vegetated slopes similar to

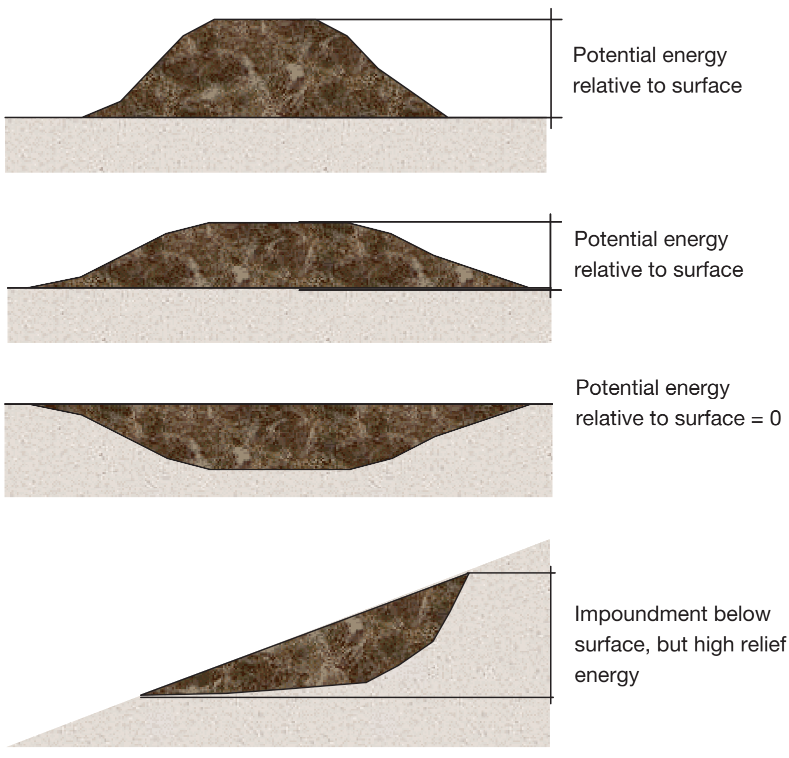

FIG. 9. Diagrams illustrating the concept of inherent potential energy in the design of impoundments.

naturally sustainable slopes in the area would probably have a good chance of surviving the long durations required for long term stewardship.

(c) Designs that mimic diagenetic processes are preferred.

(d) Designs that maximize natural systems in the area and are compatible with the surrounding area are preferred. Experience with existing disposal cells and similar structures indicates that nature soon attempts to encroach on cells. This experience favours designs with an ecosystem type of approach rather than a barrier control one.

(e) Designs that are based on natural attenuation and retention are preferred [81].

(f) Designs that include redundancies in protection are preferred.

A technical issue related to intergenerational communication is the longevity of permanent markers to warn future generations of previous land use and possible residual hazards, for example gravestones and other forms of visual sign. As this form of communication may be the final layer of defence for warning future populations, markers and signs must be developed with great care to ensure physical longevity. The problem of coding the information is discussed in Section 9.11.

8.6. REGULATORY REQUIREMENTS VERSUS TECHNOLOGICAL DEVELOPMENT

In addition to the challenges imposed by nature on a given technical solution, changing circumstances, such as regulatory requirements and standards as well as changing public opinion, may continue to give rise to new questions about the chosen solution. Technological developments and improved scientific understanding might make a chosen solution appear inadequate in hindsight, potentially in both the short and the long term. It is important that regulatory requirements reflect current scientific understanding in order to arrive at the best possible solution.

It is also important that evidence of changing large scale or global scale boundary conditions (e.g. in climatology, weather patterns and sea levels) and design bases (e.g. regional water tables and drainage patterns) be reflected in the licensing and other regulatory requirements.

8.7. RESEARCH NEEDS

8.7.1. Road mapping of technological development

The observation that current technologies do not always meet the complex requirements imposed by remediation projects has led to various technology road mapping programmes. This is seen most notably in the road mapping activities on behalf of the USDOE [82, 83]. It is very important to note that this road mapping is strictly driven by needs, rather than by scientific curiosity.

Technology databases that take into account long term stewardship needs are being developed [84]. Placing technology development into a formal context might also facilitate regulatory approval for innovative or novel techniques.

8.7.2. Learning from the past to predict the future

The section title captures programmatically a whole area of important research. It is based on the assumption that there is some continuity in natural processes and that their behaviour can be predicted using statistical or deterministic models. The intent of this is to understand natural processes that provide favourable conditions over long time periods, so that such conditions can be replicated in engineered solutions. In many cases, this may be the most significant data/knowledge source available for predictions.

Long term predictions of environmental conditions and of the behaviour of materials and structures involve uncertainties that are best addressed by stepwise research of natural processes. Analogues, both natural and human-made, have long been used to overcome the limitations inherent to short term laboratory or field experiments and short term data pertaining to environmental processes [85–88].

Two types of research are considered below; research into the conditions in which human-made objects exist and their behaviour, and research into natural processes that provide favourable conditions for long term behaviour/performance.

On the timescale of a few hundred to a few thousand years the evolution and performance of dated civil engineering structures, such as earth dams and mounds and cuttings, can be studied and put into the perspective of their surrounding environment (human-made analogues). Some known sites in Europe, Asia and South America, where human-made structures such as mounds and berms have lasted for hundreds and thousands of years, can be the subject of long term stability studies of structures (i.e. of their geotechnical stability).

The study of ancient artefacts (objects and materials) can help in the selection of durable materials (e.g. chemical and geochemical stability) taking into account the ambient environmental conditions.

On timescales exceeding a few thousand years, natural analogues may be helpful. Relevant study areas include geomorphology, diagenesis and ecosystem development. These analogues are selected to resemble as closely as possible the whole system or only parts of it. Examples include near surface ore mineralizations, natural slopes and rock faces. Research into natural processes to extend our knowledge of environmental conditions is also important in enhancing the modelling of the long term behaviour/performance of engineered structures/ barriers.

Groups of processes of interest include:

(a) *Weathering processes*: i.e. to study the parameters and factors, for example, grain size, mineralogy, geochemistry and fracturing properties, that allow certain materials to withstand weathering better than others;
(b) *Transport processes (hydraulic and geochemical processes)*: for example, to study leaching, deposition and natural immobilization processes, for instance cementation processes of all kinds of sediments, can help to provide information on the long term stability of various types of geochemical remediation;
(c) *Biochemical processes*: for example, to study the effects of organic substances on the mobility of radionuclides and the effects of the interactions of radionuclide loaded organic substances with various chemical and physical influences;
(d) *Biological processes*: for example, to study radionuclide uptake by plants at older contaminated sites in order to determine the conditions that allow various reuse scenarios to be practical;
(e) *Climatic processes*: for example, to study environmental media in order to characterize past climatological conditions and to update climatological predictions, then to evaluate the longevity of the structures and materials required to provide passive remediation or to control/isolate hazardous areas over the institutional control period;
(f) *Seismic processes*: for example, to study environmental media in order to characterize past seismological activities and to update seismic loading predictions, then evaluate the longevity of the structures and materials required to provide passive remediation or to control/isolate hazardous areas over the institutional control period.

9. INFORMATION AND KNOWLEDGE MANAGEMENT

9.1. INTRODUCTION

There is a general notion that future generations will command more knowledge and capability than the present generation. However, as is evident from many archaeological mysteries, such as the true purpose and design objectives of the Egyptian pyramids, and lost production technologies, such as the composition of some medieval stained glass, knowledge and insight might also be lost. Another example is the loss of knowledge, technology, infrastructure and institutional control associated with the decline and fall of the Roman Empire. It took nearly a millennium and a half to again reach the same level of sophistication in some areas. It is interesting to note that knowledge was slowly recovered through decentralized and redundant record keeping: much of the writings of the ancient Greek and Roman authors was preserved in the Arab world and fed back into the Western world.

It should also be noted here that the majority of texts on related subjects, such as knowledge management, are concerned with the preservation of knowledge as a corporate (or group, such as the nuclear industry as whole) asset. In this sense, it is about ensuring that the knowledge of an individual is shared with others and about making this knowledge available at any time. In the present context the time horizon is much longer and may go well beyond the lifetime of individuals or corporations, even beyond the duration of a society.

Site specific knowledge and information is much more vulnerable to loss than are generic knowledge and capabilities. An example here may be the ancient city of Troy, where knowledge of its exact location was lost but general awareness of its former existence remained, due to written sources. Eventually modern archaeological science was able to re-establish its location by interrelating a variety of decentralized sources of information. There are similar examples from other parts of the world.

Long term knowledge management and the intentional transmission of information will have to address four main issues:

(1) How to transmit knowledge over long periods of time;
(2) The kind of knowledge to be stored;
(3) The types of data and information needed;
(4) The types of storage media.

The first of the above issues is the most important and the most difficult to resolve.

9.2. KNOWLEDGE FORMS AND KNOWLEDGE SHARING

Successful stewardship, especially when with a multistakeholder base, needs to address a variety of challenges about knowledge sharing, i.e. its exchange and 'translation', allowing understanding between people in different occupations with different kinds of knowledge, and in their leisure as well as professional situations. In the science/environmental policy/sustainability fields there are many barriers to effective communication and sharing of knowledge. For example, within the scientific field itself, 'formal' scientists and technical experts do not always recognize and reciprocate the informal scientific knowledge, creativity and innovation existing at the grass-roots level of society.

Members of a community living in a given area may often have a rich informal knowledge of what has taken place in the past, of the functioning of ecosystems, of sources of risk and of hazards. Sometimes this knowledge is associated with traditional communities in an area. There is also informal knowledge in industrial contexts. Just as farmers may have good insights into local hydrology, workers in factories and mines may have intimate understandings of the workings of machines and of the properties of wastes and residuals. Awareness of what has really happened to wastes, and why, can be of great value for the design of remediation programmes and for the monitoring of contaminated sites.

For a variety of reasons, including proximity, the 'non-experts' can sometimes 'read' or 'observe' the world in ways that are not available to formal experts coming from outside. Dialogue and stakeholder consultation can, in principle, ally formal and informal expertise. Stakeholder deliberation can then, in a variety of ways, contribute to the identification of concepts and criteria for a socially satisfying solution. However, this type of pragmatic science based on observation and confronting local and day to day problems is not always articulated or acknowledged. Policy makers and resource managers sometimes evolve filters and structural barriers that prevent them from recognizing the potential that exists for blending formal and informal science. One reason that informal knowledge may not be used is that the systems for training experts, as well as some bureaucratic tendencies, favour standardized solutions — and so they treat as inconvenient the specificities of sites and ecological (as well as social) heterogeneity. Incentives for investing in knowledge and technologies with a strong site specificity, and hence with limited potential for generalization, are very low [89].

A multicultural panel on Science and Sustainable Development, held at the sixth session of the Commission for Sustainable Development (CSD6) of the United Nations in New York, considered issues such as these and made the following recommendation:

> "... every possible effort should be made to improve the processes of generating, sharing and utilizing science for sustainable development, and that this will need to include a commitment to overcome the communication gaps within the scientific community and between scientists, policy makers and the general public" (see Ref. [90]).

The panel statement suggested that appropriate elements of quality assurance, science communication and public policy processes will include:

> "new institutions and public procedures for the social evaluation of science advances; technology transfer seen in the framework of reciprocal learning and capacity building; and a reassessment of the forms and locations of the 'centres of excellence' capable of contributing knowledge and judgement needed for sustainability" (see Ref. [90]).

Mobilizing knowledge for sustainable development and stewardship requires attention to the forms of knowledge sharing, including their institutional, technical, economic, linguistic and cultural preconditions. Social trust and partnerships are constructed through dialogue and cooperation — among scientists and technical experts with policy makers, implementers and stakeholders — including experts with site specific (local) knowledge that complements methodological and coordination expertise. Knowledge as a resource must be accessible to the actors and pertinent to the context of their action [91].

Following these arguments, it is important to adopt a pluralistic approach to building the knowledge base. Science (understood as the activity of technical experts) needs to be considered as an important part of the relevant knowledge base that needs to be developed and mobilized in order to provide evidence in a decision or policy process. However, the ideal of rigorous scientific quality assurance is complemented by a commitment to open public dialogue. Citizens and stakeholders have a fundamental role in a knowledge partnership process. The strength and relevance of scientific evidence is amenable to assessment by citizens, who contribute to the framing of the issues and to judgements about the acceptability of proposed solutions. In this perspective, all parties come to the dialogue ready to learn. Through this co-production of knowledge, the extended peer community creates a (deliberative) democracy of expertise [92–94].

The 'post-normal' model of science practice, developed by risk assessment experts Funtowicz and Ravetz [92–94], places the emphasis on quality assurance through extended participation. A pluralistic, participatory and democratic view is developed of the knowledge and judgement base for policy actions:

(a) The old distinction between hard facts and soft values is replaced by a soft facts/hard values framework — admitting the complexity of emergent system properties (and hence uncertainties, etc.), and admitting the plurality of quality and legitimating criteria (e.g. there are different definitions of a problem, different ways of selecting and conceiving its relevant aspects, as well as different definitions of goals, depending not only on conflicts of interest but also on cultural factors).
(b) The highly asymmetrical distinction between experts and non-experts is reframed. In a sense, when facing a post-normal problem, all stakeholders are experts: in different ways, from different points of view and with regard to different aspects of the problem. Thus, it is necessary to extend the number and type of actors, both individual and collective, legitimated to intervene in the definition of problems as well as the selection and implementation of the connected policies. This extension does not only fulfil the requirements of democratic decision making but also improves the quality of decisions. The way of conducting a decision process dramatically influences its results. The dialogue between different actors is essential for quality, credibility and legitimacy, and hence the prospects of success of policy implementation.

The efforts to extend the time window for understanding ecosystem behaviour through recourse to what has become known as traditional ecological knowledge may serve as an example of formal and informal knowledge. Traditional ecological knowledge can be defined as any cumulative body of knowledge and beliefs, often partly tacit and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment.

An attribute of many societies with historical continuity in resource use practices is that they are non-industrial or less technologically advanced, many of them indigenous or tribal [95]. A similar characterization is put forward in Ref. [96].

There is little doubt that traditional ecological knowledge can be valuable for developing long term time horizons for system stewardship. Both the habits of thought and the substantive environmental knowledge can be sources of wisdom. Records of traditional ecological knowledge may be helpful in reconstructing the ecological history of a given area, thus extending our design base over longer time spans. Better supported predictions of future developments might be possible in conjunction with modern system analytical and modelling techniques. As this 'knowledge' typically combines digested experience with myth and has no established time frame, it is difficult to deduce the time period for which it would be valid.

However, it should not be assumed that 'traditional' practices and the knowledge and values that they embody are automatically aligned to contemporary site stewardship needs. Some commentators convey the idea that indigenous populations living on the basis of traditional ecological knowledge always do/did so in a sustainable way. This is not necessarily the case. While some behavioural patterns may have been aimed at conservation of resources, for instance those arising from hunting taboos, the lack of baseline data and a detailed analysis of the ecosystems in question make a proper judgement difficult. Historical evidence also shows that traditional ecological knowledge is not always very resilient and adaptive to changes in the ecosystem if the rate of change is too fast. It could even be argued that modern western thinking developed in response to challenges by the surrounding ecosystem. Apparently there were important incentives and drivers for such a development and they outweighed the loss of 'sustainability' [58].

Observations of indigenous populations are generally based on a rather short timescale, the observation times typically not extending beyond a few decades into the past. For a given ecosystem and indigenous population, the situation may appear stable over the observation time and the changes induced by the human population may be too small to observe. It is also important to remember that Europe once had an 'indigenous' population that, over time, showed itself to be able to shape its environment beyond recognition.

9.3. WHAT IS A RECORD?

A 'record' is an item of information about a site in question. The information may be represented or coded in a variety of ways and on a variety of materials. Typical examples are text, numerical data, maps and drawings on paper, photographic images on film, or digitized information on magnetic (tapes and floppy disks) or optical (CDs and DVDs) storage devices.

However, engraved monoliths such as those placed on some waste burial sites in the USA (Fig. 10) are also records in the sense that they are intended to

FIG. 10. Monoliths used as markers to delineate a radioactive waste burial site: granite marker plot M, in the Palos Forest preserve, Cook County Forest preserve district, photograph courtesy of R. Del Tredici .

convey some basic information on the site in question. This illustrates the second important property of a record, namely that it is not an end in itself but that it has a purpose. The purpose is to document and convey knowledge and information.

Nevertheless, to ensure such signs do not cause in future generations an effect opposite to the one that is intended, namely to raise curiosity and cause people, for instance, to dig for archaeological treasure, it is most important to put much emphasis on the transfer of information, for example, by means of education (Section 9.2).

9.4. WHY ARE RECORDS NEEDED?

Records serve two main purposes:

(1) To provide possible and actual users of a site with information on possible or actual hazards;
(2) To provide those in charge of controlling or mitigating such hazards with the necessary operational information.

Different stakeholders are likely to require different types of record.

Thus, efficient and effective stewardship and the related decisions can only be based on documentation containing all the information relating to the site in question [97, 98]. It thus constitutes the institutional memory and would cover the following fields and corresponding physical records:

(a) Documents related to the decision making process, for example, working documents justifying the decision taken.
(b) Historical records, for example, operational records that help people to understand the site and its surroundings and provide information on the origin of the potential hazards due to the site, decommissioning records, and records on remediation measures undertaken and remediation verification.
(c) Records that document the current state of the site and are 'live' documents that are necessary during the next phase, for example, the transition phase or the stewardship phase of the life cycle period; in this case, environmental management plans, enviromental monitoring results over time (such as groundwater quality and discharges) and inventories.
(d) Records and maps of the site showing the geographical location, topography, geomorphology, site boundaries, geology, hydrogeology, hydrology, water balance, meteorological information (and changes over time), site investigations and characterizations (including those relating to any pre- and post-remediation activities).
(e) Incident and accident records associated with potentially contaminating events, records of active and non-active waste disposal sites and chemical stores.
(f) Factual records relating to environmental parameters used in contaminant fate and transport modelling, for example, rock porosity, hydraulic conductivity and sorption coefficients.
(g) Interpretive records relating to the predictive behaviour of contaminants through time, quantitative risk assessments.
(h) Official records of decisions, such as licences and permits, and legal opinions on applicable laws.
(i) Copies and excerpts from official records deposited elsewhere, for example, in land registers, cadastres, deeds, registered mortgages, securities and deposits, registered land use restrictions and rights of way or access (in some countries, property or land registers, for example, cadastres in France and Kataster in Germany) have been a long standing means of conveying important information on sites. They may record not only ownership but also other important information, including use restrictions and rights of access. They often date back to the nineteenth

century, while other forms of recording ownership and rights on land sometimes even date back to the early Middle Ages, the most famous one probably being the Domesday Book in England, which was compiled in 1086 [99].

(j) Church books and registers frequently date back to the early seventeenth century and may record events that are of interest in mining areas.

9.5. RECORDS MANAGEMENT CHALLENGES

At many contaminated sites, an extended period of time is required in order to complete the active remediation, which may then be followed by institutional controls to allow passive remediation of the residual hazards. The storage of important site records must therefore be carried out for periods that may range from some decades to hundreds of years, or even thousands of years, though this is probably rather optimistic. Storing (physical protection) the records securely over these periods of time in itself is not sufficient, they must also be understandable and accessible (protection of the contents). There are many significant technological issues associated with long term storage of records, and many unknowns with regard to reasonable practices:

(a) The current practices of storing records in hard copy form (e.g. paper) and in electronic form give rise to technological issues with regard to longevity.

(b) The design and operation of records storage facilities to prevent loss events is of considerable importance. This is especially important in areas of the world where natural and human-made hazards are significant.

(c) Accessibility to records requires sound approaches to their indexing. Because many sites requiring long term institutional controls are large and complex, large volumes of records must be accessible over long time frames; hence indexing methods must be established with great care.

A decisive management issue is the classification of the importance of records, and the establishment of retention periods for the different classes of record. The development of classification criteria is not a simple matter: questions of relevance and quality arise, and may be viewed differently by different groups of stakeholders. Older records are often less in quantity and of lower quality than comparable newer records — in terms of the level of detail in the records. However, being the only records available for the period in question, they may still have to be retained.

Establishing and operating dedicated effective records management facilities is costly and the need for them is often not very well appreciated by certain groups of stakeholders, in particular when they do not see any immediate benefit for themselves. Records are often deposited with existing (national) facilities, such as archives and libraries. Cataloguing and storage practices may need to be adapted to stewardship needs.

9.6. TYPES OF DATA AND INFORMATION NEEDED

Typically, data on the type of residual contamination (chemical and physical properties), its exact geographical location and the type of remedial and other countermeasures would be included. In addition, and in particular for sites where long term changes in chemical (seepage and groundwater) or geotechnical properties are to be expected, it may be important to retain specific monitoring data. However, different stakeholders will have different data and information needs. Views on types of record to be kept and to what extent will vary between the organization responsible for the site and other stakeholders. Thus, in order to elucidate their information needs, in the context of the closure of the USDOE Mound Site, Ohio, interviews with stakeholders were conducted [100] to specifically:

(a) Identify key information need characteristics and usage patterns that would assist in creating a profile for future information needs, including preferred format, media and level of detail of information;
(b) Define the information transfer processes in order to evaluate whether future issues associated with transferring information to subsequent users/owners might exist;
(c) Identify stakeholder preferences and concerns regarding information transfer during closure and long term stewardship of the site;
(d) Document stakeholder preferences.

The main conclusions from this example probably have a wider applicability [100]:

(a) All current and future stakeholders will require information in summarized form.
(b) All stakeholders are concerned about loss of information and knowledge.
(c) Detailed data needs vary on the basis of responsibilities and are not entirely defined.

(d) A variety of stakeholders require access to photographs, aerial photographs, maps and other spatially related information.
(e) Access to post-closure monitoring data will be required should such monitoring be necessary.
(f) Access to pre-closure monitoring data will be necessary for those in charge of regulatory compliance verification.
(g) All stakeholders require access to data on monitoring institutional controls.
(h) Public stakeholders have a need for information related to the impacts of contaminants.
(i) The information needs of former site workers are rather distinct from the needs of other stakeholders, and are defined through regulations and/or litigation procedures.

In another example, the Grand Junction Office of the USDOE identified a range of information types that typically would be searched for by stakeholders [99]:

— Custody and long term care licensing;
— Site operations and treatment systems;
— Property information;
— Site surveillance/inspection reports;
— Legal documents;
— Site maintenance information;
— Site specific legal agreements;
— Community relations/public involvement;
— Institutional controls;
— Health and safety;
— Use and operations history;
— (National) environmental policy;
— Permits;
— Programmatic plans;
— Completion/closure reports;
— Physical site data;
— Waste management and disposal;
— Environmental data;
— Site specific technical studies;
— Radon and environmental hazards and related monitoring data;
— Correspondence on decisions;
— Groundwater and surface/leachate water monitoring;
— Quality assurance;
— Records.

The following spatially related information was determined to be of greatest interest [101]:

— Monitoring locations;
— Site boundary;
— Institutional control boundary;
— Contaminant plume;
— Groundwater compliance monitoring network;
— Topographic contours;
— Aerial or satellite images;
— Potentiometric surface contours;
— Disposal cell boundaries;
— Monitoring well lithology and completion log.

It is probable, however, that the data needs and the interest in information will change over time. It is likely that the interest of the public will diminish after a few years, and only those data relevant to potential redevelopment will remain of interest.

9.7. SELECTION OF RECORDS FOR RETENTION

A major challenge in record keeping anywhere is the decision about which records to retain and which records can be disposed of. As has been discussed above, the importance that is attached to a certain record may change with time and depend on the stakeholder concerned.

A categorization of records according to levels of importance, such as critical, necessary or useful, might be helpful in deciding which material requires most attention and in focusing resources on its preservation. A road map that indicates in which way the importance of a certain record changes with time might be a useful management instrument.

The timescale of retention of individual records would be determined by the needs of the stewardship programme. Certain records would be reclassified as time progresses; for instance, operational records would become historical records. A risk assessment may need to be undertaken in more complex cases to achieve a balance between the possible cost arising from no longer having certain records available and the cost of storing these records. It may actually be cheaper to store all records indiscriminately than to scrutinize them and make selections — with the risk of destroying some that may later be deemed valuable. For certain types of record there may be legal requirements to retain them for a specified period of time, for example, tax offices may require that documentation supporting tax returns be kept for a certain number of years, or a contractor may be required to retain certain records for warranty purposes.

In addition to the operator and their successors, for example the steward, the regulator may also have collected various types of record. Often, these duplicate records are generated or held by the operator and thus provide a certain redundancy. Different rules and regulations for retention may apply for the regulator and other government authorities. Some governments have a well established system for assessing and retaining records; see, for example, Ref. [102]. The regulator may require the operator to prepare a summary report on records held.

9.8. QUALITY REQUIREMENTS AND STANDARDS FOR RECORD KEEPING

A number of generic quality requirements can be formulated that may serve as guidelines for records management and for the selection of record formats and materials. Records ideally are [103]:

(a) Robust;
(b) Independent of time, or flexible enough to cope with changes over time;
(c) Not reliant on individuals, organizations or technologies;
(d) Able to withstand catastrophic events and attempts at sabotage;
(e) Reliable, i.e. capable of capturing, managing and delivering all the information that needs to be collected and collated;
(f) Transparent, i.e. the structure of the information management system must be open and clear (not a ‘black box’), and software tools to be of the open source type and to allow export of data in a structured and standardized form;
(g) Structured, i.e. records created with a contextual purpose in mind and containing metadata (data about data) must ensure that the context is clear in order to aid understanding.

The International Standards Organization [104] has produced standards for information and document structures, records management and metadata structures that describe records. The International Council on Archives [105] has produced standards designed to ensure that records are described, indexed and managed in a form that enables users to access records relative to their required context.

It is recognized that metadata are an essential instrument to ensure the integrity of records. Contextual information would be captured as an integral part of the management of records and the running of the archive. Contextual information provides an excellent source of structural information that can be used to locate records from a range of different perspectives. It provides links between ideas, relationships between records and a variety of associations between entities (people, organizations, etc.), records and publications. Contextual information is perceived as providing a road map to records and related information.

The collection and management of contextual information is not the exclusive province of a sole archivist but rather the responsibility of all those involved in information creation, preservation, publication, management and use.

9.9. RECORDS MANAGEMENT STRATEGIES

It is quite conceivable that an agreement is reached between the (former) operator, the steward and the regulatory authority as to where copies of all (historical) records are collated and kept (Section 9.10). A single institution may be made legally responsible for keeping the records, but this institution may delegate the actual record maintenance to another institution or outsource the work. In either case the ultimate responsibility would remain with the nominated steward.

During transition periods, the management of remediated sites may face certain continuity problems:

(a) One extreme is the critical situation when a site has been forgotten because all records on it have been lost;
(b) Private operators may not be able or willing to guarantee to remain responsible for the long term, especially if no specific financial arrangements are made and the scope and extent of liabilities are not clearly defined.

A proper and formalized information management strategy will help to minimize losses of crucial and valuable information and records, thus ensuring continuity [97, 98]. While loss of records is common throughout the whole life cycle, records are particularly vulnerable during the transition phase from operation to stewardship. The reason typically is that the records have little or no value to the outgoing operator and the steward may not yet have the necessary infrastructure and management structures in place. Major losses of records frequently occur where a period of loss of institutional control has occurred, for example during a period of neglect between the end of active operation and the onset of an orderly remediation programme, during instances of war or civil unrest and in the case of ‘orphan’ contamination. Experience shows that maintaining some activity on a site throughout its life cycle improves the probability of maintaining records. Alternatively, a depository for all collated records could be found until a final decision on the value of the records can be made on the basis of stewardship needs.

In addition to attempting to ensure the physical protection of records (Section 9.12), various other strategies to protect the information they contain can be considered. Duplicate records at two or more separate locations are an obvious solution. Given the concern about the longevity and viability of private enterprises and even national institutions, a centralized facility to collect and preserve records may be considered. Such redundancy will also be valuable in the case of catastrophic events at the place where the records are kept. One of the locations may even be at international level, which would offer some protection against the effects of war or civil unrest in a region. Various national and international inventories have been or are being built that collate information on contaminated sites (Table 5).

In order to maintain the memory of a site, it will not be necessary to have all records as duplicates. Some basic and summary information, such as that foreseen in the IAEA’s Directory of Radioactively Contaminated Sites (DRCS) [74], may serve this purpose.

Within one country, different types of information pertaining to a given site may be held at different locations, for example, the land register, environmental agency or local authority, which reduces the risk that a complete set of records is lost in a single incident. The various databases may be physically or conceptually interlinked to provide a comprehensive management system.

An important medium for preserving and transmitting generic information on sites and their spatial extents are maps, including geological, hydrological and land use maps. Some of these maps, geological maps, are standardized tools that have been in use for at least 130 years. Sites with restricted use could be indicated by special map signatures. There is, however, at present no general agreement on appropriate map signatures.

It is important that not only the records themselves be retained but also the means and tools for understanding them. In the case of analytical data, for instance, this would be information on sampling and analytical procedures. This also extends to the physical capability of reading, for example, digital records (Section 9.10.2).

In addition to storing information, electronic databases are also used to communicate with stakeholders and the public in general. Several of the databases listed in Table 5 contain information not only on sites that still have residual contamination above levels of concern but also on sites that have been

TABLE 5. NATIONAL AND INTERNATIONAL DATABASES AND INVENTORIES OF CONTAMINATED SITES

Country	Organization	Name and description
France	Agence nationale pour la gestion des déchets radioactifs (ANDRA)	Inventaire national des déchets radioactifs et des matières valorisables (also contains contaminated sites) (http://www.andra.fr/sommaire.php3)
	Bureau de recherches géologiques et minières (BRGM)	BASIAS or BASOL inventories of non-radioactive contaminated sites (http://basias.brgm.fr)
	Institut de radioprotection et de sûreté nucléaire (IRSN)	GEODERIS, uranium mining and milling sites
Germany	Bundesamt für Strahlenschutz (BfS)	A.LAS.KA, contaminated mining and milling sites; FbU, information on environmental radioactivity related to mining
	Sächsisches Landesamt für Umwelt und Geologie (LfUG)	KANARAS, data on enhanced natural radioactivity (including, inter alia, A.LAS.KA and FbU, will be available in 2006)
Russian Federation	Kurchatov Institute	RADLEG database of contaminated sites (http://www.kiae.ru/radleg/)
United Kingdom	Nuclear Decommissioning Authority (NDA)	Set up in April 2005; will produce a contaminated land registry for the UK
International	IAEA	Directory of Radioactively Contaminated Sites (http://www-drcs.iaea.org/)

remediated to the current levels of no concern. There is value in retaining information on such sites for two reasons:

(1) They could serve as examples or role models for successful implementation of a remediation programme.

(2) The view of regulators of what constitutes a level of no concern can change (and has changed) over time.

Sites that have been remediated to standards applicable at the time of remediation may now, with our more stringent regulations, be considered contaminated again. In this way, some degree of institutional memory of them is preserved.

9.10. RECORDING MEDIA

9.10.1. Overview

Since records may have to be kept for very long periods, the media used for storage are of crucial importance. On the basis of past experience with record keeping, a few basic requirements on the media and technology for recording can be formulated. These requirements include that records ideally should:

— Be readable without the aid of proprietary technology;
— Be capable of duplication and transfer to new media without loss of information;
— Preserve the context surrounding the information contained and its use.

The advantages and disadvantages of different recording media are summarized in Table 6. However, as has been discussed above, not all records may need to be stored for a very long time. Therefore, the choice of recording medium can be made appropriate to the length of the required retention time. Records of only short term relevance may be stored on ordinary office paper or proprietary magnetic media, whilst those records that need to be preserved for a very long time would need to be made on special papers or even on such exotic materials as silicon carbide.

In addition to concerns over the long term stability of the base medium, the stability of the actual inscription and possible detrimental interaction of the chosen materials with the base medium need to be assessed. It is known, for instance, that certain inks will fade or that they will destroy the paper due to chemical reactions. The preservation of written records on organic fibres such as papyrus leaves, or prepared animal hides (vellum), for several thousand years indicates their long term stability. Inks that form a stable inorganic compound (e.g. iron gallate or soot) after the medium has evaporated are preferable to those that rely on organic polymers. A concern is the cheap

TABLE 6. TYPES OF MEDIA AND THEIR RESPECTIVE ADVANTAGES AND DISADVANTAGES

Medium	Advantages	Disadvantages
Paper	Easily readable (by the current generation) Relatively robust Degrades slowly Relatively easy to duplicate Relatively inexpensive, so inexpensive to store duplicates in several places	Occupies significant space Inks and paper degrade in the long term Easily destroyed by fire and water
Film, photographic records	Relatively cheap Negatives require smaller storage space than paper	Media degrade Easily destroyed by fire and water
Microfiche	Storage space significantly smaller than that for many other media Can be read using relatively simple technology (magnifying glasses)	Degrades in the long term (though some fiche media have been developed that potentially last longer than paper) Requires a tool to be read
Digital records	Can be retrieved relatively easily, rapidly and from a number of areas Storage space (disks, servers, etc.) very small, and one source that is networked can be read by a number of readers Easy to attach metadata Easy to arrange contextually or by multiple contextual relationships Easy to copy	Require specialist software to be read Life expectancy of software very short Relatively sophisticated machines required to access records
Silicon carbide slabs	Very durable in the long term Corrosion resistant Wear and abrasion resistant Do not require sophisticated environmental controls to ensure no degradation	Require sophisticated equipment to form the record (e.g. laser engraving tools) Expensive

modern papers and computer inks that seem to be in general use currently to produce hard copy records. These papers may not be acid-free, and the inks or dyes are usually based on organic polymers or use binders such as those employed in laser printing technology.

9.10.2. Digital records

Over the past two or three decades, digital data processing, and hence storage of digital records, has become ubiquitous and it is now more prevalent than other forms of data storage. The main incentives have been the high data density that can be achieved, with the associated savings in storage space, the versatility of the digital format, which allows use of the stored information for a variety of purposes, and the ease of data retrieval for further use.

Given the rapid changes in information management technologies, preserving data is a major issue for a programme that must extend into the indefinite future. Many systems that were once considered high technology simply no longer exist. For instance, data stored on 5.25 in. floppy disks are now virtually useless, as very few users have been able to retain the necessary hardware (disk drives) and associated software. A similar future awaits the 3.5 in. floppy disk and other magnetic media (e.g. tape streamers) in the light of rewritable CDs and DVDs becoming common. Optical disk (CD and DVD) technology is also being challenged by issues such as media durability (disk delamination) and the changing wavelength of the light source used to read or write disks. The problem of rapid technological change and the associated technical obsolescence has been widely recognized and extensively discussed for many years, but without any agreement on how this can be resolved [106].

A recent report on spatial data preservation and archiving [107] reviewed the issues relevant to data preservation. Most newer digital media are much less robust than printed books or other paper documents because:

(a) They are less chemically stable than even poor quality paper.
(b) They deteriorate more rapidly even when stored unused in good environments.
(c) Digital data are machine dependent, i.e. they must move within machines to provide their information. Simply reading the data incurs wear on the media.
(d) They are totally system dependent for retrieval of their information. When the system (hardware, software or both) is no longer sustained, the information will be lost unless it is migrated to a newer system.
(e) Digital information technologies rely on ever greater data packing densities, making the information ever more vulnerable to large losses from small incidents.
(f) Failure of many newer digital media is often unpredictable and sudden, and may result in total loss of the information recorded.
(g) There is little experience with the maintenance and preservation of many newer types of media.

Technological obsolescence is a major concern, particularly since technical developments are not driven by, and do not take into consideration, long term information preservation needs [108]:

(a) Accessibility of digital information depends entirely on intricate edifices of hardware, operating systems, applications software and storage media.
(b) Most systems are heavily proprietary, which leaves those concerned with long term preservation dependent on the marketplace.
(c) Changes in technology are almost wholly driven by business and market forces; libraries, archives and other government institutions have virtually no influence on these developments.
(d) Although there are many crucial standards, both formal and de facto, in the digital domain, developments in technology often outpace the standards setting process.

A data mining procedure, i.e. transformation of existing records into current and long term formats might be needed to preserve records. In other words, digital media typically have very high maintenance requirements compared with those of other media, for instance paper. When deciding on the medium, these disadvantages may need to be balanced against the advantages of ease of data retrieval. In general, it appears that digital media are of more value for data preservation on the ten year time span than for the long term.

9.11. CODING OF INFORMATION

Preserving physical records is one thing, ensuring their readability another. Conceptually, reading is composed of two steps: the transformation of the stored information into a medium that is accessible to humans and the decoding of the information into a format that is understandable to them. Some storage media require only simple tools for retrieving information, for instance a projector or microscope suffices to read a microfilm, while magnetic storage devices require sophisticated and often proprietary hardware. The decoding required means, for instance, that textual information be available in a language that can be understood by the user. In addition, the conventions of formulas or drawings must be understood. Necessary decoding keys can often be obtained from the context (see above), but sometimes the context itself is coded.

Typically, redundancy and a widespread use of the coding system are likely to aid readability over prolonged periods of time. Thus, plain text is a good candidate. Bar codes, on the contrary, have very little redundancy and require a special key for deciphering. This key is not common cultural knowledge at the time they are created and may easily be lost. For instance, knowledge about some languages and their texts has been lost, at least for many centuries (e.g. Egyptian hieroglyphs and Mayan texts), but written language is a very common cultural element today, ensuring considerable redundancy.

Symbols and pictograms are another issue. People with limited experience of other cultural contexts and historical perspectives might easily overlook the fact that the understanding of the meaning of symbols might be lost or that the meaning itself might indeed change. For instance, in the Western world it is generally accepted that a bright red or yellow colour is often used in warning symbols. Colours, however, have different connotations in different cultures; the colour of mourning is black in the Western world while it is white in East Asia. Therefore, it is dangerous to take the meaning of symbols for granted and to rely on them for conveying particular messages.

9.12. RECORDS STORAGE FACILITIES

A spatial separation between the locations where records are kept and the locations of any problems is usually necessary to provide for conditions conducive to records preservation and for reasons of accessibility. In other words, the records are normally stored in an archive remote from the site under stewardship. Various proposals have been made to overcome the problem of providing for the long term stability of records stored at a given site. These include two dimensional bar codes and button memories [109].

In designing records management facilities the fact has to be taken into account that certain records, for instance those on monitoring and maintenance, are ‘living’ records. Their continuous, even if not daily, use requires ease of access while providing security for longer periods of time. Thus, certain records may have to be in close physical proximity to the steward. A possible strategy for providing both easy access and security is to maintain duplicate records. In such a case, however, mechanisms for duplicating such records in a way that ensures an exact copy are required. Typically the primary working records are paper copies or digital files, while the archived records are often transferred onto microfiche in order to reduce space requirements.

Facilities for storage of records for the short or intermediate term (say up to 25 years) are typically located in suitable accommodation, for example, the basement of the buildings in which the record creating institution is based. Records of higher importance and of wider public interest are often transferred to a State archive after a certain period of time. Records that are deemed to be of historical interest are candidates for the public archives. This is particularly true when the record creating institution ceases to function. The laws of Member States usually specify the time for which records have to be kept. In many cases it is unlimited, i.e. for the lifetime of the recording medium. In exceptional cases, restoration or other procedures to extend the lifetime, or measures to transfer the information to other media, are taken.

Records that are to be kept for an a priori unlimited period of time in some Member States are copied onto microfiche, which is then stored, for instance, in underground mines or similar facilities. The reason for placing the microfiche underground is a comparatively low risk of fire, natural disasters and major accidents such as plane crashes.

There is not much experience yet on how well these facilities would function over the very long term. The only long term experiences with storage of written or printed records are with monastery or university libraries that have been in existence for close to a thousand years. Although their continuing existence is an example of continued institutional control, there are many more examples where such control has failed or the institutions have been deliberately dissolved, for example, during various waves of secularization in the Western world. The International Council of Archives is undertaking a study of the desirable properties of archival buildings [110].

9.13. RESEARCH NEEDS

9.13.1. Records management

Research into the long term preservation of records is likely to involve experts from a wide range of disciplines, such as archivists, historians, material scientists, data storage experts (for analog, electronic and digital systems) and sociologists. Examples of research needs in this area include:

(a) Basic research into the validity and maintenance of visual signs.
(b) Identification of media suitable for the long term preservation of records.
(c) Improvements to the procedures for ensuring that records are migrated without data losses as media change over time.
(d) Improvement of methods that ensure the long term retrievability and accessibility of records and information.
(e) Research into the coding of information so that it might be readable by future generations.
(f) Research into the properties of historical records that have been successfully, albeit often unintentionally, preserved over long periods of time

(e.g. natural and anthropogenic analogues, such as old manuscripts) and into the ways in which they have been preserved.

(g) Historical research into the tradition of written records (e.g. ancient Chinese texts, ancient Egyptian texts, the Bible and the Koran) and into the properties and procedures that have kept them understandable.

(h) Further research into the long term stability of materials (e.g. paper, ink, optical storage devices and materials, and new materials) and their interaction with the storage environment.

(i) Identification of ways that are likely to ensure that records are safely kept and secured in the long term.

(j) Development of risk assessment methods for various types of records management strategies, balancing the investment into management of the records with the risk of loosing these records. This research will also aid in identifying the weaknesses of certain designs and practices, leading eventually to improvement and mitigation.

(k) Further research and development into sound methods for indexing of records.

(l) Further research and development into sound methods for classification of records.

(m) Development of internationally agreed signatures and symbols for maps, indicating restrictions on use.

9.13.2. Storage facility designs

In addition to the record media themselves the storage environment is important, and further research into this might be needed to determine:

(a) The optimal properties of hard copy storage facilities (e.g. environmental conditions, segregation, hardening and fireproofing);

(b) The optimal properties of electronic media storage facility designs (similar aspects to those in (a)).

10. MONITORING AND PERFORMANCE ASSESSMENT

10.1. OBJECTIVES

Monitoring is usually performed as part of the institutional control measures [13]. This is to verify that the site functions as designed, that regulations are complied with, and that certain aspects of institutional control are still in place and functioning. The legal basis for the requirement to monitor, and the extent of the monitoring, arises from regulations on radiation protection, regulations on environmental protection and, in the case of mining involving radioactive materials, mining regulations designed to ensure orderly closure of mines and mining sites. In addition, there may be requirements arising from relevant legislation on public safety. The sustained performance of a monitoring programme may be one of the core tasks of a steward.

For new practices, remediation planning commences with the development of a site and continues through the operations on the site; major parts of the post-closure monitoring systems usually develop from the programme of monitoring during operation. Assuming that a licensed operation would have a well developed monitoring system, the closure of the operation and the transition to long term monitoring may justify a modification and even a reduction of the extensive monitoring system operated during the operational phase. There may also be a greater focus on environmental compartments rather than on monitoring releases and discharges. Long term monitoring is a relatively new discipline, and it can be assumed that future monitoring experiences and monitoring data will show the values and shortcomings of current monitoring systems.

The characteristics and state of a site after closure and/or remediation determine the type and scope of monitoring required. In the case of mining and milling sites, on-site residues typically include covered waste rock heaps and stabilized tailings ponds. In addition there may be slightly contaminated and covered sites. Any surface structures would have been decommissioned and demolished, with contaminated debris and scrap being buried on-site if it could not be recycled or sent for disposal at a licensed facility.

Monitoring is an essential element of the long term management programme for a closed and remediated site and may need to be undertaken for a number of purposes, for instance for environmental or socioeconomic reasons. Programmes typically cover all pathways for exposure of the critical group for all identified contaminants of concern. The scope and nature of monitoring programmes will differ between sites, depending on the level of restriction for land use applied by the regulators [13].

There are three major aspects to monitoring in relation to long term stewardship and management:

(1) Monitoring the implementation of a stewardship programme;
(2) Monitoring the performance of engineered remediation solutions;
(3) Monitoring as an essential instrument of quality assurance and quality control (QA/QC).

For all cases, data quality objectives (DQOs) have to be formulated. These help to identify the questions to be addressed and then ways in which the required information can be obtained. The process is designed to ensure that all parties involved decide during the planning phase what specific decisions will be made using the data collected and what the action levels are for those decisions. In addition, the costs and tolerances of making the wrong decision are quantified so that the statistical design of the monitoring programme can be scaled appropriately. The lower the tolerance for making the wrong decision the more data are needed, and consequently the higher the cost of the programme. Once a monitoring system has been designed, the DQO process has to cycle back through the decisions with all the parties involved, to gain agreement [106].

Visible monitoring programmes and their associated QA/QC systems are valuable tools for enhancement of public confidence [106]. The data from monitoring programmes can be a significant element in a public information and education programme. The data can be made available in a variety of forums and media. An important consideration is to ensure timely dissemination of the information. This can be achieved, for instance, through use of the Internet, where data may be displayed in real time if necessary. In addition, the provision of interpretive comments and control charts enable stakeholders to become aware of the most recent data and their significance. Data may also be distributed through newsletters, notice boards and public displays (including closed circuit TV images of a site), as well as being presented at regular meetings. All of these mechanisms may be used in combination. Ownership can be created by involving the stakeholders in the monitoring programme [111].

When drawing up the monitoring programme, the steward may need to ensure that a holistic approach is used that will encompass all the relevant issues. For example, sites may be monitored by regularly collecting certain data as well as through inspections. In addition, it may be necessary to check other sources, such as land title registers, to ensure that land use requirements or other essential conditions have not been altered. Again, the reader is referred to IAEA Safety Report No. 27 [13], which contains comprehensive examples of the methods and systems that may be used for these tasks.

10.2. THE SCOPE OF MONITORING PROGRAMMES

Monitoring requirements are usually science based but also need to take into account stakeholder requirements in respect of the timing or frequency, range of parameters studied and proposed duration of a programme. Programmes are, therefore, risk based and include social and political risks.

There is a need to reassess programmes periodically to ensure that the level of monitoring activity is appropriate and continues to provide sufficient data of the correct quality to enable the programme objectives to be met, i.e. that it meets the DQOs. Reviews usually include issues of compliance with regulatory requirements, as well as an assessment of ongoing performance of the remediation work and ongoing assurance to the community.

The media to be monitored need to cover all pathways relevant to identified contaminants of concern. These will be water (possibly both surface water and groundwater), soil and vegetation; atmospheric monitoring is carried out for gases and particulates.

There may be a need to identify specific targets of concern and also to consider the natural environment as well as humans and the human-made environment. For example, one of the primary requirements of a capping design is to limit percolation of water into the impounded materials. Therefore, monitoring will focus on indicators of the performance of those elements of the capping system that are designed to prevent percolation of water, namely the hydraulic head in the drainage layer. It would need to be known whether the elements perform according to design and, if not, an early warning of potential problems would be desirable. As an example of such a targeted programme, the monitoring system parameters chosen for the cover at the Fernald (Ohio, USA) environmental management project are given in Table 7.

TABLE 7. FERNALD (OHIO, USA) ON-SITE DISPOSAL FACILITY MONITORING PARAMETERS [112]

Parameter	Critical elements	Technology
Differential settlement	Condition of barrier layer, maintenance of drainage	Topographic survey with settlement plates, ground penetrating radar targets
Head in drainage layer	Stability of cover system	Pressure transducers
Drainage layer temperature, barrier temperature	Stability of cover system, frost protection of barrier layers	Thermistor embedded in a transducer
Root zone status; vegetative soil layer status,	Erosion control	Water content reflectometers, heat dissipation units
Vegetation health and coverage	Erosion control	Topographic and vegetation surveys, webcam, remote sensing

To ensure efficiency, monitoring programmes are dynamic in nature and there are often structural changes during the life of a project to accommodate changing levels and types of activities and the associated risks. A monitoring programme will also be adapted in the scope and frequency of the parameters studied as a result of conclusions from previous observations. Monitoring at later stages of the working phase provides data that may be used in developing remediation plans. Monitoring data are collected both on-site and off-site.

10.3. CHALLENGES FOR MONITORING TECHNIQUES

A task force assembled to review the long term monitoring needs for the Fernald environmental management project identified the following aspects in need of monitoring or surveillance [113]:

(a) The ecological system associated with the vegetative cover and the ‘buffer’ area (i.e. the surrounding area);
(b) Physical changes in the cover system and the buffer area;
(c) The effectiveness of institutional controls.

Various monitoring techniques have been discussed in detail in IAEA publications [13, 114]. Monitoring activities are usually quite labour intensive and sometimes intrusive. For this reason, new technologies and techniques are being developed, for example, new (in situ) sensors [115]. Telemetry and data loggers reduce the amount of time to be spent in the field. The monitoring might also be automated with alarms triggered only when significant changes in the measured variable occur. Only certain ‘critical’ variables, for instance conductivity downstream from a site or porewater pressure in embankments, may be measured. Thus, sensors might act as sentinels against event related phenomena. New developments also include automated comparison of visual images in a time series to detect changes [116]. The targeted changes can be short term, for example the real time detection of intrusion, or long term, for example the development of erosion features. Such images can be gathered by a variety of remote sensing systems, including aerial and satellite imaging devices in the visible and other ranges. For instance, infrared images can help to detect changes in the vegetation cover, pointing to biointrusion or erosion, or indicate the presence of drainage and seepage waters. In general, the introduction of up to date techniques and strategies is likely to improve the efficiency of monitoring programmes.

10.4. PHASES OF A MONITORING PROGRAMME

A monitoring programme usually has three distinct phases:

(1) *Operational phase monitoring*: For new practices, monitoring ideally starts at the exploration stage or at the environmental impact assessment stage at the latest, i.e. prior to the commencement of operations, and aims at collection of significant baseline data. These provide inter alia the basis for environmental and other assessments in the later stages of the project's life cycle and the benchmark against which changes due to the practice are evaluated. The baseline monitoring programme elements will usually remain the same throughout the life of the project.
(2) *Remedation phase monitoring*: Monitoring continues throughout the remediation phase to assess impacts, progress and performance of the remediation programme and compliance with regulatory targets. These programmes are again adjusted to accommodate the change in risks arising as a consequence of changes in work activities.
(3) *Post-closure monitoring*: The general requirements and procedures for developing post-closure monitoring and surveillance programmes have been set out in a recent IAEA Safety Report [13].

10.5. EXAMPLE: MONITORING AT FORMER MINING SITES

10.5.1. Issues of concern

Large quantities of residues possibly containing radionuclides remaining at or near the surface and mine workings that may remain open are typical of former mining sites. Potential contaminant sources that require monitoring include areas not remediated to free release, surface and underground workings, tailings ponds and waste rock piles.

Increased surface areas underground, the opening of airflow pathways and the lowering of the groundwater table may allow radon to migrate from radionuclide bearing rocks into buildings above the mine site, thus possibly creating a radiological problem. As long as the mine ventilation is operating, the concentrations are kept below levels of concern and the radon is vented in a way that avoids significant exposures. Without ventilation the radon concentration in dwellings on the surface may increase significantly. Radon levels may need to be monitored and appropriate management strategies introduced.

10.5.2. Monitoring at waste rock piles and tailings ponds

After remediation, monitoring of seepage water for aqueous contaminants, air for radon and engineered structures, such as covers, for their stability will be required to prove the long term effectiveness of the remediation measures and to provide the necessary reassurance to the public [117, 118]. The duration of the performance verification monitoring phase is usually determined by the licensing authorities in consultation with the operators, taking into account the overall management plan. Inspections may be timed so as to efficiently capture any potential change and may be as far apart as several decades. The measurements mainly relate to the:

(a) Quality of seepage water and groundwater; the monitoring of the chemical composition may extend over considerable periods of time, possibly 20 years or more.
(b) Radon exhalation and the radon concentration of the air close to the ground over a sufficiently long time to gain confidence that stable conditions have been achieved; such measurements may need to be continued for a considerable number of years. Owing to changing seasonal exhalation conditions, two measurements per annum, one in winter and one in summer, are typically needed.
(c) Soil mechanical parameters of covers and other engineered structures in order to detect unfavourable changes in water content, porosity, density, soil fabric, etc.

Measurements are usually carried out by the operator or the site steward and are periodically reviewed by the regulatory authorities.

10.5.3. Monitoring at closed mines

Closed mines present a special category of objects requiring monitoring, particularly concerning the chemistry of any discharging mine water [119, 120]. Acid mine drainage is a common problem, which is exacerbated in some (uranium) mines by residual fluids from in situ leaching operations.

A reliable model based forecast of the mine water development can provide a good reference for the scope, frequency and likely duration of monitoring activities. The contaminants to be monitored depend very much on the specific situation, but commonly involve radioactive components, non-radioactive contaminants, such as arsenic and heavy metals, and major constituents. Comparison of measured concentrations with modelled forecasts gives an indication of how long any water treatment and monitoring may be needed.

In deep mines, depending on the mine geometry, the main processes that maintain concentration gradients are convection and diffusion. The water volumes to be treated under a stewardship programme depend on the respective recharge rates in the area and the ensuing water balance in the mine. Mine water volume streams can be as high as 500–1000 m^3/h.

Underground mines typically extend below the water table, and restoring the water table to pre-mining levels or another suitably defined operational level is part of a decommissioning and stewardship programme. The objectives of the flooding are to:

(a) Stop oxidation processes;
(b) Minimize water treatment costs and emissions and maximize the radiation protection of the workers by suitable controls on the flooding.

A stepwise flooding scheme, whereby the monitoring results provide data for corrective actions if the system does not behave as predicted or envisaged, is recommendable.

Safe mine closure requires a thorough understanding of the hydrogeology and hydraulics of the mine and the surrounding environment. Meaningful monitoring points are the basis for a model developed with this understanding, which is by no means trivial. A more detailed discussion of the respective requirements, however, is outside the scope of this report.

10.5.4. Scope of monitoring versus land use

Revegetation of covered waste rock piles is commonly allowed, or rather cannot easily be prevented in temperate or tropical climates. Other uses usually require a more involved permit procedure and appropriate monitoring. In order to determine the scope — from a radiological point of view — of potentially allowable site uses, expected exposures of critical groups or individuals are calculated for each use. The monitoring programmes are then designed to suit the site use chosen. Recreational uses with short term occupancy such as a golf course or an airfield for model aircraft, on waste rock piles, may be preferable, for instance, to industrial or residential developments.

10.6. RESEARCH NEEDS

Most monitoring programmes are labour intensive and, for large sites, the expenditure and effort required to operate monitoring programmes are significant. The focus of research and development for this stewardship activity may, therefore, be best oriented towards the development or improvement of monitoring techniques that reduce the effort and cost of operating the programmes over long periods of time:

(a) Improvement of in situ monitoring sensors with a view to increasing their stability and reliability over the longer term, thus reducing the need for and cost of maintenance;
(b) Improvement of multiparameter sensors for environmental monitoring of the various media used, including possibly the application of nanotechnology;
(c) Improvement of reliable information networks (possibly utilizing wireless technologies) to make the data collection processes used more efficient;
(d) Development of improved image processing and pattern recognition capabilities to improve automated detection of change at a site, for example, by comparison of visual light or invisible light images in a time series [116];
(e) Improvements to security monitoring instrumentation and strategies, for example intrusion detection;
(f) Improvement of back-calibration methodologies that allow modelling to be used to extend the time frames for prediction;
(g) Further development of technologies for the communication of monitoring results to stakeholders, for example utilizing the Internet (webcams and display of data in real time);
(h) Further development of sensors and automation technologies and strategies in order to trigger alarms only when significant changes in measured variables occur.

11. SUMMARY AND CONCLUSIONS

11.1. DEFINING THE ISSUE

Stewardship is the collection of provisions and processes for maintaining institutional control over prolonged periods of time for such sites that cannot be remediated to levels of residual contamination that would allow their free release.

Making predictions for economic or even social systems naturally involves large uncertainties; uncertainties that increase as the time frame increases. Reducing the risks arising from these uncertainties is the major challenge in establishing a successful long term stewardship programme. The establishment of stewardship programmes faces continuing changes in boundary conditions and processes in all social, technological and economic realms: changing stakeholders, perceptions of risk, state of the art in (remediation) science and technology, societal structures, governance systems, economic circumstances and priorities, etc. A successful stewardship programme will be a programme that has the inherent capability to adapt to these changes.

The emergence and increased adoption of the concept of life cycle management in many areas of human activities calls for the early consideration of possible stewardship issues. It is typically a requirement in the licensing procedure for new practices to have already prepared a stewardship plan. In the case of past practices or accidents, planning for long term stewardship is best undertaken during the cleanup phase. However, it must be recognized that remediation typically proceeds in an iterative fashion and that end states appear to be emerging as the de facto result of multiple interim actions.

By recognizing the requirements and challenges for a stewardship programme, a number of statements describing a likely stewardship programme can be derived. These challenges concern managerial, societal, economic and technical issues. All these issues are strongly interrelated and need to be considered simultaneously during the decision making process for stewardship.

11.2. BEING ADAPTIVE

It is worth remembering that even although the best solutions for a long term stewardship programme currently known may be implemented, these are almost certain to become obsolete in the future with changing perceptions and improved scientific and technical capabilities. It may be futile to try to anticipate all possible perceptions of future generations. There is an inherent danger to attempting to define stewardship programmes that are sufficiently broad and all-encompassing to be capable of handling every conceivable eventuality and, perhaps, even inconceivable eventualities. In particular, there needs to be an acknowledgement that it is unlikely that deliberate intrusion can be prevented over the long term. Hence, a stewardship programme needs to have provisions for being adaptive and responsive.

11.3. FOCUSING ON REALISTIC TIME FRAMES

While there may be no direct solutions for maintaining the ability to manage long term stewardship for thousands of years, focusing on shorter term (100 years or so) solutions will keep people involved in the site, which will allow for the evaluation of the changes that are needed over time. Spending too much energy on trying to solve the problems of the future with current knowledge may result in missing the opportunity to make the best decisions for the short term and may result in unreasonable or unrealistic solutions. Stewardship plans cannot be static, but have to be adapted to the development of a site, both with respect to its physical state and its use. Periodic revision of stewardship plans will be necessary.

11.4. KEEPING STAKEHOLDERS INVOLVED

Stewardship, and by inference the steward's responsibilities, must be defined at the practical level of implementation, i.e. from the bottom upwards. To be understandable and affordable, a narrow definition of stewardship is recommended. Successful and effective stewardship programmes appear to have a set of common attributes:

- Long term reliability;
- Clarity of objectives and roles;
- Adequate and sustainable funding mechanisms;
- Contingency provisions;
- Flexibility;
- Ease of implementation;
- Transparency;
- Durability or replaceability;
- Iterativity;
- Adaptability;
- Supporting mechanisms to incorporate scientific, technical and societal changes, including progress in research and development.

11.5. ALLOWANCE FOR ECONOMIC CHANGES

As for other aspects of a stewardship programme, it is extremely unlikely that a 'permanent' solution will be found for the economic issues, in particular the funding. Focusing on the nearer term and realistically implementable solutions will make the problem more tractable. This approach implicitly relies on a continued interest in the stewardship programme. Finding a (new) revenue generating site use for each stage of the stewardship period is likely to help greatly in the support of the maintenance programme.

11.6. ENGINEERING WITH NATURE

There is a temptation to develop engineering solutions to be viable for the whole perceived stewardship period, sometimes in excess of hundreds of years. As historical experience shows, engineering for long term stability poses a variety of challenges and has to cope with many uncertainties. On the basis of these experiences and system analytical considerations, two paradigms for engineering solutions seem to emerge:

(1) Engineering with, and not against, nature;
(2) Designing with a view to minimizing the potential energy stored.

In other words, the engineering designs need to minimize the driving forces for unwanted change and to maximize the potential for wanted change. Above ground structures have a lot of energy stored in them that natural processes, such as erosion, tend to release. On the other hand, natural processes, such as diagenesis, could be harnessed to foster the development of stable geochemical conditions.

11.7. KEEPING RECORDS ‘ALIVE’

It is recognized now that preservation of the physical integrity of the records alone is not a solution. Ensuring their readability and comprehensibility even over relatively short periods of time is a challenge. It appears that strategies that keep the records ‘alive’ are the most efficient solution. The same applies to knowledge, where active usage appears to be the best guarantee for its continued preservation and availability.

11.8. MONITORING PROVIDES FEEDBACK

The uncertainty over the long term effectiveness of a remediation solution requires provisions for monitoring, periodic performance assessment and possibly maintenance. It is this uncertainty that leads to the requirement for long term stewardship. While taking remediation decisions, it is important to explicitly consider long term stewardship issues and obligations when examining remedial options and implementing a final remedy [121–130].

11.9. CONCLUDING OBSERVATION

Summarizing the above discussion, it seems futile to try to develop a stewardship programme and its associated managerial, societal, economic and technical components for the whole period of the envisaged stewardship. Provision, instead, of solutions for the foreseeable future with scope for adaptation and development appears to be the way forward.

REFERENCES

[1] KOH, B., ADAMS, T.G., “A non-traditional approach to site release avoids significant offsite disposal costs”, Waste Management 1999 (Proc. Int. Symp. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999) paper 54-4, http://www.wmsym.org

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

[3] GEISER, D., KANG, J., GILMAN, J., WILSON, J., “Preparing for long-term stewardship: Current policy and future direction”, Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 549, http://www.wmsym.org

[4] SANCHEZ, F., CLARKE, J., PARKER, F., “Evaluating requirements for stewardship of contaminant isolation”, ibid., paper 350.

[5] UNITED STATES DEPARTMENT OF ENERGY, Long-Term Stewardship, Office of Legacy Management, USDOE, Washington, DC (2001), www.lm.doe.gov/pro_doc/lts/lts.htm

[6] UNITED STATES DEPARTMENT OF ENERGY, Long Term Stewardship Study — Final Study, Vol. 1, USDOE, Washington, DC (2001).

[7] UNITED STATES NATIONAL RESEARCH COUNCIL, Long-Term Stewardship of DOE Legacy Waste Sites: A Status Report, The National Academies Press, Washington, DC (2003), http://fermat.nap.edu/catalog/10703.html

[8] STRUM, M.S., ROBERTS, S.J., CUMMING, E.R., "The technical basis for the 'non-impacted area' classification associated with the decommissioning of the Yankee nuclear power station", Waste Management 1999 (Proc. Int. Symp. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999) paper 54-1, http://www.wmsym.org

[9] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Elsevier, Amsterdam and New York (1990), http://www.elsevier.com/inca/publications/store/2/9/0/8/3/

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

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Release of Sites from Regulatory Control on Termination of Practices, IAEA Safety Standards Series No. WS-G-5.1, IAEA, Vienna (2006).

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

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

[14] UNITED STATES DEPARTMENT OF ENERGY, Planning and Implementing RCRA/CERCLA Closure and Post-Closure Care when Wastes Remain Onsite, USDOE, Washington, DC (1999).

[15] KLEINRATH, A.W., PLESSINGER, M.P., "Considerations for developing a comprehensible and affordable long-term stewardship program", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[16] WRIGHT, J.A., Jr., MIDDLEMAN, L.I., "Historical perspective on subsurface contaminants focus area (SCFA) success: Counting things that really count", Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002), paper 564, http://www.wmsym.org

[17] HUSTON, K.R., "Program achievements in the formerly utilized Sites Remedial Action Program (FUSRAP)", ibid., paper 23-1.

[18] NEEDHAM, S., WAGGITT, P., "Planning mine closure and stewardship in a World Heritage area — Alligator Rivers region, Northern Territory, Australia", Long-Term Stewardship (Proc. Workshop Grand Junction, 1998), CONF-980652, United States Department of Energy, Washington, DC (1998) 147–159.

[19] CHEN, S.Y., et al., "Developing a flexible system to address multifaceted long-term risk issues", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[20] BORDELON, C., GOMEZ, E., O'CONNOR, S., "A longitudinal study of citizens' views on the fate of the Columbia River in Washington State: Tritium concerns at Hanford", Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 53-3, http://www.wmsym.org
[21] JASANOFF, S., The songlines of risk, Environ. Values **8** (1999) 135–152.
[22] HUNT, J., WYNNE, B. (Eds), Social Assumptions in Remediation Strategies, Deliverable Report of the STRATEGY Project, Contract No. FIKR-CT-2000-00018, Commission of the European Communities, Luxemburg (2002).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Non-technical Factors Impacting on the Decision Making Processes in Environmental Remediation, IAEA-TECDOC-1279, IAEA, Vienna (2002).
[24] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).
[25] INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE, Doctrine en matière de réaménagement des stockages de résidus de traitement de minerais d'uranium (Doctrine regarding the remediation of repositories for uranium mill tailings), Rep. IPSN/DPRE/SERGD N99-42, IRSN, Fonteney-aux-Roses (1999) Annexe I.
[26] PRICE, J.B., POWER, M.S., "A Washington State perspective on long-term stewardship at Hanford", Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 293, http://www.wmsym.org
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary, IAEA, Vienna, http://www-ns.iaea.org/standards/safety-glossary.htm
[28] ENVIRONMENTAL LAW INSTITUTE, The Role of Local Government in Long-Term Stewardship at DOE Facilities, ELI, Washington, DC (2001), http://www.eli.org
[29] HOCKING, E.K., SMILEY, S.L., "Applying a decision process for long-term stewardship planning at a U.S. Department of Energy site", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Symp. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.
[30] BAUER, C., PROBST, K.N., Long-Term Stewardship of Contaminated Sites: Trust Funds as Mechanisms for Financing and Oversight, Discussion Paper 00-54, Resources for the Future, Washington, DC (2000), http://www.rff.org/Documents/RFF-DP-00-54.pdf
[31] THOMPSON, A.J., PUGSLEY, C.S., Trusts for long-term stewardship at decommissioned nuclear facilities, Radwaste Solutions (Jul./Aug. 2002) 45–49.

[32] BANAEE, J., “Planning for site transition to long-term stewardship: Identification of requirements and issues”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Symp. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[33] BERGMAN-TABBERT, D., PLESSINGER, T.B., “Lessons learned: The Grand Junction office site transfer to private ownership”, Waste Management 2001 (Proc. Int. Symp. Tucson, 2001), WM Symposia, Inc., Tucson, AZ (2001), http://www.wmsym.org

[34] CLAYTON, C.J., “The transition of DOE sites from closure to long-term stewardship”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[35] KRISTOFFERSON, K., “LTS transition criteria and integrated facility closure”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[36] CANGE, S., BILOSKI, W.J., “Accelerating cleanup and savings through the use of innovative strategies on the reservation”, Waste Management 1999 (Proc. Int. Symp. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999) paper 17-6, http://www.wmsym.org

[37] BRADBURNE, J., PATTON, T.C., “Achieving closure at Fernald”, Waste Management 2001 (Proc. Int. Symp. Tucson, 2001), WM Symposia, Inc., Tucson, AZ (2001) paper 29-3, http://www.wmsym.org

[38] TUOR, N.R., SCHUBERT, A.L., “Closing Rocky Flats by 2006”, ibid., paper 29-6.

[39] SINK, C.H., YURACKO, K.L., LYNN, D.A., “Trends within the environmental management industry during the last decade of the 20th century”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[40] INTERNATIONAL SCIENCE AND TECHNOLOGY CENTER, Web site, Moscow, http://www.istc.ru/

[41] OCHS, S., “Centralized science management model of the Environmental Science and Technology Program Office, Los Alamos National Laboratory”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[42] FIORE, J.J., MURPHY, W.E., JONES, M.E., “DOE’s office of site closure: Progress towards 2006”, Waste Management 2001 (Proc. Int. Conf. Tucson, 2001), WM Symposia, Inc., Tucson, AZ (2001) paper 29-1, http://www.wmsym.org

[43] INTERNATIONAL STANDARDS ORGANIZATION, ISO 14000 — Meet the Whole Family!’, http://www.iso.ch/iso/en/iso9000-14000/pdf/iso14000.pdf

[44] OECD NUCLEAR ENERGY AGENCY, The Societal Aspects of Decision Making in Complex Radiological Situations (Proc. Workshop Villigen, 1998), OECD/NEA, Paris (1998).

[45] OECD NUCLEAR ENERGY AGENCY, Learning and Adapting to Societal Requirements for Radioactive Waste Management: Key Findings and Experience of the Forum on Stakeholder Confidence, Rep. 5296, OECD/NEA, Paris (2004).

[46] OECD NUCLEAR ENERGY AGENCY, “Addressing Issues Raised by Stakeholders: Impacts on Process, Content and Behaviour in Waste Organisations”, Topical Session, Forum on Stakeholder Confidence, Rep. NEA/RWM/FSC(2004)8, OECD/NEA, Paris (2004).
[47] OECD NUCLEAR ENERGY AGENCY, Forum on Stakeholder Confidence, OECD/NEA, Paris (including programme of workshops since 2000), http://www.nea.fr/html/civil/welcome.html
[48] UNITED STATES NATIONAL RESEARCH COUNCIL, One Step at a Time: The Staged Development of Geologic Repositories for High-level Radioactive Waste, The National Academies Press, Washington, DC (2003), http://www.nap.edu/catalog/10611.html
[49] JACOBSON, J.J., BERRETT, S., “DOE complex-wide long-term stewardship options analysis system”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.
[50] O’CONNOR, M., ‘Building relationships with the waste’, Public Confidence in the Management of Radioactive Waste: The Canadian Context (Proc. Workshop Ottawa, 2002), OECD Nuclear Energy Agency, Paris (2003) 177–190.
[51] ENGLISH, M.R., “Who are the stakeholders in environmental risk decisions?”, Stakeholder Confidence and Radioactive Waste Disposal (Proc. Workshop Paris, 2000), OECD Nuclear Energy Agency, Paris (2000) 99–102.
[52] JODHA, N.S., Waste lands management in India: Myths, motives and mechanisms, Econ. Polit. Weekly **35** 6 (2000) 466–473.
[53] BEINAT, E., VAN DRUNEN, M.A. (Eds), The REC Decision Support System to Compare Soil Remediation Alternatives, Nobis, Gouda (1997).
[54] RITTEL, H., “Systems analysis of the ‘first and second generations’”, Human and Energy Factors in Urban Planning (LACONTE, P., GIBSON, J., RAPOPORT, A., Eds), NATO Advanced Study Institutes Series, Nijhoff, The Hague (1982) 35–63.
[55] CIRIA, SAFEGROUNDS Learning Network, CIRIA, London, www.safegrounds.com
[56] BRUNDTLAND, G. (Ed.), Our Common Future: The World Commission on Environment and Development, Oxford University Press, Oxford (1987).
[57] UNITED NATIONS, Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 1992, Vol. 1, Rep. E.93.I.8, UN, New York (1992).
[58] MIDDLEMAN, L.I., WRIGHT, J.A., HICKS, H.T., Jr., KLEIN, R.D., “The challenges and opportunities of institutional controls for long-term stewardship of the former DOE weapons complex”, Waste Management 2001 (Proc. Int. Symp. Tucson, 2001), WM Symposia, Inc., Tucson, AZ (2001) paper 29-8, http://www.wmsym.org
[59] INTERNATIONAL ATOMIC ENERGY AGENCY, The Long Term Storage of Radioactive Waste: Safety and Sustainability, IAEA, Vienna (2003).

[60] KEENER, W., et al., “New model for public participation at Sandia National Laboratories: What comes after environmental restoration?”, Waste Management 2000 (Proc. Int. Symp. Tucson, 2000), WM Symposia, Inc., Tucson, AZ (2000) paper 53-5, http://www.wmsym.org

[61] SIGAL, L.L., SARNO, D.J., “Next steps for stewardship — Results of the DOE site specific advisory boards’ workshop on stewardship”, ibid., paper 65-2.

[62] BROWN, R., BUCKLEY, S., “Reindustrialization and job creation”, Waste Management 1999 (Proc. Int. Symp. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999) paper 64-5, http://www.wmsym.org

[63] HALL, J.C., CLARK, L.C., “Reindustrialization — An overview of the Department of Energy’s Oak Ridge strategy”, ibid., paper 17-2.

[64] VAN HOESEN, S.D., MYRICK, T.E., EIDAM, G.R., “Integrated planning for cleanup of Bethel valley and revitalization of the ORNL main campus”, Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (1999) paper 554, http://www.wmsym.org

[65] YOUNG, L.T., “Community reuse organization of East Tennessee — The vehicle for community diversification”, Waste Management 1999 (Proc. Int. Conf. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999) paper 17-3, http://www.wmsym.org

[66] UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, An Introduction to Environmental Accounting as a Business Management Tool: Key Concepts and Terms, Rep. EPA 742-R95-001, USEPA, Washington, DC (1995).

[67] DA ROSA, C., Financial assurance, Mining Environ. Manage. **7** 2 (1999) 10–13.

[68] UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, Brownfields Cleanup and Redevelopment, USEPA, Washington, DC (2005), www.epa.gov/brownfields

[69] INTERNATIONAL ECONOMIC DEVELOPMENT COUNCIL, International Brownfields Redevelopment, IEDC, Washington, DC (2005) http://www.iedconline.org/?p=Brownfields_Resource_Center

[70] SCHRENK, V., SCHLICHER, T., BARCZEWSKI, B., Neue Ansätze im Flächenrecycling — Die Interdisziplinäre Arbeitsgruppe FIGURA und das Project “Bewertungsmatrix”, http://www.stmugv.bayern.de/de/aktuell/download/boden/208.pdf

[71] STEWART, J.C., “Land use and real estate stewardship report”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

[72] BILOSKI, W.J., “Matching the business opportunities and the leasing process”, Waste Management 1999 (Proc. Int. Conf. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999) paper 17-5, http://www.wmsym.org

[73] JAKUBICK, A., Wismut GmbH, Chemnitz, personal communication, 1999.

[74] INTERNATIONAL ATOMIC ENERGY AGENCY, Directory of Radioactively Contaminated Sites, IAEA, Vienna, http://www-drcs.iaea.org/

[75] INTERNATIONAL ATOMIC ENERGY AGENCY, Technologies for the Remediation of Radioactively Contaminated Sites, IAEA-TECDOC-1086, IAEA, Vienna (1999).
[76] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical Options for the Remediation of Contaminated Groundwater, IAEA-TECDOC-1088, IAEA, Vienna (1999).
[77] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation of Sites with Mixed Contamination of Radioactive and Other Hazardous Substances, Technical Reports Series No. 442, IAEA, Vienna (2006).
[78] INTERNATIONAL ATOMIC ENERGY AGENCY, Current Practices for the Management and Confinement of Uranium Mill Tailings, Technical Reports Series No. 335, IAEA, Vienna (1992).
[79] KRAUSE, D.R., MASSIE, J.A., SMILEY, S., SHOEMAKER, H., "The Mound long term stewardship initiative", Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 91, http://www.wmsym.org
[80] HO, C.K., et al., "Risk-based performance assessments for long-term cover systems: Sensitivity and uncertainty analyses", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.
[81] INTERNATIONAL ATOMIC ENERGY AGENCY, Applicability of Monitored Natural Attenuation at Radioactively Contaminated Sites, Technical Reports Series No. 445, IAEA, Vienna (2006).
[82] IDAHO NATIONAL LABORATORY, EM Science & Technology Roadmapping, INL, Idaho Falls (2001), http://emi-web.inel.gov/roadmap.html
[83] HALLBERT, B.P., et al., "Long-term stewardship science and technology roadmap", Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 545, http://www.wmsym.org
[84] REILKOFF, T., O'LEARY, E., "Technology solutions for environmental management: A web-based information system supporting cleanup and closure of the weapons complex through technology transfer", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.
[85] ALEXANDER, R., CHAPMAN, N., McKINLEY, I., SMELLIE, J., MILLER, W., Geological Disposal of Radioactive Wastes and Natural Analogues, Pergamon Press, Oxford (2000).
[86] COMMISSION OF THE EUROPEAN COMMUNITIES, Natural Analogues in Radioactive Waste Disposal, Rep. EUR-11037EN, CEC, Luxemburg (1987).
[87] INTERNATIONAL ATOMIC ENERGY AGENCY, Natural Analogues in Performance Assessments for the Disposal of Long Lived Radioactive Wastes, Technical Reports Series No. 304, IAEA, Vienna (1989).

[88] SHAFER, D.S., MILLER, J.J., YOUNG, M.H., EDWARDS, S.C., RAWLINSON, S.E., “The future through the past: The use of analog sites for design criteria and long-term performance assessment of evapotranspiration landfill”, Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 162, http://www.wmsym.org
[89] GUPTA, A., Science, sustainability and social purpose: Barriers to effective articulation, dialogue and utilization of formal and informal science in public policy, Int. J. Sustain. Dev. **2** (1999) 368–371.
[90] FUNTOWICZ, S., O’CONNOR, M. (Eds), Recommendations from the panel discussion held at the Commission for Sustainable Development 6th session (CSD6), United Nations, New York, 22 April 1998, Int. J. Sustain. Dev. (Special issue) **2** 3 (1999) 353–356.
[91] FUNTOWICZ, S., RAVETZ, J., O’CONNOR, M., Challenges in the use of science for sustainable development, Int. J. Sust. Dev. **1** 1 (1998) 99–107.
[92] FUNTOWICZ, S., RAVETZ, J., Uncertainty and Quality in Science for Policy, Kluwer Academic Press, Dordrecht (1990).
[93] FUNTOWICZ, S., RAVETZ, J., “A new scientific methodology for global environmental issues”, Ecological Economics: The Science and Management of Sustainability (COSTANZA, R., Ed.), Columbia University Press, New York (1991).
[94] GALLOPIN, G., FUNTOWICZ, S., O’CONNOR, M., RAVETZ, J., Science for the 21st century: From social contract to the scientific core, Int. J. Soc. Sci. **168** (2001) 209–229.
[95] BERKES, F., “Traditional ecological knowledge in perspective”, Traditional Ecological Knowledge: Concepts and Cases (INGLIS, J.T., Ed.), International Development Research Centre, Ottawa (1993).
[96] UNESCO, Best Practices on Indigenous Knowledge, Management of Social Transformations Programme/Centre for International Research and Advisory Networks, Paris (1999), http://www.unesco.org/most/bpikpub.htm
[97] EDGE, R., PAVELKA-ZARKESH, L., “Document systems for site stewardship at the U.S. Department of Energy Grand Junction office”, Waste Management 1999 (Proc. Int. Symp. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999) paper 51-2, http://www.wmsym.org
[98] FEATHERMAN, W.D., “Records management for building closure projects: Federal facility best practices”, ibid., paper 40-1.
[99] THE DOMESDAY BOOK ONLINE, The National Archives, Kew, http://www.domesdaybook.co.uk, http://www.nationalarchives.gov.uk
[100] CRANE, L., SMILEY, S., “Involving stakeholders in identifying post-closure data needs at the Department of Energy Mound plant”, Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.
[101] GILMORE, J., et al., “Information management: The other challenge for long-term stewardship”, ibid.

[102] THE NATIONAL ARCHIVES, United States National Archives and Records Administration, College Park, MD, http://www.archives.gov/records_management/index.html
[103] INTERNATIONAL ATOMIC ENERGY AGENCY, Preservation and Transfer to Future Generations of Information Important to the Safety of Waste Disposal Facilities, IAEA, Vienna (in preparation).
[104] INTERNATIONAL STANDARDS ORGANIZATION, Geneva, http://www.iso.org
[105] INTERNATIONAL COUNCIL ON ARCHIVES, Paris, http://www.ica.org
[106] ERICKSON, M.D., CAVALLO, A.J., "Technical information for long term surveillance and monitoring", Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 386, http://www.wmsym.org
[107] BLEAKLY, D.R., Long-Term Spatial Data Preservation and Archiving: What Are the Issues?, Rep. SAND 2002-0107, Sandia Natl Labs, Albuquerque, NM (2002).
[108] STEWART, E., BANKS, P.N., "Preservation: Issues and planning", Preservation of Information in Non-Paper Formats, American Library Association, Chicago, IL (2000) 323–324.
[109] BERRETT, S., "Information retention, storage and retrieval for long term stewardship", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.
[110] INTERNATIONAL COUNCIL OF ARCHIVES, Download Centre, Archives Building Case Studies, ICA, Paris, http://www.ica.org/biblio.php?plangue=eng
[111] LOCHARD, J., "Stakeholder involvement in the rehabilitation of living conditions in contaminated territories affected by the Chernobyl accident: The ETHOS project in Belarus", Restoration of Environments with Radioactive Residues (Proc. Int. Symp. Arlington, 1999), IAEA, Vienna (2000) 495–506.
[112] PROCHASKA, M.J., KUMTHEKAR, U.A., ZEWATSKY, J.A., "The Fernald post-closure stewardship technology project and integrating stewardship technology team — Progress in the identification, implementation, and demonstration of monitoring technology for post-closure", Waste Management 2002 (Proc. Int. Symp. Tucson, 2002), WM Symposia, Inc., Tucson, AZ (2002) paper 92, http://www.wmsym.org
[113] KUMTHEKAR, U., CHIOU, J.D., PROCHASKA, M., BENSON, C.H., "Development of a long-term monitoring system to monitor cover system conditions", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.
[114] INTERNATIONAL ATOMIC ENERGY AGENCY, Compliance Monitoring for Remediated Sites, IAEA-TECDOC-1118, IAEA, Vienna (1999).

[115] HALE, D.L., RODDY, M.S., O'ROURKE, T.P., "Sensors initiative for identification of long-term stewardship research opportunities", Waste Management 2001 (Proc. Int. Conf. Tucson, 2001), WM Symposia, Inc., Tucson, AZ (2001) paper 47-7, http://www.wmsym.org

[116] REICHHARDT, D., HART, A.T., Remote sight to monitor mound site — Applying machine vision for long-term stewardship, Radwaste Solutions (Jan./Feb. 2005) 29–33.

[117] JONES, C.A., PLESSINGER, M.P., JACOBSON, C.L., EDGE, R., "Lessons learned: Monitoring and maintenance experience at completed uranium mill tailings sites, United States", Waste Management 1999 (Proc. Int. Conf. Tucson, 1999), WM Symposia, Inc., Tucson, AZ (1999), paper 51-4, http://www.wmsym.org

[118] WAUGH, W.J., "Monitoring the long-term performance of uranium mill tailings covers", ibid., paper 51-5.

[119] YOUNGER, P.L., Waste or voids: Which is the greatest pollution source?, Mining Environ. Manage. (Jul. 2003) 18–21.

[120] SZILAGYI, A.P., MARTINEZ, R., "Mining surveillance and maintenance dollars", Waste Management 2000 (Proc. Int. Conf. Tucson, 2000), WM Symposia, Inc., Tucson, AZ (2000) paper 63-7, http://www.wmsym.org

[121] EDELSON, M.C., "Factors in environmental decision making", Spectrum 2002: Nuclear and Hazardous Waste Management (Proc. Int. Conf. Reno, 2002), American Nuclear Society, La Grange Park, IL (2002) CD-ROM.

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

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

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

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

[126] INTERNATIONAL ATOMIC ENERGY AGENCY, The Long-term Stabilization of Uranium Mill Tailings, Final Report on a Co-ordinated Research Project 2000–2004, IAEA-TECDOC-1403, IAEA, Vienna (2004).

[127] 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, IAEA, Vienna (2000).

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

[129] EVERETT, L.G., “Long-term institutional and regulatory policy issues relating to the vadose zone”, Waste Management 2001 (Proc. Int. Symp. Tucson, 2001), WM Symposia, Inc., Tucson, AZ (2001) paper 63-7, http://www.wmsym.org
[130] BELFIELD, D., Environmental accounting, Mining Environ. Manage. **7** 2 (1999) 7–8.

Annex I

POST-REMEDIATION CONTROL OF RADIOACTIVELY CONTAMINATED SITES IN THE RUSSIAN FEDERATION

Regulatory, information and technological aspects of a long term stewardship programme

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Abstract

The main results of systematic studies of radiation legacies in the former Soviet Union under projects Nos 245 and 2097 (1995–2003) of the International Science and Technology Centre (ISTC) are described. A brief overview of radioactively contaminated sites (RCSs) in the Russian Federation is given, and the current legal and regulatory framework in the field of RCS remediation is outlined. The most essential requirements for the development of a long term post-remediation RCS institutional control (stewardship) programme are formulated, and the main directions for efforts made in the implementation of the stewardship programme are discussed.

I–1. INTRODUCTION

Radioactive contamination in some territories of the Russian Federation is mainly the result of nuclear weapons production and testing, operations of the nuclear industry, maintenance of the naval and civilian nuclear fleets, and nuclear test explosions in the former Soviet Union (Table I–1). Most of the contamination is the result of the major radiation accidents in Kyshtym (1957) and Chernobyl (1986).

At present some of the radioactively contaminated sites pose a potential hazard to the biosphere, therefore special remedial actions aimed at reducing their impact on the population and the environment are needed. Such

TABLE I–1. AREAS CONTAMINATED WITH RADIONUCLIDES AT FORMER MINATOM SITES AS OF 1 Jan. 2000 [I–1]
(areas in which exposure rates are above 200 μR/h are shown in brackets)

Site	Total (km^2)	Production area (km^2)	Sanitary and protective zone (km^2)	Observation zone (km^2)
Priargun Production Mining–Chemical Association, Krasnokamensk, Chita region	8.53	7.33	0.78	0.42
Almaz Mining and Chemical Plant, Lermontov Industrial Association, Stavropol region	1.34 (1.03)	1.07 (1.018)	0.27 (0.012)	—
Machine building plant (MSZ), Elektrostal	0.26 (0.26)	0.01 (0.01)	0.13 (0.13)	0.12 (0.12)
Novosibirsk Chemical Concentrate Plant (NZKhK)	0.15 (0.14)	0.07 (0.07)	0.08 (0.08)	—
Moscow Polymetals Plant	0.016 (0.001)	0.002 (0.001)	0.014	—
Chepetsk Mechanical Plant (ChMZ), Glazov, Udmurtiya	1.35 (0.062)	1.34 (0.059)	0.01 (0.003)	—
Zabaikalsky Mining and Concentrating Combine	0.04	0.04	—	—
Mayak Radioactive Waste Facilities, Chelyabinsk region	452.16 (65.70)	38.46 (17.70)	217.54 (38)	196.16 (10)
Mining and Chemical Combine, Zheleznogorsk, Krasnoyarsk region	4.71 (0.203)	4.29 (0.19)	0.07 (0.013)	0.35
Siberian Chemical Combine (SKhK), Seversk, Tomsk region	10.39 (4.191)	10.09 (4.026)	0.30 (0.165)	—
Kirovo-Chepetsk Chemical Combine, Kirov region	0.70	0.17	0.15	0.38
All-Russia Research Institute of Technical Physics, Snezhinsk, Chelyabinsk region	0.13 (0.01)	0.13 (0.01)	—	—
Research Institute of Atomic Reactors, Dimitrovgrad, Ulyanovsk region	0.39 (0.081)	0.15	0.24 (0.081)	—
Institute of Physics and Power Engineering, Obninsk, Kaluga region	0.001 (0.001)	0.001 (0.001)	—	—

TABLE I–1. AREAS CONTAMINATED WITH RADIONUCLIDES AT FORMER MINATOM SITES AS OF 1 Jan. 2000 [I–1]
(areas in which exposure rates are above 200 μR/h are shown in brackets) (cont.)

Site	Total (km^2)	Production area (km^2)	Sanitary and protective zone (km^2)	Observation zone (km^2)
Total	480.32 (71.68)	63.235 (23.08)	219.64 (38.48)	197.43 (10.12)
Total without Mayak	28.16 (5.98)	24.79 (5.38)	2.10 (0.48)	1.27 (0.12)

measures should include both remediation of contaminated land and social support programmes for the population affected by the radiation. The main task here is to mitigate the consequences of internal and external human exposures and to provide for conditions that support efficient and safe economic activities. Concrete objectives need to be developed, as well as principles and standards for radiation safety when undertaking remediation work. In addition, criteria for the evaluation of conditions prior to remediation, as well as criteria for decision making, remediation planning, selection of remediation techniques and recommendations for future land use, need to be developed.

I–2. ASSESSMENT OF LEGACIES IN THE RUSSIAN FEDERATION

I–2.1. Overview

Since 1995 a cycle of research aimed at systematic investigation of the radiation legacies of the Soviet nuclear complex has been carried out under the International Science and Technology Centre (ISTC) project Nos 245, The Development of a Sophisticated Computer Data System for Evaluation of the Radiation Legacy of the Former USSR and Setting Priorities on Remediation and Prevention Policy (RADLEG) and 2097, The Development of a Sophisticated Information System Including a Meta-Database and Regional Radioecological Cadastres for Assessment of the Radiation Impact on the Environment and Population: Evaluation Study of the North-West of Russia and

Krasnoyarsk Region (RADINFO). Financial support from the European Union and the USA (from 2002 onwards), as well as MINATOM (now the Federal Agency for Atomic Energy, ROSATOM) of the Russian Federation, has made it possible to develop the necessary database for analysis and evaluation of the contaminated lands and probable pathways of radionuclide migration. Graphical representations (both static and dynamic) of the radiation sources and possible radionuclide pathways to humans allow assessment of the impacts of radiation on population health and the natural environment. This, in its turn, allows in the next, final, stage of the study the development of recommendations for priority setting in governmental environmental protection policies, including the planning of countermeasures and setting up of a post-remediation monitoring system, which is, in essence, the ultimate goal of the investigations into the radiation legacies.

The main aim is the development of a long term State programme for remediation of radioactively contaminated sites and long term post-remediation monitoring with a view to coordinating the efforts of the various agencies, regional authorities and enterprises in this field.

A general idea of the scope of the problem, i.e. of the actually existing radioactively contaminated territories, their contamination levels and characteristics, of the expediency of taking any countermeasures and of the need for post-remediation monitoring, can be gathered from the information given below.

The total area of land contaminated with radionuclides as a result of the activities of the former MINATOM departments during 1945–2000 is about 480 km^2 [I–1]. For the most part, the contaminated land is within so-called ‘sanitary and protective zones’ and ‘observation zones’ of the departments. About 15% of the total area contaminated with radionuclides has the highest levels of gamma radiation exposure rate, i.e. above 200 μR/h (Table I–1).

I–2.2. Chernobyl

Vast areas in the Russian Federation were contaminated with radionuclides as a result of the Chernobyl disaster in April 1986. The accident at the Chernobyl nuclear power plant led to the release into the atmosphere of huge amounts of biologically damaging radionuclides. In spite of the inevitably conditional character of demarcation of the region that in this case can be considered as radioactively contaminated land, the Chernobyl associated contaminated territory is assumed to be delimited by an isoline with an initial ^{137}Cs contamination of 37 kBq/m^2 (1 Ci/km^2). The total area affected in the Russian Federation is about 28 000 km^2 ([I–2], p. 315). The most intense contamination of agricultural land is observed in the Bryansk region, where

77.8% (4010 km^2) of the land has a ^{137}Cs contamination of 37–185 kBq/m^2 (1–5 Ci/km^2), 18.9% (980 km^2) of 555–1480 kBq/m^2 (15–40 Ci/km^2) and 3.3% (170 km^2) of 1440–2880 kBq/m^2 (40–80 Ci/km^2).

In addition, land contaminated with ^{90}Sr at a level of 37–74 kBq/m^2 (1–2 Ci/m^2) is to be found in the Bryansk region.

In the Tula region, about 9% of the agricultural land (with a total of 4710 km^2 being contaminated) has a ^{137}Cs contamination of 555–1480 kBq/m^2 (15–40 Ci/km^2). In the Kaluga region, 3.3% of the total agricultural land (1580 km^2 contaminated) has a ^{137}Cs contamination of 555–1480 kBq/m^2 (15–40 Ci/km^2) ([I–2], p. 316). There is also land contaminated with ^{137}Cs as a result of the Chernobyl disaster in the Oryol, Ryazan and Kursk regions, and in a number of other regions in the European part of the Russian Federation.

I–2.3. Nuclear test sites

As a result of nuclear weapons tests at the test site on the Novaya Zemlya archipelago, some areas of the archipelago are radioactively contaminated. Data on the radiation situation at the test site and on the Novaya Zemlya archipelago as a whole for the period 1990–2000 show that the ^{137}Cs contamination in most parts of the test sectors is essentially below 37 kBq/m^2 (1 Ci/km^2). Owing to this and because the gamma exposure rate is less than 13 μR/h, the land has controlled area status according to a Federal law 'On Radiation Safety of the Population' [I–3]. Only two sectors on the test site have the status of a sanitary and protective zone (SPZ) based on ^{137}Cs contamination levels and gamma exposure rates: control sector No. 3, which is close to the A-37A shaft top (with up to 20 350 kBq/m^2 (550 Ci/km^2) and up to 360 μR/h), and control sector No. 1 located in the vicinity of a surface detonation crater on the shore of Black Bay (with up to 925 kBq/m^2 (25 Ci/km^2) and up to 100 μR/h) [I–4]. When making decisions concerning decontamination of these two sectors, the benefits from a reduction in occupational exposure need to be balanced against the inevitable damage due to disturbing the ecological equilibrium in the tundra through the use of various items of construction equipment.

Over the time period from 1965 to 1988, 124 nuclear explosions were conducted in the former Soviet Union for various experimental, industrial and scientific research purposes (81 of them on the territory of the Russian Federation). Some of these entailed accidental releases of radioactive substances into the environment [I–5, I–6].

In 1978 a borehole blowout occurred following an explosion at the Kraton-3 object in the Republic of Sakha (Yakutia), leading to formation of a radioactive trace (currently about 2 km long). In 1971 at the Globus-1 object (Ivanovo region), local radioactive contamination of soil and vegetation occurred around a well head. Immediately after the detonation, a partial decontamination of the most polluted sites was performed and an SPZ was delineated. The radiation exposure rate level in the SPZ territory reached 750 mR/h, while outside the territory the level was below 15 mR/h. At present, elevated (compared with the natural background) radiation exposure rate levels of 200–250 μR/h are detected on a plot of 0.01 km^2 close to the well head. The object is under continuous observation. In addition, partial decontamination and remediation of the plot near the well head is planned.

After the Taiga explosion (1971 in the Perm region) a local radioactive trace was formed. The length of the zone contaminated to a dose value of 0.5 μSv, accumulated in the first year after the detonation, was about 25 km.

Radioactive products from the explosion were detected outside the former USSR in a number of states, including Sweden and the USA. According to 1990 data, the radiation exposure rate in the most contaminated SPZ sectors was within the range 30–200 μR/h (at one point a maximum level of exposure rate of 1.4 mR/h was detected). At present the radiation level at distances of 250–350 m outside the SPZ does not exceed natural background values. There is periodic radiation monitoring at the Taiga object and this will be continued in future [I–5].

I–2.4. Navy bases

Former onshore maintenance bases for the nuclear fleet (at Andreyeva Bay and Gremikha naval base) are also significant radiation hazards to the population and the environment. Over the last few years, intensive radiation investigations have been carried out there and information has been gathered systematically on the actual radiation situation of the bases and in the adjacent waters [I–7]. The part of the Andreyeva Bay base close to a former spent nuclear fuel repository is to a great extent contaminated with radionuclides, and permissible levels are significantly exceeded. At some points the specific activity of the soil reaches 106–107 Bq/kg for ^{137}Cs and 105–106 Bq/kg for ^{90}Sr. At Gremikha base the highest level of radioactive soil contamination (5107 Bq/kg for ^{137}Cs and 5106 Bq/kg for ^{90}Sr) with a gamma radiation effective dose rate within the range 500–800 μSv/h was detected around a solid radioactive waste storage site. There is evidence of partial carry-over of radioactive products from the site territory with atmospheric deposits [I–7]. Work has been started in Andreyeva Bay on decontamination of some objects and removal of radionuclides from the territory. Preparations are being made to start similar decontamination work at Gremikha.

I–2.5. Sites contaminated with naturally occurring radioactive material

There are also territories in the Russian Federation that are radioactively contaminated due to prospecting for, and mining and processing of, uranium and thorium, as well as extraction and processing of other raw materials (conventional metals, coal, oil and gas) containing naturally occurring radioactive materials (NORMs), and as a result of inadequate management of radioactive materials and radioactive waste during the early phase of nuclear research and the nuclear industry. Therefore, an urgent task is to draw up a complete inventory of such sites within the framework of a unified Federal system of accounting and control of radioactively contaminated sites. This will form the necessary basis for developing a well grounded programme of remediation of such sites and for carrying out appropriate radiation monitoring at the sites and in adjacent areas.

I–3. REMEDIATION INITIATIVES

I–3.1. Objectives

By now some practical experience and relevant knowledge have been gathered in the Russian Federation with respect to remediation of radioactively contaminated sites. This includes the land contaminated as a result of the Chernobyl disaster, as well as the contaminated sites at the Mayak enterprise in Chelyabinsk, the Siberian Chemical Combine in Tomsk, the Machine Building Plant at Elektrostal, near Moscow, the Almaz uranium ore mining enterprise in Stavropol, etc. However, it should be kept in mind that it is not always possible, for either technical or economic reasons, to reach such a level of residual radionuclide concentration in the surrounding environment that a site can be used without any restrictions and would not need any form of control in the future. Some robust estimates show that no less than 200 billion US dollars would be needed to reach such residual activity levels on all the contaminated sites in the Russian Federation. It is clear that it would not be possible to raise funds on such a scale either now or in the foreseeable future. That is why setting priorities in remediation policies on the basis of strictly justified criteria and with authorization by the competent State governing bodies, as well as the development of a national long term stewardship programme, are now among the most pressing tasks.

Long term stewardship encompasses the arrangements for a system of measures for the post-remediation administration and control of sites, including the management responsibilities, legal regime and environmental monitoring as well as a complex of measures to provide for safety and security.

I–3.2. Legal framework

At present the legal framework of such activities in the Russian Federation is not clearly defined. In practice, the remediation activities at radioactively contaminated sites are regulated by a number of Federal laws (such as those ‘On Radiation Safety of the Population’ [I–3] and ‘On Special Ecological Programs of Rehabilitation of Radioactively Contaminated Land Sites’ [I–8]), the normative acts of Federal agencies, and the guidelines and criteria set by the IAEA and the International Commission on Radiation Protection (ICRP).

However, the currently valid legislative and normative acts of the Russian Federation do not give a unique definition of the term ‘radioactively contaminated site’. Article 1 of the Federal Law on special ecological programmes mentioned above [I–8] determines ‘radiation contaminated land’ to be

> “a part of a territory (land site), posing hazards to the public health and the natural environment, which is subject to remediation of radioactive contamination resulting from human activities or where contaminated objects remain after decommissioning.”

It is of importance that in this definition the concept of a site as part of a territory is introduced, thus making it possible to differentiate sites on the same territory by the level of their respective contamination. In addition, radioactively contaminated sites are delineated for the purpose of ensuring public and environmental safety by indicating the type and cause of contamination.

The ‘Regulations for the State Control & Accounting of Radioactive Wastes in the Russian Federation’ [I–6] determine ‘territories contaminated with radionuclides’ as:

> “territories (lands and water bodies at ‘production sites’, in ‘sanitary & protective’ and ‘observation zones’) of atomic energy use, where radioactive substances are present, and their amounts exceed minimum values set by federal rules and standards, in such a way as being capable of causing exposure exceeding the acceptable levels.”

In this definition, specific limits or reference values for the radiation safety are not given. Hence, the regulations remain valid irrespective of changes to the Federal rules and standards. However, the definition does not take into account radioactively contaminated lands that are located outside the indicated areas.

The ‘Methodical Guidelines on Remediation of Lands Contaminated with Man-Made Radionuclides’ [I–9] give a definition as follows:

> “lands contaminated with man-made radionuclides are lands where the presence of man-made radioactive substances on material surfaces or in their interior can cause individual radiation exposure exceeding 10 μSv/a or a collective dose exceeding 1 man Sv/a”.

This definition is based on standards set by the radiation safety regulations of 1996 (NRB-96) [I–10] and confirmed by sanitary rules NRB-99 [I–11], which are regulating norms of the Federal law concerning the safety of humans affected by ionizing radiation [I–3].

Thus, in order to develop a long term stewardship programme, it is first of all necessary to carry out an assessment of the whole set of applicable Russian legislative, regulatory and methodological documents. On the basis of such an assessment, recommendations need to be developed for elimination of existing discrepancies, and clear definitions of the most important concepts should be given.

The next step towards improvement of the legal and regulatory framework in the field of radioecology should envisage determination of the main criteria and requirements for the design and implementation of long term stewardship programmes. The passing of bills and creation of normative documents taking account of new conceptual approaches to the problem of protecting the population and the natural environment against the effects of radiation (or the combined effects of radiation and chemicals), and long term control of radioactively contaminated sites, are a necessary stage of the life cycle. The main requirements are maintaining institutional control at sites with radiation hazards after their decommissioning and carrying out cleanup and other remediation work. Long term control will need to go beyond a time period of 10^2–10^3 years, considering the half-lives in the range of 10^3–10^6 years of relevant nuclides, but there is practically no precedent for this in rule making in the history of States.

Therefore, special attention needs to be paid to issues such as:

(a) Identification of sites that may need to be subject to long term stewardship;
(b) Procedures for the transition to the State of stewardship of such sites;
(c) Selection of principles and procedures as well as appointment of stewards (institutions responsible for long term control and management of sites);

(d) Forms and scope of institutional control;
(e) Concepts for monitoring the efficacy of natural and engineered protective barriers;
(f) Information management;
(g) Quality control and assurance.

I–4. IMPLEMENTATION OF STEWARDSHIP

I–4.1. Record keeping

Identification of sites that require long term stewardship is a first priority task, and this should be based on clear definitions and criteria laid down in the corresponding legal and regulatory documents. It is necessary to continue the development of an information system on radioactively contaminated sites (RCSs) and pertinent remediation and long term stewardship measures on the basis of the above definitions and international guidelines for their identification [I–12, I–13]. The information system should contain all sites in the country that are found to be contaminated as a result of:

(a) Radiation accidents;
(b) Nuclear weapons production and testing;
(c) Industrial nuclear explosions;
(d) Inadequate radioactive waste management and disposal;
(e) Industrial production linked with use of radioactive materials;
(f) Mining and processing of uranium and thorium ores;
(g) Enhancement of natural radionuclide concentrations as a result of non-actinide ore and fossil fuel extraction and processing.

This work will result in the formation of a geo-referenced information radioecological cadastre (GIRC) of the territory of the Russian Federation. It is envisaged to make the structure of the data tables of the GIRC compatible with the structure of the data in the worldwide Directory of Radioactively Contaminated Sites (DRCS) compiled by the IAEA [I–12].

I–4.2. Transition to stewardship

The precise determination of the procedure for transition of a site to the stage of long term stewardship is of significant importance. Depending on the type of site and its history, such a transition can be achieved on the basis of a decision of the competent executive powers either directly on completion of the decommissioning and remediation or irrespective of any countermeasures at all. Such decisions are usually made on the basis of an optimization, taking into account economic, technical or social and political criteria, which typically would not result in further remediation actions with a view to bringing the site to a greenfield state.

In practice, the transition to the stewardship stage can only be effected after a steward has been chosen and appointed. The steward is the entity that is to be charged with site administration, maintenance of institutional control and assurance of safety to the population. Longevity seems to be one of the main requirements of a steward. Unfortunately, Russia's history, particularly over the last century, does not give very many examples of the existence of such kinds of entity. A relative stability, perhaps, is inherent to the country's administrative and territorial division (provinces or oblasts), which had been formed in the main in the second half of the eighteenth century and still remains almost the same. The transfer of stewardship functions to executive bodies of the federation (republics or provinces) is an option that is worthy of serious consideration. It is obvious that the regulations and methodological support for the activities of stewards would need to remain the competence of the central Federal structures.

The forms and limits of institutional control (including rights and liabilities of entities in charge of long term stewardship) may be essentially different for the various types of site, but they should be in strict compliance with the general requirements and approaches that are determined by the legislator and regulated by the rules and standards of the related executive powers.

The main goal of institutional control is to prevent deterioration of the environment at the site, to minimize radiation risk to the public and the natural environment, and to provide favourable conditions for the use of the remaining resources and other potentials of the site in the interests of society. At the same time, it is reasonable to take into account and utilize for long term stewardship those approaches and measures for risk minimization that have proved to be efficient in the preceding stages of the life cycle of the site.

Thus, in the area affected by the activities at the Mayak combine in the valley of the Techa and Iset rivers (Chelyabinsk region), construction of a sequence of water reservoirs in the upper Techa river turned out to be the most effective measure with respect to an abatement in the exposure of the local population (Ref. [I–2], p. 124). For the Chernobyl induced ^{137}Cs contamination, the socially and economically best results in minimizing the radiation risk were achieved by administrative measures, for example, by making the transition from agriculture to forestry (^{137}Cs concentration reduction by a factor of 10^2–10^3), from arable farming to cattle breeding (10–10^2) or from vegetable cultivation to cereals production (five times) (Ref. [I–2], p. 386).

I–4.3. Monitoring

Environmental, including radiation, monitoring, as well as monitoring of the condition of engineered protective barriers, is an indispensable component of active institutional controls. The extremely long time horizon of stewardship leads to the expectation that there will be various generations of monitoring technologies. The management of monitoring activities should include the assessment of technological progress and timely re-equipment of the respective systems in order to provide up to date services.

For instance, the use of wireless sensor networks seems to be very promising. Their efficiency is expected to grow in the coming decades due to rapid progress in the field of nanotechnologies and the manufacturing of highly sensitive (particularly for chemical compounds) sensors, as well as progress in the field of the associated computer technologies. This is of special importance for applications connected with the monitoring of the combined effects of radiation and chemicals.

I–4.4. Information management

The formation and development of information support systems for the programme of RCS remediation and long tem stewardship is a basic condition for success in this direction. As was mentioned above, the development of a GIRC for the territory of the Russian Federation should be one of the first steps. Information management systems in the field of post-remediation control should also include monitoring data on the environment and the condition of engineered barriers, legal and normative documentation, chronology of events at every site and around it, etc.

Issues of information storage should be solved taking into account data categorization (critical, necessary or useful), unavoidable changes of data media types during the long term stewardship period, and data access requirements.

Special attention should be paid to the issues of data quality and data adequacy, as the quality of decisions made depends on such factors. It is evident that decisions made on the basis of invalid and incorrect data can lead to an increase in the hazards to human health and the natural environment, as well as to a loss of public confidence. Therefore the development of requirements for data quality assurance will become a permanent element of the regulatory activities, and these requirements should be included in the basic set of documents for each of the sites.

I–4.5. Decision aiding

In the context of complex remediation and post-remediation control projects, decisions on technologies and techniques to be applied, considering the set of natural, social and economic factors as well as the external constraints (e.g. financial, legal and organizational), require in-depth systems analysis. Efficient tools for support of decision making in this field are required. Such needs can be met by the development of a strategic plan for the environmental remediation of RCSs and their long term stewardship in the Russian Federation. The plan would:

(a) Be a basis for decision making by competent executive bodies or by the management of enterprises with respect to environmental remediation strategies and post-remediation control;
(b) Be a basis for selection of remediation programmes at RCSs, as well as of systems, technical means and procedures for post-remediation control;
(c) Include technical and economic assessments of the efficiency of the implementation of specific remediation programmes, with a special emphasis on reduction of the level of vulnerability of the population and the environment to the radiation and chemical risk factors;
(d) Facilitate decision making, taking into account the interest of regions and the local population.

I–5. CONCLUSIONS

It may be stated at present that, although vast territories in the Russian Federation are recognized to be radioactively contaminated, the contribution of radiation risks to the total risk, including toxic chemicals, transport accidents and societal deterioration, to human health and the natural environment is rather small. Nevertheless, the Federal Agency for Atomic Energy and the nuclear community as a whole do not consider it possible to reduce their efforts in protecting the population and the natural environment from the possible effects of radiation. The task of protecting the natural environment around nuclear sites and nuclear power plants, of remediating land contaminated with radionuclides as a result of nuclear weapons tests or major radiation accidents, and of dealing with wastes arising from routine operation of the nuclear naval and civilian fleets, remains one of the top priorities for ROSATOM’s activities.

It is evident that remediation efforts will entail significant expenditures and will take many decades to complete. This is why setting priorities in remediation policies based on strictly justified criteria and authorized by the competent State governing bodies, as well as the development of a national long term stewardship programme, are among the most pressing tasks at present.

Long term stewardship encompasses the arrangements for a system of post-remediation measures for the administration and control of sites, including the management responsibilities, legal regime, environmental monitoring and a complex of measures to provide for safety and security.

It is clear that a great deal of time, effort and money will be required to develop the necessary set of regulatory documents and the basic concepts for post-remediation long term institutional control and information management at the stewardship stage. This problem should not be underestimated, as it is a major future challenge.

REFERENCES TO ANNEX I

[I–1] LEBEDEV, V.A., "The radiation legacy of Russia", Radiation Legacy of the 20th Century: Environmental Restoration (Proc. Int. Conf. Moscow, 2000), IAEA-TECDOC-1280, IAEA, Vienna (2002) 9–29.

[I–2] ALEKSAKHIN, R.M., et al., "Major radiation accidents: Aftermaths and countermeasures", Major Radiation Accidents: Aftermaths and Countermeasures (ILYIN, L.A., GUBANOV, V.A., Eds), Izdat, Moscow (2001).

[I–3] RUSSIAN FEDERATION, Federal law of 09.01.1996, No. 3-FZ: On radiation safety of the population, Rossiiskaya Gaz. (17 Jan. 1996).

[I–4] LOGACHEV, V.A., et al., USSR Nuclear Tests: Present-day Radioecological Condition of the Test Sites, Izdat, Moscow (2002).

[I–5] LOGACHEV, V.A., et al., Peaceful Nuclear Explosions: Providing General and Radiation Safety When Conducting Them, Izdat, Moscow (2001).

[I–6] RUSSIAN FEDERATION, Regulations for the State Control and Accounting of Radioactive Wastes in the Russian Federation, Government Decree of 11.10.1997, No. 1298.

[I–7] ORLOV, Y., et al., "Radiation survey of on-shore maintenance bases in the northwestern region and problem of their rehabilitation", Ecological Problems of Nuclear Powered Submarines Decommissioning (Proc. Int. Sem. Severodvinsk, 2001), Onega Research and Design Bureau, Severodvinsk (2001) 126–128.

[I–8] RUSSIAN FEDERATION, Federal law of 10.07.2001, No. 92-FZ: On special ecological programs of rehabilitation of radioactively contaminated land sites, Rossiiskaya Gaz. (18 Jul. 2001).

[I–9] RUSSIAN FEDERATION, Methodical Guidelines on Remediation of Lands Contaminated with Man-Made Radionuclides, MINATOM, Moscow (1997).

[I–10] RUSSIAN FEDERATION, Radiation Safety Regulations — 1996, Rep. NRB-96, ROSENERATOM, Moscow (1999).

[I–11] RUSSIAN FEDERATION, Sanitary Rules SP 2.6.1.758-99, Ionizing Radiation Safety: Radiation Safety Regulations, Rep. NRB-99, ROSENERATOM, Moscow (1999).

[I–12] INTERNATIONAL ATOMIC ENERGY AGENCY, Design Criteria for a Worldwide Directory of Radioactively Contaminated Sites (DRCS), IAEA-TECDOC-1251, IAEA, Vienna (2001).

[I–13] FALCK, W.E., "The IAEA directory of radioactively contaminated sites (DRCS)", Waste Management 2004 (Proc. Int. Conf. Tucson, 2004), WM Symposia, Inc., Tucson, AZ (2004) CD-ROM.

Annex II

AECL'S APPROACH TO MANAGING LONG TERM LIABILITIES AT CHALK RIVER LABORATORIES

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Abstract

Chalk River Laboratories (CRL) is a large nuclear research and development/industrial site operated by Atomic Energy of Canada Limited (AECL). Construction of the site started in 1944, and it now includes over 100 buildings/facilities operating in various nuclear fields. A well developed decommissioning programme exists at CRL, with progress being made on decommissioning older redundant buildings, in parallel with ongoing site operations and development. The decommissioning programme is predicated on the assumption that the current nuclear operations will continue over a 100 year operating period, but with a decline towards the end of the period. Although decommissioning and remediation work will be carried out throughout the operational period, residual levels of activity remaining in a few areas will require institutional control (IC) for an assumed period of 300 years. The intention is to complete all necessary active remediation work before the start of the IC period and thereafter rely only on passive means to reduce residual contamination to levels that do not require IC measures. The latter include environmental monitoring, active and passive controls to prevent intrusion, and management controls to prohibit access or development. A formal information and records management programme at CRL has been initiated.

II–1. CHALK RIVER LABORATORIES SITE HISTORY AND CURRENT STATE

Chalk River Laboratories (CRL) is a large nuclear research and development/industrial site operated by Atomic Energy of Canada Limited (AECL). The CRL site consists of a 70 hectare developed (industrial) site located within a larger undeveloped area (a supervised area of 37 km^2 (or 3700 hectares)) that serves primarily as an exclusion zone (Fig. II–1). The developed area, or inner area, includes over 100 buildings and facilities (Fig. II–2).

Construction of the CRL site started in 1944, and its development and operating history includes the construction and operation of seven research reactors and numerous associated/supporting nuclear laboratories. The

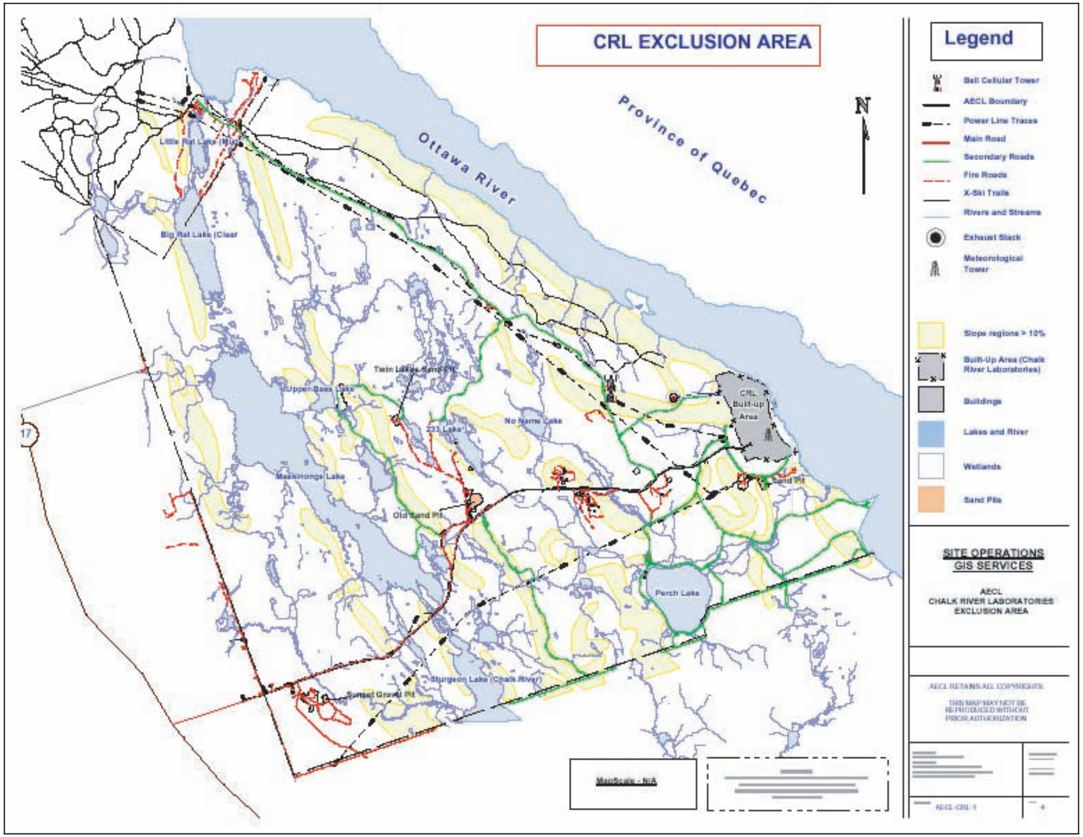

FIG. II–1. CRL site — the supervised area.

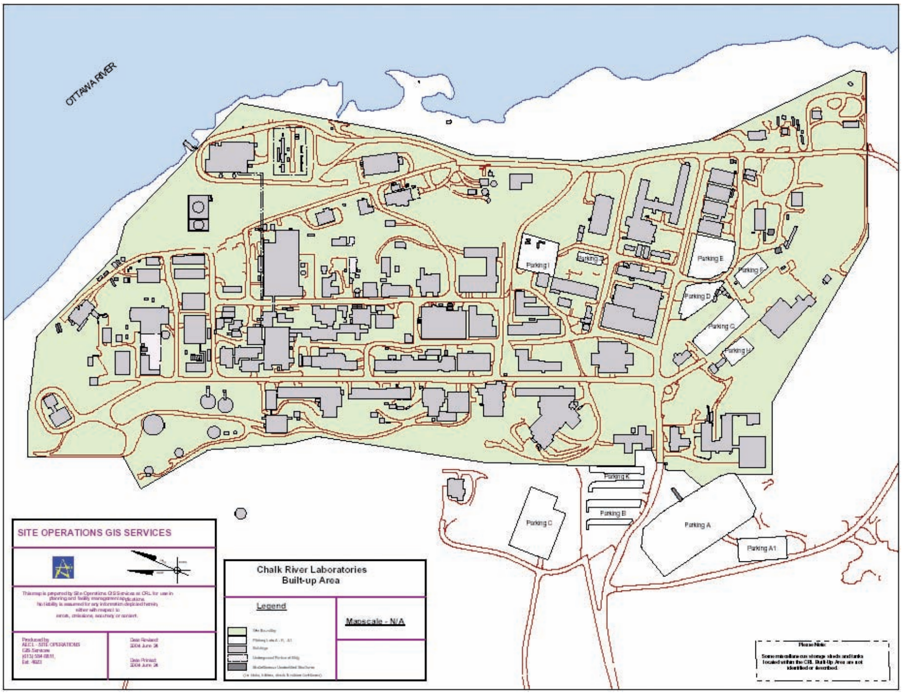

FIG. II–2. CRL site — the developed area (controlled area).

development and operation of the site can be broadly divided into two phases. The initial phase, starting in 1945 when nuclear research began, was oriented towards the production and recovery of plutonium and ^{233}U (i.e. the defence role). Hence, the facilities constructed in the early years included, in addition to one laboratory scale test reactor and one larger research reactor (20 MW(th)), facilities for processing irradiated uranium and thorium and packaging the recovered products, as well as development laboratories, administrative buildings and facilities for key site support services.

In the second phase, starting in 1954, the research focus shifted to include the application of nuclear technology to electric power generation based on the natural uranium fuelled, heavy water moderated concept, subsequently dubbed CANDU (CANada Deuterium Uranium). By the late 1950s the defence role ended. To support the new mandate, existing facilities were used and new facilities were constructed, for example, facilities for fuel development and for fabrication, testing and post-irradiation examination of fuels and reactor components. In addition, engineering programmes were initiated to support the development of prototypes for the CANDU nuclear power reactor and advanced reactor concepts. Support facilities and services, such as machine and instrument shops, analytical laboratories, an engineering works, computation facilities, stores, a radiation protection unit, environmental and biological research laboratories, nuclear materials laboratories, waste management facilities, administration buildings and a cafeteria, were constructed as required.

At present, the site continues to operate in the fields of nuclear research and development, CANDU development and medical isotope production.

Within this operating environment, a number of buildings, facilities and reactors, particularly the facilities used during the initial phase of site operation, have become redundant and have been shut down for various reasons. Redundant buildings are currently shut down within the operating organization and turned over to the decommissioning organization for decommissioning, but in the early years, in the absence of a decommissioning programme, redundant buildings were most often simply placed in storage. As a result, there are a significant number of buildings at CRL that have been declared redundant (roughly 20), particularly those constructed in the early years of site development. Furthermore, with many buildings at CRL approaching the end of their design lives, a significant number of other buildings will become redundant during the next decade (an additional 20).

The second nuclear research site, Whiteshell Laboratories, of AECL is currently shut down and is undergoing decommissioning.

II–2. CRL DECOMMISSIONING PROGRAMME

II–2.1. Planning basis

One of the key objectives of AECL's Decommissioning Planning & Operations (DPO) programme is to decommission redundant facilities, buildings and land in an optimally safe and cost effective manner. The underlying principles applied to meet this objective are:

(a) To reduce/minimize health and safety (worker and public) risks, as well as health, safety and environmental (HSE) risks;
(b) To reduce/minimize decommissioning costs and business risks to site operations;
(c) To reduce/minimize future decommissioning costs;
(d) To accomplish the objective in a coordinated way that benefits the continued effective operation of the site for many decades.

To meet the objective of the top tier cost–risk optimization programme, the decommissioning programme is risk based, with one of the key management tools being a prioritization process, in turn supported by the types of technical evaluations described later in this annex. The prioritization process is a methodology that identifies, assesses and ranks (prioritizes) HSE and business risks in a systematic fashion. Through this process, major top priority initiatives have been undertaken to reduce HSE risks and to make advances towards achieving the desired end state of the site.

A site-wide (CRL) decommissioning plan provides the overall planning basis for not only the most significant facilities such as research reactors but also the lesser facilities (administrative buildings), the waste management areas (WMAs), contaminated (affected) land and site infrastructure (e.g. active drain piping). Also listed in the plan are 'enabling facilities' that will be required in the future in order to carry out the work in a safe and cost effective manner.

In general, the CRL decommissioning plan employs the following decommissioning strategies:

(a) *Prompt removal*: From turnover to a decommissioned site in less than two years (e.g. administrative buildings and laboratories).
(b) *Deferred removal*: To allow for additional storage to facilitate dose reduction (e.g. research reactors). (Note that where deferred removal is the optimal approach, the decommissioning activities are structured around a three phase approach — initial decommissioning to prepare the building for storage, which involves establishing a safe, secure storage state, including the removal of hazards and the modification of the building structure and supporting systems, followed by storage with surveillance and maintenance, followed by final decommissioning (e.g. dismantlement.)
(c) *In situ disposal*: Where predicted future doses are low enough that the costs involved in retrieving and repackaging the wastes are not justified (e.g. low level waste management facilities).

The current use of the CRL site can be expected to continue for the foreseeable future; hence the reference planning assumption for the CRL decommissioning programme is that the site will continue to operate for a 100 year period (with concurrent decommissioning of facilities that become redundant), but at some point the operations will decline in scope. It is also assumed that, over this period of time, one or more waste disposal facilities will be constructed at the site, for example, a shallow rock cavity for low and intermediate level wastes and/or an intrusion resistant underground structure for near surface burial of low level wastes. Furthermore, for planning purposes it is assumed that by the year 2100 nuclear R&D/industrial activities will have terminated, that at that time most facilities will have been decommissioned and that the facilities constructed in the most recent decades will be undergoing decommissioning. The last tier of decommissioning will be to remove the enabling facilities required for the final decommissioning of the site. Closure of the waste disposal facilities would also occur at this time. Therefore, by 2100, most facilities/buildings will have been removed and the building sites taken to a final end state of unrestricted use or industrial reuse, but a small number (e.g., certain waste management areas) will have been qualified for long term institutional control (IC). Similarly, most affected land will have been stabilized and qualified, through remediation and monitoring programmes, for either unrestricted use or industrial reuse, but some will be subject to long term IC.

Another key reference planning assumption is that, following the 100 year operating period, the IC period will last for 300 years (based upon the radioactive decay of residual ^{90}Sr and ^{137}Cs, i.e. roughly 10 half-lives). During the IC period the areas within the site requiring IC will reduce in hazard (passively through radioactive decay and dispersion), and by the end of the period all such areas will qualify (substantiated by continued monitoring) for industrial reuse. Therefore, following the reference 300 year IC period, all areas of the site will have been qualified for reuse with minor, if any, restrictions.

There are different types of uncertainty identified at this time that could influence the evolution of the CRL decommissioning plan; those that could influence the assumed final end state of the site include:

(a) Uncertainties in the nature and extent of the liabilities (characterization uncertainties);
(b) Uncertainties in the future use of the site, and corresponding regulatory requirements and responses;
(c) Technical uncertainties (technical capabilities in remediating the sites).

Given these uncertainties, it is possible that the IC period could be extended beyond 300 years.

A discussion of the management and physical measures to be applied during the IC period is provided in Section II–2.5.

II–2.2. Site characterization

The uncertainties regarding the effects of past operations/activities on the environment are resolved to the extent possible through the following types of characterization work:

(a) Research and documentation of the history of past operations/facilities (historical site assessments (HSAs));
(b) Characterization of the surface and subsurface physical conditions at the sites (field studies — features mapping and geophysical surveys);
(c) Characterization of the environmental impacts from past activities/operations (field studies — surface water, groundwater, soil, marine sediments, vegetation and ambient radiation);
(d) Characterization of the conditions of waste storage structures via condition assessments (field studies — excavations of buried structures and groundwater monitoring).

Given the complex nature of the site (its history, use and age), a considerable effort will be required to develop a thorough understanding of the conditions present. While progress is being made through the field programmes, the characterization requirements have gradually increased with time, with (for example) the identification of new (undocumented) affected land, as well as the recent requirements to evaluate new (non-radiological) parameters and the impacts of radiological and non-radiological parameters on non-human biota. Another issue, related to the first example, is the loss of historical knowledge (process knowledge) that is occurring as the number of employees from the early years of site operation remaining alive falls. The interviewing of these individuals is a key source of information in researching the history of the sites, and there is an increasing urgency to complete HSAs in order to document the remaining available knowledge.

The intention in the CRL decommissioning programme is for site characterization work (with ongoing environmental monitoring) to be carried out throughout the 100 year site operating period, with only monitoring continuing into the ensuing IC period, but, given the uncertainties discussed previously, it may be necessary to carry out further characterization work during the IC period.

II–2.3. Monitoring programmes

Data from the monitoring of environmental conditions in the groundwater and throughout the biosphere are an essential input to the risk based decommissioning programme. While the monitoring of certain waste management areas was initiated in the 1950s (e.g. periodic plume studies), the scope of environmental monitoring has gradually expanded over time. In 1997, the programme was formalized, and is currently subject to optimization and integration with other similar monitoring programmes at CRL, as well as the AECL environmental management system.

The different types of monitoring carried out at CRL are oriented towards evaluating the behaviour of waste storage facilities, disposal facilities (dispersal pits) and contaminated sites (affected lands), as well as the operation (effectiveness) of plume interception and treatment systems. Groundwater quality is the focus of the decommissioning programme's groundwater monitoring programme (GWMP) but, through integration with the AECL environmental (surface water) and effluent (facility effluents) programmes, a broad range of environmental data are available to the decommissioning programme. Additional media such as vegetation, marine sediments and soils are sampled and analysed as part of the characterization work discussed previously, enabling a comprehensive understanding of the fate of contaminants in the environment.

The monitoring programme includes both radiological and non-radiological parameters, and although the monitoring programmes have been oriented towards protection of humans (under the assumption that other organisms would be reasonably protected), the programmes are evolving towards evaluation of the potential effects on non-human biota in different compartments of the ecosystem, i.e. independently of the evaluation of potential effects on humans. An ecological effects review (EER) was recently carried out at CRL, and the results will be used to define/derive environmental markers (benchmark concentrations) to evaluate potential environmental impacts.

The temporal and spatial characteristics (trends) indicate that the environmental conditions downstream of the WMAs and affected lands are most often either stable or improving with time. Where conditions are observed to be degrading or changing suddenly, investigative (characterization) studies are initiated, in some cases leading to remedial measures (e.g., infiltration barriers, plume interception and treatment systems).

Continued monitoring will generate data that will be essential to safety cases for the in situ disposal of candidate sites. As such, monitoring will be carried out throughout the operational phase of the site, as well as throughout the IC period, although at a reduced scope. The planning assumption is that monitoring will be discontinued at the end of the 300 year IC period once the site has been fully released for reuse, but because of uncertainties it is possible that the IC period (and the requirement for monitoring) may need to be extended.

II–2.4. Remediation activities

To achieve the desired end state for the site of industrial reuse without IC, all hazard sources must be reduced by active or passive means to the residual levels deemed to be reasonably low. With the passive means of decay being of benefit to only radionuclides with half-lives shorter than 30 years (^{90}Sr and ^{137}Cs), elevated concentrations of the longer lived nuclides must be reduced by active remediation measures in order to achieve the desired site end state. Accordingly, the planning assumption is that this remediation work will be carried out during the 100 year site operational period, with the residual concentrations of contaminants being low enough that sufficient hazard reduction can be achieved over the IC period by passive means. As discussed previously, ongoing environmental monitoring is an essential element of this approach.

Progress has been made at CRL in implementing active remedial measures, for example:

(a) Three plume interception and treatment systems are in operation (one passive and two active), and a fourth system is being designed.
(b) Two waste management sites are equipped with infiltration barriers.
(c) Hazard sources have been removed at several sites.

Remedial actions are assigned on a priority basis as an outcome of the decommissioning prioritization process, with the technical input to this process including characterization and monitoring data. Progress towards reducing risks and liabilities through remediation continues to be made, but the evolution of environmental protection into protection of non-human biota, and protection against non-radiological parameters, introduces uncertainties in future remediation requirements. Protection of non-human biota may not be a significant issue at CRL, based on the results of the CRL EER — the maximum exposures to the most sensitive species were judged to be ‘probably unimportant’ to the assessment end point of population abundance. Protection against non-radiological parameters may be a more significant issue, as elevated concentrations of certain metals and organic compounds exist in the groundwaters downstream of some of the WMAs (including an inactive landfill site).

The intention is for all active remedial work to be completed before the start of the IC period; however, given the uncertainties discussed previously, it is possible that additional active remedial measures may need to be carried out during the IC period.

II–2.5. Management and physical measures for institutional control

Although the CRL site is expected to continue to operate as a nuclear industrial site for many decades to come (100 years is assumed for planning purposes), basic planning for the protective measures to be applied during the IC period has been carried out, and initial progress has been made towards the installation of protective barriers.

The intention is to apply both active and passive controls, with the active controls being applied in conjunction with the basic monitoring and surveillance required over the period. The types of control include:

(a) Provision and maintenance of signs, fences, gates, locks, lighting, etc.;
(b) Excavation barriers to prevent unintended intrusion into subsurface hazard sources (e.g. concrete caps and infiltration barriers);
(c) Regular patrols of the site by security personnel;
(d) Placement of permanent markers (probably granite) to delineate and identify the hazardous sites.

Land ownership is the most compelling management measure to be applied — it is assumed that ownership of the site will be retained by AECL or the Federal government during the IC period. Additional measures, however, will be applied to protect against failure of this provision, including:

(a) Records of the site and hazardous zones retained in the Ontario land registry office;
(b) Marking of the site on topographic maps and marine charts of the adjacent Ottawa River;
(c) By-laws and bills incorporated into municipal, county, provincial and Federal statutes warning against intrusion into, or development of, the site;
(d) Regulations issued by Environment Canada and the Ontario Ministry of the Environment prohibiting access to or development of the site;
(e) Registration in property deeds and/or municipal offices of caveats on land use.

II–2.6. Information and records management

With the CRL decommissioning programme based upon key planning assumptions such as a 100 year site operational period followed by a 300 year IC period, the management of information and records required to support the decommissioning programme is of considerable importance. The development of a formal information and records management programme was initiated in recent years at CRL and is progressing, with a focus on both near term and long term needs.

The near term needs are associated more with ongoing decommissioning activities at the site — efficient and effective planning, assessment, storage and execution of decommissioning projects are highly dependent on a sound information base upon which decisions can be made. Accordingly, key elements of the programme include:

(a) Creation of a decision process for sorting the information available into different categories of importance, with different retention and storage requirements (for protection against inadvertent destruction of essential records);
(b) Creation of an electronic information database that provides easy access of information to decommissioning staff to support their decommissioning activities (which includes establishing the database framework, then populating the database by scanning records).

These tasks are significant because of the large volume of information available, the broad range of types of information available (drawings, logs, memos, reports, photographs, maps, notes and forms) and variations in format in different storage media (paper, film and electronic). The diverse range of activities at the site over the years and the length of site operations are the other factors that add to the complexity. While the newer facilities at CRL will benefit from modern views on the importance of retention of records, in the early years of site operation the need for documentation and retention of information for later decommissioning (and IC) purposes was not recognized. Early waste disposal records, for example, do not always provide details as to nuclide content, waste size or, in some cases, the specific location of the waste emplacement. Over the decades of site operation, records have been destroyed because the retention periods defined did not recognize the long term needs, and in one case a building containing key waste management records was destroyed by fire. As a result, the quantity and quality of records from the early years is variable. This variability complicates the development of criteria for categorizing the importance of records.

The longer term needs are more associated with ensuring that records are securely retained over the site operational period and the IC period that will follow (i.e. 400 years in total). With decommissioning activities ongoing over the operational period, secure storage and accessibility will be of benefit to future decommissioning activities, but over the IC period the records will be of benefit to future populations residing in the area, forming another type of IC measure (i.e. hazard and historical knowledge). Accordingly, the types of record that will be subject to long term retention include those dealing with:

— Concept development and site selection (including baseline environmental conditions);
— Design, construction and commissioning;
— Operations, maintenance and facility modifications (e.g. changes in use);
— Shutdown and decommissioning;
— Post-decommissioning (and in situ disposal) environmental monitoring.

With the importance of long term retention of records being recognized, a key element of the information and records management programme is the collection, organization and storage of the records required for long term retention, i.e. records management. This task is significant because important records are at present stored in numerous locations, in different types of storage facility (ranging from fireproof vaults to cabinets in basement areas), each with different levels of protection. In addition, these records are stored following different practices by different organizational units, raising jurisdictional issues. With the retention requirements (duration, protection and control) of the decommissioning programme far exceeding those of current holders of records, the jurisdictional issue is a challenge.

In order to quantify the issue regarding storage conditions, and to initiate improvements for reducing the risks of record loss due to events such as fire and flooding, a records storage risk assessment programme is being developed at CRL. To date, a review of best practices for records storage (per published guidance or design information for modern archival facilities) has been carried out, and a risk assessment checklist has been generated. This checklist will be used to evaluate the hazards and protective barriers/features at the different storage facilities at CRL. The results of this programme will also provide the justification needed to pursue a project for the design and construction of a centralized modern records storage facility that meets the needs of the decommissioning programme.

II–3. STEWARDSHIP PROGRAMME

II–3.1. Stewards and stewardship planning and funding

As described previously, and summarized below, the CRL decommissioning programme includes all of the core elements of a stewardship programme. In addition, stewardship planning is included in the decommissioning planning documentation. It can therefore be said that a reasonable stewardship programme exists (within the decommissioning programme), and the programme is documented in the planning documentation.

The future steward beyond the continued operational period is envisioned to be either AECL or some other Federal agency. The current funding sources for the decommissioning programme also finance the stewardship activities, and this funding structure is also the model for the future.

II–3.2. Remediation and institutional control requirements

At the CRL site, an IC period of 300 years is a key assumption in the decommissioning plan for the site. This period will follow after an assumed 100 year operating period in which the current nuclear R&D/industrial operations at the site (and ongoing decommissioning activities) will continue for decades, but with an assumed decline in site operations/activity towards the end of the operational period.

At the end of the 100 year operational period, most facilities will have been decommissioned, and the facilities constructed in the most recent decades will be undergoing decommissioning. The last tier of decommissioning will be to remove the enabling facilities required to decommission the site. Closure of any waste disposal facilities at the site would also occur at this time. Therefore, by the end of the operational period, most facilities/buildings will have been removed and the building sites taken to a final end state of unrestricted use or industrial reuse, but a small number (e.g. certain waste management areas) will have been qualified for long term IC. Similarly, most affected land will have been stabilized and qualified, through remediation and monitoring programmes, for either unrestricted use or industrial reuse, but some will be subject to long term IC.

The intention is to complete all necessary active remediation work before the start of the IC period and rely only on passive means (decay and dispersion) to reduce residual contamination to levels that do not require IC measures. However, because of uncertainties (characterization, technical and regulatory), it may be necessary to carry out additional active remedial work during the IC period. Similarly, although the intention is for the entire CRL site to have been qualified for industrial reuse by the end of the 300 year IC period, it may be necessary to extend the IC period.

Recognizing that residual hazards will remain at a few areas on the CRL site during the IC period, the types of IC measure planned to be instituted include:

(a) Environmental monitoring (to support the case for termination of the IC period, i.e. removal of the need for a licence);

(b) Active and passive controls to prevent inadvertent intrusion (e.g. signs, fences, excavation barriers, patrols of the site by security personnel and permanent markers);
(c) Management controls (e.g. by-laws, bills, regulations and land use caveats on registered property deeds prohibiting access or development of the site).

With regard to the stewardship requirement to securely store site records for the duration of the site operational period and the ensuing IC period (totalling 400 years), the management of information and records at CRL is of considerable importance. The development of a formal information and records management programme has been initiated and is progressing with a focus on both near term and long term needs. Key aspects include:

(a) Development of a decision process (with criteria) to use in sorting the information available into different categories of importance, with different retention and storage requirements (to protect against inadvertent destruction of essential records);
(b) Collection and organization of the records required for long term retention (to consolidate the many collections of records at CRL);
(c) Appraisal (risk assessment) of the existing records storage facilities in order to initiate improvements (near term objective) and to quantify the need for a centralized modern records storage facility that provides the degree of protection required (long term objective).

Cumulatively, these activities represent a reasoned approach to the stewardship issues associated with the management of long term liability issues.

II–4. CONCLUSIONS

The stewardship challenges associated with the management of long term liability issues at CRL are addressed within the decommissioning programme for the site.

The CRL decommissioning programme is predicated on the assumption that the current nuclear R&D/industrial operations at the site (and ongoing decommissioning activities) will continue over a 100 year operating period, but with a decline in site operations towards the end of the period. Although decommissioning and remediation work will be carried out throughout the operational period, which will result in the removal of most hazard sources, there will be residual levels of activity remaining in a few areas that will require

IC, for a period that is assumed to last for 300 years. During the IC period, the areas within the site requiring IC will reduce in hazard (passively, through radioactive decay and dispersion), and all such areas will qualify (substantiated by continued monitoring) for industrial reuse by the end of the period.

The CRL decommissioning programme includes all of the core elements of a stewardship programme, i.e.:

- Site characterization and remediation (active and passive);
- Environmental monitoring;
- IC measures (active and passive physical measures, and management measures);
- Information and records management (retention).

Because of the complex operational history of the site and the resulting wide range of long term liability issues, progress in the areas of characterization and remediation has been challenging. Nevertheless, progress is being made with these and the other stewardship issues, and taken together these activities represent a reasoned approach to the management of long term liability issues.

Annex III

INSTITUTIONAL CONTROL: FOLLOWING SITE CLEARANCE

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Preamble

The annex presents the views of the author. It is not a statement of the United Kingdom position on these matters and it does not necessarily reflect the views of the Health and Safety Executive or the Nuclear Installations Inspectorate. It was prepared with the aim of stimulating discussions during the preparation of this Technical Report.

Abstract

The current position in the United Kingdom on the continuing management of contaminated sites following cleanup is reviewed. The requirements are placed in the current regulatory and practical context. This is timely as at present the existing policies on site clearance and radioactive waste management are under review. The topic is set in context. The various regulatory regimes and current policy are described. The pressures for examination of options are explained and potential changes considered.

III–1. CONTAMINATED SITES IN THE UNITED KINGDOM

Sites that are or have been contaminated with radioactive materials in the United Kingdom (UK) include nuclear power stations, reactor fuel fabrication plants, research and experimental reactor facilities, waste storage facilities, fuel reprocessing facilities, current and previous military establishments, the sites of old luminizing works, disposal locations, isotope production facilities, and industrial sites involving, for example, uranium catalysts, thoria and rare earth works. Each of these has characteristics specific to the site, with both the practicality and standard of cleanup varying from site to site. Some of these sites have been contaminated from events many years ago.

At the present time the old research laboratories, trial reactors and nuclear chemical plants associated with the UK nuclear power programme are at various stages of decommissioning. Land remediation is an important aspect of this work. Different sites are at various stages of planning for, or achieving, this task. Similarly, the earlier generation of nuclear power stations has reached the stage of being taken out of service, fuel removal, waste treatment and decommissioning. This work is well advanced in the case of those plants that have been out of service for some time.

Radioactive waste in the past has been disposed of by burial in the ground or, for liquid and gaseous wastes, by dispersal ('dilute and disperse' was an accepted technique in the past). Not all of these disposal techniques would be accepted under current standards for waste management. Radioactive contaminated land also remains as a consequence of past (non-nuclear) industrial processes. Separate regulations apply to the various categories of site.

III–2. REGULATORY ENVIRONMENT OF THE VARIOUS CATEGORIES OF SITE

III–2.1. Non-licensed sites

The regulation of radioactive waste disposal at all sites is undertaken by the Environment Agency. The Scottish Environment Protection Agency regulates an equivalent regime in Scotland, as does the Industrial Pollution and Radiochemical Inspectorate in Northern Ireland. Although the regulatory regimes of the three agencies have detailed differences, they are sufficiently similar to be considered together. Reference in this annex to the 'agencies' should be read to refer as applicable to each of these environment agencies. The regulation of radioactive waste disposal by the relevant environment agency applies to all sites in the UK, including nuclear licensed sites, which are described below.

Except in the case of nuclear licensed sites, which are described below, the agencies also regulate the registration for the use and accumulation of radioactive material under the Radioactive Substances Act 1993 [III–1] and, if there is a change of use of the site, the cleanup of the site in association with the relevant local authority (LA) under planning legislation. In association with the LA for each area, the agencies also enforce the requirements for contaminated land management associated with non-radioactive contamination on sites, including nuclear licensed sites.

The environment agencies, being the bodies that grant authority for waste disposal (including disposal on, and from, nuclear licensed sites), increasingly impose requirements on the site operator as a part of the approval process. To implement the European Commission (EC) Landfill Directive [III–2], the landfill regulations came into force in England and Wales in 2002 [III–3], with equivalent controls being introduced in Scotland in 2003 and in Northern

Ireland in 2004. This is a licensing regime for non-radioactive material. It is being backfitted to existing waste disposal facilities. In some cases, site cleanup can require burial of significant quantities of radioactive material and non-radioactive waste either on-site or off-site. The major disposal facilities for low level radioactive waste are located at nuclear licensed sites. Additional controls apply as a consequence. There are no intermediate or high level waste repositories in the UK.

In the specific case of non-radioactive material, the contaminated land regulations (Part IIA of the Environment Protection Act 1990 [III–4], inserted by Section 57 of the Environment Act 1995 [III–5], which came into force in 2000) require potentially contaminated locations to be identified and recorded by the LA. These regulations introduce the requirement that a site must be classified as being contaminated if all of the following are found to exist: a source of pollution, a receptor of potential harm arising from the pollution with a pathway linking the source and the receptor, and whether 'significant harm' or 'significant possibility of significant harm' to a receptor exists. For certain categories of site, including nuclear licensed sites, if there is considered to be a significant pollution problem the LA can declare it to be a 'special site', thereby transferring the regulation of the site under these regulations to the appropriate environment agency. The liability for management and clearance of contaminated sites falls on the occupier of the land (unless the polluter can be identified). Owing to the requirement for a contaminated site to have a source, pathway and receptor, it is possible under these regulations to remove the contaminated status by removal or modification of any one of these three features.

There are currently no equivalent regulations for radioactively contaminated land.

III–2.2. Sites licensed under the Nuclear Installations Act 1965

The major nuclear sites in the UK are subject to the Nuclear Installations Act 1965 (NIA65) [III–6]. This act has application to all the regions of the UK: England, Wales, Scotland and Northern Ireland. It requires a licence to be held before specified work involving nuclear material may be undertaken. The licence is issued by the Health & Safety Executive (HSE), and the associated obligations are enforced by HM Nuclear Installations Inspectorate (NII). Conditions, on the licensee, accompany the granting of a site licence. These conditions cover all aspects of work undertaken on the site affecting health, safety and radioactive waste management. These are in addition to the requirements of the Health and Safety at Work Act 1974 [III–7], which are also enforced by HSE and apply to all workplaces in the UK. Once a licence has been granted, the liability on the operator of the site continues until the site has been remediated. The licence regime is continuous from the start of preparation work for the installation, through construction, commissioning, operation, dismantling and site cleanup.

The sites regulated under this regime include all civilian nuclear reactors, facilities associated with fuel manufacture and reprocessing, isotope production and management facilities, sites storing significant amounts of radioactive material and the major low level waste repositories, which are located in England and in Scotland. These are known as nuclear licensed sites. In addition to these civil facilities, a number of militarily related facilities have become licensed sites in recent years where the work falls into similar categories to those described above, and where the management of the facility is under the control of civilian personnel.

Two important factors in NIA65 [III–6], in respect of contaminated land and radioactive material buried on the site, are that all radioactive material on the site (not just radioactive waste) is regulated under the licence and that control applies to all aspects of the site, not just the nuclear related work. It is the site, not the process, that is licensed, and the licensing regime remains in place until the site has been cleared. In respect of radioactive material in the ground, whether placed there or resulting from leakage, this is regulated as an accumulation of radioactive material and the legal obligations for appropriate management of waste apply.

As the major nuclear installations of the UK are regulated under the Nuclear Installations Act 1965 [III–6], they are subject to a final end state of ‘no danger’ before the operator/licensee is relieved of their liability under the Act. This is referred to as ‘delicensing’ in this annex. The standard of clearance to be achieved for delicensing is very onerous and realistically it may be unachievable for the more complex sites.

In respect of the decommissioning of nuclear reactors (which will be on a licensed site) additional regulations apply: the Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999 [III–8]. These regulations, which are enforced by the NII, require potential and actual impacts on the environment to be addressed prior to commencement of decommissioning.

III–3. EXISTING POLICIES

The existing policy for decommissioning of nuclear facilities and radioactive waste management in the UK was established by the issuing in 1995 of a White Paper ‘Review of Radioactive Waste Management Policy: Final

Conclusions' (Cm 2919) [III–9]. This included the requirement for operators to manage their sites to achieve a systematic and progressive reduction of the hazard presented. Although there was no obligation upon a licensee to make the site fit for it to be delicensed, it has been assumed that the licensees would wish to move towards a situation where no danger from ionizing radiation remains on the site and the licensee's liability ceases. Under these arrangements, sites would move to a clean state where continuing institutional control might be expected to be necessary. However, this may not be achievable in some cases, and in other instances would take many years. In these circumstances, the institutional control required under the nuclear site licence will continue to be required.

For material in the ground the following controls are required, as far as is reasonably possible:

(a) Locating, characterizing and recording details of all nuclear matter on, or in, the site;
(b) Ensuring minimization, control and management of the material;
(c) Preparing a safety case for accumulation of the material in this condition;
(d) Mitigating the situation, if found appropriate;
(e) Undertaking monitoring to ensure the assumptions of the safety case are being maintained and to detect any change in this condition;
(f) Preparing a contingency plan and a programme for remediation of the situation.

These requirements are indicated in HSE/NII's guidance to inspectors [III–10]. Records are required to be maintained beyond the time when the site remediation has been completed. This institutional control will continue to be required even following partial remedial work.

The delicensing process itself is based upon a submission by the licensee for consideration by NII. The HSE has indicated in a paper in the Journal of Radiological Protection (1998) [III–11] what it expects to find in the submission. This includes:

— The history of use of the site;
— A report about the dismantling of the plant or buildings and the subsequent cleanup;
— Details of the management of radioactive waste;
— The arrangements for preservation of records;
— Evidence that no radioactivity remains on the site;
— Information on natural background radioactivity;
— Site survey information.

In addition, the NII will have an independent radiological survey undertaken. It is only when the above questions are considered acceptable that delicensing can be considered.

The above arrangements apply to nuclear licensed sites. These have clearly defined bodies responsible for management of the site and liable for the costs of remediation. The NII has powers to require the investigative work necessary to identify any contamination.

The situation regarding sites outside the nuclear licensing regime is more diverse and it is not certain yet that all contaminated sites have been identified. However, they will be known in many cases. For example, in the case when a site has been used for authorized disposal of radioactive material, the location will be fully documented and the applicable environment agency can require monitoring of the environment during the operational phase and a post-closure safety case supported by a continuing monitoring and institutional control regime.

Nevertheless, remediation of contaminated land on non-licensed sites does take place and has been completed successfully in many locations. The levels of clearance that have been used in the past have been guided by the 'below regulatory concern' level under the radioactive substances act: for artificial radioactivity the Radioactive Substances (Substances of Low Activity) Exemption Order [III–12]. These values have been assessed as satisfying the requirements of the 1996 EU Basic Safety Standards [III–13]. However, reduction of activity to these specific activities is not always justified on the basis of considerations of doses to workers, potential dose to future users of the site and waste management implications. Guidance on estimating doses from future land use has been developed by the National Radiological Protection Board [III–14]. The Board has also recommended the level of additional risk to a member of the critical group that should not be exceeded due to leaving contaminated land in place.

For non-radiological pollution, where the arrangements under the Part IIA regime [III–5] already apply, the LA has the responsibility to identify and record sites of contamination and to monitor these as appropriate. Remediation is the responsibility of the polluter or the landowner. Radioactive contamination does not, at the present time, fall under this regulatory regime but, upon identification, similar arrangements apply in practice. It is reasonable to expect that in each case the appropriate environment agency would be involved (a breach of the Radioactive Substances Act [III–1] may have occurred) and that the applicable agency's authorization would be required before any radioactive waste is disposed of, or removed from or left on the site. Institutional control can be expected to form one strand in the management arrangements required.

Guidance on good practice in decommissioning and associated waste management has been established by the SAFEGROUNDS project [III–15]. This is a national grouping consisting of representatives from government departments, regulators, non-government organizations (NGOs) and industry that was created in response to concerns about difficulties in estimating and managing contaminated land liabilities. SAFEGROUNDS specifically addresses land management at nuclear licensed sites and at those Ministry of Defence locations that are not licensed sites (some Ministry of Defence sites are licensed), but the advice has universal applicability. The guidance is that the option for site remediation should be developed with the involvement of stakeholders who may have an interest in the outcome and that the option selected should be based on a consideration of all relevant factors. This could mean that the option may not lead to complete remediation of the site. The SAFEGROUNDS guidance is that monitoring will usually be required after the elected remediation option has been implemented, as well as during the remediation process. It is recommended that post-remediation monitoring should make use of, and be consistent with, the approach used during implementation.

For many years, national agencies have monitored the environment in the UK for radioactivity on land and at sea. In particular, the Food Standards Agency in association with the environment agencies publish annually the Radioactivity in Food and the Environment report [III–16] of the results of the national surveillance monitoring programme of aquatic and terrestrial radioactivity around UK nuclear sites.

III–4. CURRENT DEVELOPMENTS

In view of the magnitude of the decommissioning of increasingly ageing nuclear facilities, the UK government is creating a dedicated agency, the Nuclear Decommissioning Authority, to take strategic responsibility for the cleanup and decommissioning of all UK public sector civil nuclear sites. This process has identified the key issues that require to be addressed to remove bottlenecks in or constraints on the future work; for example, waste handling facilities and clarity on the end point for remediation of contaminated sites.

The interpretation of ‘no danger’ in the context of delicensing of nuclear licensed sites has not been tested in the courts. When the site, or part of the site, that is being removed from the nuclear site licensing regime has not been subjected to contamination this is not a major problem: verification of no radioactive material remaining on the site using the criteria identified above enables removal of institutional control. Now that the UK decommissioning programme is accelerating, it will be necessary for HSE to judge whether sites with a more complex history are ready to be delicensed. The Health and Safety Commission has recently undertaken a public consultation on interpretation of the 'no danger' criteria. The responses to this consultation are currently being considered.

In considering matters relating to future decommissioning and site remediation, the UK government has recently issued a revision [III–17] of part of the policy on decommissioning covered by Cm 2919 [III–9]. The new policy statement covers all, both existing and new, UK nuclear facilities and their sites. This includes power stations and other reactors, research facilities, fuel fabrication and reprocessing plants, and laboratories on sites licensed under NIA65 [III–6]. It extends the breadth of application of Cm 2919 and includes the fusion research laboratory at Culham, relevant sites owned by the Ministry of Defence and nuclear submarines, as well as their liabilities.

The revised national policy emphasizes that decommissioning and remedial treatment or restoration of the land is a staged process and that the objective is to progressively reduce the hazard that the facility poses. The aim is 'in the longer term' to reduce the number of sites and the area of land remaining under regulatory control but to recognize that decommissioning operations may involve two or more separate stages spanning a number of decades. Institutional control will clearly be expected to continue in these circumstances. The revised policy notes that complete decommissioning to a point where there is unrestricted use of the site may not be possible nor be the best option in all cases. Once again continued institutional control will be required. A 'fit for purpose' decommissioning and waste management strategy will be expected for each site, identifying the proposed future use of the site and the maintenance of adequate site stewardship. Regulation will be expected to continue but will be proportionate to the level of risk to safety, the environment or security posed by the site. The NII's regulatory oversight will not be removed until the 'no danger' state has been achieved.

In addition to the revision of the UK policy on decommissioning of major nuclear facilities, the policies on radioactive waste management are also under review. The government has carried out a consultation under the title 'Managing Radioactive Waste Safely'. Following on from this, it has created an advisory body, the Committee on Radioactive Waste Management [III–18], with a membership having a wide range of skills. This committee has been set the task of proposing national waste management strategies for the long term protection of humans and the environment, and is expected to complete this by 2007. It is involving stakeholders and raising public awareness. The outcome of these considerations will inform UK waste policy development. Until the strategy has been implemented, waste material will accumulate on sites and institutional control will be essential.

Consultation with stakeholders is now the norm in decision making in the UK nuclear industry. The term stakeholder is defined widely. The involvement of various NGOs in this process has emphasized the importance of transparency and monitoring, as well as reporting of results. The use of so-called optioneering studies (the acronym BPEO for best practical environmental option is often used) that take account of all relevant factors is now widespread in the UK and is specifically expected by the government's decommissioning policy. The factors include waste management and disposal, costs, public acceptance, transport, intergenerational considerations, long term stability of the solution, radiological protection of the human and ecological environment, groundwater protection and institution control (lifetime costs and ability to be maintained).

Through ratification of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [III–19], the UK is committed to implementation of IAEA safety requirements. The IAEA has recently published its safety standard on remediation of contaminated areas [III–20]. This delineates the need for post cleanup surveillance and verification monitoring in addition to consideration of continuing controls. The recently published IAEA safety guide on exclusion, exemption and clearance [III–21] provides information for use in making decisions on clearance of bulk materials.

With the current progress of the UK decommissioning work, the importance of institutional control of sites that are not completely clear of radioactive material has been brought to higher prominence. In this regard, an IAEA publication on radiation protection principles for remediation of contaminated areas [III–22] suggests that acceptable end points for site remediation might include conditions where institutional restrictions are maintained.

The current absence of specific regulations for land contaminated by radioactivity equivalent to those for non-radioactively contaminated land (under Part IIA of the Environment Act 1995) [III–5] is currently being addressed by the UK government, and it is anticipated that legislation will be proposed in this area. Work to support this is under way. The details of the new regime have yet to be decided. If the source–pathway–receptor philosophy of the existing non-radioactive regulations is selected, it would imply that controlling the pathway could be critical and that monitoring would be necessary.

Water environment regulations have been introduced to implement the EU framework directive [III–23]. This directive is broad in its scope. The UK

Technical Advisory Group (TAG) has been established to develop both implementation strategy and guidance. The potential for contaminated land to affect groundwater would suggest at least a monitoring regime.

III–5. CONCLUSIONS

The current arrangements for land remediation are being implemented effectively. In respect of post-cleanup or partial cleanup:

(a) Institutional control is required on nuclear licensed sites until the site is deemed suitable for delicensing (i.e. unrestricted future use).
(b) Remediation to a state appropriate for future use or development implies maintenance of institutional control.
(c) Disposal facilities are subject to a monitoring regime and a control regime agreed with the relevant environment agency. This usually includes post-closure monitoring.
(d) A national programme of monitoring the environment around nuclear sites has been in operation for many years.
(e) A regime for the identification, recording and monitoring of contaminated land in all areas of the UK has been established for non-radioactively contaminated sites.

A number of current developments and reviews of existing site remediation considerations are under way. These may be expected to increase the circumstances requiring continuing surveillance:

(1) The revised policy for major site remediation suggests that at least some nuclear sites will have periods of extended institutional control before a state suitable for delicensing is achieved.
(2) The end point of remediation of the sites that are subjected to the nuclear site licensing regime is being developed.
(3) Groundwater protection arrangements are being developed and can be expected to involve a monitoring regime.
(4) The increased use of BPEO studies is expected to lead to the decision that in some cases complete removal of radioactivity from a site may not be the most appropriate option; institutional control could be the alternative selected.
(5) IAEA safety requirements are being introduced that could require institutional control.

Each of these areas is the subject of current work. Further information is expected to be available in the relatively near future.

REFERENCES TO ANNEX III

[III–1] ELIZABETH II, Radioactive Substances Act 1993 (c. 12), Office of Public Sector Information, London (1993), http://www.opsi.gov.uk/ACTS/acts1993/Ukpga_19930012_en_1.htm

[III–2] THE COUNCIL OF THE EUROPEAN UNION, Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, Off. J. Eur. Commun. (16.07.1999) L182/1–L182/19.

[III–3] DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS, The Landfill (England and Wales) Regulations 2002, Statutory Instrument No. SI 1559, Office of Public Sector Information, London (2002), http://www.opsi.gov.uk/SI/si2002/20021559.htm

[III–4] ELIZABETH II, Environmental Protection Act 1990 (c. 43), Office of Public Sector Information, London (1990), http://www.opsi.gov.uk/acts/acts1990/Ukpga_19900043_en_1.htm

[III–5] ELIZABETH II, Environment Act 1995 (c. 25), Part IIA, Section 57, Office of Public Sector Information, London (1995), http://www.opsi.gov.uk/acts/acts1995/Ukpga_19950025_en_5.htm

[III–6] ELIZABETH II, Nuclear Installations Act 1965, Office of Public Sector Information, London (1965).

[III–7] ELIZABETH II, Health and Safety at Work etc. Act 1974, Office of Public Sector Information, London (1974).

[III–8] THE SECRETARY OF STATE FOR THE ENVIRONMENT, TRANSPORT AND THE REGIONS, Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999, Statutory Instruments No. 2892, Office of Public Sector Information, London (1999), http://www.opsi.gov.uk/SI/si1999/19992892.htm

[III–9] RADIOACTIVE WASTE MANAGEMENT ADVISORY COMMITTEE, Review of Radioactive Waste Management Policy: Final Conclusions, Cm 2919, Office of Public Sector Information, London (1995).

[III–10] HEALTH AND SAFETY EXECUTIVE/NUCLEAR SAFETY DIRECTORATE, Management of Radioactively Contaminated Land, Guidance to Inspectors, Appendix 8, Rep. T/AST/024, Health & Safety Executive, London (2001), http://www.hse.gov.uk/

[III–11] ROBINSON, I.F., A nuclear inspector's perspective on decommissioning at UK nuclear sites, J. Radiol. Prot. **19** 3 (1998) 203–212.

[III–12] THE SECRETARIES OF STATE FOR THE ENVIRONMENT, WALES AND SCOTLAND, The Radioactive Substances (Substances of Low Activity) Exemption Order 1992, SI 1992, No. 647, Office of Public Sector Information, London (1992).

[III–13] THE COUNCIL OF THE EUROPEAN UNION, Council Directive 96/29/ Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation, Off. J. Eur. Commun. (29.06.96) L159/1–L159/29.

[III–14] OATWAY, W.B., MOBBS, S.F., Methodology for Estimating the Doses to Members of the Public from the Future Use of Land Previously Contaminated with Radioactivity, Rep. NRPB-W36, Health Protection Agency, London (2003).

[III–15] CIRIA, Good Practice Guidance for the Management of Contaminated Land on Nuclear and Defence Sites, SAFEGROUNDS Learning Network, CIRIA, London,
http://www.ciria.org/safegrounds/main_guidance.htm

[III–16] ENVIRONMENT AGENCY, ENVIRONMENT AND HERITAGE SERVICE, FOOD STANDARDS AGENCY, SCOTTISH ENVIRONMENT PROTECTION AGENCY, Radioactivity in Food and the Environment, Rep. RIFE-10, Office of Public Sector Information, London (2004).

[III–17] DEPARTMENT OF TRADE AND INDUSTRY, A Public Consultation on Modernising the Policy for Decommissioning the UK's Nuclear Facilities, DTI, London (2003).

[III–18] COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT, Information Centre, www.CoRWM.org.uk

[III–19] INTERNATIONAL ATOMIC ENERGY AGENCY, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997).

[III–20] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation of Areas Contaminated by Past Activities and Accidents, IAEA Safety Standards Series No. WS-R-3, IAEA, Vienna (2003).

[III–21] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Concepts of Exclusion, Exemption and Clearance, IAEA Safety Standards Series No. RS-G-1.7, IAEA, Vienna (2004).

[III–22] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of Radiation Protection Principles to the Clean-up of Contaminated Areas: Interim Report for Comment, IAEA-TECDOC-987, IAEA, Vienna (1997).

[III–23] EUROPEAN PARLIAMENT, THE COUNCIL OF THE EUROPEAN UNION, Directive 2000/60/EC of 23 October 2000 establishing a framework for Community action in the field of water policy, Off. J. Eur. Commun. (22.12.2000) L327/1–L327/72.

Annex IV

POST-REMEDIAL HANDLING OF URANIUM MINING AND MILLING RESIDUES

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Abstract

A considerable number of German uranium mining waste sites are located in Saxony. The remedial designs for those sites in need of long term monitoring and maintenance vary according to the specific radiological situation. Some general guidelines, which are adjusted on a case by case basis, have been developed concerning the covering of the waste rock piles and tailings ponds. The goal of any remediation is to provide for stable conditions over a period of 200–1000 years. The objective for flooding the mines is to arrive at natural background concentrations in the groundwater as soon as is reasonably achievable. In particular, the requirement that the water table of flooded mines should approach pre-mining levels is enforced. Experience and prognoses indicate that even in cases where there are severe changes, conditions close to natural can be reached within 20–30 years. In addition, the environmental protection authorities have started to develop a digital archive of radiologically relevant issues on all former uranium mining sites.

IV–1. INTRODUCTION

Uranium mining in Saxony was undertaken by SAG/SDAG Wismut between 1945 and 1990. Exploration for uranium ore was performed more or less over the whole area of the former German Democratic Republic (GDR). Nevertheless, the main focus was on the southern part of the country. Mineable deposits were found in Saxony and Thuringia. In Saxony, three major sites were mined:

— Aue (‘Ore Mountains’, hydrothermal vein deposits);

— Königstein Cretaceous sandstone deposits (uranium fixed on organic constituents);
— Gittersee Permian coal deposits (uranium enriched coal seams).

In addition to these sites, uranium was also mined at some smaller sites in the Ore Mountain area before 1962. Wismut produced a total of 251 000 t of ore from the different deposits:

Ore Mountains (mainly Aue)	103 000 t
Königstein	19 000 t
Gittersee	4 000 t
(Thuringian deposits	125 000 t).

IV–2. MINING RESIDUES

The residues from conventional underground mining include:

— Waste rock piles;
— Open mine shafts and drifts;
— Tailings ponds;
— Contaminated mine water.

Originating from in situ leach mining activities, acidic solutions (sulphuric acid with pH1.5–pH3) remain in the pore spaces, fissures of the host rock, mine shafts and drifts.

In addition, in former mining and milling areas, soils and building materials may be contaminated.

IV–3. MINING AND MILLING WASTES

The residues from uranium production, waste rock heaps and mill tailings, were deposited close to the production sites. Because the ore grade was very low (around 0.1%), the amounts of waste produced were comparatively high. Waste rock piles and tailings ponds exhale radon. Infiltration of atmospheric precipitation results in pyrite oxidation with acid drainage as a consequence. At Aue, where most of the Saxonian ore was produced, the host rock fortunately contains enough buffering minerals to prevent this. The infiltrating water may dissolve pyrite and produce sulphuric acid that dissolves heavy metals and radionuclides, but the carbonates in the rock act as a buffer and inhibit further solution processes. Seepage waters from waste rock piles at Aue typically contain about 2 g dissolved solids per litre. The Helmsdorf tailings ponds consist of tailings from an alkaline milling process. Owing to the different host rocks from which the ore was mined, the pH of the tailings is neutral to slightly alkaline.

Table IV–1 shows the number of sites, the areas covered by waste rock and tailings, and their volumes.

IV–4. LEGAL BACKGROUND AND REMEDIATION GUIDELINES

In Germany the fundamental legal act for radiation protection is the Atomic Energy Act (Atomgesetz). The executive legislation for uranium mining remediation is further based on two protection regulations. The ‘Directive on the Assurance of Atomic Safety and Radiation Protection’ (Verordnung über die Gewährleistung von Atomsicherheit und Strahlenschutz (VOAS)) is a former GDR regulation that is still in force. Before reunification, in West Germany no specific regulation for uranium mining existed. In the united Germany, remediation had to be initiated promptly; for this a legal basis was needed, so an agreement was reached to apply GDR legislation. In addition, in 2001 the Federal German regulation ‘Directive on Radiation Protection’ (Strahlenschutzverordnung (StrlSchV)) was amended to cover the radiation protection of uranium mining remediation workers. For the public, the dose limit of the VOAS (1 mSv/a) is still valid. Hence all remediation

TABLE IV–1. NUMBER OF SAXONIAN SITES, AREAS COVERED BY WASTE ROCK PILES AND TAILINGS PONDS, AND THEIR VOLUMES

Location	Number of objects	Area (ha)	Volume ($\times 10^6$ m^3)	Tailings/ waste rock
Aue	42	345	47	Waste rock
Königstein/Gittersee	3	38	5	Waste rock
Helmsdorf	2	218	50	Tailings
Aue	1	6.5	0.28	Tailings
Old sites	≈3000			Waste rock (total)
Old sites	≈300			Waste rock (radiol. relevant)
Old sites	10			Tailings

measures aim for a long term limitation of the dose from former uranium mining and milling sites to 1 mSv/a — additional to the natural background.

The regulatory authority requested that the following circumstances be taken into account in remediation decisions:

(a) The existing radiological situation (radon emanation, gamma dose rate and seepage water);
(b) Distances to population centres;
(c) Geotechnical stability;
(d) Geochemical conditions (e.g. present and likely future development of water quality) of the mine waste or contaminated area.

IV–5. BENCHMARKS FOR LONG TERM ISSUES

In the mid-1990s, as a result of many discussions between the Federal and State radiation protection authorities, agreement was reached that the remediation measures have to be planned so as to ensure stability (human interference excluded) for 200–1000 years. Thus, for the stability of waste rock piles (Fig. IV–1), three basic boundary conditions were stipulated:

(1) Reshaping of embankments (minimum slope to be 1:2.5) and plateaus (minimum slope to be 1:20).
(2) Contours should be without sharp edges (i.e. erosion gives rise to rounded contours).
(3) Covers should have a minimum thickness of 1 m (i.e. two 45 cm layers of low permeability material with $k_f < 10^{-7}$ m/s and 10 cm of top soil, with grass as vegetation cover).

As a result, acceptable long term safety (minimization) with respect to radon exhalation and radionuclide emission in seepage water, as well as geotechnical stability and erosion resistance, can be expected.

All remediation permits stipulate long term monitoring and maintenance conditions. For example, a monitoring and maintenance programme for waste rock piles and tailings ponds covering at least 25 years is required.

For the remediation of tailings ponds (Fig. IV–2), the following conditions were stipulated:

(a) Removal of free water;

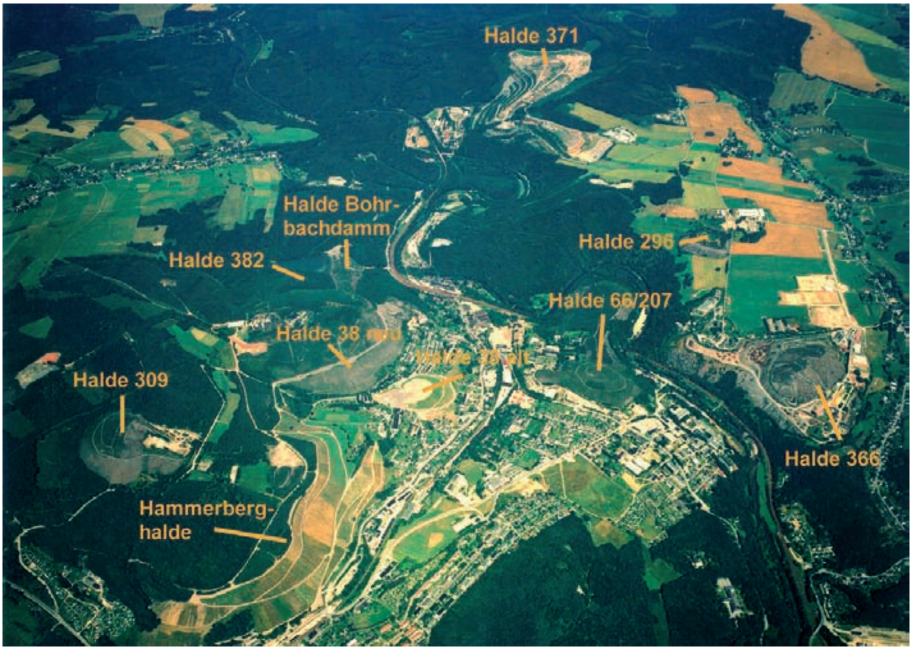

FIG. IV–1. Aerial view of the former mining community at Schlema. Schlema is now a radon spa. Shown in yellow are the names of waste rock piles (with the permission of Wismut GmbH).

(b) Reshaping of dams (toes 1:4, upper part 1:5) and plateaus (minimum slope 1:20);
(c) Contours without sharp edges (i.e. erosion gives rise to round shapes);
(d) Covers with a minimum thickness of 2.5 m (i.e. 1 m of waste rock, 1.3 m of low permeability material with $k_f < 10^{-7}$ m/s and 20 cm of top soil, with grass vegetation cover).

This design should provide geotechnical stability and erosion safety (provided by grass roots) over an unlimited period of time, as well as long term safety with respect to radon exhalation and radionuclide emission in seepage water.

For both types of site, i.e. waste rock piles and tailings ponds, no restrictions on plant growth are stipulated since it is deemed impossible to inhibit the invasion of unwanted plant species over long time periods. Some research on the uptake of radionuclides by different plants that grew for more than 30 years on an old tailings pond with a relatively thin cover of 30–100 cm was

FIG. IV–2. Aerial view of the Helmsdorf and Dänkritz tailings pond sites in the year 2000 (with the permission of Wismut GmbH). Since then most of the water has been removed and the larger part of the main dam reshaped.

undertaken in the mid-1990s. The results showed no elevated radionuclide concentrations in most parts of the tailings pond.

Remediated underground mines may not need to be subject to long term stewardship, as the relevant water and radiation protection authorities have stipulated that the flooding of mines should result in a natural background concentration of the groundwater as soon as is reasonably achievable. The definition of what is a 'reasonable length of the time' to reach these background concentrations is judged on the basis of existing boundary conditions and of the degree to which the groundwater has been affected by the mining activities. In particular, the requirement that the water table of the flooded mines should approach pre-mining levels is enforced. Experiences and prognoses indicate that, even in cases where severe changes have occurred, conditions close to natural can be reached within 20–30 years.

The elements foreseen for approaching natural conditions in conventional and in situ leaching mines may be:

— Flooding and water treatment;
— Stepwise flooding and monitoring;

— Conventional water treatment and passive treatment for long term solutions.

IV–6. TREATMENT OF LONG TERM SEEPAGE WATER

Some waste rock piles and tailings pond sites are located in valleys (Figs IV–3 and IV–4). The catchment areas of these valleys are still active and result in seepage water at the bottom of the waste rock or the tailings. Because of the oxidizing conditions, uranium dissolution is to be expected to continue for many decades or even for centuries. Sustainable water treatment methods have to be developed for these cases.

The factors needed for sustainability are:

— Systems to be self-regulating;
— No chemical additives to be necessary;

FIG. IV–3. Aerial view of the Königstein mine site, with the valley of the river Elbe shrouded in clouds in the background (with the permission of Wismut GmbH).

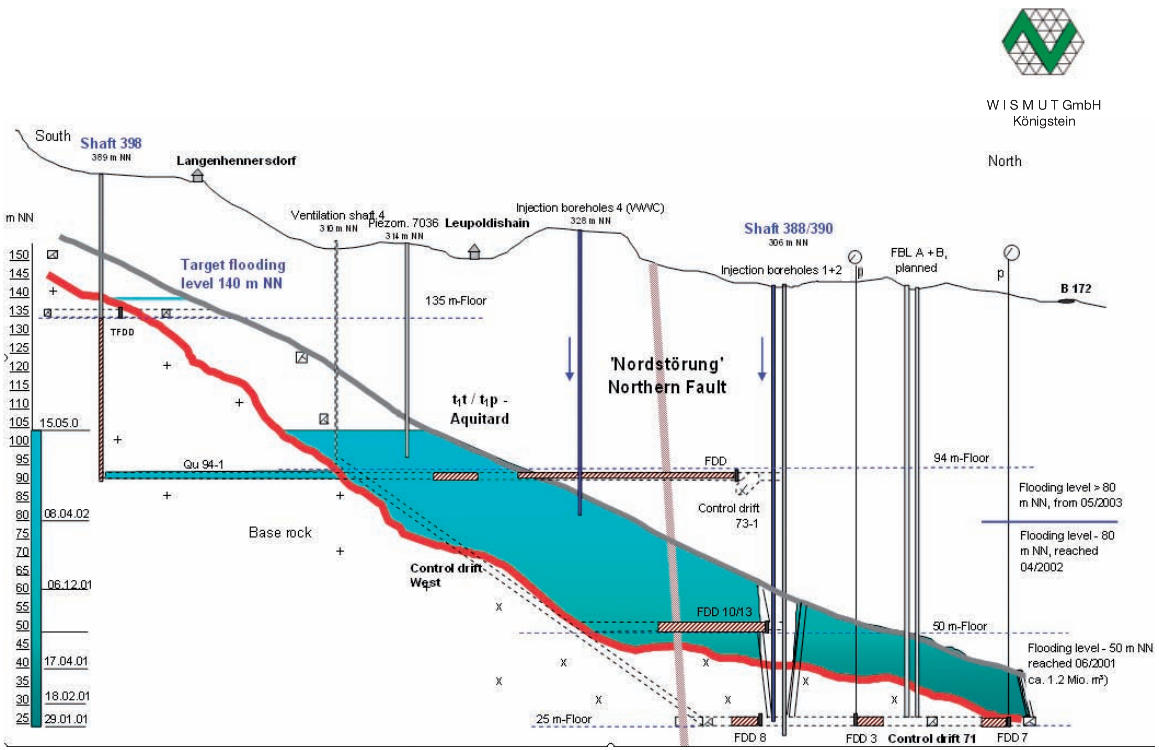

FIG. IV–4. Schematic cross-section through the Königstein mining area. Flooding will have an effect on the affected aquifer in a limited area for a limited time (with the permission of Wismut GmbH).

— No external energy to be necessary;
— No residues to be produced.

Two fundamentally different approaches seem to be possible:

(1) To inhibit dissolution, for example by in situ immobilization of radionuclides, heavy metals, arsenic, etc. (crust formation, i.e. formation of secondary minerals and gels on rock surfaces, is a possible strategy);
(2) To treat seepage water by bioremediation/ecological engineering.

Further research and development efforts are needed for both approaches.

IV–7. FUNDING OF LONG TERM ACTIVITIES

A fundamental legal provision is the responsibility of the owner for the funding of long term measures. In the case of the Wismut legacy, the Federal German government has to provide the financial means. Transfer of ownership to the State of Saxony has been under discussion, which would also entail the responsibility for funding and long term stewardship. In such a case, the former owner would have to provide the new owner with the necessary financial means. In general, when ownership changes, the responsibility for funding of long term measures also changes. The new owner will have to assume the responsibility for all the issues associated with long term stewardship if no other agreements are made.

When determining the extent of the financial means needed for long term measures, the possible future development of interest rates has to be considered. Thus, a conservative estimate would be based on a rate of not more than 1% per annum. This figure is the result of a review of the development of interest rates in the USA between the years 1950 and 2000.

IV–8. LONG TERM MONITORING AND MAINTENANCE

The long term monitoring of remediated sites will comprise the water (seepage, surface and groundwater), the air pathway (radon) and the stability of the cover (damage, land slides and erosion).

While water and air monitoring require a certain sampling and analytical effort, visual inspections at intervals are sufficient for monitoring the stability of the cover. The measurement effort can be reduced over time on the basis of evaluations of the monitoring data.

Maintenance is started as soon as repair of the cover or other features of the remedial solution is needed. Defects in covers must be repaired as soon as they are detected. An important feature of the functionality of covers is also the growth (quality) of vegetation.

Figure IV–5 shows a surface water runoff channel. Its main useful period is during the first two decades or so after remediation, before a stable vegetative cover has established itself.

Part of the maintenance may also be the planning of new and additional measures if previous measures have been shown to be ineffective.

IV–9. RECORD KEEPING

In general, two types of data have to be managed: site data (properties of the site) and monitoring data (from field and laboratory measurements or visual inspections). Monitoring data represent the 'living' part of the database, while site data represent the 'stationary' part. Monitoring data are the basis of all future technical decisions about, for example, ongoing water treatment, need for cover repairs, monitoring frequencies or change of restrictions on use.

The monitoring database systems should contain tools for evaluation of the data (trends, statistics, etc.) and for representation of the state of the site

FIG. IV–5. Surface water runoff channel at waste pile 366, Schlema.

(graphics, reports, etc.). There should be tools to relate monitoring data to site data, and to report information to the public so as to fulfil the relevant stipulations in the environmental information laws. The German environmental information law of February 2005 was developed on the basis of the European Union Directive on Public Access to Environmental Information (2003/4/EC).

In Saxony, a comprehensive database (KANARAS (cadastre for natural radioactivity in Saxony)) is under construction. It will draw on data from:

(a) The Wismut databases (Wismut sites, compiled by Wismut GmbH);
(b) A.LAS.KA (radiological data on contaminated sites, Federal Office of Radiation Protection (BfS));
(c) FbU (radiological and geographical data on contaminated sites, BfS);
(d) DURAS (radiological analyses of the Saxon State laboratory (UBG)).

There is no experience at all on long term preservation of digital data. On the other hand, the longevity of hard copy information stored on paper has been proven in many cases. Currently, it still seems reasonable to preserve as many paper documents as possible.

There will be a need for long term conservation of some important site information in the Saxonian State archive. The legal and material conditions for this step have not yet been developed.

IV–10. FUTURE ROLE OF LOCAL COMMUNITIES

The main issue for the future will be to make the information on the restricted use of remediated sites stable in the long term. The local communities are the group most concerned. It is they who will make decisions on the future use of the land in their municipalities. A sense of responsibility for a remediated site is a prerequisite for its long term stability. For this reason, permanent contact and exchange are required with these communities from the start of remediation onwards. The remediated sites will have to be accepted as harmonically and aesthetically fitting components of the natural scenery. On such a basis, the communities should ensure that money for remediation measures is well spent. A good symbiosis has developed in Saxony over the last 12 years between the State authorities responsible for remediation licensing and the communities concerned.

IV–11. CONCLUSIONS

Two main elements are required for successful long term stewardship:

(1) A sophisticated technical approach taking into account the specific situation and its natural long term setting, i.e. the regional hydrological, climatic and ecological conditions. Additionally, the effects of long term hydrological and climatic variations have to be taken into account. All technical, chemical or biological measures must be planned in this framework.

(2) Awareness by the communities concerned of their long term responsibilities. This awareness may result from education or information passed on from one generation to the next. Remaining conscious of the fact that it is important to retain an objective view of the situation, to prevent, for instance, erosion of covers, will help in taking the correct decisions about, for example, urban land use planning.

For both elements it is indispensable that information be kept in a way that is not only simple and easy to access but also adequate and site relevant.

Annex V

LONG TERM MANAGEMENT OF URANIUM MILL WASTE
Proposal for stewardship after closure of the tailings pond

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Abstract

Many countries around the world are engaged in the mining and processing of uranium ores with grades varying from below 0.1% to over 21% U_3O_8. Many low grade uranium ore deposits have been identified in India. Mining and ore processing operations commenced in India at Jaduguda in the mid-1960s, and three other underground mines have been opened in nearby areas. Some new mining and milling facilities are planned in other parts of India. The tailings from the uranium milling operations contain material of low radioactivity and other contaminants. These are treated before disposal in well designed tailings containment facilities, and releases from these facilities are monitored. However, in view of the very long half-lives of the radionuclides present in the tailings and the potential for a long term environmental impact, although small for tailings from low grades of ore, stewardship is very important. The annex outlines the tailings management system for the control of the impact and environmental surveillance practices in India. The likely stakeholders concerned with long term stewardship are identified who could take care of the surveillance and monitoring over long periods of time. A land use for after closure is also suggested, which will be subject to regulatory approval.

V–1. INTRODUCTION

Many low grade uranium ore deposits have been identified in India. Mining and processing of uranium ore commenced at Jaduguda in eastern India in the mid-1960s in order to sustain the nuclear power generation programme. Since then new mines have been opened at Bhatin, Narwapahar and Turamdih, all within 25 km of Jaduguda, to augment the production of uranium [V–1, V–2]. A few more uranium mines and mills are currently proposed for development in the same region, and some in other parts of the country will be in the near future. The processing of low grade ore results in the generation of large quantities of low activity mill tailings. These are treated and contained in tailings ponds in a valley nearby with hills on three sides and an engineered dam downstream [V–3]. Two tailings ponds at Jaduguda have been filled to their capacity and a third is currently in use. Sites for the emplacement of the tailings from the proposed mines and mills have already been identified. The estimated quantity of about five to six million tonnes of tailings accumulated in the containment ponds up to now in India is small compared with the several million tonnes of tailings generated annually in some of the major uranium producing countries.

The grade of uranium ore mined in different countries varies over a wide range, from less than 0.1% to about 21.0% U_3O_8. The estimated annual world uranium production from mines in recent years has been around 36 000 tonnes [V–4]. If we consider an average grade of ore of 0.25% U_3O_8, the total tailings produced in the world would be around 14 million tonnes per annum. Even after backfilling about 50% of the tailings in the worked out mine excavations, about seven million tonnes of tailings require appropriate disposal. In terms of the grade of ore from which the tailings are derived and the quantity of tailings generated, the problem of uranium waste in India is of small magnitude. Nevertheless, effective management of these tailings and long term surveillance and monitoring are important, as is the issue of stewardship.

V–2. URANIUM TAILINGS MANAGEMENT SYSTEM

V–2.1. Tailings management and disposal

The uranium mill tailings management system at present comprises treatment of a barren liquor from the ion exchange columns in uranium mills with limestone slurry, followed by addition of lime slurry to raise the pH to 10.0–10.5. These slurries are mixed with the barren cake slurry obtained after filtration of the dissolved uranium. A final pH of 9.5–10.0 is maintained to keep the residual uranium, radium, and other radionuclide and chemical contaminants, including manganese, in a solid form with the tailings. The treated slurry is classified into coarse and fine fractions. The coarse material, forming nearly 50% of the total mass, is backfilled into the mines. The fine tailings are pumped to an engineered tailings pond for permanent containment. The slimes settle down with the precipitates, and the clear liquid is decanted and sent to an effluent treatment plant (ETP).

At present there are three tailings ponds of the valley dam type at Jaduguda. The first and second stage tailings ponds of about 33 and 14 ha surface areas, respectively, located adjacent to each other are now nearly filled up. The third stage of the tailings pond having an area of about 30 ha is currently in use. The underlying soil and the bedrock of these tailings ponds have very low permeabilities. The tailings ponds are fenced in to prevent unauthorized access.

Although lime treatment of tailings largely takes care of the dissolved contaminants in the process effluents, subsequent reduction of pH in the tailings pond due to sulphide mineral oxidation may increase the concentrations of some radionuclides and chemical constituents in the decanted effluents. The effluents from the tailings ponds are clarified in the ETP and part of them is reused in the milling process. The rest is treated first with $BaCl_2$ and then with lime slurry to precipitate the radioactive and chemical contaminants, particularly ^{226}Ra and Mn. They are then clarified, and the settled sludge carrying the $Ba(Ra)SO_4$ and $Mn(OH)_2$ precipitates is returned to the tailings pond with the main tailings, while the clear effluents are discharged to the environment after monitoring.

V–3. THE TAILINGS CONTAINMENT DAMS AT JADUGUDA

The location of the three tailings containment ponds at Jaduguda is shown in Fig. V–1. For impounding the tailings, a first stage tailings dam was constructed in the mid-1960s between two hills to convert the valley into a reservoir. Figure V–2 shows an image of two tailings ponds (TPs), TP-I and TP-II, the latter

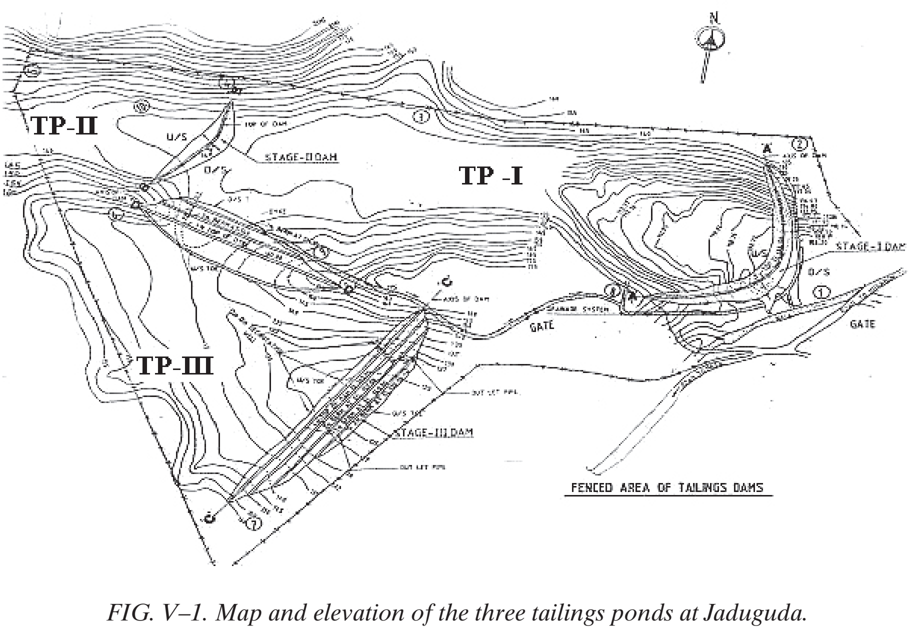

FIG. V–1. Map and elevation of the three tailings ponds at Jaduguda.

FIG. V–2. The tailings pond TP-I, with TP-II in the far distance.

in the foothills at the far upper end. From the initial elevation level of 107 m, the dam for TP-I was raised in stages to a height of 130 m. Figure V–3 shows the embankment of TP-I, and Fig. V–4 shows the strengthened dam. The second stage tailings dam (TP-II) was constructed upstream of TP-I from the initial level of 126 m to 150 m, to generate additional capacity. These tailings ponds

FIG. V–3. The embankments of tailings pond TP-I.

FIG. V–4. The strengthened dam of tailings pond TP-I.

are now almost full, and the third stage tailings pond (TP-III) has been constructed on the south side of the first stage pond (Fig. V–5). The height of TP-III starts from an initial elevation of 125 m and will reach a final height of 160 m. For this pond, an additional embankment has been constructed on the upstream side to prevent the outflow of tailings to TP-I (Fig. V–1) [V–5].

FIG. V–5. The improved dam of tailings pond TP-III.

The dams of tailings ponds TP-I and TP-II were constructed by the upstream method, in which an initial dam is constructed at the downstream toe. The central line of the top of the embankment is shifted towards the pond area as the height of the dam increases. The downstream toe of each subsequent dyke rests over the previous dyke, while the upstream portion is supported over the consolidated tailings. Additional strengthening was undertaken for better stability at TP-I (Fig. V–4), and steps are being taken to further strengthen the dam of TP-II [V–5].

The dam of tailings pond TP-III was constructed using the centre line method. In this method, the central line of the top of the embankment remains the same and the downstream toe of each subsequent dyke rests on firm ground, so that tailings dams of this type are much more stable than those constructed by the upstream method.

V–4. ENVIRONMENTAL SURVEILLANCE

A comprehensive surveillance programme is maintained around the mines, mills and tailings ponds to evaluate the effectiveness of the control measures, assess the environmental impacts and ensure regulatory compliance. Uranium mill tailings, being of low specific radioactivity, are a source of low levels of gamma radiation and environmental radon. The liquid effluents released after treatment may marginally contribute to the radioactivity level of the recipient surface water systems. Any underground migration of radionuclides from the tailings ponds may be revealed in the local groundwater. The surveillance of the environment, therefore, includes the monitoring of gamma radiation, atmospheric radon and radioactivity in the surface water and groundwater in the vicinity of the tailings pond.

The gamma radiation levels are measured over the tailings ponds and nearby areas. The ^{226}Ra content, of the order of 5.0–8.5 Bq/g, in the tailings is expected to give rise to a radiation level of about 2.5–4.0 μGy/h at 1 m above the tailings surface. The radiation levels observed at different locations above the tailings surface vary from 0.8 to 3.3 μGy/h over the three tailings ponds. This falls to about 0.5 μGy/h at the embankment and to about 0.25–0.30 μGy/h at about 20 m from the embankment. Background radiation levels of 0.10–0.15 μGy/h are attained within a short distance. Environmental thermoluminescence dosimeters are deployed at several locations up to about 25 km away, in order to assess the cumulative natural radiation exposure. The annual radiation exposure level at about 20 m from the tailings pond is around 2440 μGy/a. The natural background levels in the region vary from 785 to 1862 μGy/a, with an average of about 1150 μGy/a. Radon emanation rates from the tailings pile average around 1.5 Bq · m^{-2} · s^{-1} compared with 0.02–0.05 Bq · m^{-2} · s^{-1} from the soil. The atmospheric radon over the tailings pond averages around 35 Bq/m^3 compared with the natural background of 10–15 Bq/m^3 [V–6].

The groundwater near the tailings pond and other areas in the region is monitored for uranium (natural) and ^{226}Ra to estimate the local natural background and assess the impact of the tailings pond, if any. The average pH and the uranium and radium levels in the groundwater at different distances from the tailings pond over the last few years are shown in Fig. V–6. The uranium and radium contents of the groundwater in the vicinity of the tailings pond, even after about four decades of operations, are well within permissible limits. They are of the order of the local natural background.

V–5. PROPOSAL FOR CLOSURE AND STEWARDSHIP ISSUES

V–5.1. General considerations

The long half-life (≈80 000 years) of the ^{230}Th present in the tailings will support formation of its radioactive progeny, including radon, for a long time; hence long term management of the tailings system is required. For this reason, although difficult to accomplish, it is desirable that the structural integrity of

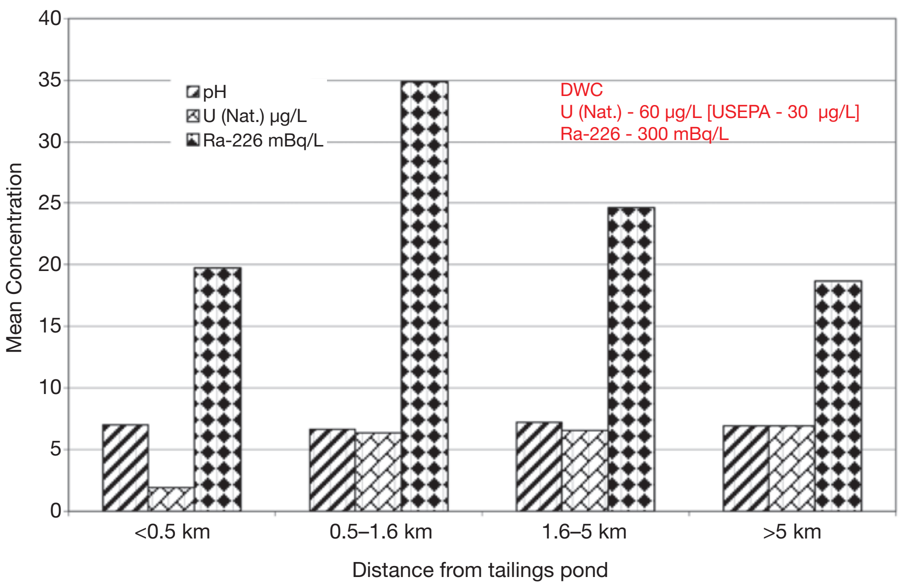

FIG. V–6. Groundwater quality around the tailing ponds at Jaduguda.

the tailings dam be designed for about 200 years, which means that it may remain effective for about 1000 years [V–7]. Natural cavities, mined out areas or valley dams appear to be the most suitable options for ensuring the long term integrity of the containment system. The design should be such that the need for long term active institutional control is minimized.

V–5.2. Desirable design criteria for long term management of tailings

In view of the very large quantities of tailings, of the order of several million tonnes, disposed of at a site, it may be physically and financially unfeasible to relocate them at a later time. Hence, it is necessary that careful thought be given to the proper design of the tailings disposal and containment facility so that a minimum of maintenance is required later. The design of a tailings containment facility is essentially site specific; however, it should aim at:

(a) Limiting the potential for groundwater contamination by providing appropriate natural or synthetic liners at the bottom;
(b) Constructing the dam structure to withstand the forces of nature such as seismic and climatic influences (extremes of temperature, wind, flood, etc.) over a long period of time;
(c) Diverting the water from catchment areas through side channels;
(d) Modelling the long term environmental behaviour and incorporating remedial measures for control of radioactive as well as non-radioactive constituents, such as manganese, arsenic and nickel, that may either be present in the ore or be used as reagents during processing;
(e) Providing a good conceptual plan for the closure at the design stage itself;
(f) Providing appropriate layers of cover material to reduce ingress of any runoff water into the tailings pile and to achieve a reduction of gamma radiation, as well as radon flux, from the remediated tailings;
(g) Providing sufficient funds by way of insurance or by generation of funds from future land use options for the long term surveillance, maintenance and monitoring required;
(h) Creating a mechanism for public consultation and information.

Some of these objectives may be partly met by proper site selection and appropriate treatment of tailings before disposal, such as a thickened tailings disposal system to reduce moisture, thereby minimizing the potential for seepage of contaminated water into the groundwater table.

V–5.3. Remediation of the tailings facilities

On completion, the dry tailings surface needs to be effectively covered with layers of different materials, such as a mixture of moist bentonite and clay or silt to serve as a radon barrier, followed by fine grained soil or sand, and finally rock and native soil. The thickness of the cover material may be site specific but the aim should be to reduce the gamma radiation to 0.2 μGy/h above background and the radon emanation rate to 0.74 $Bq \cdot m^{-2} \cdot s^{-1}$ [V–8], or as approved by the regulatory body. Surface vegetation with small rooted grass or shrubs may control erosion. Side diversion channels may be provided to prevent water from catchment areas reaching the covered surface. This will help to reduce the potential for groundwater contamination from runoff water percolating through the covered tailings.

V–5.4. Modelling for radiological impact of tailings on groundwater

The development of a few new uranium mining projects is under consideration in India, and if these projects go ahead they will require appropriate disposal options for the mill tailings. Modelling exercises are under way to evaluate the appropriate lining, with a view to minimizing the radiological impact on the groundwater in the long term. For the tailings from low grades of uranium ore, a lining of clay mixed with bentonite may be considered. A thickness of 1 m may provide a hydraulic conductivity of about 10^{-9} m/s.

The likely dose from seepage into groundwater of uranium and decay products from a tailings pond lined with a material of effective hydraulic conductivity of 10^{-9} m/s has been estimated. Figure V–7 shows the likely impact of radionuclides in the groundwater due to leaching or seepage at a distance of 0.2 km from the source. It may be seen that only trivial levels of exposure start appearing through the groundwater pathway after several hundred years. The resulting dose to members of the public may reach a level of 0.01 mSv/a only after about 800–1000 years. It will remain constant thereafter. This is about 10% of the present World Health Organization (WHO) reference level [V–9] and about 1% of the annual dose limit of 1 mSv/a for the public [V–10]. Figure V–7 also shows the dose to members of the public through the groundwater pathway at distances of 1 and 2 km from the tailings pond. This indicates that there will not be any perceptible impact on the groundwater due to seepage of radionuclides for very long periods of time. Only trivial doses will start appearing after several thousand years. Even after a long span of time, around 8000–10 000 years, the doses from the groundwater will remain at 10%

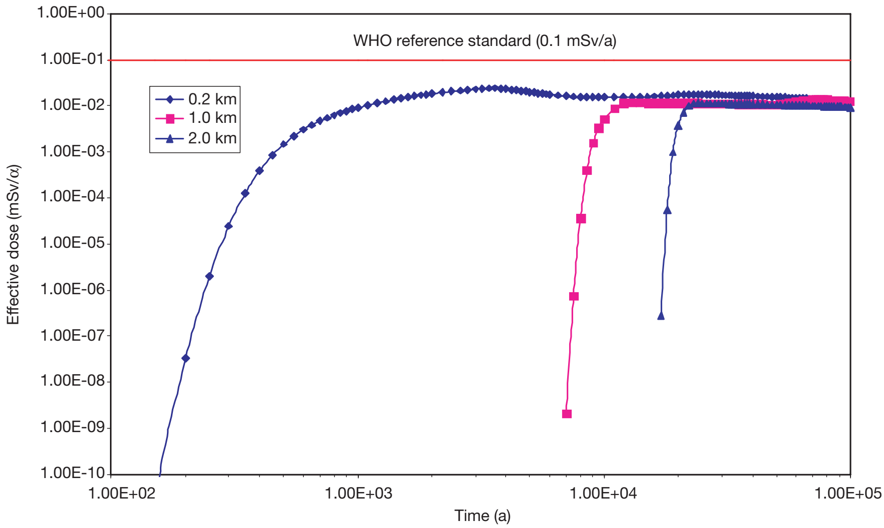

FIG. V–7. Total annual effective dose to members of the public due to the consumption of groundwater as a function of distance from the tailings pond.

of the current reference dose of 0.1 mSv/a. Similar projections are available for the McClean mine tailings at Saskatchewan in Canada, where the processed ore grade is much higher [V–11].

The cost of lining to a level of hydraulic conductivity of 10^{-9} m/s may be prohibitive. The question is whether such a low hydraulic conductivity is really necessary. This should be optimized in consultation with the regulatory authority and the licensee. In Canada, where much higher grade uranium ores are processed, the regulations prescribe that tailings repositories must be designed with a hydraulic conductivity of 10^{-8} m/s [V–12]. Thus, in the Indian context, a conductivity of 10^{-8} m/s may also be adequate for the tailings derived from low grades of ore. The local community, an important stakeholder, may not have sufficient information or understanding of the issue. However, it may also be appropriate to inform and consult the local community.

V–5.5. Long term surveillance, land use and stewardship

The licensee, regulatory body, district or State administration and the local community may be considered as the stakeholders for the short and long terms. After closure and installation of a proper cover, the radiation and radon exposure levels on the reclaimed land are expected to be trivial. However, the surface of the remediated tailings may take a very long time to consolidate and may not be able to support large structures in its early phase. Hence, depending on the site, the land may be used for warehousing, floriculture, plantation or recreational activities after obtaining regulatory consent. This will also help in preventing unplanned growth of vegetation or encroachment, which could affect the integrity of the surface cover.

The issue of post-remediation monitoring or institutional control is a complex one. As mining activity in a region may continue for a few decades even after closure of an exhausted tailings facility, short term surveillance, maintenance and monitoring of groundwater quality may be looked after by the licensee. The experience gained over 10–20 years may be helpful in designing future institutional control. After closure of the facility, the licensee may move out of the site. Hence, the licensee may not be in a position to provide institutional control in perpetuity. It may, therefore, be necessary to transfer this responsibility to the district or other appropriate authority that may be identified by the regulatory authority. The regulatory authority together with the district and State administration responsible for the land and land revenue will always exist in some form or other. It is, therefore, reasonable to entrust the stewardship to such a body, whose existence is likely in some form or other in perpetuity.

Delegation of stewardship responsibility to the district or State administration, with the active participation of the regulatory authority and the local community, should be accompanied by adequate funds. This may be achieved either by way of earmarking a fund by the licensee or by way of generating an income from the future use of the land. The licensee may consider adding a small but reasonable amount to the cost of the uranium produced and designate this for long term management, surveillance, monitoring and stewardship. Any income generated from the land use may be designated for long term surveillance and maintenance. The financial burden of surveillance and maintenance need not be passed on to the local community or future generations.

Complete records of the size of the tailings dam, approximate quantity and radioactivity content of the disposed tailings, cover material used and perceived future impact should by maintained by the licensee and transferred to the national authority identified for future maintenance and surveillance. Commensurate with the scale of operations, national authorities may consider creating a body for stewardship or entrusting this function to the district authorities and concerned regulatory bodies.

V–6. THE INDIAN SCENARIO

Two exhausted tailings ponds at Jaduguda are ready for closure. Experiments are under way to study the thickness of different layers of the clay, sand, and native soil and waste rock cover to reduce the gamma radiation and radon emanation rates to as close to the background as achievable and to obtain regulatory approval. The cover is to be designed such that water percolation through the tailings to the groundwater is minimized, to prevent contaminant leaching. A vegetation cover of non-edible grasses and shrubs such as *Saccharum spontaneum* (Kans), *Typha latifolia* (cat's tail) and *Ipomoea carnea* (Amari) grown over the exhausted portion of the first two tailings ponds is found to be effective in consolidation of the tailings and in suppressing generation and dispersal of dust, in addition to merging it with the local landscape. The uptake of radionuclides by these plants and shrubs is being studied. After adding the appropriate layers of cover over the tailings surface, these types of vegetation may be grown to provide stability against erosion.

Provision of suitable liners may be considered for future tailings facilities in order to reduce the potential for contamination of the groundwater. Modelling exercises indicate that lining with a material of hydraulic conductivity of about 10^{-9} m/s will ensure that radionuclides will not appear in groundwater for several thousand years. Even after they appear, their concentrations may remain below 10% of the current guideline values. However, the optimum hydraulic conductivity required and the cost effectiveness need to be worked out. In view of the regulations applicable to the tailings from higher grades of ore in Canada, a natural or synthetic lining with a hydraulic conductivity in the range of 10^{-8}–10^{-9} m/s may be adequate for the tailings generated in India.

V–7. REGULATORY PROVISIONS

Rules framed under the Indian Atomic Energy Act – 1962 take care of radiological safety in the mining and processing of prescribed materials as well as safe disposal of radioactive wastes. The Atomic Energy Regulatory Board (AERB) is the competent national authority to suggest the present and future surveillance and monitoring requirements, and to ensure stewardship of the facilities for the long term. The AERB is preparing a safety guide on management of waste from the mining and milling of uranium and thorium as well as that from the processing of naturally occurring radioactive materials. For conventional pollutants, the State and/or central pollution control boards are empowered to frame guidelines and ensure their implementation. These national regulatory bodies are the competent authorities to ensure safety and compliance with applicable national and international norms.

V–8. CONCLUSIONS

Long term stewardship of uranium mill tailings is required worldwide. Although the tailings derived from low grade uranium ores such as those in India have a correspondingly low potential for environmental impact, they are being managed with state of the art technology. Monitoring of the environment around the tailings pond is an integral part of the system. Closure of tailings ponds filled to capacity is proposed to reduce gamma radiation and radon emanation to the levels stated in regulatory requirements. Modelling of future tailings sites, assuming a hydraulic conductivity of about 10^{-9} m/s for the tailings containment system, indicates that doses to members of the public from groundwater sources even at a distance of 0.20 km from the site will be negligible for several thousand years. Even after 10 000 years, the estimated dose works out to be 10% of the WHO reference dose of 0.1 mSv/a. Hence, the hydraulic conductivity of the tailings system actually required may be much lower. In Canada, where much higher grades of ore are mined, the regulations require a hydraulic conductivity of about 10^{-8} m/s.

After closure and due approval by the regulatory body, the consolidated tailings surface, with an appropriate runoff water diversion system in place, may be used for warehouses, floriculture, plantations or recreational activities. The licensee, regulatory body, district or State administration and local community may be considered as the stakeholders for both the short and long terms. It is suggested that delegation of stewardship responsibility for surveillance and monitoring may be transferred to the district or State administration and the concerned regulatory authority, as these institutions are likely to exist in perpetuity. The transfer of responsibility may be supported by appropriate funds.

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REFERENCES TO ANNEX V

[V–1] BHASIN, J.L., Impact of New Environmental and Safety Regulations on Uranium Exploration, Mining, Milling and Management of its Waste (Proc. Mtg Vienna, 1998), IAEA-TECDOC-1244, IAEA, Vienna (2001) 189–200.

[V–2] BHASIN, J.L., Uranium exploration and mining, Nu-Power **12** 1 (1998).

[V–3] BERI, K.K., Uranium ore processing and environmental implications, Met. Mater. Process. **10** 1 (1998) 99–108.

[V–4] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2003: Resources, Production and Demand, OECD Publishing, Paris (2004).

[V–5] GUPTA, R., SIDDIQUE, S., Management of the tailings and liquid effluents in uranium mining and milling operations, Radiat. Prot. Environ. **26** 3–4 (2003) 506–515.

[V–6] KHAN, A.H., BASU, S.K., JHA, V.N., JHA, S., KUMAR R., “Assessment of environmental impact of mining and processing of uranium ore at Jaduguda, India”, The Uranium Production Cycle and the Environment (Proc. Int. Symp. Vienna, 2000), C&S Papers Series No. 10/P, IAEA, Vienna (2002) 184–190.

[V–7] INTERNATIONAL ATOMIC ENERGY AGENCY, Safe Management of Wastes from the Mining and Milling of Uranium and Thorium Ores, Safety Series No. 85, IAEA, Vienna (1987).

[V–8] WORLD HEALTH ORGANIZATION, Guidelines for Drinking-water Quality, 3rd edn, Vol. 1, WHO, Geneva (2004), http://www.who.int/water_sanitation_health/dwq/gdwq3/en/

[V–9] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[V–10] ROWSON, J.W., “Tailings management at COGEMA Resource Inc.’s McClean Lake operation”, The Uranium Production Cycle and the Environment (Proc. Int. Symp. Vienna, 2000), IAEA, Vienna (2000) 343–351.

[V–11] INTERNATIONAL ATOMIC ENERGY AGENCY, The Long Term Stabilization of Uranium Mill Tailings, Final Report on a Co-ordinated Research Project 2000–2004, IAEA-TECDOC-1403, IAEA, Vienna (2004).

[V–12] INTERNATIONAL ATOMIC ENERGY AGENCY, Current Practices for the Management and Confinement of Uranium Mill Tailings, Technical Reports Series No. 335, IAEA, Vienna (1992).

Annex VI

MANAGEMENT OF LONG TERM RADIOLOGICAL LIABILITIES: STEWARDHIP CHALLENGES — AN ARGENTINIAN CASE STUDY

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Abstract

Low and intermediate level wastes generated in Argentina have been managed by the Comisión Nacional de Energía Atómica (CNEA) from 1971 onwards on a site known as Ezeiza Radioactive Waste Management Area (AGE), which is part of the Centro Atómico Ezeiza (CAE), located in the province of Buenos Aires. In view of the design characteristics and the operating licence governing the AGE final disposal facilities, only conditioned wastes that are considered low level wastes requiring isolation periods of up to 50 years are subject to final disposal. The main disposal systems consist of two trenches for low level solid radioactive wastes, three ionic exchange beds for low level and very short half-life liquid radioactive wastes, and two deep underground silos for structural radioactive wastes and sealed sources. In recent years, the AGE zone has experienced substantial demographic growth. This, combined with changing weather conditions that have modified the groundwater level, has led to a reassessment of the impact that such facilities might have on the environment and nearby populations. The safety reassessment was initiated in 2001 at the same time as operation of all disposal systems was suspended. Studies for the characterization of the site and surrounding areas were started in order to reassess area safety, maintain appropriate surveillance and decide on future actions. These studies are included in a project initiated in January 2003 with the technical assistance of the United States Department of Energy (USDOE) through an agreement between it and the CNEA. The annex describes the existing disposal facilities, the present situation, the probable future measures needed depending on the result of the safety reassessment, the stewardship programme and the stewardship challenges that are expected to be faced in the near future.

VI–1. INTRODUCTION

Since its creation in 1950, the Comisión Nacional de Energía Atómica (CNEA) of Argentina has worked on the development of applications for the peaceful use of nuclear energy. These have included, among others, research and development activities in basic science and nuclear technology, operation of important facilities working on the production of radioisotopes for medical and industrial applications, and performance of tasks in connection with the nuclear fuel cycle, mining and uranium processing activities, manufacture of fuel elements, production of heavy water and operation of two nuclear power plants. Demonstration reprocessing programmes were carried out at the appropriate time.

As a result of such activities, and of other activities performed in the nuclear field by other private and public entities, various types of radioactive waste have been and are being produced. Since the early 1960s, CNEA has implemented through their Safety and Radiological Protection Department a programme of safe management of such wastes and started radioecological studies concerning release of radionuclides into the environment. The basic experience necessary to develop the criteria and models to be used in environmental assessments has been acquired through these studies.

VI–2. DESCRIPTION OF THE EXISTING FACILITIES

VI–2.1. Overview

The Ezeiza Radioactive Waste Management Area (AGE) covers an area of 8 ha used for treatment, conditioning and final disposal of low level solid and liquid wastes. In addition, the area is used for temporary storage of wastes that, because of their characteristics, type of radionuclide and activity concentration, cannot be disposed of in AGE and are awaiting the construction of an appropriate repository. In this area, disused sealed sources, as well as spent fuels from the RA 3 research and production reactor, are also stored.

Only these disposal systems will be described in this annex, because they are the type of facility directly related to management of long term radiological liabilities. The locations of these facilities on the AGE site are shown in Fig. VI–1.

VI–2.2. Near surface disposal system for low level solid radioactive wastes

The AGE system comprises two facilities commonly called trenches. The first trench, 140 m long and 10 m wide, completed its capacity with 3400 drums of conditioned waste. It was commissioned in 1974, and in 1980 a cover was placed over the first part; closure was completed in 1988. This trench was operated for its full service life without an operating licence, and the waste

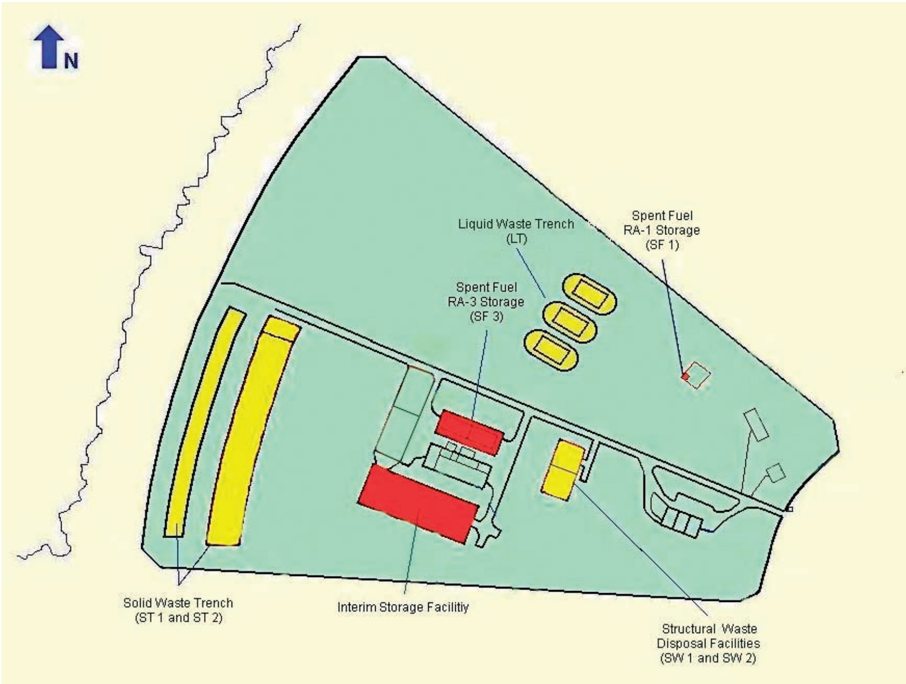

FIG. VI–1. Ezeiza radioactive waste management area: different disposal facilities.

emplaced in it is considered historic waste. The trench was built on natural soil without any type of engineering improvement.

The second trench, 120 m long and 20 m wide, with a capacity for 5600 conditioned drums, was commissioned in 1989, which is only one third of the total capacity available. The rest of the trench has neither been completed nor closed, because, from 2001 onwards, it has no longer been in operation due to commencement of the safety re-evaluation phase. This second trench was operated without a licence until 1995, when the Argentine nuclear authority, Autoridad Regulatoria Nuclear (ARN), issued such a document, and for that reason all the waste emplaced until that date is considered historic. This second trench was built in calcareous silty soil, compacted to 98% of its maximum theoretical density, supporting a graded broken stone bed with slopes towards both sides and 30 cm thick concrete perimeter retaining walls. The rainwater drainage system prevents water accumulation around the bases of the drums.

Covering of the last section of the first trench, as well as of the first third of the second trench, was carried out following the same engineering concept. In order to eliminate interstitial spaces between drums, the spaces were filled with classified dry sand. Drums were then covered in hill shaped mounds of selected highly compacted calcareous silty soil. The compacted soil was sprayed with hot bituminous material at a pressure of 2 kg/m^2. A layer of fine dry sand applied on top was covered with a thoroughly welded 200 μm thick polyethylene sheet to prevent rainwater seepage. Finally, a 0.15 m thick layer of calcareous silty soil was applied and covered with a 0.10 m thick layer of wet soil suitable for grass seeding to fix the soil and restore the original landscape.

VI–2.3. Near surface disposal system for low level and very short half-life liquid radioactive wastes

The system used is comprised of three ionic exchange beds formed by selected soil mixtures with a larger proportion of calcareous silts and sand added to improve the efficiency of the partition process by increasing the infiltration coefficient. These soils allow radionuclides with very short half-lives to decay to insignificant levels during their residence time in the bed. These systems are 20 m long, 10 m wide and 3 m deep. The operating capacity of each of these systems was approximately 2 m^3/day. A network of piezometers allows periodic groundwater monitoring. Liquid waste produced in production facilities at the Centro Atómico Ezeiza (CAE) is distributed into the system by means of pipes or, in certain cases, by means of transport casks.

The systems were commissioned in 1971. Two units ended operations in 1986, while the third unit functioned until 2001, when the safety reassessment of the complete AGE site was initiated. In view of the fact that the operating licence for these systems was not granted by ARN until 1995, all liquid waste disposed of prior to 1995 is considered historic.

VI–2.4. System for disposal of structural radioactive wastes and sealed sources

The system is comprised of two underground silos of 3 m diameter and 9.20 m depth with 30 cm thick reinforced concrete side walls and bottom. The waste disposed of in this system usually consists of metal parts from contaminated areas. Grout is periodically cast into the silos in order to immobilize the contaminated materials, preventing contaminant dispersion and reducing the dose rate at the access door in order to facilitate operation.

The first silo was commissioned in 1972 and closed in 1995, while the second was in operation from 1999 to 2001, when the safety reassessment of the complete AGE site commenced. In consequence, the first silo operated without an operating licence, and therefore the waste stored is considered historic waste, while the second silo started operation with the relevant licence.

VI–3. PRESENT SITUATION

Some important changes have occurred at the AGE site and its surroundings. In recent years, the AGE zone has experienced substantial population growth, as well as an increase in economic activity. This, combined with meteorological phenomena such as tornados and more frequent heavy rain, that have modified the groundwater levels, has led to a reassessment of the impact that such facilities could have on the environment and the nearby population.

The potential contamination defines the necessity for improving the monitoring system to characterize the migration of contaminants from the trenches through the vadose zone to the groundwater. For these reasons, studies for characterization of the site and its surroundings were started in order to reassess the safety of the area, to maintain an appropriate radiological and environmental surveillance, and to come to a decision about future measures. These studies are included in a project initiated in January 2003 with technical assistance from the United States Department of Energy (USDOE) provided through an agreement for scientific and technical cooperation between CNEA and USDOE. It is worthy of note that demographic, social and economic evolution studies are planned over the coming years.

All of this information will be used to complete the safety reassessment of the AGE site and will be presented to ARN for evaluation and a decision on future measures.

Taking into account the present state of the evaluation, there is a wide range of possible measures:

(a) Definite closure of the disposal facilities and initiation of institutional control;
(b) Upgrading to comply with additional remediation requirements;
(c) Removal of historic buried wastes in cases where they cannot be properly isolated by additional engineered barriers;
(d) Implementation of a long term stewardship programme to maintain control of the site after 50 years, in case the permanence of the alpha contaminated buried wastes or the residual contamination in groundwater or soil after cleanup activities may represent a risk to the public (according to ARN regulatory standard AR-10.12.1 [VI–1]).

VI–4. STEWARDSHIP PROGRAMME

VI–4.1. Institutional measures after closure

The institutional measures foreseen by the responsible organization (CNEA) after closure constitute the necessary basis for carrying out the safety assessment. This basis was already defined in the licensing process of previous stages. In Argentina, the information presented by the organization responsible for licensing of final disposal systems located at the AGE site implies an active institutional control for 50 years after closure and then the release of the land for unrestricted use.

Nevertheless, it is anticipated that this premise will be periodically updated following the evolution of the site's characteristics from the climatological, hydrogeological and demographic points of view, as well as of the social factors associated with this type of activity. Present or future evaluations may lead to a decision to extend the institutional control period beyond 50 years or to release the site with restrictions after the institutional control period and to cover management of the land use by the stewardship process.

VI–4.2. Institutional control

The safety criteria applied to the post-closure stage were established by regulatory standard AR-10.12.1 [VI–1]. Articles 19 and 30–34 of this standard establish the general guidelines to be taken into consideration:

(a) Suitable multiple barriers shall be used to keep the radioactive waste isolated from the part of the environment accessible to humans for the period of time necessary for it to decay to acceptable levels.
(b) During the design, construction, operation and final closure stages, the responsible organization shall carry out appropriate safety assessments of final disposal systems for radioactive waste.
(c) Assessment of the radiological impact of final disposal systems shall take into consideration a normal scenario where the design purpose and the situation resulting from conceivable disruptive events during the anticipated isolation period are satisfied.
(d) The safety assessment for normal scenarios must demonstrate that the estimated doses which future generations will be exposed to will not exceed the dose restriction applicable to the most exposed members of the public at the beginning of the isolation period.
(e) Hazards associated with conceivable disruptive events during the anticipated isolation period shall not exceed the acceptable risk levels

established during the design stage of the final disposal system for radioactive waste.

The criteria stated above apply to the various phases of the disposal system and above all to the institutional control phase. In particular, the institutional controls in Argentina are active controls, contributing, as a major safety factor, to providing an appropriate confinement of the disposed radioactive waste and allowing compliance with the criteria stated above.

As stipulated in regulatory standard AR-10.12.1, article 37 [VI–1], the institutional control measures anticipated by the Argentine regulatory system imply that the responsible organization shall be responsible for safety during the post-closure period authorized by the regulatory authority, the definition of which will be part of the corresponding licence and will be based on the length of time necessary to maintain regulatory control while the risk due to the radioactivity contained falls to levels compatible with the established criterion.

In particular, the institutional control measures foreseen for the AGE site are:

(a) A radiological monitoring plan for the final disposal facilities and their surrounding areas to check the absence of unacceptable radiological impacts and evaluate the changes in design parameters;
(b) A preventive maintenance plan for the final disposal facilities, including periodic inspections of the drainage systems, coverage, security fences, monitoring and surveillance instruments.
(c) An action plan in case of the need to implement improvements in situations requiring control and/or mitigation of effects from unforeseeable releases of radioactive material.

VI–5. STEWARDSHIP CHALLENGES

The long term stewardship activities will be carried out by the same organization that is responsible for the Radioactive Waste Management Programme at present, i.e. the CNEA.

The main stewardship challenges for the future (and in some cases also for the present) are to:

(a) Convince stakeholders and politicians of the feasibility of the measures to be implemented at the AGE site (depending on the conclusions from the safety reassessment). The public close to the AGE site is strongly influenced by some environmental non-governmental organizations

(NGOs) and some antinuclear groups. It is necessary to implement a social communication programme to change the current negative public perception of radioactive waste management, in order to fulfil the objectives of the stewardship programme. Furthermore, Argentina will require new locations for the siting of radioactive waste repositories. It is currently mandatory to have a social and political consensus to obtain agreement. It is very important to involve the local community near AGE in future decisions about this site because it will be the pilot case for working towards the acceptance of new sites by other communities (another future challenge). The strategy also requires the implementation of a public participation programme, which must be carefully developed. This will allow the public to have access to the scope of the activities included in the stewardship programme. It will also report on the direct and indirect benefits or impacts on the communities close to the repository. For this reason, permanent communication links are necessary with the legitimate national, provincial and municipal representatives of society, together with other opinion leaders such as NGOs, private companies, schools, professionals and neighbourhood associations. It is essential to clearly identify all stakeholders and involve them from the very beginning of the stewardship programme.

(b) Provide available specific funds to support all the activities, including the stewardship programme, proposed in the Strategic Plan for the Radioactive Waste Management in Argentina, created by Law 25018.

(c) Evaluate the results from predictive modelling of the migration of contaminants to the groundwater and from the implementation of new models, if necessary. The software selected to model the site will be used to generate a three dimensional groundwater flow and contaminant transport model that will be used for a retrospective analysis of plume behaviour and source identification. This software tool can also be used for predictive modelling of natural attenuation of the plume and simulation of different remediation options. On the basis of the needs for site characterization and numerical simulation of the transport and fate of contaminants, geological, hydrogeological and geochemical investigations are being carried out. Once site characterization has been completed, the conceptual model established and the safety reassessment completed (planned for the middle of 2007), the stewardship programme may include additional remedial measures or cleanup of the site, if it is considered necessary. Environmental surveillance with specific monitoring and sampling of water and soil at different depths to verify that the plume behaves as predicted must be carried out during the stewardship period. Additional efforts in the form of more detailed studies would have to be undertaken, including new conceptual models, in case the predictions were to fail. Corrective measures will have to be implemented in case these deviations were to increase the human radiological risk. Although it is expected that the environmental parameters are not going to change in the short term and considering that the software selected to model the site was successfully used at some USDOE sites, the model performance in the long term must be validated.

(d) Study the long term performance of the waste packages buried in the near surface disposal system for low level solid radioactive waste. A test was conducted in the context of an IAEA Coordinated Research Project, studying the behaviour of two drums with conditioned wastes in simulated extreme repository conditions. One of the drums, containing cemented liquid wastes from the Atucha I nuclear power plant, was tested to obtain values of the radionuclide leaching rate and the corrosion rate of the steel drum. The other drum, containing compacted solid wastes generated in the same plant, was intended to study gas generation from the biological degradation of compacted organic material. These experiments are now being evaluated after running for five years.

(e) Complete and preserve records and documentation related to the different stages of the life cycle management of the disposal facilities in a contextual framework that makes them understandable to future generations and in a supporting medium that preserves their content and retrievability. Preservation mechanisms should be updated from time to time in accordance with the latest technologies (active information transfer mechanisms). Passive systems must be implemented to contribute to safety by minimizing the risk of inadvertent intrusion into disposal facilities. The IAEA has identified the problem under the Waste Safety Action Plan, Action No. 6 [VI–2]:

"This action arises from the need to ensure appropriate institutional control for all types of waste storage and disposal facilities (especially near surface facilities containing intermediate and long lived waste and facilities awaiting deferred decommissioning). One view on how such institutional controls might operate is that the present generation should pass on information, skills and knowledge to the next generation so that the latter can ensure the safety of the facility and decide on the need to continue with controls or to take some other course of action. It is thus a process that emphasizes transfer between generations. The establishment of specific records is also a means of helping the process of long term information transfer."

Some efforts have already been made in this direction. For instance, an IAEA Technical Meeting (Vienna, 14–18 June 2004) reviewed the draft Safety Report, 'Preservation and Transfer to Future Generations of Information Important to the Safety of Waste Disposal Facilities'. Most of the aspects related to this challenge were discussed as well as possible solutions.

(f) Plan the land use according to the restrictions or conditions for the free release of the site, if this is possible. The AGE site is located on a national government property that was transferred to CNEA in 1954. It is adjacent to Ezeiza international airport. The urban planning code designated the zone for recreational and low density residential use, taking into account the specific use made by CNEA and by the airport of their respective zones. In the future, when decisions will have been taken on land use restrictions at the AGE site, it will be necessary to register them in the property register of the Province of Buenos Aires. The final use of this site will have to be discussed and negotiated with all stakeholders, trying to satisfy reasonable requirements. It is expected that the public participation programme will make an important contribution to arriving at a successful and reasonable conclusion on the use of the land. It is worth mentioning that demographic, social and economic development studies are planned to be carried out over the next two years.

(g) Maintaining qualified staff in charge of the different activities in the long term is a permanent concern of the National Programme for Radioactive Waste Management. Young professionals and technicians are taken on as fellows, trained in specific disciplines and may, later, become permanent staff members.

Currently, the strategies for dealing with these issues are at different stages of planning or implementation. Some of these depend on decisions that cannot be taken yet, and it is very difficult to predict the future course of events.

VI–6. CONCLUSIONS

Completion of the studies to characterize the site and its surroundings is planned for the middle of 2006. The data obtained from the site characterization activities will be used in developing a conceptual model of groundwater flow and transport processes to be incorporated into prediction models. The results of demographic, social and economic development studies, which are planned to be carried out over the next two years, must also be considered.

All this information will be used to complete the safety reassessment of the AGE site, when it will be presented to the nuclear regulatory authority for evaluation and for decisions to be taken about future measures. It is expected that a decision may be taken by the end of 2007.

This annex presents the stewardship challenges identified to date that must be taken into consideration for the management in the near future of the long term radiological liabilities associated with the Ezeiza Waste Management Area. It is very important to clearly identify the necessary requirements and resources to address these challenges, as well as to integrate them into a rational planning procedure for the stewardship programme at the appropriate time.

REFERENCES TO ANNEX VI

[VI–1] AUTORIDAD REGULATORIA NUCLEAR, Radioactive Waste Management, Regulatory Standard No. AR-10.12.1, ARN, Buenos Aires, (2002), http://www.arn.gov.ar

[VI–2] INTERNATIONAL ATOMIC ENERGY AGENCY, Waste Safety Action Plan, Action No. 6, http://www-ns.iaea.org/tech-areas/waste-safety/disposable.htm

Annex VII

THE UNITED STATES NATIONAL ACADEMIES PERSPECTIVE ON LONG TERM STEWARDSHIP

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Abstract

The United States Department of Energy (USDOE) is the agency that cleans up and establishes long term stewardship programmes for nuclear weapons complex sites in the United States of America (USA). The annex summarizes the most recent findings and recommendations from the National Research Council of the National Academies on long term stewardship at USDOE sites, as reflected in two previous reports published by The National Academies. The published reports discuss the roles of a 'long term steward' as well as the institutional requirements for setting up an effective stewardship programme. A dialogue among the National Academies and several Federal agencies is under way concerning a new study on current long term stewardship practices. This proposed collaborative study would investigate methods for sharing the most effective practices, in order to achieve consistency between remedies and long term stewardship programmes across the USA.

VII–1. INTRODUCTION

The United States National Academies and its operating arm, the National Research Council[1], have published several reports on long term stewardship[2]. Among the issues discussed are the roles of a 'long term steward' and the distinction between two terms that are often used interchangeably — long term stewardship and long term institutional management.

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[1] The National Academies are composed of the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine and the National Research Council. The National Academies are private, non-profit institutions that provide science, technology and health policy advice under a congressional charter. All National Research Council reports are readable on-line free of charge at www.nap.edu.

[2] A large body of work on long term stewardship already exists. An annotated bibliography can be found in Appendix D of the National Research Council report entitled 'Long-Term Stewardship of DOE Legacy Waste Sites: A Status Report' [VII–2].

A recent series of National Research Council reports has focused on the nuclear weapons complex [VII–1, VII–2] of the United States Department of Energy (USDOE). The USDOE is the agency responsible for cleaning up and for setting up long term stewardship programmes for its nuclear waste legacy sites. In 2003, the USDOE created the Office of Legacy Management (DOE-LM) to conduct long term management activities for former nuclear weapon complex sites that that have been cleaned up but still have residual contamination. The USDOE estimates that, by the end of 2007, DOE-LM will provide a long term management service for 96 sites and that at least 20 more sites could be transferred to this office after 2007 [VII–3, VII–4]. The mission of DOE-LM is to ensure that contaminated material remains isolated from the environment, that the safety of the public and the environment is maintained, and that all applicable regulations are met.

VII–2. DEFINITIONS OF LONG TERM STEWARDSHIP AND INSTITUTIONAL MANAGEMENT

VII–2.1. Roles of a long term steward

The Board on Radioactive Waste Management (which has become the Nuclear and Radiation Studies Board as of March 2005) of the National Academies has been involved in several projects on long term stewardship, mostly involving USDOE nuclear legacy waste sites but also in a broader context. In April 2001, for example, the Board organized a workshop on long term stewardship to gather views from Federal agencies, researchers and representatives of institutions with long term stewardship missions[3]. In 2000 and in 2003, the Board oversaw two National Research Council studies on long term stewardship in which terms such as ‘long term institutional management’, ‘steward’ and ‘long term stewardship’ were discussed and defined. For example, a steward of very long lived hazards [VII–2] acts as:

(a) A *guardian*, stopping activities that could be dangerous;
(b) A *watchman*, looking for problems as they arise through a monitoring programme that is effective in design and in practice, activating responses and notifying responsible parties as needed;

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[3] Workshop participants included representatives from US Federal agencies such as the USDOE, the Environmental Protection Agency, the Department of Defense and the Park Service, but also from the Catholic Church and some Native American tribes.

(c) A *land manager*, facilitating ecological processes and human use;
(d) A *repairer*, repairing engineered and ecological structures as failures occur and as they are discovered, as unexpected problems are found, and as re-remediation is needed;
(e) An *archivist*, archiving knowledge and data, to inform people in the future;
(f) An *educator*, educating affected communities, renewing memory of the site's history, hazards and burdens;
(g) A *trustee*, assuring the financial means to accomplish all the other functions.

The term 'long term institutional management' is often used as a synonym of long term stewardship. Long term stewardship and long term institutional management are closely related, but not equivalent, concepts. Essentially, stewardship is only one of the elements of institutional management. The relationship is illustrated by a 'three legged stool', as shown in Fig. VII–1 [VII–1].

The three legged stool image is useful for two reasons. First, the image represents long term institutional management, viewed as a system. The three legged stool shows all the components necessary, including stewardship activities, for a complete and stable system. Second, the illustration emphasizes the interrelationships to maintain the integrity and stability of the system over time.

VII–2.2. Deciphering the three legged stool

The seat of the stool (Fig. VII–1) symbolizes the planned end state. This end state may or may not be the final goal envisaged for the site. The legs of the stool represent three measures that lead from current site conditions to the disposition end state:

(1) Contaminant reduction;
(2) Contaminant isolation;
(3) Long term stewardship.

Contaminant reduction measures (e.g. bioremediation or natural attenuation) are actions that lead to a removal or a reduction of the amount of contamination. Contaminant isolation measures are engineered measures implemented to stabilize, fix or limit access to contamination at a site.

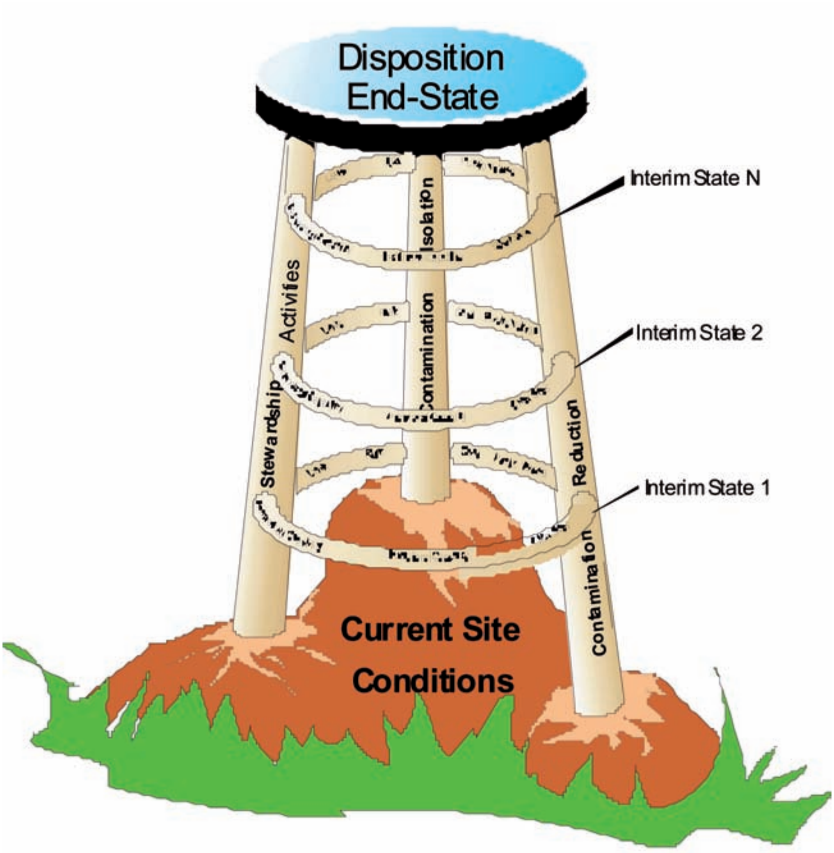

FIG. VII–1. Relationship between long term stewardship and long term institutional management [VII–1, VII–2].

Examples of contaminant isolation methods are: physical barriers, chemical or thermal fixation, and ‘pump and treat’ (or ‘pump and reinject’). Any combination of contaminant reduction and contaminant isolation measures is often referred to as ‘remedial actions’ for a contaminated site. These actions are generally implemented during the cleanup phase of the site.

Stewardship activities include:

(a) Monitoring contaminant isolation and reduction;
(b) Emplacing and maintaining land use controls and access restrictions (i.e. institutional controls);
(c) Overseeing and enforcing information management;

(d) Periodically re-evaluating contaminant isolation and reduction systems, taking into account new or updated scientific or technological advances.

In Fig. VII–1, the 'current site conditions' show the complexity of the site's initial needs, such as the characteristics and geographical distribution of contaminants. For instance, the level and type of contamination may vary greatly within the same site, depending on the activities in the past and the remedial activities undertaken then, if any. The rugged terrain represents this complexity.

VII–2.3. Shortcomings of the stool illustration

VII–2.3.1. Remedial action versus long term stewardship

As with any analogy, a simple picture cannot convey all the elements of a complex reality. For example, stool legs are usually of equal size. However, the site's condition and broader contextual factors dictate the relative emphases of contaminant reduction, isolation and stewardship in Fig. VII–1. At some sites, contaminant reduction is sufficient to allow unrestricted use, and contaminant isolation and stewardship are not required. Conversely, at more complex sites, reliance on long term stewardship may dominate contaminant reduction and/or isolation activities.

VII–2.3.2. Serial decision making: Site conditions and broader contextual factors

The biggest shortcoming of the illustration in Fig. VII–1 is its failure to distinguish parallel from serial decision making processes.

Site conditions and broader contextual factors affect the unique balance between remedial actions and stewardship decisions. Decisions about implementation of contaminant isolation and reduction measures during the cleanup phase affect what remains to be achieved to reach the site's end state during the long term stewardship period. The extent of the contamination left in place after active cleanup has ended forces an increase in reliance on engineered barriers and institutional controls at the site to limit the hazards. Hence, decisions about remedial actions and long term stewardship need to occur in parallel.

Broader contextual factors also play an important role in decision making. The rungs of the stool that connect and fix the legs represent ancillary off-site conditions, such as risks, costs, public values and expectations, legal and regulatory requirements, technical and institutional capabilities, and the current status of scientific knowledge and technology. Cleanup and stewardship decisions made at one site can have an impact at other sites because of public perceptions of equality and newly established expectations on cleanup levels. In other words, broader contextual factors have an impact on decisions about remedial actions, and long term stewards and site managers need to consider all these elements when planning for the final end state.

VII–2.3.3. Serial decision making: Interim states

Progress towards planned goals occurs in stages. In Fig. VII–1, the rungs represent serial interim states, i.e. the rungs depict an iterative and phased approach towards the final end state. Interim cleanup goals are currently in wide use throughout USDOE complexes. Even where end state goals have been selected, they may have been set provisionally, or the remedial actions necessary to achieve the end state may need to unfold in successive stages over fairly long periods of time. Periodic re-evaluation could involve reconsideration of the goals previously selected or adjustment of how contaminant isolation, reduction and stewardship activities are to be applied to attain the selected goals. Finally, the nature and relative importance of the individual contextual factors that make up the rungs, and the interrelationships among these factors, can also change in the course of time.

To summarize, because the three legs are not independent of each other, the seat of the stool may not represent the final disposition end state, as capabilities to anticipate changes at a site or in society and its technologies are limited. For example, the range of possible future land uses may broaden as remediation technologies improve. Alternatively, the range of potential land uses may become narrower if contaminant isolation or stewardship measures begin to fail or if new information about residual contaminants becomes available that indicates an increase in the hazard for people living at or near the site.

VII–2.4. Findings and recommendations of the National Academies

Nevertheless, the value of the three legged stool analogy exceeds its shortcomings. Applying the illustration to the legacy waste sites of the USDOE, the National Academies published two reports, one in 2000 and one in 2003 [VII–1, VII–2].

The main findings from the 2000 report [VII–1] can be summarized as follows:

(a) Effective long term stewardship will probably be difficult to achieve.
(b) Almost all sites will require future oversight.

(c) Engineered barriers have limited lives.
(d) Institutional controls will eventually fail.
(e) Current remediation planning does not always include long term management needs (e.g. possible future re-remediation).
(f) Transport modelling is often inadequate to gauge long term remediation effectiveness.
(g) No plan developed in the present is likely to remain effective for the complete period when there is a hazard.

The main recommendations from the 2000 report [VII–1] can be summarized as follows:

(a) While stewardship is essential, a broader based, more systematic, approach is needed.
(b) Contaminant reduction, contaminant isolation and stewardship should be treated as an integrated complementary system.
(c) Contemporary waste management actions should become an integral part of stewardship planning.
(d) Deficiencies and knowledge gaps should be acknowledged and, where possible, investments in research should be made to correct them.

The 2003 report focused on the institutional requirements for an effective stewardship programme at USDOE sites. The main finding and recommendations from this report are summarized below. However, because the USDOE abbreviated the study, this finding and the recommendations do not fully address the original scope of the study.

The main finding from the 2003 report [VII–2] can be summarized as follows: The committee observed a compartmentalization of cleanup and long term stewardship planning at USDOE sites, leaving stewardship to address the end state rather than to evolve with cleanup.

The main recommendations from the 2003 report [VII–2] are that, when setting up a long term stewardship programme, the USDOE should:

(a) Plan for uncertainty;
(b) Plan for fallibility;
(c) Develop substantive incentive structures;
(d) Undertake scientific, technical and social research and development;
(e) Seek to maximize follow-through using long term approaches that are phased, iterative and adaptive.

The committee that originated the 2003 report visited a number of USDOE sites and observed a compartmentalization of cleanup and long term stewardship decisions. Cleanup planning and execution that was concluded at certain USDOE sites left long term stewardship to address the resultant end state. The USDOE did not appear to plan explicitly for its stewardship responsibilities when making cleanup decisions.

In the same study, the committee published the attributes of an effective stewardship programme and the institutional implementation criteria and requirements to achieve such a programme. The following are attributes of an effective stewardship programme [VII–2]:

— Reliability over time;
— Redundancy;
— Complementarity and consistency;
— Foresight;
— Feasibility;
— Transparency and visibility;
— Stability through time;
— Iterativity;
— Flexibility.

The following are institutional criteria to implement an effective stewardship programme [VII–2]:

(a) Establishing clear objectives and a follow-through system;
(b) Defining a clear system of governance (what is to be done by whom, as an enduring but flexible precept);
(c) Setting up a system of accountability;
(d) Establishing an overall, coordinated and collaborative approach;
(e) Setting up positive incentives that encourage diligent execution over time.

VII–2.5. Institutional requirements for an effective long term stewardship programme

VII–2.5.1. Trust is the key

In the 2003 National Academies report, the committee gave considerable attention to the relationship between stakeholders and the agency responsible for long term stewardship. The key to success is trust between stakeholders, the custodial agency and the steward (which may or may not be the same agency).

According to the committee that authored the report, institutional interactions and institutional constancy are key elements to maintaining and enhancing trust.

VII–2.5.2. Institutional interactions

Some observations from the 2003 report (Ref. [VII–2] and references therein) on means of maintaining and enhancing trust in organizations that need to enjoy public trust and exhibit constancy are listed below:

(a) Interactions with external parties:
   (i) Early, continuous involvement of stakeholder advisory groups with frequent contacts, complete candour, and rapid and full responses;
   (ii) Timely accomplishment of agreements unless modified through an open process agreed to in advance;
   (iii) Consistent and respectful reaching out to State and community leaders and to the general public to inform them about, and consult with them about, technical, operational, societal and equity aspects of agency activities;
   (iv) Active, periodic presence of leaders at the highest echelons, visible and accessible to citizens at sites and in neighbouring communities;
   (v) Consistency in approach;
   (vi) Willingness to acknowledge mistakes;
   (vii) Visible presence of agency and contractor in neighbouring communities, with staff contributing to community affairs and paying their fair share of taxes and other common burdens;
   (viii) Assurance of negotiated benefits to the community, including resources for the affected host communities to detect and respond to unexpected costs.
(b) Internal organizational conditions:
   (i) Encouraging high professional and managerial competence and discipline in meeting technically realistic schedules with high transparency in achieving schedules and goals;
   (ii) Fostering by executives at the highest echelons of participating organizations of an organizational culture that emphasizes safety for workers and the public;
   (iii) Connecting technical decisions to public concerns;
   (iv) Presenting clearly the decision making process to broad segments of the public;

(v) Ensuring self-assessment processes that permit the agency to find problems and openly acknowledge them before they are discovered by outsiders;
(vi) Putting in place demanding internal processes to review and discover actual operating errors that include stakeholders;
(vii) Assigning clear institutional responsibility to sustain public trust and confidence, to regain it if necessary and to ensure constancy.

These organizations are characterized by certain types of interaction with external parties and certain internal organizational conditions.

VII–2.5.3. Institutional constancy

Constancy is the quality of being free from change or variation in spite of varying circumstances. The goal of institutional constancy is to give the public confidence that organizations will 'keep their word' from one management generation to another. The essentially permanent responsibility of long term stewardship and the inherent uncertainties involved make it especially challenging to cultivate trust. The longer a project, and the more generations of managerial leaders required, the greater the likelihood of a loss of institutional memory and diffusion of commitment — and the greater the need for institutional constancy. No formal human institution has endured as long as the projected life of some of these hazards. Institutional constancy entails organizational perseverance and faithful adherence to the mission and its imperatives over long time periods. The characteristics of institutional constancy (Ref. [VII–2] and references therein) are listed below:

(a) Assurance of steadfast political will:
  (i) A culture of commitment, including periodic reaffirmation of unswerving adherence to the spirit of the initial agreement;
  (ii) Strong articulation of commitments by leaders at the upper echelons of all participating organizations, requiring staff to sustain constancy;
  (iii) Clear evidence of organizational continuity with institutional norms that nurture the persistence of commitments across many generations;
  (iv) Vigorous external reinforcement of commitment from regulatory agencies, stakeholders and an attentive public.
(b) Organizational infrastructure of constancy:
  (i) Administrative and technical capacity to carry out activities that reinforce constancy backed by agency incentives;

(ii) Adequate resources to assure the transfer of requisite technical, cultural and institutional knowledge from one worker and management generation to another;
(iii) Analytical and resource support for a careful examination of the impacts of future technical developments;
(iv) Capacity to detect and rectify inevitable failures and their effects, with the assurance of remediation when failures occur.

The USDOE continues to face a challenge in building public trust and strengthening confidence in the constancy of the institutions charged with stewardship. This National Academies committee and several others have noted that, at many of its sites, the USDOE operates in a social environment of public distrust mainly associated with its history [VII–5, VII–6]. These committees have noted that USDOE needs public trust if the department is to have sufficient flexibility to reach its cleanup objectives and to undertake long term stewardship.

VII–3. UPDATE ON A CURRENT NATIONAL ACADEMIES PROJECT ON LONG TERM STEWARDSHIP

VII–3.1. The 2004 National Academies workshop

In the last decade, the USDOE has transferred over 50 sites to long term stewardship and many more are on the verge of being transferred (for a list of sites, see Ref. [VII–3]). As sites move from cleanup to stewardship, stakeholder involvement issues are emerging, such as participation in remedy selection, communication with agencies and regulators, and long term commitment during the stewardship phase. Further investigation has made it evident that long term stewardship involves several Federal, State, local agency and private organizations, making it a nationwide issue.

As a result, in 2004 the National Academies convened another workshop on long term stewardship. This workshop addressed long term stewardship at sites with both radioactive and hazardous contamination. Representatives from the USDOE, the US Department of Defense, the US Environmental Protection Agency (USEPA), the US Nuclear Regulatory Commission (USNRC) and the National Aeronautics and Space Administration, as well as of States and private organizations, attended the workshop. These agencies either have legacy waste sites or anticipate gaining responsibility for such sites.

Workshop participants expressed the following main ideas[4], outlined in Sections VII–3.2 to VII–3.6.

VII–3.2. Significant difference of views on cleanup end states between 'remediator' and 'steward'

Outside parties other than the Federal agencies responsible for the contamination and cleanup are likely to implement long term stewardship at most US sites. In such cases, 'remediator' and 'steward' may not agree on fiscal responsibility and the environmental liability that should be left behind. Indeed, workshop presentations showed that the remediator and the steward may have significantly different views about a site's cleanup end state.

On the one hand, the 'remediator' generally accepts that completely removing contaminants is not possible at many sites and embraces the long term stewardship concept. The remediator's challenge is twofold:

(1) To balance public and worker safety with reasonable costs;
(2) To effectively communicate the trade-offs to the steward and stakeholders.

The USNRC, which is responsible for commercial sites that store radioactive waste, pointed out that quantitative approaches to risk assessment exist in its regulations.

On the other hand, the 'steward' (such as the US Department of Interior, States or municipalities) and stakeholders generally expect the land to be returned to a pristine state. To them, complete environmental cleanup and unrestricted land use of the site are more acceptable than long term stewardship.

VII–3.3. Regulatory barriers to periodic reviews of selected remedies

Workshop participants identified significant regulatory barriers to periodic reviews of selected remedies. A workshop participant remarked that there are no strong regulatory incentives or enforcement practices for periodic reviews of selected remedies. Others pointed out that mechanisms to modify selected remedies do exist — the five year review process of the USEPA's Comprehensive Environmental Response, Compensation, and Liability Act

[4] The comments by workshop participants reported in this annex do not represent the position of the National Academies.

(CERCLA), the USNRC's licence renewal process, formal amendments to decision records, permit modifications to the Resource Conservation and Recovery Act (RCRA), various other documents such as the Explanation of Significant Differences in CERCLA, contingency records of decisions, or waivers because of technical impracticability. However, these mechanisms are not required by law or enforced by the regulatory authorities [VII–2, VII–7].

Participants noted that the remediation technologies specified in the US regulations are quite prescriptive. These regulatory requirements are often based on 1970s technologies. Because there are no enforcement requirements, the remediator has no incentive to implement scientific and technological advances. Similarly, if anticipated land use changes, the steward has no recourse but to pay for the more aggressive remedial goals themselves.

Participants also added that in the absence of regulatory enforcement actions, Federal cleanup programmes may not have extra funds to implement voluntary periodic reviews. Pressure to end cleanup and reliance on engineered barriers and institutional controls discourage the responsible parties from periodically reviewing the protective systems of a site, in particular if ownership of the site has changed. Discussions during and after the workshop suggested a need for policy changes to environmental regulations, to allow periodic reviews of remedies already implemented.

VII–3.4. Different long term stewardship needs of different sites

A workshop participant noted the wide range of end states for contaminated sites. Some sites need passive-only institutional controls, some may require long term monitoring and others need additional remedial work. Different end states mean different residual risks. End states may change with time. For example, possible future land uses may broaden as remediation technologies improve. Property development pressure may increase at sites near densely populated areas. On the other hand, potential land uses may narrow if contaminant isolation or stewardship measures begin to fail or if new information on environmental toxicology becomes available[5].

Different compliance standards and long term stewardship provisions are site specific as is enforcement authority[6]. The USEPA's plethora of regulatory

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[5] A recent example of new information on an environmental contaminant concerns the updated health risk linked to trichloroethylene [VII–8].

[6] For example, regulatory authority and enforcement rights may rest with the USEPA, the responsible Federal agency, the State or the local government, depending on whether a site is on the National Priorities List or has a CERCLA or RCRA statute.

requirements for the management and cleanup of contaminated sites is evident from the following list:

— Solid and hazardous waste laws, regulations and policies;
— CERCLA laws, regulations, policies and guidance;
— Legislation and regulations of the Chemical Emergency Preparedness and Prevention Office;
— Laws and regulations of the Federal Facilities Restoration and Reuse Office;
— Laws and regulations related to brownfield sites;
— Environmental justice laws and regulations;
— Laws and regulations related to oil and chemical emergency response;
— Laws and regulations of the Federal Underground Storage Tanks Office.

The USEPA recognizes that:

> "The regulated community has expressed concern that inconsistent and duplicative approaches taken by different regulatory agencies create inefficiency and confusion. Increased effectiveness of cleanups and more efficient use of resources can be achieved by sharing lessons learned, recognizing successful alternative approaches, and developing more consistent policies and guidance. Cleanup programmes should work together to make greater use of all available authorities, and select the optimum programmatic tools to increase the pace, efficiency, and quality of cleanups" (see Ref. [VII–9]).

To untangle this regulatory morass, the USEPA recently created the One Cleanup Program, whose mission is to apply cross-programme, cross-agency thinking and planning to all contaminated sites.

VII–3.5. Lessons to share

Workshop participants reported that implementation of long term stewardship agreements is typically negotiated individually at each site. More broadly, there is little evidence that lessons have been learned from cases of successful stewardship elsewhere in the Federal estate, at national parks, closed mill tailings sites and military bases that have been transferred to commercial reuse. A major step forward in cross-agency fertilization is the memorandum of understanding that identifies long term stewardship principles and components, signed by the Environmental Council of States, USDOE, US Department of Defense, USEPA and US Department of the Interior [VII–10].

Workshop participants also pointed out that the private sector has employed original solutions to manage, purchase or sell real estate with minor long term contamination issues. Therefore, the private sector could be a valuable resource to Federal agencies.

VII–3.6. Need for a national multi-institutional perspective on long term stewardship

Participants at the 2004 National Academies workshop raised technical as well as institutional and policy challenges in relation to long term stewardship. The technical challenges mentioned are related to:

(a) Long term monitoring to anticipate or activate an alert to failures of remedial actions;
(b) Environmental engineering, such as biotechnologies;
(c) Work by social science specialists to improve stakeholder participation in the planning and implementation of long term stewardship.

Institutional and policy challenges mentioned are related to:

(a) Measuring the 'success' of a long term stewardship programme;
(b) Balancing short and long term costs;
(c) Managing land use controls;
(d) Managing and preserving records;
(e) Coordinating efforts with local governmental and Federal agencies;
(f) Allocating funds for site monitoring and maintenance.

Most workshop participants agreed that there is a need to adopt a broad perspective on long term stewardship, taking into account what has been done so far by different Federal agencies, States, municipalities and even owners of private sites.

Some participants expressed reluctance to embark on yet another study of long term stewardship, because of the risks of repeating earlier work. The USDOE, in particular, believes that most of the challenges are policy and institutional ones, and must be dealt with inside the USDOE. However, the overall results of the 2004 National Academies workshop indicated the need for a study to identify best practices (including those in the private sector) and the strategies needed to build more effective long term stewardship programmes.

The National Academies are now designing a study on long term stewardship that will address the identification of the various stewards and their concerns. The study will encompass the differences in cleanup and long term stewardship regulations and practices depending on the type of contamination, the sites, and the responsible Federal, State or private agency.

REFERENCES TO ANNEX VII

[VII–1] UNITED STATES NATIONAL RESEARCH COUNCIL, Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites, The National Academies Press, Washington, DC (2000), http://fermat.nap.edu/catalog/9949.html

[VII–2] UNITED STATES NATIONAL RESEARCH COUNCIL, Long-Term Stewardship of DOE Legacy Waste Sites: A Status Report, The National Academies Press, Washington, DC (2003), http://fermat.nap.edu/catalog/10703.html

[VII–3] UNITED STATES DEPARTMENT OF ENERGY, Long-Term Surveillance and Maintenance Report, Rep. DOE-LM/GJ548-2004, USDOE, Washington, DC (2004).

[VII–4] UNITED STATES DEPARTMENT OF ENERGY, Office of Legacy Management Web Site, http://www.gjo.doe.gov/LM/

[VII–5] UNITED STATES NATIONAL RESEARCH COUNCIL, Improving Risk Communication, The National Academies Press, Washington, DC (1989), http://fermat.nap.edu/catalog/1189.html

[VII–6] UNITED STATES NATIONAL RESEARCH COUNCIL, One Step at a Time, The Staged Development of Geologic Repositories for High-Level Radioactive Waste, The National Academies Press, Washington, DC (2003), http://fermat.nap.edu/catalog/10611.html

[VII–7] UNITED STATES NATIONAL RESEARCH COUNCIL, Environmental Cleanup at Navy Facilities: Adaptive Site Management, The National Academies Press, Washington, DC (2003), http://fermat.nap.edu/catalog/10599.html

[VII–8] UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, Review of Draft Trichloroethylene Health Risk Assessment: Synthesis and Characterization, An EPA Science Advisory Board Report, Rep. EPA-SAB-EHC-03-002, USEPA, Washington, DC (2002).

[VII–9] UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, One Cleanup Program Web Site, http://www.epa.gov/oswer/onecleanupprogram/

[VII–10] ENVIRONMENTAL COUNCIL OF THE STATES, Memorandum of Understanding on Long-Term Stewardship at Federal Facilities in the United States between the Environmental Council of the States, United States (US) Department of Defense, US Department of the Interior, US Department of Energy, US Environmental Protection Agency (2003), http://www.epa.gov/swerffrr/pdf/ecos_lts_mou.pdf

Annex VIII

PLANNING FOR THE LONG TERM STEWARDSHIP OF THE UKAEA DOUNREAY SITE

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Abstract

For the UK site at Dounreay, long term stewardship refers to the post-decommissioning phase of the site, i.e. the site after decontamination, dismantling, demolition and remediation to an appropriate level of passive safety. Completion of the decommissioning phase is envisaged within the next 30–50 years. The period of long term stewardship thus covers the following phases of site restoration and closure: the care and surveillance phase (envisaged to be up to 300 years) and the post-restoration phase, for which no institutional controls are assumed other than normal planning authority controls.

Although the conditions for site post-decommissioning have yet to be decided through consultation with the stakeholders, including the regulators and the public, it is anticipated that there will be some residual radioactivity and chemical substances left in the ground. The aim of the site restoration programme is to ensure that residual contamination is passively safe and meets appropriate regulatory requirements. To support this strategy, long term safety cases are being developed. These will address all aspects of the radiological and non-radiological impacts of the site. They will include a performance assessment involving the use of mathematical models to represent the environment, which, together with the subsurface radiological and chemical inventory data, can be used to evaluate doses to a number of potential receptors during the care and surveillance phase, as well as the post-restoration evolution of the site. The preliminary performance assessment model indicates that the long term radiological consequences to human health and the environment should be at an acceptably low risk level. However, this is a preliminary model and there are many uncertainties both in the data and in some of the model parameters themselves. Regarding the records associated with long term stewardship, it is envisaged they will need to include factual information, at the level of the global site and its surroundings, down to the level of the individual area, as well as interpretive information, particularly that related to performance assessment modelling and risk assessment.

VIII–1. INTRODUCTION

This annex outlines the issues being considered for planning long term stewardship of the United Kingdom Atomic Energy Authority (UKAEA) site at Dounreay. In planning for long term stewardship, the annex considers the:

(a) Definition of long term stewardship of Dounreay;
(b) Anticipated post-decommissioning status of the site with respect to residual contamination at the site;
(c) Work required to justify the risk acceptable to humans and the environment from residual contamination;
(d) Records required.

VIII–2. BACKGROUND INFORMATION

VIII–2.1. Dounreay site restoration plan

The UKAEA has developed a suite of documents, each of which addresses a different aspect of the overall task of site decommissioning and restoration. Taken together they form the Dounreay site restoration plan (DSRP) [VIII–1].

The restoration strategy (Vol. 2 of the DSRP) discusses the evolution of the site during decommissioning and the target end point conditions for the completion of decommissioning, at the end of the restoration period and beyond into the distant future. Decommissioning and site restoration are envisaged to be in three phases, namely:

(1) The *decommissioning phase* — involving decontamination, dismantling, demolition and remediation to an appropriate passively safe level.
(2) The *care and surveillance phase* — during which residual radioactive material can be monitored to ensure long term safety, and during which further radioactive decay will take place. The timescale for this phase is envisaged to be up to 300 years (which is based on the time for significant decay of some of the more important radionuclides to residual levels of activity).
(3) The *post-restoration phase* — in which no institutional controls are assumed other than normal planning authority controls, and justification of the safe and environmentally acceptable condition of the site is through a post-closure safety case.

The goals of the strategy for decommissioning and site restoration are to:

(a) Ensure the safety of the public, the workforce and the environment;
(b) Achieve value for money for the United Kingdom taxpayer;
(c) Generate appropriate records and quality arrangement systems;
(d) Minimize waste production;
(e) Gain the approval of Dounreay's stakeholders.

The general philosophy is to progressively decontaminate, dismantle and remediate in order to reduce the number of facilities on the site, with treatment and packaging of waste so that it is suitable for long term storage or disposal. Conditioned waste will be housed in modern, purpose built, facilities before the eventual removal of the intermediate level waste from the site for disposal. The superstructures of buildings will generally be demolished and removed, whilst some substructures may be left in the ground.

Although the condition of the site post-decommissioning has yet to be decided through consultation with the stakeholders, including the regulators and the public, it is anticipated that there will be some residual radioactivity and chemical substances left in the form of:

(a) Residual contamination within building substructures;
(b) Residual contamination from the remediation of the Dounreay shaft;
(c) Contaminated ground;
(d) A closed landfill adjacent to the nuclear licensed boundary;
(e) Possible on-site low level waste (LLW) disposal facilities.

VIII–3. APPROACH TO ADDRESSING LONG TERM STEWARDSHIP ISSUES

VIII–3.1. General considerations

The aim of the site restoration programme is to ensure that any residual contamination is passively safe and meets appropriate regulatory requirements with respect to being of acceptably low risk to human health and the environment, now and in the future.

During the care and surveillance phase, it is anticipated that the site could be subject to restrictions in land use in order to maintain an acceptably low level of risk to human health and the environment, for example, to prevent excavations of disposed LLW.

During the post-restoration phase it is anticipated that most, if not all, of the site could be released from institutional care — with future land use being decided on risk based arguments for no restrictions on land use.

VIII–3.2. Framework for assessing the post-decommissioning status of the site

A number of different end point options are being considered for the post-decommissioning status of the site. These are as follows.

(a) The *minimum restoration activity option*, which aims to reduce the amount of restoration activity compared with the DSRP programme, minimizing costs. There would be less remediation of contaminated land, and wastes might be stored for an extended period of time.
(b) The *DSRP end state option*, which assumes that the site would be remediated with and on the timescales described in the DSRP. Risk based arguments would be used to justify leaving some residual radioactivity.
(c) The *minimize licensed site area option*, which aims to enable regulatory controls to be removed from as much of the site as possible, as quickly as possible. This approach has been adopted at other nuclear sites. It is sensitive to the de-licensing targets, and so two alternatives are considered; one with a risk based target and one with a concentration based target (e.g. total activity less than 0.4 Bq/g above background levels).

In addition, a further option is being considered where closure is anticipated to occur on a shorter timescale than that envisaged in the DSRP. This is known as the:

(d) *Accelerated and enhanced DSRP option*, which envisages an accelerated programme of site restoration, with higher standards of remediation.

A framework has been devised on the basis of the *best practicable environmental option* methodology [VIII–2, VIII–3], against which the different end point options could be evaluated. This is shown in Table VIII–1.

A consultation process to gain stakeholder views on the most appropriate end point for the site is currently being planned.

VIII–3.3. Post-decommissioning safety cases

In parallel to considering the status of the site post-decommissioning options, strategies to support care and surveillance and site closure safety cases are being developed. These safety cases will address all aspects of radiological

TABLE VIII–1. ATTRIBUTES FOR EVALUATING SITE CONDITION AT CLOSURE

Health and safety attributes	Public: transport hazards Public: hazards from operations Public: long term hazards from the site Workers: radiological hazards Workers: non-radiological hazards
Environmental impact attributes	Air quality Water quality Land quality Visual amenity Noise Transport issues
Flora and fauna attributes	Preservation of habitat Conservation of species
Technical attributes	Reliability of technology Removal of activity Project risk Flexibility Concentration and containment Regulatory and planning effort
Social and economic attributes	Local community Culture and heritage Intergenerational equity
Financial costs	Discounted costs Undiscounted costs

and non-radiological impacts from the site, and it is envisaged that they will include the following:

— Performance assessments;
— Monitoring;
— An environmental impact assessment;
— A best practicable environmental options study of the site end point.

VIII–3.3.1. Components of the safety case

VIII–3.3.1.1. Performance assessments

Performance assessment techniques use mathematical models to represent the environment and, together with subsurface radiological and chemical inventory data, can be used to evaluate doses to a number of potential receptors during the care and surveillance stage and during the post-closure evolution of the site. The performance assessment will demonstrate that the level of environmental risk of the restored site is acceptable to the regulators and to other stakeholders.

VIII–3.3.1.2. Monitoring

Monitoring to acquire radiological and chemical contamination data, as well as other environmental parameters during the care and surveillance phase, will be used to demonstrate that the predicted conditions used in the modelling for the post-closure period are reasonable.

VIII–3.3.1.3. Environmental impact assessment

To be considered are those aspects of the environment that could be significantly affected during the post-closure phase, including, for example:

— Ecology;
— Climate;
— Air quality;
— Noise;
— Local economic factors;
— Agriculture;
— Oceanography;
— Geology;
— Hydrology;
— Land use;
— Architectural and archaeological heritage;
— Local population;
— Fisheries;
— Environmental monitoring;
— Interrelationships between the above factors.

The potential impacts that will be considered are those on:

— The use of resources;
— The creation of nuisances;
— The emission of pollutants;
— Residual contamination and the disposal of wastes.

VIII–3.4. Performance assessment modelling

As well as the expected evolution of the site caused by changes through natural processes such as coastal erosion and water movement (the 'normal evolution scenario'), other events such as redevelopment of the site or catastrophic events such as a tsunami ('altered evolution scenarios') were also considered.

In the model, the Dounreay site and surrounding environment is split up into 138 separate model compartments, each of which is representative of a human-made structure (such as a waste disposal facility) or a region of soil, rock or water. The simulated transport of radionuclides between the compartments takes account of a wide range of environmental processes such as water movement (e.g. percolation of rainwater into soil) and bulk solid movement (e.g. erosion). Sixty-two different radionuclides are considered.

The preliminary performance assessment model indicates that the long term radiological consequences to human health and the environment should be at an acceptably low risk level. The model calculations allow the long term radiological impact of different restoration strategies to be compared. The findings suggest that higher standards of restoration are unlikely to be warranted on radiation protection grounds.

However, it has been recognized that this is a preliminary model and there are many uncertainties both in the data and in some of the model parameters themselves. These include potential uncertainties in:

(a) Scenario definition — particularly with respect to human activities in the future after the site has been released from institutional control;
(b) Conceptualization of the processes within the model and their interactions, including any engineered structures that remain on-site;
(c) Key parameter measurements (e.g. partition coefficient, hydraulic gradient and porosity);
(d) Modelling of the variability of natural processes and potentially catastrophic events through long periods of time (e.g. global warming, sea level changes, coastal erosion, flooding, seismic activity and extreme meteorological events);
(e) The subsurface inventory data.

Work is currently planned to assess the effects of these uncertainties by:

— Carrying out a sensitivity analysis of the data and parameters used in the model;
— Making a comparison with other predictive models.

Where possible, a programme of work will then be developed to resolve the uncertainties associated with key parameters.

It should be noted that, although the performance assessment will be key to the argument presented to the regulators that the risk to human health and the environment will be negligible after decommissioning, environmental monitoring will be carried out during the care and surveillance period, for reassurance.

VIII–4. LONG TERM STEWARDSHIP RECORDS

It is envisaged that the records associated with long term stewardship will need to include:

(a) Factual information at a global site and surrounds level down to an individual area level, i.e. from geographical, geomorphological and geological setting, to area specific data relating to historical building and land usage, infrastructure, decommissioning reports, investigation reports, monitoring records, remediation reports, land condition reports and validation surveys.
(b) Interpretive information, particularly performance assessment modelling and risk assessment.

Many of these records have been kept over the years, whilst other data are currently being generated. There are currently several projects involved in collating these data into a readily accessible form through the use of appropriate data management systems. The type of information being collected is summarized in Table VIII–2.

In more recent times there have been developments that have allowed both access to and visualization of what are mostly spatially related data through the use of georeferenced information systems.

Whilst electronic capture of data is considered an important part of being able to readily access data, it has also been recognized that these systems require maintenance so that records do not become inaccessible and unreadable as the software driving the databases changes.

TABLE VIII–2. TYPE OF INFORMATION COLLECTED AS STEWARDSHIP RECORDS

Factual	Type of information
Setting	Present use of land area Location of land area (with respect to a national grid system) Topography Geological, geomorphological and hydrological features Summary of previous uses of the land area Statement of land use restrictions
Facilities	Previous use Types and forms of radioactive and chemical materials used Discharges Wastes generated (in normal operation and as a consequence of decommissioning) and waste disposal routes Decommissioning records, particularly with respect to residual structures left in the ground and any residual radiological or chemical contamination
Drainage systems	Active or non-active Natural drainage Land drains (as potential preferential pathways for contaminant migration) Discharges Decommissioning records
Land	Past and present uses Soils and geology Structural geology and geotechnical properties Hydrogeology and hydrology Human-made materials and influences Subsurface radiological and chemical contamination, investigations Remediation and validation records
Monitoring	Ongoing monitoring records, especially on land surfaces and groundwater Meteorological data
Interpretive	Site conceptual model Contaminant fate and transport modelling and verification Quantitative risk assessments

VIII–5. CONCLUSIONS

Residual contamination and chemical substances are likely to be left in the ground following the decommissioning phase of the restoration of the Dounreay site. A strategy to assess the impact on human health and the environment has therefore been developed which involves a number of elements. These are:

(a) The development of models to assess the potential impacts of residual contamination against a number of predictions about the future evolution of the site;
(b) The development of records management systems to store information about the site;
(c) Planned future consultations with regulators and other stakeholders about the end state of the site;
(d) The development of safety cases to support the long term stewardship of the site.

REFERENCES TO ANNEX VIII

[VIII–1] UNITED KINGDOM ATOMIC ENERGY AUTHORITY, Dounreay Site Restoration Plan, UKAEA, Dounreay (2000), http://www.ukaea.org.uk/index.htm

[VIII–2] ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION, Best Practicable Environmental Option, 12th Report, Cm 310, Office of Public Sector Information, London (1988).

[VIII–3] ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION, Setting Environmental Standards: The Royal Commission Launches its 21st Report, Cm 4053, Office of Public Sector Information, London (1998).

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Experience in Member States has often shown that sites with radiation legacies and liabilities cannot be remediated to residual levels of radioactivity that are below concern, so that they cannot be released for unrestricted use. With long lived radionuclides present, maintenance of institutional control will probably be required for nearly unlimited periods of time. The present publication describes the relevant issues in various Member States and attempts by them to deal with the conceptual, management and technical problems associated with maintenance of institutional control over hundreds or even thousands of years.

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