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POLICY AND STRATEGIES FOR ENVIRONMENTAL REMEDIATION

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FOREWORD

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

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

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

This publication provides guidance on formulating a national policy and strategies for environmental remediation of radioactively contaminated sites. A national environmental remediation policy is essential for establishing the core values on which remediation is to be based, and incorporates a set of principles to ensure the safe and efficient management of remediation situations. Environmental remediation strategies set out the means for achieving the principles and requirements in the national policy, and may be elaborated in several different components. This publication is intended to assist States in the proper, systematic planning and safe implementation of environmental remediation efforts.

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

EDITORIAL NOTE

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SUMMARY

In the environmental remediation of a given site, concerned and interested parties have diverse and often conflicting interests with regard to remediation goals, the time frames involved, reuse of the site, the efforts necessary and cost allocation. An environmental remediation policy is essential for establishing the core values on which remediation is to be based. It incorporates a set of principles to ensure the safe and efficient management of remediation situations. Policy is mainly established by the national government and may become codified in the national legislative system. An environmental remediation strategy sets out the means for satisfying the principles and requirements of the national policy. It is normally established by the relevant remediation implementer or by the government in the case of legacy sites. Thus, the national policy may be elaborated in several different strategies. To ensure the safe, technically optimal and cost effective management of remediation situations, countries are advised to formulate an appropriate policy and strategies.

Situations involving remediation include remediation of legacy sites (sites where past activities were not stringently regulated or adequately supervised), remediation after emergencies (nuclear and radiological) and remediation after planned ongoing operation and decommissioning. The environmental policy involves the principles of justification, optimization of protection, protection of future generations and the environment, efficiency in the use of resources, and transparent interaction with stakeholders. A typical policy will also take into account the national legal framework and institutional structure and applicable international conventions while providing for the allocation of responsibilities and resources, in addition to safety and security objectives and public information and participation in the decision making process.

The strategy reflects and elaborates the goals and requirements set out in the policy statement. For its formulation, detailed information is needed on the current situation in the country (organizational, technical and legislative). The technical solutions proposed for the remediation of sites in the country need to be politically, technically and economically feasible. When selecting a set of technological procedures, an appropriate end point must be identified, usually a suitable end state. The steps in formulating and implementing the strategy include selecting the technical procedures, allocating the responsibility for implementing the identified procedures, establishing supervisory mechanisms and developing implementation plans.

The policy and strategies may need to be updated because of new national circumstances (legislative changes, plans for new nuclear facilities), new international agreements and/or experience obtained with the original policy and

strategies. The lead in making changes is to be taken by the body responsible for the initial formulation of the policy (government) and strategy, but all relevant parties in the country are to be involved and consulted in this process.

1. INTRODUCTION

1.1. BACKGROUND

A site may be contaminated by a variety of substances, such as heavy metals, organic compounds and radioactive material. Radioactive contamination is to be dealt with similarly to chemical contamination, except that technical differences between radionuclides and chemicals will need to be considered. Therefore, elements of the policy and strategy for remediation of contaminated land may be comprehensive enough to include all types of contaminant or can be specifically dedicated to situations in which the contamination is mainly or exclusively caused by radioactive substances.

In terms of contamination of land by radioactive material, remediation is to be understood as any measure that may be carried out to reduce the radiation exposure from existing contamination of terrestrial areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans [1]. The IAEA Fundamental Safety Principles [2] and IAEA safety standards set safety principles and criteria for use as a basis for deciding whether remediation is needed. Requirements and guidance on the implementation of remediation are also available [3, 4].

It is important to note that remediation does not involve the complete removal of the contamination and that the more informal term 'cleanup' (i.e. to make a site clean, free from impurities) is not to be taken as being synonymous with remediation. Similarly, the terms 'rehabilitation' and 'restoration' may imply that the conditions that prevailed prior to contamination can be restored, which is not normally the case (e.g. owing to the effects of the remediation itself). The use of such terms is therefore discouraged.

Within the nuclear fuel cycle, there is a wide range of installations and their associated activities that produce artificial ('human-made') radioactive material which have the potential to elevate the radioactivity in the environment to levels above the natural background level. Outside the nuclear industry, elevated levels of radioactivity in the environment might be the consequence of military operations, such as weapons testing, the use of radioactive sources in industry and medicine, or radiological accidents. Human activities, such as mining and oil and gas production, and some natural processes can sometimes concentrate naturally occurring radioactive material (NORM)[1] to levels that require remediation. Situations may exist in which there are primordial natural radionuclides in the environment or where their appearance is due to natural phenomena; such situations are normally excluded from regulatory control, as their remediation is unwarranted or unfeasible.

Radioactive substances may spread from their source through any environmental medium, such as groundwater, surface water or soil, or via airborne pathways and biota. Elevated levels of radioactivity in the environment may lead to a radiation risk to human health and/or to the environment. Environmental remediation is undertaken with the goal of preventing or greatly reducing the radiation risk by removing or reducing the source causing the exposure and/or reducing or removing the pathway to the source.

Environmental media contaminated with short lived materials (e.g. accelerator produced radioisotopes used in medicine and research, some fission products) may not require remediation if the contaminated area can be monitored and controlled for a reasonable time to allow radioactive decay. Many radionuclides — notably caesium radioisotopes — bind to geological media (clays or rocks) and move very slowly, all the while decaying and becoming more diffuse. Such processes, referred to as natural attenuation, can reduce environmental contamination to acceptable levels. Conversely, site characterization may determine that active remediation measures are necessary.

Once a characterization of a contaminated site and a dose assessment have been made, it may be decided that some form of remediation is necessary, taking into account the reference levels set by authorities and the remediation principles. The remediation strategy is formulated to be commensurate with the associated

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[1] The term ‘naturally occurring radioactive material’, or NORM, means material containing no significant amounts of radionuclides, other than radionuclides of natural origin. The term ‘radionuclides of natural origin’ is used restrictively to mean only ^{40}K and radionuclides in the decay chains of the primordial radionuclides. The isotope ^{40}K is a generalized contributor to exposure by virtue of its widespread distribution in nature and because it is an important constituent of the human body. The primordial radionuclide decay chains are: the thorium series, headed by ^{232}Th, the most abundant of all naturally occurring radionuclides, and comprising mainly ^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl and ^{208}Pb (stable); the uranium series, headed by ^{238}U and comprising mainly ^{234}Th, ^{234m}Pa, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po and ^{206}Pb (stable); and, less important for the purpose of this report, the actinium series, headed by ^{235}U and comprising mainly ^{231}Th, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Fr, ^{223}Ra, ^{219}Rn, ^{215}Po, ^{211}Pb, ^{211}Bi, ^{207}Tl and ^{207}Pb (stable). Radionuclides produced by the action of cosmic rays such as ^{3}H (tritium), ^{14}C and ^{22}Na, which are isotopes of elements with metabolic roles in the human body, and several other natural radionuclides, such as ^{87}Rb, ^{138}La, ^{147}Sm and ^{176}Lu, are widespread in nature but at such low levels that their contribution to human exposure is negligible.

radiation risks and to provide sufficient benefits. This means that costs and other social and environmental impacts need to be assessed and all strategies discussed with the interested parties. All of these procedures and responsibilities should be defined within a national policy, with a strategy planned for each different case.

To fulfil the requirement for a national remediation strategy, areas that have been identified as contaminated need to be prioritized. Following the initial characterization of each area, an inventory of contaminated areas is prepared, including their locations, the types and properties of the contaminants, the size and environmental characteristics of the areas, the populations actually or potentially exposed and any other relevant factors.

The inventory of contaminated areas is then prioritized in accordance with the level of risk to human health and to the environment. Other factors such as socioeconomic impacts, availability of funds, availability of remediation techniques, availability of scientific data and potential effects on neighbouring States may also have a strong influence in determining the priorities for remediation. If the parties responsible for some of the identified sites are ready to perform the remediation activities at their own cost, the remediation of these sites should proceed without delay.

Environmental remediation is fundamentally different from radioactive waste management and decommissioning of nuclear installations in that the radioactive material of concern is mixed and/or incorporated into the natural environmental media. However, the remediation policy and strategies need to be coherent and consistent with those of decommissioning and waste management. Related reports published by the IAEA address policy and strategy for managing radioactive waste [5] and for decommissioning radiological facilities [6].

Locations requiring environmental remediation can be broadly classified as follows:

(a) Legacy sites, where radioactive material has already entered the soil and groundwater, perhaps decades in the past;
(b) Sites with existing nuclear or radiological facilities or sites where such facilities are planned to be terminated and/or decommissioned;
(c) Sites that may require remediation in the aftermath of an emergency situation or any unplanned event, such as a nuclear/radiological accident or act of sabotage.

The approach to remediation can vary, for example:

(a) Natural radioactive decay of radionuclides may be used to reduce the overall hazard, with only monitoring and assessment being applied (sometimes referred to as monitored natural attenuation).

(b) The site may be treated to remove radionuclides.
(c) Radioactively contaminated media may be removed from the site.
(d) Use of the site may be prevented or restricted.

Combinations of these approaches may also be used.

Generally, and as described in this publication, environmental remediation is applied to the near surface terrestrial environment (rather than, for example, to airborne radioactive substances). Developing a national policy and an underlying strategy or strategies to implement environmental remediation is therefore imperative if the problem holders and decision makers are to succeed in applying the most appropriate and sustainable solutions to their environmental problems.

Government policy on land contamination should be built around the twin ideas of stopping contamination of land while taking a risk based approach to tackling historical contamination.

1.2. OBJECTIVE

The objective of this publication is to set out the fundamental elements of a national policy and derived strategies for remediation of radioactively contaminated sites to serve as an aid, resource and reference for those engaged in the development or updating of national policy and strategies for environmental remediation. This guidance is intended to benefit those organizations charged with implementing environmental remediation or agencies seeking to establish this competence. Along with previously published IAEA safety standards for remediation [7], this guidance will encourage national authorities to recognize the necessity of including environmental protection and remediation as essential components in the planning and conduct of nuclear related initiatives.

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

1.3. SCOPE

This publication is concerned with the development of policy and strategies in the area of environmental remediation. Although limited to the area of radiological risk, it recognizes that, in optimizing remediation efforts, the overall related risks present will be taken into account. It provides guidance on the content of a national policy and strategies, but does not prescribe the content, as this will be highly dependent on national priorities and circumstances.

Important areas to be covered are:

(a) Definition of responsibility and engagement across the spectrum of stakeholders, including the site operators, regulators, and local, regional and national government;
(b) Definition of possible remediation outcomes based on objectives for the site (strategy);
(c) Remediation resourcing, encompassing the availability of funding, infrastructure, skills and people;
(d) Planning and scheduling;
(e) Management of waste from remediation.

The types of remedial work considered are classified in Section 1.1 and discussed in more detail in Section 2; these can be thought of essentially as circumstances which can be planned for and circumstances which cannot be specifically planned for but which need to be considered as possibilities in national policy.

1.4. STRUCTURE

Section 2 provides some classification of remediation situations dealt with in this report. Section 3 sets out the principles for remediation policy and strategy. Sections 4 and 5 cover typical components of remediation policy and strategies, respectively.

2. CLASSIFICATION OF REMEDIATION SITUATIONS

The remediation of sites where the presence of radioactive substances has been detected may be required under different situations.

2.1. LEGACY SITUATIONS

Legacy situations involve radioactive residues at a site resulting from past activities or events such as:

(a) Past activities that were not stringently regulated, where the termination of the activity and the handling of the remaining residues most probably were not adequately considered when the activity was initiated, e.g. activities involving mining and milling of ores containing natural radioactive substances;
(b) Long term, prolonged presence of radioactive residues from accidents and other unforeseen events that were not adequately managed;
(c) Radioactive residues from military activities, such as nuclear weapon production and testing.

Thus, in legacy situations, radioactive substances may have already been present at the site long before a decision on remediation is made. However, legacy situations may also be created when an operator goes bankrupt, and the remediation of the site then falls under the responsibility of the State. In this case, the contamination may not have been present for a long period of time.

Legacy situations can be complex, as they may involve several pathways and generally give rise to wide distributions of radioactive substances, ranging from normally very low or low concentrations to, in rare cases, very high levels.

2.2. REMEDIATION AFTER EMERGENCY SITUATIONS

2.2.1. Remediation in the post-emergency phase of a nuclear accident

These situations may occur as a result of an accident during a planned operation. The release of large amounts of radioactive substances can result in contamination of sites and large territories. The resulting situation can be complex in that many independent pathways for exposure might exist, perhaps acting simultaneously, making remediation very difficult. However, the populations potentially affected and the environmental characteristics are known, thereby allowing the planning of some remediation strategies.

The transition from an emergency exposure situation to an existing exposure situation where remediation starts is characterized by a change in management strategies, from those mainly driven by urgency, with potentially high levels of exposure and predominantly centralized decision making, to more decentralized strategies aimed at improving living conditions and reducing exposure to levels as low as reasonably achievable, given the circumstances.

2.2.2. Remediation in the post-emergency phase of a radiological emergency or unforeseen event

These situations may occur as a result of unplanned events such as those resulting from the loss and dissemination of a radioactive source or radioactive substances, a malicious act or any other unexpected situation. In these cases, the environment and the population affected are not known in advance. Therefore, strategies for remediation can only be planned in a generic way.

Furthermore, radioactive substances may be accompanied by other pollutants (e.g. chemical or biological hazards). These kinds of emergency situation are inherently unpredictable and the exact nature of the necessary remediation measures cannot be known in advance.

2.3. REMEDIATION AFTER PLANNED ONGOING OPERATION AND DECOMMISSIONING

There may also be radioactive remnants from ongoing operations or after the termination of a practice and decommissioning of associated installations. These are planned situations, and the magnitude and extent of the environmental contamination can be reasonably followed up or predicted and some necessary environmental remediation measures planned in advance.

3. PRINCIPLES FOR REMEDIATION

The ‘polluter pays’ principle, the precautionary principle, and sustainability and subsidiarity are principles that can be applied regarding contamination of the environment. In those countries that follow the polluter pays principle, the polluter is expected to pay for all necessary remediation. In some situations, there may be subsidies or grants available to reduce polluter liability. However, the polluter pays principle does not solve the issue of orphan sites, that is, areas that do not have an obvious responsible party or instances where the polluter cannot pay. In these cases, the State takes the liability into public ownership using public money for remediation. The precautionary principle assumes that it is better to prevent pollution from occurring than to have to remediate a site.

Sustainability seeks to ensure that the needs of the present generation are met without compromising the ability of future generations to meet their own needs. The principle of subsidiarity can also be evoked, but it is unlikely that any State would be willing to forgo this principle and allow policy on contaminated land to be dictated by any other State, or even a regional arrangement, without considerable discretion to formulate the policy to suit its individual needs.

In the scope of radioactively contaminated sites, the main principles for establishing a policy and strategy for remediation are based on the principles established in Refs [2, 8]. The principles relevant for remediation are as follows:

(a) Justification for undertaking remediation;
(b) Optimization of the remediation;
(c) Appropriate protection of future generations and the environment;
(d) Efficiency in the use of resources;
(e) Open and transparent interactions with stakeholders.

While these principles, approaches and considerations may not be explicitly present in the national policy, they should be taken into account when the policy is defined, as well as in the relevant national laws, regulations and guidance that flow from it. As is established in the International Basic Safety Standards (BSS) [3], the government, in the legal and regulatory framework, is to specify, among other things, the general principles underlying the protection strategies developed to reduce exposure when remediation has been determined to be justified. The appropriate safety criteria to be applied for remediation of sites containing radioactive substances (existing exposure situations), based on reference levels of dose to the public below which optimization is performed, are also set out in Ref. [3].

4. REMEDIATION POLICY

4.1. WHY A REMEDIATION POLICY IS NEEDED

In the environmental remediation of a given site, concerned and interested parties have diverse and often conflicting interests with regard to remediation goals, the time frames involved, reuse of the site, the efforts necessary and cost allocation. An established remediation policy, on either a national or an international level (e.g. for a site close to a border and/or affecting the interests of more than one country), is essential for establishing the core values on which remediation is to be based. In addition, the environmental remediation policy will set the nationally agreed position and plan, and will give visible evidence of the concerns and intent of the country.

Policy makers tend to rely on objective and widely (internationally) accepted criteria and processes for assessing remediation needs, determining responsibilities and partitioning work, including the sharing of financial burdens. This framework requires formulation of a policy that is as generic as possible and not specific to the needs of individual sites. The formulation of a national policy will encourage the establishment of a legal framework for ensuring coherent and consistent remediation approaches.

There may also be a need to revisit established policies. Existing legislation in a given country, especially with regard to groundwater resource protection, may require political authorities to assess remediation needs in the entire national territory. This is normally the case in countries that already have a proven remediation policy. Nonetheless, these countries might profit from a comparison with international approaches in resolving internal disputes on remediation necessities.

4.2. INITIAL CONSIDERATIONS

Prior to the development or updating of a national policy for the environmental remediation of contaminated sites, it is necessary for those engaged in preparing the policy to be aware of any related legislation and frameworks in their country, as well as any international prerequisites. They should, among other things, consider and understand the following topics.

4.2.1. National legal framework and institutional structure

The existing national legal structure and regulatory framework, and their suitability for assisting in the establishment of implementable policies towards the sustainable remediation of contaminated sites, are to be taken into account.

It will be necessary to clearly identify:

— Existing (environmental) legislation and rules to be applied in the specific case of sites contaminated with radioactive substances;
— Existing waste management legislation;
— The need for involvement of stakeholders and the public;
— The availability of a funding system.

The existing legislation should establish, or be updated to establish, the institutional structure to be involved in the formulation, approval and ultimate implementation of the policy. This includes:

- — The safety authority responsible for the remediation process;
- — Technical support organizations, for safety assessment and measurements of the radiation levels in the environment, for example;
- — The organization responsible for waste management;
- — Remediation implementers (e.g. site owners and site operators), local planning authorities and others within the country.

4.2.2. Applicable international conventions

The relevant international instruments and the obligations undertaken by the country as a result of these instruments must be adhered to. An example of this might relate to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [9].

4.2.3. Inventory of potential sites for remediation

An indicative national inventory of sites that could have been contaminated by radioactive substances and that may require remediation should be available for those involved in the policy preparation.

4.2.4. Availability of resources

The scale of the resources (human, financial, economic, social and technical) available in the country to facilitate implementation of the policy needs to be taken into account by the policy makers.

4.2.5. Potential transboundary issues

It may be necessary to consider transboundary issues, owing to the potential migration of contamination through the air, groundwater or surface waters. This may relate to a situation existing prior to remediation or to one arising as a consequence of the remediation itself. In a positive sense, there may be value in considering any remediation solutions being applied to address similar challenges within the region and the potential for sharing facilities or technologies available in neighbouring countries.

4.3. TYPICAL ELEMENTS OF A NATIONAL POLICY

Taking into account the considerations identified in Section 4.2, the policy will define a target framework for dealing with remediation problems. The policy might define the milestones necessary to reach the target and how to evaluate the progress towards achieving this target.

The following considerations are to be taken into account during policy definition:

(a) The national policy for remediation of contaminated sites needs to reflect the magnitude and scale of the potential hazard posed and be linked to any existing radioactive waste management policy. Environmental concerns are to be given a high priority, and planning for new facilities and operations needs to ensure that the likelihood of future remediation is reduced or eliminated, and that, as a minimum, financial provision for any such remediation is established.

(b) The national policy needs to reflect national priorities, circumstances and human and financial resources. It may be influenced by a number of factors, such as the timing of site decommissioning or the release of sites for reuse. Potential developments in the field of environmental remediation need to be considered, which may be of a regulatory or technological nature.

It is important to recognize that the types and sources of environmental hazards requiring remediation may vary between countries, and thus the policy developed will need to reflect these differences. Some of the main elements to be considered in establishing a national policy for environmental remediation are discussed below, although it should be recognized that not all of these points may be relevant to every country.

In summary, a law should be adopted establishing a framework that sets out clear missions, a clear budget and a clear role for each actor.

4.3.1. Allocation of responsibilities

The responsibilities for remediation of areas with residual radioactive material are defined in Ref. [3]. They can be divided into those responsibilities assigned to the government, to the regulatory body and to other relevant authorities and, as appropriate, to registrants, licensees and other parties (persons or organizations) responsible for planning and implementing remediation.

In most countries, it is generally accepted that the (physical or legal) person or organization that creates or has created the contamination is responsible for its safe management and potential remediation (the polluter pays principle;

see Section 3). However, national governments may also have responsibilities in this context, especially where the original polluter either no longer exists or cannot be traced.

The national policy needs to identify:

(a) The regulatory body responsible for the approval of the overall strategy, the definition of the remediation process and the approval of each step of the process;
(b) The organizations responsible for strategy proposal, implementation and operation, including waste management.

Each organization should have a clear mission defined in the policy. It is also worthwhile to establish an organization with ownership of the contaminated sites and responsibility for coordinating the overall works. The establishment of requirements for the protection of workers and their enforcement is the responsibility of the relevant regulatory body [3].

4.3.2. Provision of resources

The site owner/operator is generally considered to be financially responsible for ensuring that contaminated land is properly and safely managed; that is, in accordance with the polluter pays principle described in Section 3. However, the arrangements for long term management may sometimes be coordinated or overseen at the national level. In such instances, each acting party will take the appropriate steps to ensure that:

- Qualified staff are available as needed for all activities during the operating lifetime of a site as well as any subsequent remediation activities, and that they are adequately trained with regard to safety aspects of remediation.
- Adequate financial resources are available to support the characterization, assessment and remediation of contaminated land.
- Financial provision is made to enable the appropriate institutional controls and monitoring arrangements to be continued for any period deemed necessary following remediation activities (i.e. long term stewardship).

Thus, the national policy will set out the arrangements for:

(a) Establishing the mechanisms for providing the resources or funds for the safe management of contaminated land and remediation;

(b) Ensuring that adequate human resources are available to provide for the safe management and remediation of contaminated land, including, as necessary, resources for training and R&D;
(c) Providing institutional controls and monitoring arrangements to ensure the safety of the remediated sites once operations and site activities have ceased.

4.3.3. Safety and security objectives

An overarching theme in a national policy on the remediation of contaminated sites is the safety objective of protecting individuals, society and the environment from harmful effects of ionizing radiation, both now and in the future. The policy should include the requirements to be applied, where appropriate, for remediation. It should include access to the site and to any removed radioactive material. Some physical protection and security recommendations should be taken into consideration, as appropriate.

4.3.4. Public information and participation

The overall decision making process and the resulting remediation solutions may be of interest to a wide range of stakeholders, including the general public and especially local communities. Stakeholders constitute a highly heterogeneous group with varying levels of knowledge and experience. Ideally, all stakeholders will be involved in the decision making process, with due weight given to professional and lay knowledge. The aim is to achieve a shared understanding of the situation and its implications for all parties. Overall considerations include the relevant medical and scientific literature, the history of the sites and knowledge derived from the experience of local people. The economic, social and health impacts of leaving sites in their present condition, and of different methods of remediation, should be discussed openly.

4.4. POLICY INSTRUMENTS

Policy instruments used in controlling contaminated land fall into two main categories: (i) ‘command and control’ approaches and (ii) economic approaches [10]. Command and control approaches are used in most countries to trigger remediation and to restrict the uses to which contaminated land may be put. This is particularly necessary when remediation is designed to fit the ‘suitable for use’ standard. A market (economic) based approach is an example of an economic policy instrument. This approach encourages market action wherever possible and holds regulatory intervention in reserve for when there is no prospect of a market solution. Subsidies are given by some countries to help meet remediation costs.

5. REMEDIATION STRATEGIES

Different countries may take different approaches to establishing remediation strategies, depending on the type of contamination involved and national and site specific factors. The remediation strategy needs to be developed on a case by case basis and codified by regulators and/or the responsible national bodies.

5.1. OBJECTIVES AND APPROACHES

The objectives of remediation were formulated as follows [7]:

(a) To reduce the doses to those individuals or groups of individuals being exposed;
(b) To avert likely future doses to individuals or groups of individuals;
(c) To prevent or reduce environmental impacts from the radionuclides present in the contaminated area.

The operating organization or the organization with responsibility for remediation normally defines a remediation strategy on which the planning for remediation will be based. Some countries rely on a national remediation strategy to guide remediation planning. Such strategies need to be aligned with the national remediation policy and consistent with the relevant decommissioning and waste management policies and strategies. The strategy will define at least the following:

(a) The inventory of the contaminated sites, its content and who will elaborate this inventory.
(b) The process for site remediation, including who will do what. Milestones should be introduced into this process in order to take into account the particular situation of each site to be remediated and public expectations, if relevant.
(c) How the waste produced by the site remediation will be managed in line with the waste classification currently available in the country.

(d) The funding for each site remediation case, including waste management and follow-up of the site, if relevant.
(e) The prioritization of remediation actions based on political and public perceptions, risk assessments and the resources available.

The strategy should be codified by the responsible national bodies.

The commitment of political decision makers is fundamental: transparency and 'visibility' of decisions are indispensable, especially when explaining to the public the process of assessment and the determination of remediation targets. An important part of this commitment is to be aware, and to explain to the public, that:

— The site, after successful remediation, will be different from its original state. It will also be necessary to draw on benefits for the population and the country from having used the site; this may apply, for example, to former mining sites, sites for nuclear installations after decommissioning (e.g. nuclear power plants), former military sites or any other contaminated site.
— Remediation prioritization is inevitable if there are many sites and limited resources. Sites where the level of radioactive contamination does not require or justify remediation action may nevertheless be the focus of public attention owing to other factors such as the presence of other toxic substances, 'secret' activities carried out on the site in the past or severe visible changes on the surface. In these cases, precise presentation of the facts from accepted technical authorities based on an objective measurement and evaluation procedure is required for decision makers in order to avoid 'irrational' decisions being made out of fear of radioactivity. A decision on the decommissioning strategy may be influenced by the intentions of the site owner or the government with respect to the future use of the site. The strategy and the timing of remediation may differ depending on whether the site is urgently required for new facilities or if a decision has been made to remove the facility and to release the land.

5.2. INVENTORY OF REMEDIABLE SITES

Sites need to be registered to facilitate remediation prioritization [10]. Registers also give the limits of any remediation and any planning restrictions that may apply. Public registers also protect against fraudulent land transactions and reduce the likelihood of an innocent landowner becoming liable for remediation costs.

The number of sites and the extent of remediation required (or potentially required) on a national scale influence and emphasize the need for a specific remediation strategy; for example, a country with extensive mining and milling operations would benefit from a clear national strategy for the remediation of such sites. Such a strategy could also support the sustainability and life cycle management of a particular industry. Therefore, an inventory of sites classified according to the criteria defined by the relevant authority is needed.

The outcome of the site characterization is an important consideration in the development of a remediation strategy, in order to implement and optimize actions for the protection of workers, the public and the environment. Detailed site characterization is necessary for the development of a site specific remediation plan.

5.3. CONSIDERATIONS FOR REMEDIATION SITUATIONS

5.3.1. Legacy situations

For situations involving legacy sites, the objective is to implement optimized remediation strategies aimed at reducing doses to below the reference level for as many people as feasible. However, levels below the reference level should not automatically be ignored. It is important to ascertain whether remediation is optimized or if further remediation measures are needed. An endpoint for the optimization process must not be fixed a priori, and the optimal level will depend on the situation. It is the responsibility of the regulatory body to decide on the legal status of reference levels. When remediation has been undertaken, reference levels may also be used retrospectively as benchmarks for assessing the effectiveness of the remediation strategy.

Interested stakeholders should receive general information on the legacy situation and on the possible remediation needed to improve the situation. In situations where individual lifestyles are key drivers of exposure, education and training may be important requirements. Living on contaminated land in the extended aftermath of a nuclear accident or a radiological event is one such situation.

The main factors to be considered in setting reference levels for legacy situations are the feasibility of controlling the situation and the past experience of managing similar situations. In most legacy situations, there is a desire by members of the public, as well as the authorities, to reduce contamination to levels that are close or similar to situations considered ‘normal’. This applies particularly in situations relating to exposures to material resulting from human actions.

5.3.2. Aftermath of emergency situations

In existing exposure situations after an emergency, an important milestone is the transition from an emergency exposure situation to an existing exposure situation. It may be the case that different geographical areas affected by the same emergency undergo the transition at different times.

As post-Chernobyl experience has indicated [11, 12], in such situations the success of remedial measures taken to control doses to members of the public depends greatly on the behaviour of those exposed. Opportunities to control doses to the public should be exploited through the involvement of key stakeholders.

These situations are very complex in general, and, in addition to radiological considerations (i.e. doses and the special distribution of contamination), their management needs to address all relevant dimensions, such as health, environmental, economic, social, psychological, cultural, ethical and political aspects. One such example is the management of contaminated foodstuffs and other commodities produced in areas affected by an accident, which presents a problem because of market acceptance. Maintaining long term restrictions on the production and consumption of foodstuffs may affect the sustainable development of the contaminated areas.

Post-accident remediation strategies should be foreseen by authorities as part of the national accident response planning.

5.3.3. Ongoing planned situations and after decommissioning

Potential situations that may lead to a need for remediation should be considered at the planning stage of the introduction of such an activity. If the operation is ongoing, the expected releases of radioactive substances to the site, the consequent environmental contamination and the necessary remediation measures can be controlled by optimization procedures under the constraining operational limits specified by the national regulatory body. Where the operations involve long lived radionuclides, assessments need to take into account any reasonable combination or buildup of contamination and to consider whether such a buildup would result in the limits being exceeded. The planned remediation should ensure that the buildup of radioactive substances from the ongoing operation over its lifetime does not cause limits to be exceeded in the future. This is particularly important when the remediation strategy is planned to be implemented after the termination and decommissioning of the practice.

It should be noted, however, that in planned situations involving NORM, this limitation may not be feasible. Some flexibility may be required for particular situations involving long lived natural radionuclides, such as mining and milling activities.

5.4. IMPLEMENTATION OF THE STRATEGY

5.4.1. Radiological assessment

Contamination should be quantified in terms of average additional dose to the public, assessed by environmental modelling of the exposure pathways to the public, based on the concentration of radioactive substances in different environmental media and the use of the site [13, 14]. This dose should be compared with the reference level, which represents the level that is intended not to be exceeded. Efforts should be made to reduce individual exposures as far below this level as is reasonably achievable, with social and economic factors being taken into account [3].

The optimization process should be guided by reference levels of individual exposure. The possibility of multiple, independent, simultaneous and time varying pathways makes it important to focus on the overall exposure that may occur from all pathways when developing and implementing remedial measures. As such, an overall remediation strategy is necessary, which generally includes an assessment of the situation and implementation of different measures.

States may have set soil quality standards. These may be used as an absolute measure, defining the condition of contamination and serving as the standard that sites must meet to be considered decontaminated.

5.4.2. Financial issues

The availability of funds is a key issue for the development of a remediation strategy and can determine whether or not remediation can go ahead, the rate at which it can be implemented and whether some deferral will be necessary. Funding, and more precisely funding through direct grants, is a variable that can affect the speed of the remediation process [15]. If full funding is not available, then early spending might be focused on ensuring short term safety of the site, or a phased remediation programme might be implemented. In such a programme, priority will be given to tackling those tasks that reduce the most serious sources of exposure.

For the purposes of planning, it is necessary to have some estimate of the likely cost of the remediation options, as this will be an important factor in determining the site specific remediation strategy. Ideally, funding arrangements for remediation will be established early in the lifetime of any facility, particularly in the nuclear fuel cycle, to enable remediation to be carried out in a safe, timely and efficient manner. These arrangements can range from an independent remediation fund to the provision of funds directly from the government.

Most decommissioning funds for nuclear power plants are accumulated through electricity surcharges. However, there is still little experience with regard to accumulation of funds for remediation in the long term. For many nuclear facilities, no funds for remediation are available when the facilities reach the end of their operating lives. If no funds are available from the operating organization or from the government, the facility must consider searching for other funding mechanisms. This is the usual case for legacy sites.

5.4.3. Technology

5.4.3.1. Technical resources

Environmental remediation programmes require the availability of a wide range of methodologies, equipment, technologies, facilities and supporting infrastructure in the appropriate quantities and of the appropriate quality. Furthermore, the types of technology required for remedial work vary at different stages of a project. In deciding the technologies required, experience from other countries can be used. These technical resources typically include:

(a) Methodologies for characterizing radionuclides in the environmental media, groundwater flow, etc., and for modelling contaminant behaviour;
(b) Characterization equipment;
(c) Radiation and environmental monitoring equipment;
(d) Personal and respiratory protective equipment;
(e) Analytical equipment for field and laboratory use;
(f) Data processing equipment, hardware and software;
(g) Medical screening equipment.

5.4.3.2. Volume of contaminated media and the nature of its radioactive contaminants

Two important factors influencing the technology choices for remedial work are:

(i) The volume of environmental media affected by the contamination;
(ii) The characteristics (half-life and environmental mobility) of the radionuclides responsible for the exposure.

Often, but not always, there is an inverse relation between the volume of contaminated media and the degree of contamination. For example, media may be contaminated by a leak or spill, resulting in contamination of a relatively small volume of media but with a relatively high concentration of radionuclides. Conversely, a mining operation may produce millions of cubic metres of materials, which can lead to the contamination of different environmental media containing only relatively low levels of NORM. In the first instance, physical removal of the contaminated media and their subsequent treatment as radioactive waste may be feasible and necessary. In the second case, stabilizing the media in situ may provide an optimized solution.

Some radionuclides, notably tritium and ^{99}Tc, move freely with water and are thus very mobile in the environment. Radionuclides carried in acidic mine drainages are also particularly mobile. Such mobile radionuclides usually require special environmental remediation efforts. Removal of these sources or measures to circumvent water flow are usually implemented to prevent mobile radionuclides from migrating away from the remediation site and thus greatly increasing the spread of contamination. Migration of radionuclides into potable water supplies and other transboundary effects can be serious and therefore may require long term groundwater treatment and control.

5.4.3.3. Waste management aspects

Waste management issues can exist in environmental remediation projects. Wastes arise directly from the decommissioning of facilities and cleanup of contaminated soils, groundwater, etc. While treatment of contaminated soils or groundwater may largely eliminate the original problem, secondary wastes may be produced. Methods commonly used to manage these wastes include the following:

(a) In situ or on-site management using engineered facilities (covers, cells) of varying degrees of complexity or technologies such as in situ vitrification;
(b) Reuse or recycling of uncontaminated materials or materials that have been decontaminated or treated to meet release criteria for unrestricted use;
(c) Reuse or recycling of contaminated materials for specified purposes, such as the recycling of contaminated steel into waste disposal containers;
(d) Classification and segregation of radioactive waste for off-site disposal in appropriately licensed facilities.

Some countries may define contaminated soil as waste. Therefore, the availability of a national radioactive waste management system could also influence the available options and strategies for remediation. In particular, this will apply if the remediation options could result in the separation and concentration of radionuclides into radioactive waste or lead to a change in the waste class of radioactive waste.

If there is no available disposal facility for the category and class of waste from the remediation process, options involving the separation or extraction of radionuclides from the contaminated media may be less attractive.

5.4.3.4. Multi-facility sites

Strategies for remediation are likely to be influenced when the site under remediation hosts operational facilities or facilities under decommissioning (i.e. in the post-operational clean-out phase).

5.4.4. Human resources

In order to implement the remediation strategy, it is very important to identify the training capacity and the human resources available in the country in terms of skills for radiological characterization of sites, remediation technologies, waste management and project management. In countries where remediation has not been undertaken, it is likely that regulations relating to remediation will have to be developed and that regulators will have to be appropriately trained in the special requirements for remediation.

For planned situations, problems can arise due to the loss of knowledge if there are significant time delays between termination of activities and decommissioning and remediation of a site. If remediation cannot be performed soon after the completion of decommissioning, arrangements should be put in place to ensure that the necessary information is preserved. The subject of knowledge management in the context of decommissioning is discussed in Refs [16, 17].

5.4.5. Implementation schedule

Once the prioritization of sites has been undertaken, it is necessary to establish a schedule of implementation, including all the sites to be remediated. As well as the prioritization of sites, the schedule must take into account available resources, feasibility and sociopolitical issues.

5.4.6. Involvement of the public

The existence of and possible conflict between the different types of knowledge and perceptions held by experts and laypeople indicates that providing information alone is unlikely to be sufficient. Members of the public may demand that stringent controls be applied to what experts would consider to be trivial levels of dose due to radioactive substances remaining as a result of planned operations, but they may be less demanding in legacy situations, even where exposure is similar. Demands for inappropriate remediation measures may be encouraged by lobbying groups, especially where there is lack of trust between the site operators and the local community. A participatory approach is necessary in order to resolve any conflicts and to contribute to finding a way forward, with remediation measures that are appropriate with regard to the costs incurred and the benefits derived.

Meetings of the stakeholder group should be accessible to members in terms of time, location and support for lay members. If and when remediation becomes an issue, the stakeholder group will constitute a well informed and diverse forum able to discuss proposals and possible solutions.

From studies of stakeholder involvement in the past, the one general conclusion that can be drawn is that each decision is unique. The diversity of relevant social, political, economic and cultural environments makes it difficult to develop guidance that is universally applicable.

Stakeholder involvement in nuclear issues is discussed in Ref. [18].

5.5. SITE RELEASE CRITERIA

The first problem to confront those trying to remediate a site is to answer the question, How clean is clean? Site release criteria need to take into account the current and anticipated future uses of an area. These are important considerations for deciding the degree to which a contaminated area is to be remediated and whether it is to be released for restricted or unrestricted use. Here, it is important to establish how society's resources can best be spent to save lives as well as the level of health risk that is acceptable at contaminated sites and how and why this level differs from what is acceptable in terms of other health risks [19].

The potential economic value of the area, if it can be restored to productive use, can be an especially strong incentive. For example, if the area is residential, both health and economic considerations will likely demand a remediation effort commensurate with unrestricted use of the area. If the land is designated for industrial purposes, remediation considerations for restricted use will be required. In the case of restricted use, a follow-up of the radiological conditions and the use of the area should be planned in order to ensure compliance with remediation goals.

There may also be legal requirements to return an area of contaminated land to a condition where it can be gainfully reused. Such requirements often apply if legal ownership of the land is being transferred to another owner. This situation could give rise to difficult legal issues; for example, legal liabilities can arise if even slightly contaminated land is sold without due disclosure of its condition.

In order to assess the evolution of the exposure situation and the effectiveness of the remediation strategies, a monitoring record system needs to be established under the responsibility of the relevant authorities. Such records are particularly important for determining potential groups at risk, in conjunction with health surveillance. Furthermore, to allow effective long term health surveillance of the affected population, health registries need to be established for the population in the contaminated areas.

6. CONCLUSIONS

National policies and strategies for the remediation of contaminated land vary from country to country but share some common elements. There is no single policy model for dealing with the subject, and no single model would be workable for the entire world. However, policy and strategy elements need to be addressed adequately with regard to the extent of the remediation problem. Much of the policy and legislation on environmental remediation is in its infancy; thus, there is little evidence as to which approach is the most likely to produce the best results. However, by comparing current experience, a system of good practices could be suggested to aid those countries that do not yet have an environmental remediation policy.

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GLOSSARY

Cleanup. To make clean, free of contamination (impurities); an act or instance of cleaning.

Justification. The process of determining whether a proposed intervention is likely, overall, to be beneficial, i.e. whether the benefits to individuals and to society (including the reduction in radiation detriment) from introducing or continuing the intervention outweigh the cost of the intervention and any harm or damage caused by the intervention.

Legacy site. A site contaminated by activities carried out in the past. In most cases, a legacy site was generated due to a lack of appropriate legislation when a facility or an operation was taking place at the particular site.

Optimization. The process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and social factors being taken into account.

Rehabilitation. To restore to good condition, operation or capacity. The term implies that the land will be returned to a form and productivity in conformity with a prior land use plan, including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values.

Reclamation. The process of reconverting disturbed land to its former or other productive uses. All practicable and reasonable methods of designing and conducting an activity to ensure:

(i) Stable, non-hazardous, non-erodible, favourably drained soil conditions;
(ii) Equivalent land capability.

Remediation. Any measures that may be carried out to reduce the radiation exposure from existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans.

Restoration. The act of restoring or state of being restored as to a former or original condition, place. In the context of remediation, the term has the meaning of bringing a site back to its original condition, something that may not be achievable or necessary from the radiation protection point of view.

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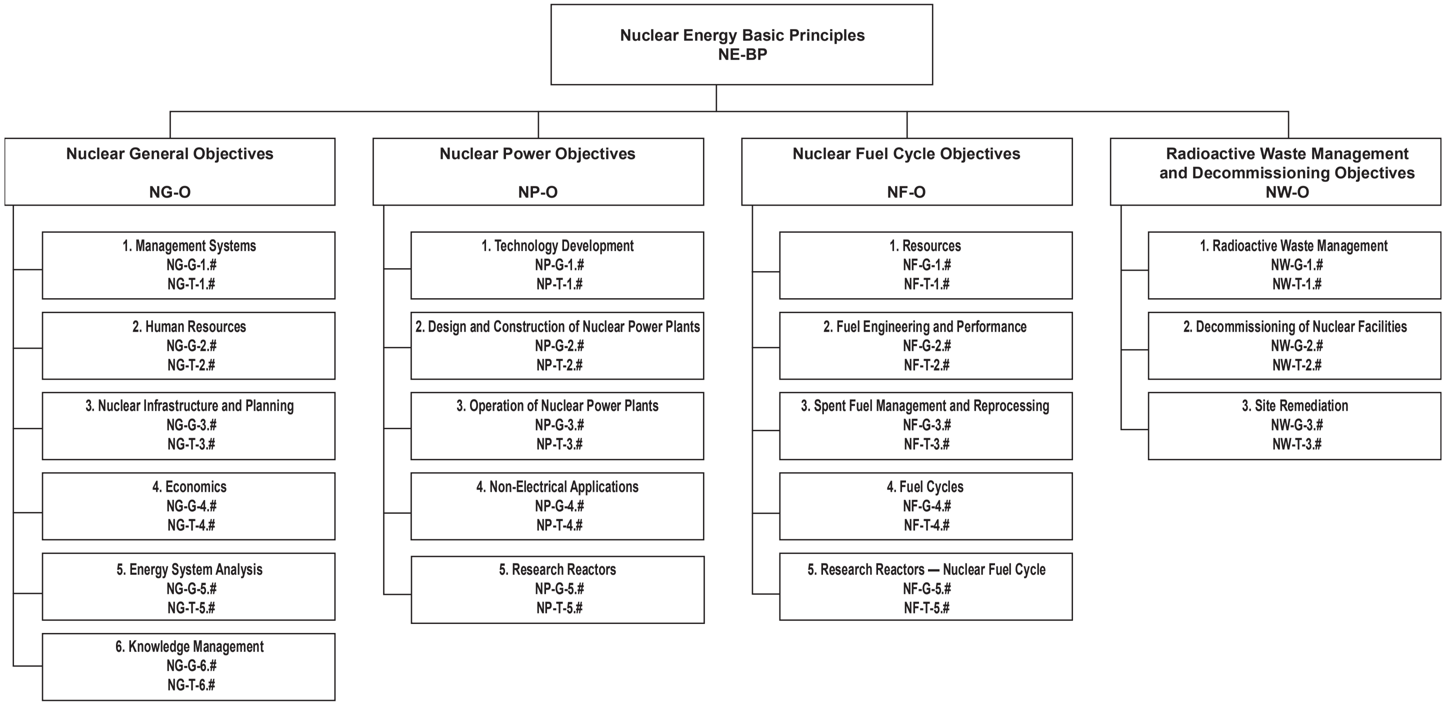

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