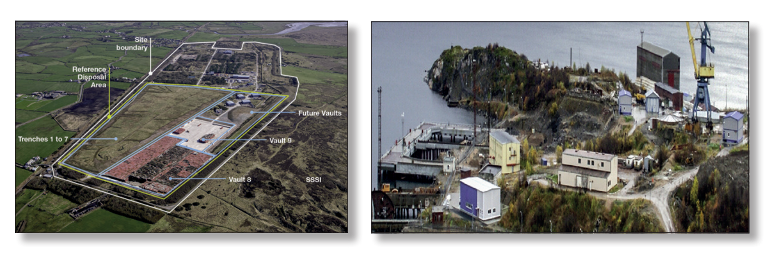
Radiological Protection
2019

Challenges in Nuclear and Radiological Legacy Site Management

Towards a Common Regulatory Framework



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NUCLEAR ENERGY AGENCY

Radiological Protection

Challenges in Nuclear and Radiological Legacy Site Management

Towards a Common Regulatory Framework

NEA No. 7419

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Korea, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Cover photos: Aerial photograph of the LLWR site (LLWR); Andreeva Bay site (FMBA of Russia – Rosatom).

Foreword

Many countries around the world today are facing challenges in relation to nuclear and radiological legacy sites, and in engaging stakeholders in the decision-making process in order to build confidence in the solutions being developed. With the overall goal of developing a practical and harmonised approach for the regulation of nuclear and radiological legacy sites around the world, the Nuclear Energy Agency, through its Committee on Radiological Protection and Public Health (CRPPH), decided in 2016 to establish an Expert Group on Legacy Management (EGLM).

The specific goal of the EGLM is to develop a practical and harmonised approach to the regulation of nuclear and radiological legacy sites and installations,[1] taking into account the results of other relevant activities of the NEA, of the International Atomic Energy Agency (IAEA) and of the International Commission on Radiological Protection (ICRP), while accounting for good practice at different types of legacy sites, as illustrated through specific examples.

Members of the EGLM include experts who have experience in the management of a range of different legacy sites, from the perspective of operators, regulators, technical support organisations and specialists in radiological protection. Included among the formal activities of the EGLM, are very informative site visits, one of which was hosted at Sellafield in the United Kingdom and another at Andreeva Bay in Russia. This reports documents these site visits, as well as a total of 13 case studies to reflect the situation on the ground, with each of the case studies and site visits presenting different prevailing circumstances.

The work of the EGLM has also benefited from discussions with representatives of the ICRP and IAEA, and from presentations and discussions at a workshop held in November 2017, on “Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution”, hosted by the Norwegian Radiation and Nuclear Safety Authority (DSA)[2] and organised jointly by the DSA, IAEA, ICRP and NEA.

The present report provides information on the challenges and lessons learnt in legacy management and regulation, based on these broad discussions and on the case study and site visit experiences documented in this report. This information and experience has in turn been drawn upon to develop a preliminary framework for a stepwise process to help reach an appropriate end-state to resolve legacy issues. The report also illustrates the complex challenges and interactions among stakeholders in progressing in a harmonised, step-by-step manner.

It thus represents a major step towards achieving the NEA goal of establishing a common regulatory framework to address legacy site issues in NEA member countries. NEA work on this subject has been designed to build consensus on how to meet significant challenges identified to date. One item that has proven to be of particular interest is how to achieve a balance between:

- the need for regulatory flexibility that allows easy adaptation of the regulations to a wide variety of prevailing and evolving circumstances and technology;
- the need to include appropriately precise and detailed requirements and criteria, which provide clarity to and confidence in the safety standards, as well as facilitate the demonstration that standards are being met.

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1. A “legacy site” includes both the area and the installations within it. Land, water, buildings, structures (above ground and subsurface) and any decommissioning materials that may be reused are thus included in the definition of the term, as used in this report.
2. Formerly the Norwegian Radiation Protection Authority (NRPA).

Accordingly, *Challenges in Nuclear and Radiological Legacy Site Management: Towards a Common Regulatory Framework* is presented as preliminary guidance to all interested parties. Recommendations for future international collaborative work to improve and test the preliminary framework, and to examine and address the complexity of the relevant interactions, are also provided within the report. NEA member countries are encouraged to continue contributing to this firm basis of NEA recommendations in order to move further towards the preparation and finalisation of a practical and harmonised framework for the regulation of nuclear and radiological legacy sites and to provide advice on its application.

Acknowledgements

This report was prepared by the EGLM set up under the programme of work of the NEA Committee on Radiological Protection and Public Health (CRPPH). The EGLM was chaired by Malgorzata Karpow Sneve from the Norwegian Nuclear and Radiation Safety Authority. Ms Sneve provided extensive encouragement and support to the work of the EGLM. The NEA Secretariat is very grateful to the following for having contributed to the report, and in particular to those providing the case study and site visit experiences that provided the basic information to support the discussion, conclusions and recommendations:

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Table of contents

List of annexes

List of figures

List of tables

List of abbreviations and acronyms

AAEC	Australian Atomic Energy Commission
ALARA	As low as reasonably achievable
ANSTO	Australian Nuclear Science and Technology Organisation
BAG	Federal Office of Public Health (Switzerland)
CRPPH	Committee on Radiological Protection and Public Health (NEA)
CS	Case study
CSM	Conceptual site model
DOE	Department of Energy (United States)
DISR	Department of Industry, Science and Resources (Australia)
EGLM	Expert Group on Legacy Management (NEA)
EIS	Environmental impact statement
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
EPA	Environmental Protection Agency (United States)
EW	Exempt waste
EuCAS	European and Central Asia Safety Network
FEPs	Features, events and processes
FMBA	Federal Medical Biological Agency (Russia)
FMBC	Burnysian Federal Medical Biophysical Centre of FMBA
FOGH	Federal Office of Public Health (Switzerland)
HLW	High-level waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICSRM	Industrial Complex for Solid Radioactive Waste Management
ILW	Intermediate-level waste

Ispra	National Institute for Environmental Protection and Research (Italy)
LFLS	Little Forest Legacy Site (Australia)
LLW	Low-level waste
LLWR	Low Level Waste Repository (United Kingdom)
MLIT	Ministry of Land, Infrastructure, Transport and Tourism (Japan)
MOE	Ministry of the Environment (Japan)
MTIF	Ministry of Trade, Industry and Fisheries (Norway)
NCRP	National Council on Radiation Protection and Measurements (United States)
NEA	Nuclear Energy Agency
NERH	Nuclear Emergency Response Headquarters (Japan)
NORM	Naturally occurring radioactive material
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission (United States)
NRPA	Norwegian Radiation Protection Authority
NSC	Nuclear Safety Commission of Japan
OECD	Organisation for Economic Co-operation and Development
RIC	RanstadIndustricentrum AB (Sweden)
SV	Site visit
SÚJB	State Office for Nuclear Safety (Czech Republic)
SURF	Sustainable Remediation Forum
SSM	Swedish Radiation Safety Authority
TAG	Technical Assessment Group
TEDE	Total effective dose equivalent
TVRP	Target Values for Remedial Parameters
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
VLLW	Very low-level waste
VSLW	Very short-lived waste
WHO	World Health Organization

Public and policy summary

Legacy sites should be managed in an open and transparent way, addressing the views of relevant stakeholders so as to build confidence in the solutions being developed. The development of such solutions should also help the many countries facing these challenges in relation to nuclear and radiological legacy sites to ensure that the creation of new legacy sites is avoided in the future.

While it may be convenient to provide a definition of the term "legacy site" for the purposes of this report, experience has shown that the term is already used with so many different legal and generic meanings in different countries that it would be challenging to apply a single definition internationally, or even consistently at the national level. The term also has diverse cultural connotations, particularly after translation into languages other than English. It could, however, be claimed that certain common characteristics bind the development of a practical approach to legacy site management and regulation, including the following:

- Each legacy site presents unusual features; typically, a complex combination of radiological, chemical and physical hazards, along with other operational challenges.
- Radiological and other hazard characteristics are, initially, broadly unknown. For example, appropriate and adequate records may have been lost or were never kept; former site operators with knowledge of the site are unavailable, or site ownership has changed hands several times and responsibilities for the site are unclear.
- Regulatory circumstances are complex because the site was not operated in line with up to date standards, recommendations and guidance, for example, and the current regulatory framework was not designed to address these circumstances.

Taking note of such issues, the Nuclear Energy Agency (NEA), through its Expert Group on Legacy Management (EGLM), began in 2016 assisting NEA member countries in the preparation of guidance on the practical interpretation and application of generic radiological protection to legacy management, and to support the development of corresponding regulatory guidance. The overall goal of the NEA in this area is to develop a practical and harmonised approach for the regulation of nuclear and radiological legacy sites[1], taking into account the results of other relevant activities of the NEA, of the International Atomic Energy Agency (IAEA) and of the International Commission on Radiological Protection (ICRP), while also accounting for good practice at different types of legacy sites, as illustrated through specific examples.

To this end, the NEA has gathered experience from 13 case studies and site visits around the world, covering a wide range of prevailing circumstances, and is considering how to address the identified challenges under the following headings:

- regulatory frameworks;
- characterisation of circumstances;
- societal aspects;
- deciding upon and achieving end-states;
- long-term protection values.

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[1] A "legacy site" includes both the area and the installations within it. Land, water, buildings, structures (above ground and subsurface) and any decommissioning materials that may be reused are thus included in the definition of the term, as used in this report.

The information presented in this report is intended for regulatory and/or management use for those legacy sites that have prevailing circumstances similar to those considered in this study. It should be noted that local regulatory frameworks may have been established to address specific, legacy site circumstances (i.e. in a site-specific fashion), and that these may differ from the scope of experience reflected in this report.

Key results and messages from this work are as follows:

- Experience from the case studies and site visits confirms that legacy sites may present mixed situations in terms of radiation exposure, as well as other, non-radiation related hazards that do not fit readily into existing regulatory and management arrangements.
- In developing an effective and efficient regulatory framework, it is of particular interest to achieve a balance between:
  - the need for regulatory flexibility that allows easy adaptation of the regulations to a wide variety of prevailing and evolving circumstances and technologies;
  - the need to include appropriately precise and detailed requirements, and criteria that provide clarity to and confidence in the safety standards and that clearly show that standards are being met.
- A holistic approach to management and regulation of the hazards and risks is warranted in order to achieve proportionate risk management and overall optimisation.
- Overall optimisation implies the need to consider chemical and other hazards alongside the radiological hazards, adopting proportionate health, safety and risk management strategies and applying corresponding regulatory requirements based on common protection objectives.
- An important corollary is the use of graded assessment methods so as to support and promote proportionate approaches to demonstrating or confirming regulatory compliance in line with the common protection objectives.
- Strategies for the management and regulation of legacy sites should take into account strategies for radioactive waste management and vice versa. This is especially important for legacy sites that involve large volumes of contaminated waste, which incorporate old disposal facilities or which have contamination in underground structures, for which in situ disposal may be an appropriate management option.
- It is necessary, and of long-term advantage, to broadly involve all stakeholders in the process so as to manage and resolve legacy sites in the short term after these have been recognised.
- A staged process is likely to be needed since it will not be possible to achieve an appropriate end-state in only one step, except in trivial cases.
- The case studies and site visits in this report demonstrate that there has been significant, practical progress to resolve some of the issues mentioned above, including scope for avoiding the development of a legacy site altogether. Such experience is of potential relevance for other sites.
- The process for legacy resolution should take all of the above factors and experiences into account, not only at the time of recognition but also through each step leading to resolution of the legacy site and achieving an appropriate end-state.

A preliminary framework taking into account the above points is thus presented in this report so as to design a process for the logical progression of activities leading to successful selection and achievement of an appropriate end-state. It has been recognised, however, that the arrangement of interactions among relevant organisations and interested parties is a complex and dynamic activity in and of itself. Recommendations have therefore been provided in this report to support the testing and extension of a preliminary framework into an effective and sustainable guiding instrument, in line with NEA recommendations.

Executive summary

Many countries with nuclear energy and related programmes, which may involve artificial and naturally occurring radioactive material, are today facing challenges with legacy sites.[1] These sites should be managed in an open and transparent way, addressing the views of all relevant stakeholders so as to build confidence in the solutions being developed, and ensure that through this process further legacy sites are not being created in the future.

The Nuclear Energy Agency (NEA), through its Expert Group on Legacy Management (EGLM), has been assisting NEA member countries by preparing guidance on the practical interpretation and application of generic radiological protection to legacy site management, and supporting the development of corresponding regulatory guidance. The overall goal is to develop a practical and harmonised approach for the regulation of nuclear and radiological legacy sites, taking into account the results of other relevant activities of the NEA, of the International Atomic Energy Agency (IAEA) and of the International Commission on Radiological Protection (ICRP), while also accounting for good practice at different types of legacy sites, as illustrated through specific examples.

The specific objectives of the NEA in this regard are:

- to assist NEA member countries in deriving practical interpretation and application of generic radiological protection guidance to nuclear and radiological legacy site management, and develop or support the development of international guidance specific to the regulation of nuclear and radiological legacy sites;
- to enhance safety and security culture as it applies to legacy sites and make transparent the application of the principle of optimisation in the context of the regulation of legacy sites;
- to address specific situations at real sites within NEA member countries;
- to support a holistic approach to risk management, to which end it may be appropriate to include international organisations concerned with chemical and other risks, including other parts of the Organisation for Economic Co-operation and Development (OECD), as well as the United Nations Environment Programme and the World Health Organization (WHO);
- to consider risk management by developing a better understanding of the diverse types of radiation-induced risk to different groups of people on various temporal and spatial scales.

In this report, a "legacy site" has been taken to include an area and the installations within it (i.e. land, water, buildings, structures [above ground and subsurface] and decommissioning materials that may be reused), and may refer to part of a larger site or the entire area. The NEA has found that the use of a single definition of a nuclear or radiological legacy site is not likely to be helpful, not only because different definitions already exist in different jurisdictions, but also because of the cultural connotations that arise when the term is translated from English to other languages. The approach of the NEA has been to be inclusive so as to allow all potentially relevant experience from many types of legacy sites to be taken into account and thereby make

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[1] A "legacy site" includes both the area and the installations within it. Land, water, buildings, structures (above ground and subsurface) and any decommissioning materials that may be reused are thus included in the definition of the term, as used in this report.

this study's results as widely relevant as possible. Nonetheless, a short explanation is needed for the types of sites under consideration. The following working description – and not a definition – is therefore being proposed. Broadly, a nuclear or radiological legacy site is one:

- that has radioactivity considered of concern to the regulator;
- that has not completed remediation.

In the context of this report, and framed by this broad description, the legacy sites discussed herein are ones for which current circumstances, by their very nature, were not planned, or not originally planned, and have been:

- "unrecognised" (e.g. an old uranium mining/milling site in a remote location and unused for decades);
- "abandoned" (e.g. a building long-ago used for making radium dials for watches and instruments);
- "long-term unused or redundant" (e.g. a hot cell facility unused for decades, but on a regulated site with operating installations).

It should be noted that once remediation has been completed, the legacy has been resolved, at least from a technical safety perspective. A legacy situation may be identified by regulatory authorities as a result of stakeholders' concerns, but if the level of radioactivity is not of concern to the regulator, for the purposes of radiological protection, it is not a nuclear or radiological legacy site.

The information presented in this report is intended for regulatory and/or management use for those legacy sites that have prevailing circumstances similar to those considered in this study. It should be noted that local regulatory frameworks may have been established to address specific, legacy site circumstances (i.e. in a site-specific fashion), and that these may differ from the scope of experience gathered in this report.

The NEA has reviewed the challenges associated with legacy management and regulation based on a wide range of international experience, and is now examining how to address these challenges under the following headings:

- regulatory frameworks;
- characterisation of circumstances;
- societal aspects;
- deciding upon and achieving end-states;
- long-term protection values.

The material in this report has been structured and discussed in this way, based on the practical experiences described during the 2 site visits and 11 case studies prepared by participants in the NEA Expert Group on Legacy Management. These site visits and case studies include examples from a wide variety of sites that illustrate a range of prevailing circumstances.

Site visits

- Old nuclear technology sites:
  - Site visit 1: Sellafield, United Kingdom (A. Clark, Nuclear Decommissioning Authority [NDA]; R. Cowton, Sellafield Ltd; G. Smith, GMS Abingdon Ltd);
  - Site visit 2: Andreeva Bay site, with temporary storage of spent nuclear fuel and radioactive waste, Russia (N. Shandala, Federal Medical Biophysical Centre [FMBC]).

Case studies

- Old radioactive waste disposal facilities:
  - Case study 1: Little Forest Legacy Site, Australia (H. Griffiths, Australian Nuclear Science and Technology Organisation [ANSTO]);
  - Case study 2: The Low Level Radioactive Waste Repository, United Kingdom (G. Smith, GMS Abingdon).
- Facilities for long-term storage and or disposal of naturally occurring radioactive material (NORM), uranium and other ore mining and milling facilities:
  - Case study 3: Ranstad uranium milling plant, Sweden (H. Wijk, Swedish Radiation Safety Authority [SSM]);
  - Case study 4: Søve: A former Niobium mine, Norway (M. Sneve, Norwegian Radiation Protection Authority [NRPA]);
  - Case study 5: Stráž Pod Ralskem and Rožná legacy sites, Czech Republic (M. Jurda, SUJB);
  - Case study 6: Shiprock Disposal Site in New Mexico, United States (C. Barr, US Nuclear Regulatory Commission [NRC]).
- Radium affected areas:
  - Case study 7: Radium Action Plan 2015 to 2019, Switzerland (E. Christen, Swiss Federal Office of Public Health).
- Disposal sites found to have emplaced, unplanned radioactive waste:
  - Case study 8: Capriano Del Colle special waste dump, Italy (M. Altavilla, National Institute for Environmental Protection and Research [Ispra]).
- Old nuclear technology sites:
  - Case study 9: Hanford, United States (P. Washington, US Department of Energy [DOE]);
  - Case study 10: Western New York Nuclear Service Center and West Valley Demonstration Project, United States (C. Barr, NRC).

The case studies provide the perspectives of those involved in managing and/or regulating the sites, reflecting the real historic, current and planned future legacy context and activities. They are presented as shared examples of actual practice and experience in applying safety measures to address legacy sites, and to inform the development of international guidance specific to the regulation of nuclear and radiological legacy sites. They have not been edited to correspond to international preconceptions but present perspective from those producing them.

An important reason to examine historic legacy experience is to avoid having current installations and sites evolve into new legacy sites. To this end, a further case study has been provided, as follows:

- Case study 11: The Challenges of preventing the development of a legacy situation at Fukushima, Japan (S. Takeda and T. Tanaka, Japan Atomic Energy Agency [JAEA]).

Lessons learnt and conclusions

Regulatory frameworks designed for nuclear or radiological sites and installations that are operational or in managed decommissioning address radiological circumstances that are individual, but largely known and broadly common, in line with up-to-date recommendations, standards and guidance. Such sites tend to have "family" commonalities, so that an effective regulatory framework can, to a useful degree, be specific in nature. In contrast, regulatory frameworks designed for legacy sites need to address circumstances that are generally unknown and uncertain, or for which no planning was carried out in line with current standards. A greater degree of flexibility is therefore needed, relative to a framework developed for normal operational circumstances, so as to allow better efficiency for the protection of people and the environment.

A common characteristic of legacy sites is that in the initial stage, their radiological characterisation is broadly unknown because records have been lost, former site operators with knowledge of the sites are unavailable and/or site ownership has changed hands several times. Poorly characterised chemical and physical hazards, as well as other operational challenges, may also exist. Updates and improvements in regulations can result in a particular site newly attracting regulatory interest although it had not done so in the past.

The absence of adequate records at many older sites strongly underlines the need to ensure knowledge management at currently operating and new sites. This need for knowledge management applies in particular to facilities that are currently not considered legacy sites, but where it is important to avoid them evolving into new legacies.

Since specific legacy circumstances are difficult to anticipate, it is not possible to provide advance regulations that will be effective in all future cases. Some caution is therefore needed to avoid prescriptions that could mitigate against optimal solutions in particular circumstances. It should be possible, however, to establish in advance some procedures and plans, including the role of regulators and other stakeholders, to address legacy sites when they are recognised or arise. A similar lesson has been highlighted with respect to planning for waste management after major accidents. The overall process should include how legacy sites can be recognised in a legal context so that responsibilities can then be exercised within a proper regulatory framework.

Prescriptive regulations require a detailed knowledge and considerable experience with regard to the activities being regulated, which is commonly not the case for legacy sites, and suggests the need for a goal-setting or performance-based approach. There are advantages to having a precise set of rules available for prompt application, but this approach moves the responsibility for adequate characterisation from the operator to the regulator, who should then be in a position to know the nature of all possible legacy situations. A balance has to be found between being prepared for every eventuality and not being prepared for any eventuality. In the end, that balance can only be achieved through the development of an adequate understanding of the circumstances and the various stakeholder interests, which normally is derived from a staged and iterative process.

Experience from the case studies and site visits suggests that such a process is more likely to be successfully implemented when supported by a close dialogue among operators, regulators and engineering and scientific support organisations, along with other relevant stakeholders. The most relevant stakeholders are those directly affected by remediation decisions. These individuals and groups are likely to contribute valuable input into the selection of the most appropriate end-state, and throughout the stages through which that end-state can be achieved.

Allocation of responsibilities is a key issue, but responsibilities cannot be effectively managed without a corresponding and adequate allocation of resources. In situations where there are very limited or inadequate resources, scheduling of a staged approach to the desired end-state might be especially relevant in order to identify what is truly feasible on a realistic timescale.

Part of the government's role is to allocate substantial responsibilities in the context of a coherent regulatory framework that can support government policy. This includes allocation of responsibilities to investigate suspected legacy sites. Initial investigation may identify a need for urgent action, and hence it may be related to emergency response, while not necessarily being related to accidents.

The steps to achieving an identified end-state should also typically be supported by a radiological safety case, which is potentially supported by a wider environmental impact assessment. The development of a safety case is an iterative process, and should be ongoing throughout the steps of remediation, with each step accounting for improved source term data, further understanding of the site and stakeholder interests, design options and wider planning issues.

Optimisation is also important. Although minimising a particular impact can be interesting to investigate, for example to see what is viable with respect to reduction of that impact, establishing the minimisation of a particular impact as a regulatory objective is likely to lead to non-minimisation of another impact, and is thus contrary to optimisation. A balance needs to be made between the interests of safety and security.

As part of optimisation, further consideration of how to select reference levels, or the appropriate dose constraints in the case of legacy sites that are regulated as planned exposure situations, has also been recognised as important. In particular, international guidance is needed on how to address situations that are a mixture of planned and existing exposure situations. Local regulatory authorities should decide the status of a site according to the prevailing circumstances, including the existing regulatory framework.

There is also a need to account for other environmental and human health risks arising alongside the radiological risks, as part of an overall optimisation process. It has been noted that there is no chemical equivalent of an existing exposure situation or the reference level approach used in radiological protection. Absence of a coherent, proportionate and common approach to management of all risks could lead to the misallocation of resources.

Radiological, other safety and wider technical assessments, including the assessment of stakeholder values, are subject to uncertainties. The transparent recognition of uncertainties, and a documented approach to addressing them, is an important step in building confidence in the results of a safety assessment sufficient to support decisions (NEA, 2005).

A proportionate and graded approach to environmental and human health risk assessment is likely to be most efficient. Proportionality, as used here, refers to the allocation of resources for risk assessment so as to match the scale of hazard and the potential for harm. A graded approach can include using simple, but less data and resource intensive assessment tools in a first iteration, and only progressing to more detailed analysis if the initial results suggest that this is appropriate or needed to support a robust decision. Confidence in the conclusions is likely to be enhanced by effective communication of the objectives, conduct and assumptions in the assessments. A common understanding of the assessment context is important from the very beginning of the assessment process, involving those commissioning the assessment, the intended audience and those carrying out the assessment.

Communication is of great importance throughout any activities addressing legacy situations. Reaching a common understanding on the many issues will involve what may be complex and lengthy discussions, tailored to the knowledge and understanding of the stakeholders. Some of the issues discussed may include:

- the difference between radioactivity and radiation dose;
- the difference between contamination and the presence of detectable radioactivity;
- the link between a given radiation dose and health risk;
- the difference between hazards and risks;
- radiological protection system issues;
- the rationale behind the numeric level of radiological protection criteria;
- application of reference levels alongside dose limits and constraints;
- radiological protection implementation issues;
- the need to balance risks and resources;
- the need to take potentially harmful action now in order to avoid larger problems later.

An important issue in relation to the last bullet point is that, in some circumstances, if no action is taken, the situation will eventually deteriorate, leading to a significantly disruptive event, for example a large, nuclear, radiological or chemical accident, or the collapse of a mine tailings pile onto occupied buildings. In order to improve long-term management and reduce the likelihood of such major events, some short-term increase in risks may be necessary. Reasonable uncertainties should not, on the basis of precaution, delay action needed to mitigate a major hazard. A decision to delay may not be prudent. The key issue is to effectively manage any temporary increase in risk by understanding the uncertainties in the context of a holistic risk assessment. An adaptable regulatory framework is needed to address such circumstances.

Multi-criteria analyses may help in identifying a sustainable remediation option (NEA, 2016). Such studies should be recognised as informing a decision rather than making it. However, the systematic consideration of all the issues within a clearly scoped analysis can be very informative. Such an analysis may help to avoid creating an expectation that contaminated land should automatically be remediated without first verifying that such work would generate a net benefit and is in the interests of affected people. It may not be straightforward to determine the net benefits, given conflicting views on how to value the different attributes of available options, but it is more productive to examine these issues than to ignore them. This approach would also support confidence in decisions if it is carried out in an open and transparent way. For example, publishing such studies would help to make the motivation of decision makers transparent (see NEA, 2016).

Experience shows that regulations and regulatory processes have to be applicable to a wide range of circumstances, which typically differ from those arising in planned situations. To assist in reaching agreements on complex decisions, the close involvement of all stakeholders is needed, along with the adoption of a holistic approach including all other hazards alongside the radiological hazards, and greater adaptability of regulators and operators in finding appropriate responses to the challenges presented.

The case studies and site visits presented in this report demonstrate that there has been significant practical progress to reduce uncertainties, build stakeholder confidence and resolve the issues mentioned above, including the scope for avoiding the development of a new legacy site altogether. Such experience is of significant potential relevance for other sites.

Recommendations

Examination of the documented case studies and site visits outlined in this report has allowed for the identification of many issues related to legacy site management and regulation, which illustrate challenges alongside potentially suitable approaches to their resolution.

Holistic optimisation

It has been recognised that there is value in sharing experience in the application of optimisation, including, in a holistic sense, not only radiological experience but also other aspects of protection and decision making. While the term “holistic” in this context leans towards inclusion, further examination is needed to determine what should be included, and recommendations should be provided for processes that demonstrate how these aspects should be taken into account in an integrated and balanced manner. The development of a common set of protection objectives, and hence assessment endpoints and methods, is extremely challenging but would prove to be very beneficial. In parallel, regulatory development that helps to ensure the process for managing chemical and radiological hazards and risks in a consistent and commensurate manner is worth further consideration.

Aspects to consider, alongside a wide range of economic and social factors, include:

- radiological protection of the public, workers and the environment;
- protection from non-radiological hazards, including psycho-social health detriment and well-being;
- protection of property, human health and the environment, all of which may be linked;
- protection of resources, such as groundwater, soil and forests;
- consideration of short-, medium- and long-term aspects related to all of the above, as well as the number of people impacted;
- consideration of security alongside safety for all of the above.

A holistic approach to optimisation is important, with the aim of balancing all the issues in a transparent and proportionate manner. Further work on how to achieve this objection is recommended, including interpretation of the precautionary principle in the face of competing protection objectives.

Corresponding assessments and safety cases designed to support optimisation should be as simple as possible but as complex as necessary to be "fit for purpose". Presenting complex issues in a simplistic manner should be avoided since it will mislead rather than improve communication and the implementation of the radiological protection system.

Overall optimisation of protection should concurrently address radiological, chemical, physical and other hazards. However, there is no equivalent of radiological exposure situations for protection from chemically contaminated land, and balancing of mixtures of chemical, physical and radiological hazards presents regulatory challenges as well as challenges to societal understanding. Collaborative work involving the relevant international organisations would be useful to address these points, although such a discussion was not pursued in the context of this report because of its preliminary nature.

Type of exposure situation

International recommendations, such as ICRP Publication 103, the international basic safety standards and the European Union basic safety standards directive all describe control of exposure in different exposure situations. The case studies and site visits examined in the present report suggest that identification of the relevant exposure situation is not always clear for legacy sites. Several examples suggest that some sites present mixed exposure situations. It is recommended, therefore, that consideration be given to preparing further international guidance on sites presenting mixed exposure situations. In addition, in order to develop a common understanding of radiological circumstances, risk communication will be an important aspect of recovery management, and further work is needed in this area.

Prescriptive and performance-related regulations

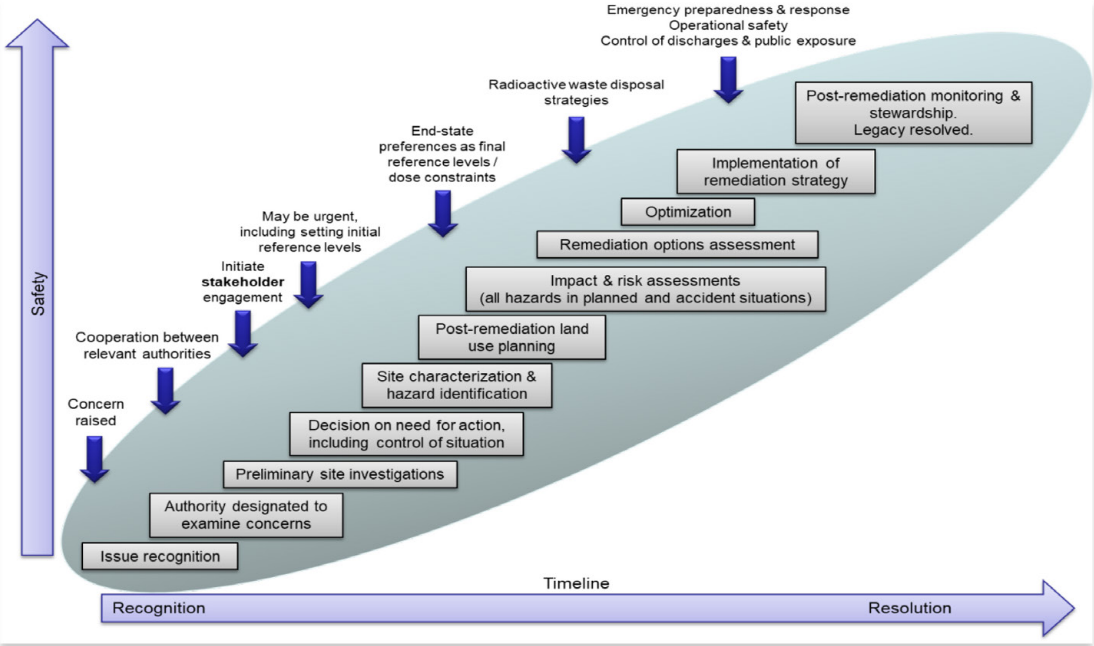
Experience supports the need for a regulatory framework that is adaptable enough to support the identification and implementation of the optimum, sustainable solution. Prescriptive regulations require more detailed knowledge and considerable experience in the specific activity in question by those drafting regulations. Such regulations are narrowly applicable to a specific situation and may need to be amended frequently to keep pace with technological changes. In particular, they are best suited to widespread practices where the equipment and procedures do not vary significantly among users, which is commonly not the case for legacy sites. Further collaborative work to show how to find an appropriate balance would thus be useful.

While consideration of the above factors should facilitate effective regulatory and decisional processes, it should be noted that the responsibility for decisions rests with the organisation that has been designated to make such decisions. If no organisation is identified, the gap has to be filled by government. The emphasis is on developing an effective process from the very beginning so that impacted parties can see the direction being taken and their respective roles within it. Figure ES1 attempts to describe this process as a preliminary framework for a logical and linear progression to an appropriate and sustainable end-state.

Figure ES1 supposes a linear, step-by-step approach. Iterations may be needed at each step, and there may be stages of implementation during this process, that is staged progress from interim to final end-states. It should be underlined that everyone should feel empowered to raise a concern, and that the regulatory authority needs to be empowered and prepared to address any such concern. At the other end, it is the regulator who signs off on the resolution of the legacy site. However, there may be no final end-state resolution in the case of a policy of long-term stewardship.

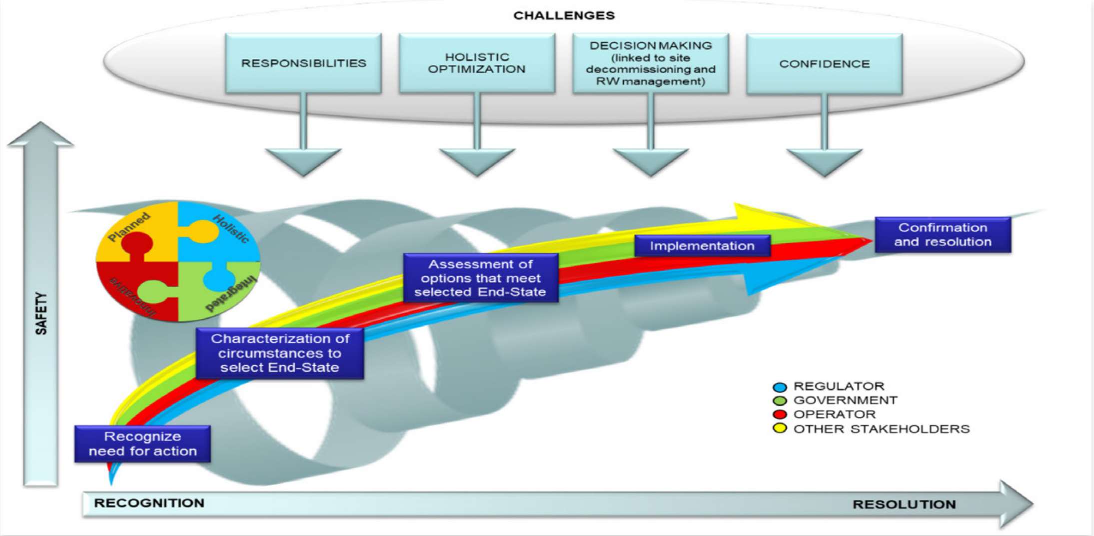
The above type of illustration is helpful in explaining the way forward for interested parties, but it does not recognise some of the real-life complications and interactions that experience suggests may arise at many legacy sites. Figure ES2 attempts to illustrate the challenges and interactions in progressing through the linear steps outlined in Figure ES1. Note the emphasis on increasing confidence as progress is made towards resolution through a virtuous spiral of reduced uncertainties. Note also the simultaneous engagement among government (controlling policy), operators (delivering safe solutions), regulators (setting standards and monitoring compliance, and taking action if the operator falls short of the standards), and all other stakeholders who need to have confidence in the resolution.

Figure ES1. **Preliminary framework for a logical progression to an appropriate end-state**



Source: Norwegian Radiation and Nuclear Safety Authority.

Figure ES2. **Illustration of challenges and interactions in progressing through the linear steps**



Source: Norwegian Radiation and Nuclear Safety Authority.

Proposed follow-up

To support further development of a framework, accounting for the complex interactions and the value of a planned, innovative, integrated and holistic process, several additional recommendations for further work are provided below:

- The usually separate communities engaged in assessments of radioactive waste management (including disposal) and legacy site management could usefully share information, with scope for partial model validation based on available data and monitoring experience. Both of these communities also need to work with those involved in the technological and safety aspects of decommissioning.
- National strategies for decommissioning, legacy management and radioactive waste management, including disposal, all need to be developed in parallel and then updated with knowledge of progress in all areas, including security management.
- The above point underlines the need for long-term planning with political support, including action in case a plan fails (i.e. awareness of the possible causes of failure and pre-planning to reduce risks of this happening, to mitigate possible consequences and to maintain responsibilities in the event of failure). Further study of long-term planning would be of value to determine where pre-planning can be useful without prejudicing future decisions on as yet uncharacterised or unrecognised legacy sites.
- A review of historical events/incidents that may have led to a legacy contamination should be undertaken, to understand how such situations can be avoided in the future.
- In the next steps of this process of developing a framework, it would be beneficial to reach out to the OECD Environment Directorate, the United Nations Environment Programme and the World Health Organization, as well as to chemical regulators, with a view to both sharing experiences in legacy site management and to working co-operatively to develop guidance on holistic optimisation.

References

NEA (2016), *Strategic Considerations for the Sustainable Remediation of Nuclear Installations*, OECD Publishing, Paris

NEA (2005), *Management of Uncertainty in Safety Cases and the Role of Risk: Workshop Proceedings,* Stockholm, Sweden, 2-4 February 2004, OECD Publishing, Paris.

Chapter 1. **Introduction, objectives and scope**

1.1. **Background**

Many countries are today facing challenges in relation to nuclear and radiological legacy sites (IAEA, 2002). Even countries without nuclear energy and related programmes may be faced with such issues, which involve artificial or naturally occurring radioactive material. In order to build confidence in sustainable solutions, legacy sites (i.e. both on-site and off-site areas) should be managed in an open, transparent and coherent fashion (NEA, 2007). Currently, however, no overall regulatory framework has been established for the management of legacy situations.

The Nuclear Energy Agency has long been addressing issues that are an integral part of legacy management – notably through its Committee on Radiological Protection and Public Health (CRPPH) – for example, stakeholder involvement in radiological protection decisions and post-accident recovery management. The Villigen workshops (1998, 2001 and 2003), work on Chernobyl (1987-2011) and the Science and Values workshops (2008, 2009, 2012, 2015, and 2018) have contributed the following results in this regard:

- In circumstances that require decisions affecting the radiological protection of stakeholders, radiological protection aspects should be integrated into societal decisions, rather than integrating societal values into radiological protection decisions.
- The radiological protection expert is rarely the decision maker, but rather should be at the service of stakeholders.
- Decisions are informed by science, but are driven by social values.

Since 2011, work with people directly affected by the Fukushima Daiichi NPP accident has illustrated that:

- Governmental decisions should actively reflect that stakeholder concerns have been taken into account.
- Expert resources needed to address stakeholder concerns can be extensive, and should be planned in the context of an all-hazards framework (NEA, 2018).

Building on this experience, a topical session on recovery management was held during the annual meeting of the CRPPH in 2013, which identified the following aspects as possible topics for future work (NEA, 2013):

- identification of a framework for national recovery strategies;
- identification of aspects requiring new legislation;
- development of elements for communications strategies;
- integration of self-help protection activities in national recovery strategies;
- characterisation of the role of stakeholders in radiological protection decisions;
- compilation of lessons learnt and approaches to knowledge management;
- continuation of work to harmonise terminology.

More directly, the issue of legacy site management was revisited during the 4th NEA Science and Values Workshop held in Russia in 2015, and again during a workshop organised by the Norwegian Radiation Protection Authority (NRPA) on "Regulatory Supervision of Legacy Sites:

From Recognition to Resolution" (Sneve and Strand, 2016). The following key points were raised during these workshops:

- Numerous, major legacy sites and installations of different kinds exist across NEA member countries. Many were created before, or arose outside, current recommendations and guidance on radiological protection, as well as associated regulations and regulatory frameworks, and/or were the result of accidents or neglect.
- Little or no guidance has been prepared at the international level to address the application of international recommendations and standards on the many aspects of radiological protection involved in the integrated management of legacy sites.
- Practical guidance addressing the following issues would be useful:
  - Applying recommendations for both existing and planned exposure situations to a single legacy site; in particular, establishing criteria for the management of legacy site remediation activities using both dose limits/constraints and reference levels, in addition to using standards related to waste management.
  - Developing communication strategies and stakeholder involvement strategies for outreach (e.g. to potentially affected populations living in the vicinity of legacies).
  - Identifying radiological protection methods needed to develop coherent and optimised approaches for regulatory oversight and site management.

1.2. Objectives and mandate

To address these issues, in 2016 the NEA set up the CRPPH Expert Group on Legacy Management (EGLM). The overall goal of the EGLM is to develop a practical and harmonised approach for the regulation of nuclear and radiological legacy sites, taking into account the results of other relevant activities such as:

- Those carried out by the NEA, notably:
  - *Nuclear Site Remediation and Restoration during Decommissioning of Nuclear Installations* (NEA, 2014);
  - *Stakeholder Involvement in Decision Making: A Short Guide to Issues, Approaches and Resources* (NEA, 2015);
  - *Strategic Considerations for the Sustainable Remediation of Nuclear Installations* (NEA, 2016a);
  - *Management of Radioactive Waste after a Nuclear Power Plant Accident* (NEA, 2016b).
- Those of the International Atomic Energy Agency (IAEA), notably:
  - *Safety Fundamentals* (IAEA, 2006), *International Basic Safety Standards* (IAEA, 2014);
  - relevant guidance documents, such as Safety Guide WS-G-3.1 on the *Remediation Process for Areas Affected by Past Activities and Accidents* (IAEA, 2007) and *Policy and Strategies for Environmental Remediation*, Nuclear Energy Series No. NW-G-3.1 (IAEA, 2015).
- Those of the International Commission on Radiological Protection (ICRP), notably:
  - ICRP Publication 103, *The 2007 Recommendations of the International Commission on Radiological Protection* (ICRP, 2007);
  - progress in various ICRP task groups developing guidance on ICRP recommendations for existing exposure situations.
- good practice at different types of legacy sites as illustrated through specific examples at these sites.

The specific objectives of the EGLM include:

- assist NEA member countries in deriving practical interpretation and application of generic radiological protection guidance to nuclear and radiological legacy site management, and in developing or supporting the development of international guidance specific to the regulation of nuclear and radiological legacy sites;
- enhance safety and security culture as it applies to legacy sites and make transparent the application of the principle of optimisation in the context of the regulation of legacy sites;
- address specific situations at real sites within NEA member countries;
- support a holistic approach to risk management, to which end it may be appropriate to include international organisations concerned with chemical and other risks, including other parts of the OECD, as well as the UN Environment Programme and the World Health Organization;
- consider risk management by developing a better understanding of the various types of radiation-induced risk to diverse groups of people on different temporal and spatial scales.

Important challenges remain to accommodate these issues within an effective regulatory framework, particularly in terms of the complexity of achieving optimisation across competing objectives. A key driver for this work has been to avoid the creation of future legacy sites. The EGLM was therefore asked to also consider the following potentially relevant factors.

Regulatory threat assessments[1] provide an effective procedure to identify possible gaps in the regulations, as well as priority tasks and activities with clear objectives and scope. The results can help define a strategy from a protection and regulatory perspective.

A holistic process for radiological regulation should cover the full range of radiological protection issues. A fully **integrated process** should, however, include many other factors. Addressing these issues involves i**nnovative measures** that address the technical and other challenges at legacy sites, and should include such aspects as:

- use of modern assessment methods supported by new science and technical tools:
  - prognostic assessment of radiological impacts on humans and the environment;
  - safety assessments of technologies to identify priorities for regulatory focus.
- practical application of methods to address specific regulatory issues at specific sites.

1.3. Scope and method of work

The EGLM has held two formal meetings, and two very informative site visits were hosted at Sellafield (United Kingdom) and at Andreeva Bay (Russia). It has also benefitted from discussions with representatives of the ICRP and IAEA, and from presentations and discussions at a workshop in November 2017, on “Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution”, hosted by the NRPA and organised jointly by the NRPA, IAEA, ICRP and NEA (reported in Sneve and Popic, 2018).

The key approach has been to share and build on practical experience. This practical experience includes related activities ongoing in IAEA projects such as the European and Central Asia Safety Network (EuCAS, 2018), ICRP task groups, and a wide range of bi-lateral co-operation initiatives and national activities.

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[1] Regulatory assessment refers in this report to the identification of regulatory gaps, and priority radiological risks and challenges from a regulatory perspective, as analysed, referred to as “Regulatory Threat Assessments”, in Ilyin et al. (2005), Zhunussova et al. (2013) and Sneve et al. (2016).

The initial steps in the EGLM approach to meeting its objectives was to develop a common understanding of the need for the project and the challenges that continue to be faced by member countries. Chapter 2 of this report provides an overview of these initial steps and includes consideration of a wide range of nuclear legacy sites. It also includes substantial discussion on significant issues that may at first appear to be unrelated to legacy sites, but that are indeed pertinent in this regard.

There is a great deal of evidence indicating that a single definition of a legacy site is not likely to be helpful in all circumstances (Sneve and Strand, 2016; Sneve and Popic, 2018) because use of the word legacy in different contexts, ranging from simple common language to binding legal frameworks, is further complicated by translation into languages other than English. Useful descriptions exist of the characteristics of a "legacy site", as well as the type of site (i.e. the area and installations) under consideration, but these characteristics should not be considered as exclusive or comprehensive. The approach of the EGLM is to be inclusive, so as to allow all potentially relevant experience to be taken into account. Any attempt to provide a strict definition of a legacy site is not considered helpful, not only because different definitions already exist in difference jurisdictions but also because of the differing cultural connotations, particularly when the term is translated from English. However, the EGLM has found that it is important to provide a short explanation for the types of sites under consideration. The following working description (and not a definition) for a nuclear or radiological legacy site has therefore been put forward as one that:

- has radioactivity which is of concern to the regulator;
- has not completed remediation.

Once remediation is complete, the so-called "legacy" in relation to the site in question has been resolved, at least from a technical, safety perspective. A legacy situation may be identified by regulatory authorities as a result of stakeholder concerns, but for the purposes of radiological protection, it does not necessarily constitute a nuclear or radiological legacy if the level of radioactivity is not of concern to the regulator.

Chapter 2 examines these challenges, taking into account a range of inputs, including the 2 site visits (SVs) mentioned above, as well as 11 case studies (CS) that were prepared by members of the EGLM. The discussion in the next chapter is divided into the following topics:

- regulatory frameworks;
- characterisation of circumstances;
- societal aspects;
- deciding upon and achieving end-states;
- long-term protection values.

Practical experience and challenges have been identified from the site visits and case studies, and these include examples from a wide variety of sites from around the world that illustrate a range of prevailing circumstances outlined in the following, specific cases:

- Old radioactive waste disposal sites
  - Case study 1: Little Forest Legacy Site (Australia);
  - Case study 2: The Low Level Radioactive Waste Repository (United Kingdom);
- Facilities for long-term storage and or disposal of naturally occurring radioactive material (NORM), and uranium or other ore mining and milling facilities
  - Case study 3: Ranstad uranium milling plant (Sweden);
  - Case study 4: Søve: A former Niobium mine (Norway);
  - Case study 5: Stráž Pod Ralskem and Rožná legacy sites (Czech Republic);
  - Case study 6: Shiprock disposal site (United States).

- Radium affected areas
  - Case study 7: Radium Action Plan 2015 to 2019 (Switzerland).
- Disposal sites found to have emplaced, unplanned radioactive waste
  - Case study 8: Capriano Del Colle special waste dump (Italy).
- Old nuclear technology sites
  - Case study 9: Hanford, United States;
  - Case study 10: Western New York Nuclear Service Center and West Valley Demonstration Project (United States);
  - Site visit 1: Sellafield, United Kingdom;
  - Site visit 2: Andreeva Bay temporary spent nuclear fuel and radioactive waste storage site (Russia).

These documented case studies and site visits provide the perspectives of those involved in managing and/or regulating the sites, reflecting the real, historic, current and planned legacy context and activities. They are presented as shared examples of actual practice and experience in applying safety measures to address legacy sites. They have not been edited to correspond to international preconceptions, but are instead the perspectives of those producing them and are intended to help inform the development of international guidance.

The aim when examining historic legacy experience is to help ensure that current installations or sites do not evolve into new legacy sites. To this end, a further case study has been provided, as follows:

- Case study 11: The Challenges of preventing the development of a legacy situation at Fukushima, Japan.

Chapter 3 examines important factors involved in meeting challenges and addressing uncertainties. Closing chapters provide lessons learnt, conclusions and recommendations that might be taken into account when developing a practical and harmonised approach for the regulation of nuclear and radiological legacy sites.[2]

References

EuCAS (2018), "2017 Annual Report", https://gnssn.iaea.org/main/EuCAS/Documents/News/EuCAS%20Annual%20Report2017.pdf.

IAEA (2015), *Policy and Strategies for Environmental Remediation*, Nuclear Energy Series No. NW-G-3.1, IAEA, Vienna.

IAEA (2014), *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, General Safety Requirements Part 3, IAEA, Vienna.

IAEA (2007), *Remediation Process for Areas Affected by Past Activities and Accidents*, IAEA Safety Standards Series WS-G-3.1, IAEA, Vienna.

IAEA (2006), *Fundamental Safety Principles*, Standards Series No. SF-1, IAEA, Vienna.

IAEA (2002), *Radiation Legacy of the 20th Century: Environmental Restoration*, IAEA-TECDOC-1280, IAEA, Vienna.

ICRP (2007), "The 2007 Recommendations of the International Commission on Radiological Protection", ICRP Publication 103, *Annals of the ICRP*, Vol. 37, Nos 2-4, Elsevier.

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[2] Members of the EGLM are listed in Annex 1. The site visits are documented in Annex 2, and the case studies in Annex 3.

Ilyin, L. et al. (2005), *Initial Threat Assessment: Radiological Risks Associated with SevRAO Facilities Falling Within the Regulatory Supervision Responsibilities of FMBA*, Strålevern Rapport 17, NRPA, Østerås.

NEA (2018), *Towards an All-Hazards Approach to Emergency Preparedness and Response. Lessons Learnt from Non-Nuclear Events*, OECD Publishing, Paris.

NEA (2016a), *Strategic Considerations for the Sustainable Remediation of Nuclear Installations*, OECD Publishing, Paris.

NEA (2016b), *Management of Radioactive Waste after a Nuclear Power Plant Accident*, OECD Publishing, Paris.

NEA (2015), *Stakeholder Involvement in Decision Making: A Short Guide to Issues, Approaches and Resources*, OECD Publishing, Paris.

NEA (2014), *Nuclear Site Remediation and Restoration during Decommissioning of Nuclear Installations*, OECD Publishing, Paris.

NEA (2013), "2013 Topical Session on Recovery Management Summary Report", NEA/CRPPH/R(2014)1.

NEA (2007), *Radiation Protection in Today's World: Towards Sustainability*, OECD Publishing, Paris.

Sneve, M.K. et al. (2016), *Ukrainian Regulatory Threat Assessment: Identifying Priorities for Improving Supervision of Nuclear and Radiation Safety and Security*, NRPA, Østerås.

Sneve, M.K. and J. Popic (Eds) (2018), *Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution: Report of an International Workshop held in Lillehammer, 21-23 November 2017*, NRPA, Østerås.

Sneve, M.K. and P. Strand (2016), *Regulatory Supervision of Legacy Sites: From Recognition to Resolution – Report of an International Workshop, Oslo, 17-19 November 2015*, NRPA, Østerås.

Zhunussova, T. et al. (2013), *Norwegian Support to Regulatory Authorities in Central Asia in Radioactive Waste Management*, NRPA, Østerås.

Chapter 2. Recognising the challenges at legacy sites

The decision-making process for the remediation of sites impacted by radioactive material should involve a transparent, sound, scientifically defensible process that has been proven to be socially acceptable among stakeholders. The ultimate objective of any decision-making process should be to reach an accepted and sustainable option for the particular situation. Effective decision making about environmental remediation involves identifying feasible remedial alternatives, forecasting the various anticipated outcomes, and their associated costs, risks and benefits. Analyses should be based on available information, accounting for uncertainties, and they should be supported through input from interested parties to determine which option provides an acceptable and sustainable outcome given the prevailing circumstances.

In order to sustain the entire process from initiation through to completion, however, a number of resources and conditions must be in place prior to commencing the decision-making process. Important requirements include the following:

- a national and site-specific strategy for future site management;
- a national and site-specific strategy for financial resources;
- an appropriate legal and regulatory framework;
- clear allocation of responsibilities;
- adequately resourced and experienced regulators;
- an identified, responsible party for the site remediation;
- a process for stakeholder engagement.

It is often a characteristic of legacy sites that one or more of these resources and conditions is unfortunately not in place, at least at the time of legacy recognition (Sneve and Strand, 2016). Even when resources are available, decision making on how to manage decommissioning and remediation of existing contamination may be complex and challenging. Key points and challenges that should be recognised when moving from legacy recognition to resolution are listed below, and have emerged from continuing efforts, including those discussed above, to share experiences.[1]

- Every legacy is different and presents a complex variety of prevailing circumstances.
- Technical methods for remediation and regulatory supervision are well developed, with considerable amount of useful experience to date. At the same time, there is scope for improvement in terms of the development of adaptive management and regulatory processes, which would facilitate consideration of the prevailing circumstances in the country and at the site. It may also lead to different solutions at different sites that in turn could lead to further concerns, unless the reasons for the differences are effectively communicated.

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1. The site visits and case studies in Annexes 2 and 3 provide substantial evidence to confirm and illustrate these points.

- To ensure success, it is important to engage a wide range of stakeholders, and to use their historic and practical knowledge and experience of the legacy site to address concerns in a transparent and traceable process so as to define a stepwise plan. Effectively reaching a common understanding of the risks involved is a very important part of the engagement process.
- A substantial gap exists between theory and practice and further guidance on the practical application of international standards, recommendations and current guidance would thus be valuable. This guidance could include clarification on the application of the concept of an "emergency", as well as on existing and planned exposure situations and the boundaries between them in the context of legacy management.
- A holistic approach to proportionate management of different risks should be encouraged. This type of approach may require a review of protection objectives and standards that are applied to different contaminants in different contexts.
- Common needs for further research and/or technical development should be identified based on current experience, including the results of assessments that have already been made.
- Methods are available to assess future impacts related to legacy sites, which present common, relevant features such as the nature and the extent of contamination. However, there is scope to improve assessments and to bring them into alignment within a common framework of protection objectives so as to support the consistent application of the principle of optimisation.
- National strategies for legacy site remediation should be linked to strategies for the management and regulation of radioactive substances. One challenging factor is that a national radioactive waste strategy may not be readily able to accommodate waste from legacy remediation, including mixed, hazardous waste (see NEA, 2016b).
- Since many legacy sites are complex, remediation often can be most effectively managed by using a staged process, and the remediation methodology should reflect this process, focusing on overall optimisation that integrates the views of stakeholders.

Remedial action will be associated with environmental, social and economic drawbacks and benefits, both in the short and long term. Sustainable remediation implies a holistic approach that considers all the detrimental and beneficial, aiming to balance the net effects. Sustainable remediation should encourage the appropriate management of materials, including "reuse" and remediation of land. Though the potential benefits can be enormous, there is often a lack of awareness of methods for the selection and implementation of sustainable remediation options (NEA, 2016a). In fact, no single definition of "sustainable remediation" exists since the term can mean different things to different people.

Regulators can take advantage of various approaches for achieving safety and environmental protection goals, including through consideration of approaches from other industries (NEA, 2016a), such as the requirements for environmental impact assessments of nuclear decommissioning.[2] Unfortunately, such horizontal considerations are typically lacking at the international guidance level, and may not be considered for particular legacy sites even when multiple hazards, in addition to radiological hazards, are present.

Special factors include the need to establish appropriate criteria, such as reference levels, as well as derived standards and monitoring procedures to support demonstration of compliance.

Because of the complexity of individual circumstances, generating an integrated approach can be a challenge. Although redundancy in organisational functions is expensive and difficult to manage, some degree of redundancy may be prudent to ensure that all challenges, management options and potential solutions are considered.

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[2] See, for example, in the United Kingdom, the Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999, made under the European Communities Act 1972.

Remediation of radioactive contamination on legacy sites should, as far as reasonably practicable, be consistent with approaches to the management of non-radioactive contaminants in land and groundwater, as well as the management of off-site contamination and waste disposal (NEA, 2016a). An internationally agreed approach has yet to be developed in this regard (NEA, 2016a).

In recognition of the need to consider waste management as an integral part of legacy management, and to address chemotoxic substances alongside radioactive substances, two international workshops have been organised. These workshops examined the scientific basis (BIOPROTA, 2013) of radioactive and non-radioactive hazardous substances (NRPA, 2015), comparing methods of assessment. A recent, internationally supported study also focused on issues affecting assessments of the impacts of radioactive and hazardous waste disposal (NRPA, 2018). The study was designed with the objective of providing information to support the development of a consensus on how to address chemotoxic and radioactive substances in waste, which could lead to the application of more coherent and consistent assessment methods. Currently, certain factors form the bases for continuing with separate approaches, including traditional behaviour, regulatory and institutional differences, lack of common language in addressing aspects with respect to both waste types, lack of international guidance on criteria for assessments, as well as lack of supporting information from scientific research. The development of a common set of objectives and, hence, assessment endpoints and time frames for the different waste types, is extremely challenging but would ultimately be very beneficial, since it would promote, in particular, the proportionate allocation of resources to the different types of hazards associated with remediation and waste management. In cases where technical differences are necessary, a clear understanding of the reasons for the different approaches should be provided to allow for these differences to be understood and communicated among all stakeholders.

Post-accident site remediation may present challenges similar to those associated with legacy sites. An integrated approach may thus be an effective way to avoid creation of an additional legacy site after an accident.

There is also likely to be a need for the iteration of a strategy, with more detail added at each stage, after taking into account information obtained from the previous stages. This iterative process should include site and radioactive waste characterisation data, updated and improved to be more relevant in the context of regulatory requirements. Responsibilities for the implementation and resourcing of tasks at each stage may also need to be updated. At the early stages, for example it may be useful to pursue flexible/parallel approaches. In all cases, however, a careful step-by-step approach is strongly advised so as to reduce the chance of creating new legacy sites that will require management in future. It is also important to note that decisions made during the management of the emergency phase may impact, or limit, the options subsequently available in the recovery phase.

Excessive caution or a tendency to follow existing processes designed for other circumstances may delay the appropriate timing of decisions (see Sneve et al. [2017] and the discussion in Annex 2). Examples include a delay in the return to normal land use, despite safety not being an issue, and a delay in the introduction of appropriate restrictions, which results in a continuation of conditions of risk, as well as a potential for additional costs. Part of the problem arises as a result of technical uncertainties, as well as the uncertainties associated with identifying social preferences. This problem should be acknowledged, alongside the need for a balanced approach to managing different risks to different people on different timescales, supported through stakeholder engagement.

In developing an iterative strategy, it is important to allow sufficient time to obtain regulatory approval. Communicating effectively with stakeholders can be time consuming, but is generally necessary as part of the identification of site management approaches. The long-term nature of such discussions was demonstrated during the management of Three Mile Island and Chernobyl, and the Windscale Pile (NEA, 2016b).

References

BIOPROTA (2013), "Scientific Basis for Long-term Radiological and Hazardous Waste Disposal Assessments", report of an International Workshop, Ljubljana, Slovenia, 22-24 May 2013.

Sneve, M.K. et al. (2017), "Spent Fuel Management at the Andreeva Bay Site for Temporary Storage in the Kola Peninsula", *Proceedings International HLW Management Conference*, Charlotte, N Carolina April 2017, American Nuclear Society.

Sneve, M.K. and P. Strand (2016), *Regulatory Supervision of Legacy Sites: From Recognition to Resolution – Report of an International Workshop, Oslo, 17-19 November 2015*, NRPA, Østerås.

NEA (2016a), *Strategic Considerations for the Sustainable Remediation of Nuclear Installations*, OECD Publishing, Paris.

NEA (2016b), *Management of Radioactive Waste after a Nuclear Power Plant Accident*, OECD Publishing, Paris.

NRPA (2018), *Study of Issues Affecting the Assessment of Impacts of Disposal of Radioactive and Hazardous Waste*, NRPA, Østerås.

NRPA (2015), "Comparison of Safety and Environmental Impact Assessments for Disposal of Radioactive Waste and Hazardous Waste", report of a BIOPROTA workshop held on 10-12 February 2015, Asker, Norway.

Chapter 3. Meeting challenges and addressing uncertainties

Regulatory frameworks have been designed for application at sites and facilities that have been operated according to plan and in line with up-to-date recommendations, standards and guidance. These frameworks may address radiological circumstances specific to a particular site, but generally follow a common pattern.

In contrast, regulatory frameworks designed for legacy sites need to address circumstances that, by their very nature, were not planned, and have been :

- "unrecognised" (e.g. a site that had been used previously for making radium-dial watches and at which no-one was previously aware of the significance of the radiological contamination);
- "abandoned" (e.g. a building that was long-ago used for making radium dials for watches and instruments);
- "unused over the long-term, or redundant" (e.g. a hot cell facility that has not been used for decades, but is located on a regulated site with operating installations).

These circumstances tend to be challenging from a regulatory standpoint, not least because the framework for the regulation of legacy sites will need to be broadly consistent with the inherently more prescriptive framework developed for normal operational circumstances.

The following sections are the results of ongoing discussions within the NEA Expert Group on Legacy Management (EGLM), as well as the wider engagement of EGLM participants. The intention of presenting this information here is to promote further sharing of experience of mutual benefit and to support conversion of the preliminary framework into a practical and effective tool. The comments and suggestions are provided to explain or justify lessons learnt (Chapter 4) and to inform the suggested next steps (Chapter 5). They are not intended as a prescription. Similar challenges, lessons and recommendations emerge under different headings. Repetitions in the text simply highlight the difficulty of addressing such cross-cutting issues, and the challenges that arise from examining the different perspectives of stakeholders, who may identify different, preferred solutions.

3.1. Regulatory framework

Regulatory structures and processes, addressing radiological and nuclear safety, form a legally binding framework in the jurisdiction under consideration, within which legacy site management must be planned and implemented. The wide variety of legacy situations, in national, regional and local contexts, and even of the cultural aspects related to these situations, suggest that the framework should be sufficiently flexible to allow the emergence of management approaches and objectives best suited to site-specific circumstances.

3.1.1. Governmental responsibility

Specific roles and responsibilities of the government, the regulatory body or of other relevant authorities and parties responsible for legacy site remedial actions are nationally defined, appropriately taking into account existing recommendations on requirements, such as the International Atomic Energy Agency (IAEA) General Safety Requirements (GSR) Part 3 Requirements 47, 48, 49, and 52 (IAEA, 2014). In general, the government's national policy should set out who is responsible for ensuring that the legacy situations that have been identified are then evaluated. It should also determine which occupational and public exposures and environment are of regulatory concern, identify those persons or organisations who are responsible for areas with residual radioactive material and for ensuring that remedial actions are justified, and ensure that protection and safety are optimised in the context of meeting regulatory requirements, while taking into account stakeholder concerns in a transparent manner.

A national policy, and a strategy to deliver that policy, together with a legal framework, should provide a mechanism for identifying and evaluating potential legacy sites, and for deciding on and prioritising the need for remediation. To achieve a sustainable solution, it is essential to involve all interested stakeholders and ensure liaison among them – the importance of implicating stakeholders was exemplified in the case of radium sites in Switzerland (see case study 7). The national policy should also provide a mechanism for investigating potential legacy sites if they are brought to the attention of the authorities, as illustrated in the case when Cs-137 was discovered at the Capriano Del Colle disposal site (see case study 8).

3.1.2. *A transparent and balanced decision-making process*

It is important for the government or competent authority to provide a process that allows the benefits and drawbacks of different options to be transparently analysed. Examples of such an approach are discussed in a paper from the UK Environment Agency (Environment Agency, 2009).

The management of legacy sites should include consideration of the site situation at present, the historical aspects that have contributed to the current situation and the desired end-state of the site or installation. The details described in relation to several of the case studies and the site visits presented in Annexes 2 and 3 demonstrate that safety requirements, wider expectations and other circumstances can change with time. This is particularly true for activities described at old disposal sites see case studies 1 and 2).

Drivers for change need to be understood as they may impact on stakeholder expectations, remediation timelines, endpoints and ongoing institutional control. These drivers can include:

- public health concerns;
- a proposed change of land use;
- the need to impose institutional controls;
- changes in standards (e.g. for a previously “approved” disposal site).

The site situation and drivers for change have a direct effect on the timescales required to implement any required remedial action.

Where there are identified public health concerns, or an identified deterioration in existing engineered or natural barriers, there may be an urgent need for immediate remedial action (e.g. stabilisation, installation of bunds/interceptors, restriction of land use) to prevent major exposure or environmental contamination.

Where the site conditions are relatively stable, more detailed consideration and longer-term studies can be allowed, for example, completing studies on historic and continued monitoring, as in the case of site visit 2 or case study 2 (see Section 3.4 for further discussion).

3.1.3. *Identification/assigning of responsible organisations*

Once a legacy site is identified, an organisation should be assigned as responsible for addressing legacy management issues, and these responsibilities may be in addition to existing management responsibilities. An investigation may be carried out to identify the responsible organisation, as for example in the case of Ranstad (see case study 3), when the responsibility was traced through the records and demonstrated to have been transferred from the original, AB Atomenergi, to the current operator, Studsvik AB.

Identifying previous ownership of a site can also offer some indication of the types of activities conducted, while identifying companies or individuals with an enduring responsibility or obligation for the remediation and clean-up. If ownership or responsibility cannot be identified, the state or federal government would normally assume responsibility and assign an operator, along with funds or fund contributors. The responsibility for such orphan legacies should be clearly identified in national strategies, and appropriate provision should be made for managing the liabilities. It has been suggested that it would be reasonable to assign financial contributions for the legacy site to the organisations that benefited from the legacy, for example nuclear fuel cycle facilities that benefited from the work of historical fuel research facilities in the country.

If it is not possible to identify a responsible organisation or person, a new entity would need to be designated and given legal authority, with stipulation of its responsibilities. Responsibilities may also be transferred during a remediation programme, as in the case of the various aspects of supervision related to the Andreeva Bay site (see site visit 2). One of the challenges is that, it can be difficult to allocate responsibility until the characterisation of the legacy site is complete, which in turn complicates financial provision. After the site characterisation is completed, financial provision may need to be updated in order to allow responsibilities to be properly addressed.

3.1.4. ***Regulatory responsibilities***

The International Commission on Radiological Protection (ICRP) most recently issued general radiological protection recommendations in Publication 103 (ICRP, 2007). This publication introduced radiological protection approaches based on three types of exposure situations, legacy sites being considered as existing situations, or situations that already exist when a protection decision needs to be taken. This is significant in that the regulatory management of legacy sites now falls within this framework in virtually all countries around the world.

In the ICRP framework, existing situations are subject to the principles of justification and optimisation as mechanisms for dose management, but they are not subject to individual dose limitation such as those applied to planned situations. The ICRP uses the term "reference level" in the context of emergency and existing exposure situations "for the restriction on dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur, and below which optimisation of protection should be implemented". Options resulting in doses greater than the reference level should be rejected at the planning stage. Other approaches to setting of dose criteria may need to be recognised at the national or local level (NCRP, 2018).

In ICRP Publication 103, the principle of "justification" is defined for existing exposure situations as the condition in which the "benefits to individuals and to society (including the reduction in radiation detriment) from introducing or continuing the remedial action out-weigh its cost and any harm or damage it causes".[1] Here, it is recognised that reduction in radiation detriment is only one of many factors to be considered in the context of management and regulatory decisions.

Using the ICRP framework, regulatory oversight of legacy sites includes an assessment of the operator's capability to meet the standards and apply the procedures. The unknown and uncertain nature of radiological circumstances at many legacy sites can make oversight challenging, including that of judging the adequacy of arrangements for optimisation.

There is therefore likely to be a need for iteration of the regulatory strategy as more detailed information is obtained. The strategy may evolve as new information is obtained concerning hazards at the site, site characteristics, results of various risk and other assessments and improved information that supports the selection of reference levels (see Balonov et al., 2018).

The selection of dose criteria involves qualitative and quantitative judgements, and requires broad and informed consultations. The main factors to be considered are the feasibility of controlling the situation and past experience with the management of similar situations (ICRP, 2007). Because legacy situations can be unusual, they can also be challenging to address.

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1. The updated Russian radioactive waste classification scheme mentions the use of collective dose as contributing to the demonstration of net benefits in the context of decisions to leave in place or to move radioactive waste (see Section 3.5.2).

Experience has shown, however, that stakeholder concerns often drive choices (see Annexes 2 and 3).

Local stakeholders in general need to be involved in discussions concerning the selection or approval of remediation end-state criteria, and they bring with them local knowledge, expertise and wider safety and other concerns. Given that stakeholders are generally concerned with their own well-being, in a broad sense, an all-hazards approach, addressing all hazards and taking economic and social aspects into account, may be helpful, when examining existing experience (NEA, 2018). This may in turn impact upon radiological regulatory activities.

Factors to consider during the establishment of reference levels, and the selection of end-state objectives and other criteria for legacy sites are listed below, with examples of these factors and how they might be taken into consideration provided in Annexes 2 and 3:

- the prevailing circumstances of the current exposure situation (contaminants and their amounts and concentrations, chemical and physical forms of the radionuclides, mobility of radionuclides in the local environment, pathways for radionuclide transfer and modes of exposure);
- the projected doses from contamination, the spatial extent of contamination, the number of people exposed;
- evaluation of remedial actions in terms of the ease of implementation, time and cost for remediation, the potential volume of radioactive material that could be produced (including transport), residual materials/waste, the environmental impact, etc.;
- the likely effectiveness of remedial measures (short term) and the practicability of long-term controlling/constraining certain human activities in specific geographical areas (e.g. residence, agriculture, excavation, collection of foodstuffs and forestry);
- anticipated outcomes to be achieved (as compared to other similar situations);
- societal disruption that would be produced through remediation;
- impact on important environmental, social and cultural resources;
- interested parties' views, risk perception, regulatory and public acceptance.

The need to account for non-radiological risks in overall optimisation decisions has been recognised. However, there is no direct equivalent to the concept of "reference level" used in radiological protection, and which could be used in the context of chemical pollution (NRPA, 2018). Radiation and nuclear safety regulators may benefit from work with the regulators responsible for other hazards, including physical and chemical hazards that may exist at a legacy site (see for example, site visit 2 and NEA, 2018).

The presence of non-radiological hazards may also affect remediation options where, for example, chemicals, explosives and physical hazards are regulated by different statutory authorities. A variety of physical hazards may be present, such as a possible collapse of tailings piles or the collapse of other ageing structures. Experience suggests that where this is the case, regulatory bodies should work together to manage the licensing and supervision of residual hazards on a common risk-informed basis.

3.1.5. *Responsible party roles*

The International Basic Safety Standards (IAEA, 2014) establish responsibilities for the organisation or institution charged with remediation. The persons or organisations responsible for the planning, implementation and verification of remedial actions need to ensure that:

i. A remedial action plan, supported by a safety assessment, is prepared and is submitted to the regulatory body or other relevant authority for approval.

ii. The remedial action plan is aimed at the timely and progressive reduction of radiation and other risks, and if possible, at the eventual removal of restrictions on the use of, or access to, the area.

iii. Any additional doses received by members of the public as a result of remedial actions are justified on the basis of the resulting net benefit, including consideration of the consequent reduction of the annual dose.

iv. In the case of optimised remediation:

- radiological impacts on people and the environment are considered together with non-radiological impacts, and with technical, societal and economic factors;
- the costs of transport and the management of radioactive waste, the radiation exposure of, and health risks to, workers managing the radioactive waste, and any subsequent public exposure associated with waste disposal are all taken into account.

v. A mechanism for public information is in place, and interested parties are involved in the planning, implementation and verification of the remedial actions, including any monitoring following remediation.

vi. A monitoring programme is established and implemented.

vii. A system is in place for maintaining adequate records relating to the existing exposure situation and to actions taken for protection and safety.

viii. Procedures are in place for reporting to the regulatory body or other relevant authority on any abnormal conditions relevant to protection and safety.

Further IAEA requirements are specified in relation to occupational exposure in existing and planned exposure situations in *Occupational Radiation Protection: International Basic Safety Standards* (IAEA, 2018). The implementation of these requirements should recognise the practical challenges associated with legacy sites, such as the typical lack of information compared with planned exposure situations, and of experience from sites presenting multiple exposure situations.

In addition to the above, the person or organisation responsible for post-remediation control measures should establish and maintain, for as long as required by the regulatory body or other relevant authority, an appropriate programme, including any necessary provision for monitoring, to verify the long-term effectiveness of the completed remedial actions for areas in which controls are required after remediation (see NEA, 2016a and CS6). Criteria for demonstrating the effectiveness of control measures should be established, along with any derived quantities that can be measured.

Local authorities may have a special role in maintaining institutional control and knowledge of the site history, as may be appropriate once remediation is complete (NEA, 2014b). The basis for allowing an operator to relinquish responsibility, for example to surrender their operating licence, continues to be a challenging issue. (See CS1, CS2, CS6 and CS13.)

Even if roles are clearly identified, it can be difficult to work together effectively without first establishing trusting working relationships. Such relationships can develop under a clear long-term strategy that has political support. It takes time to build trust, an important and dynamic feature of the overall process. (For a more detailed discussion on trust see Section 3.3.)

3.1.6. *Prescriptive or goal-setting/performance-based approaches*

The development of any regulation concerning the remediation of contaminated sites will involve a balance between two differing requirements:

- the need for flexibility to permit easy adaptation of the regulation to a wide variety of prevailing and evolving circumstances and technology;
- the need to include the appropriate precision and detailed requirements, which contributes to confidence building by demonstrating that a clear framework of standards must be followed and that it is possible to determine if the standards are being met.

A "performance-type" regulation, applicable in the case where more flexibility is required, is more general and simply specifies the overall safety requirements and basic operational parameters (that is, "what" is to be accomplished in terms of safety objectives). A "prescriptive" regulation, applicable in the case where more precision is necessary, outlines in greater detail "how" to achieve such safety objectives.

In practice, most regulations contain both performance and prescriptive requirements, but they can often be characterised as being either predominantly performance-oriented or prescriptive. An example of a performance-oriented regulation would be one which requires the user to plan and organise operations so that exposures are maintained as low as reasonably achievable (ALARA), and economic and social factors are taken into account, demonstrated through the use of "adequate" workplace monitoring and "appropriate" instruments. The performance-oriented regulation might also require the maintenance of adequate records to demonstrate compliance. The role of the regulator is then to ensure compliance with safety objectives rather than to specify the delivery of safety. The equivalent prescriptive regulation would be more specific and might define exactly how to achieve adequate restriction of exposure, as well as how, when and where to conduct workplace monitoring, what type of instrument should be used, and how and what records should be maintained. Such prescriptions may be difficult to finalise until a legacy site has been adequately characterised, so there may be benefit in delaying specification of the prescription. It should also be noted that it is difficult to prescribe matters related to optimisation since the economic and social factors will usually be locally driven.

In practice, national regulations will often combine performance-oriented requirements with prescriptive requirements. The relative importance of these two approaches depends upon wider aspects of national policies and strategies, with some countries having a more prescriptive approach to all their regulations and others not. The legacy management process has to include safety and security culture in all cases so as to achieve optimisation. Because of the wide variety of legacy situations within individual countries, national regulatory approaches will need to be applicable or adaptable to a variety of circumstances.

3.1.7. *Safety and security measures and safety assessment, a staged process*

One key factor throughout the remediation process is that of understanding radiological and non-radiological risks. Such an understanding is based on knowledge of the hazardous source terms and the site conditions, which is necessary to underpin the application of prognostic assessment methods.

The government and/or the regulatory body should review the safety assessments performed by the responsible organisation. The results of a safety assessment may provide significant input into decision making at various points in the remediation process, for example, in terms of:

- the decision as to whether or not to remediate;
- prioritisation of remediation projects as part of a national strategy;
- development of remediation objectives and criteria;
- evaluation of remediation options;
- selection of the most appropriate option;
- evaluation of implemented remedies;
- evaluation of post-remediation performance of the selected option.

The complexity of the assessment is likely to evolve over time as additional knowledge is accrued in relation to the site and associated risks, and remedial options and projected end-states are evaluated. The results of initial assessments developed during the early stage of a project should be presented as provisional and be subject to refinement as new information is made available and innovative remediation technologies are developed. Typically, the objectives of initial assessments can be limited to identifying priorities so as to obtain a better understanding of the prevailing circumstances, including the need for specific regulations and guidance that are relevant to those circumstances (see, for example, Ilyin et al., 2005, Zhunussova et al., 2013, Sneve et al., 2016 and site visit 2).

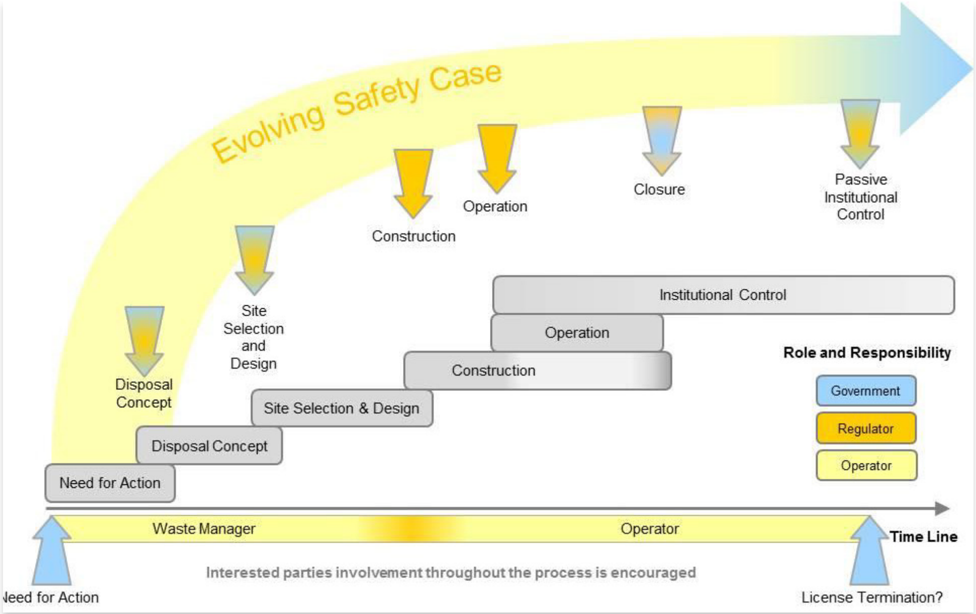
This initial assessment is likely to be followed by a phase assessing management options, with further assessment taking place during the implementation phase. These assessments will need to include an evaluation of the potential risks to the public, workers and the environment, both in terms of the site and its immediate surroundings, and including any on-site and off-site waste management. Later assessments will be needed of the completed remediation project, to confirm compliance with remediation objectives.

Overall optimisation will generally need to consider the implications of off-site disposal, to answer the question of whether it is better to leave waste where it is, or to move it – see Section 3.5.2.

Many near-surface disposal sites and waste tailings piles, especially from older such facilities, present the characteristics and challenges associated with legacy sites, including the process for release from operational control, as well as regulatory supervision and knowledge management. Figure 3.1 below was developed in the context of safety case development for radioactive waste disposal, and then applied to the management of sites after disposal is completed (Seitz et al., 2016). It illustrates the need for a staged development programme, starting from recognition of the need to manage and dispose of radioactive waste through to licence termination. This process parallels that of moving from legacy site recognition to resolution (Sneve and Strand, 2016). It includes stages that may involve assessment and iteration at each stage of the process, including:

- Initial recognition, possibly involving urgent action to control access to the site, to exclude or limit access to limit exposures, but also to reduce the risks of malicious activities.
- Site and source characterisation.
- Operational phase, which for legacy sites may mean, for example, first achieving brown field (site access allowed but limited land use, during which further investigation and planning is carried out), then a pause followed by further operational work to achieve green field status (unlimited land use), as found appropriate (see site visit 2).
- A further pause to check compliance and green field status approval/release from regulatory control.
- Passive institutional controls and memory arrangements to allow for changes in protection standards, which might result in the need to re-examine the site.

Figure 3.1. **Evolution of the development of a safety case for radioactive waste disposal**

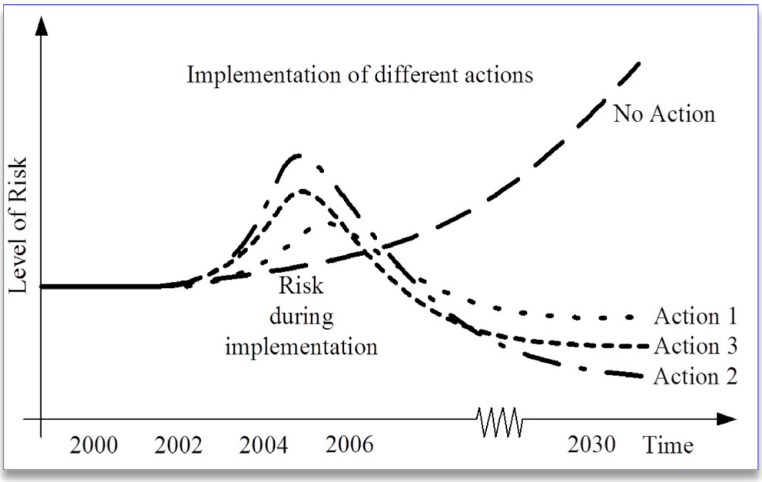


Source: IAEA.

These issues are considered to be very similar in near-surface disposal and legacy sites, and many old disposal sites may include some legacy features (see case studies 1, 2, 4 and 6).

In developing a remediation plan, it may be convenient to recognise that remediation activities may cause risks to rise temporarily, but that remediation activities are intended to avoid a major radiological event, or to reduce risks in the longer term. This point is illustrated in Figure 3.2 below, which was developed in relation to risk management in decommissioning of the Lepse storage vessel for spent fuel and radioactive waste (Sneve et al., 2000). A similar but more advanced concept is being applied to hazard reduction at Sellafield (see site visit 1).

Figure 3.2. **Illustration of temporarily increased risks associated with remedial actions**



Source: Norwegian Radiation and Nuclear Safety Authority.

The important issue is that in the case of many legacy sites, if no action is taken, some incident may eventually occur, such as the significant spreading of radiological contamination or the collapse of a mine tailings pile onto occupied buildings. In order to avoid such events, however, some short-term increase in radiological and other risks may be necessary, for example while waste is being recovered. This increase in risk should be constrained appropriately both in terms of the extent and the duration of the risk, and it should lead to an overall net reduction in risk, from the pre-remediation condition to the period following completion of the remediation activities.

Uncertainties should not be allowed to delay action on the basis of so-called precaution. Precautionary inaction may lead to larger problems at a later date. A decision to delay may therefore not be prudent. One possible solution is to manage any temporary increase in risk effectively by understanding the uncertainties within the framework of a holistic risk assessment. A legislative example of this is given in the Australian Environment Protection and Biodiversity Conservation Act 1999,[2] which states:

> The lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment where there are threats of serious or unreversable environmental damage.

Safety and security measures have in common the aim of protecting human life and health, and the environment. Safety and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

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[2] www.environment.gov.au/epbc.

Dose reduction measures that may be considered at a legacy site, pending the implementation of a long-term remediation programme, may include a combination of security and safety measures:

i. changing the behaviour of the public in terms of their interaction with the site;
ii. restricting access to the site;
iii. relocating the public from the site and from areas close to the site;
iv. providing alternative, uncontaminated food or water supplies;
v. directly remediating the contaminated areas of the site;
vi. reducing the magnitude of the off-site radiological impact;
vii. removing contaminated material from the site.

The actions adopted will be site-specific and will depend on the human, technical and financial resources available, and on discussions with affected populations. Methods of restricting public access to a site, or portions of a site, include actions such as:

i. blocking access roads with barriers;
ii. fencing the site;
iii. sealing the buildings on the site;
iv. using security guards.

3.2. Characterisation of circumstances

Current nuclear sites or activities are expected to operate using best available techniques and good practice so that contamination of soil and groundwater on the site does not occur. Historically, on the other hand, many sites became contaminated either as a result of poor practice, accidents, poor design or adherence to historical standards that were less stringent than those expected today.

The current or anticipated future conditions of these legacy sites may require remediation in order to meet society's expectations and to ensure adequate protection of people and the environment. This current section explores the characterisation of current circumstances, the information that is important and that may influence key decisions, the desired end-state for the site and the principle of sustainable remediation (see also Section 3.5).

The information here draws on the NEA Task Group on Nuclear Site Restoration, which reports to the NEA Working Party on Decommissioning and Dismantling (WPDD) under the Radioactive Waste Management Committee (RWMC). The work is focused on addressing planned decommissioning and remediation; however, the strategic considerations outlined in the NEA's *Strategic Considerations for the Sustainable Remediation of Nuclear Installations* (NEA, 2016a), also apply to legacy sites, albeit with a range of options that may be reduced for such sites.

3.2.1. Site situation and source term

The management of legacy sites must take into account the existing site situation and the historical context that may have contributed to the current situation, as illustrated in the examples provided in Annexes 2 and 3.

The drivers for remediation or other action need to be understood as they may have an impact on stakeholder expectations, remediation timelines, endpoints and ongoing institutional control. The site situation and these drivers for change will also have a direct effect on the timescales required to implement remedial action. These drivers could include:

- public health and environmental protection concerns;
- proposed change of use, or the sale of land;

- need to impose institutional controls;
- changes in standards (e.g. for a previously "approved" disposal site).

Where public health concerns or a deterioration in existing engineered or natural barriers have been identified, there may be an urgent need for immediate remedial actions (e.g. stabilisation, installation of bunds/interceptors, restriction of land use) to prevent major exposure or environmental contamination. Where the site conditions are relatively stable, more detailed consideration of the prevailing circumstances must be carried out before action is taken.

Understanding the radiological source term, in the terms described below, is a crucial factor in determining what needs to be achieved in the context of remediation so as to reach the intended end-state. Determination of the source term can include assessment of historical records and environmental monitoring, but it should also address uncertainty in historical records. In some cases, it is possible to reconstruct the source term using additional information, examining, for example, the operations that took place on the site or sites that produced the source term. Many sites have provided experience on source term reconstruction (see LLWR, 2011a and case studies 1, 2 and 6).

Information that will affect the decision-making process will include the amount and concentrations of potentially relevant or dominant radionuclides present on-site, their chemical form and the degree of uncertainty surrounding their inventory. Dominant in this case is meant in the sense of having the greatest potential radiological impact (i.e. not just in terms of abundance).

It is important for larger communication issues to explain the difference between radioactivity and radiation dose. Radiologically significant isotopes will be a major driver in determining the exposure pathways of most concern, which in turn will be crucial in assessing the most effective mitigation strategies. The chemical form will also be an important factor in determining the environmental mobility and bioavailability of certain radioactive species, and the selection of the appropriate dose coefficient. These issues have been discussed in the context of legacy sites in Mrdakovic and Sneve (2018). Communities engaged in assessments for radioactive waste disposal and legacy site management could usefully share such information (e.g. see the IAEA MODARIA modelling and assessment programme[3]), and there is scope for partial model validation based on available site data and monitoring experience.

The half-life of key isotopes will also have a significant effect. Where the source term is dominated by relatively short half-life radionuclides (e.g. up to 31 years), engineered remediation can be supported by institutional control, if this is determined to be a sustainable option (see case study 8). Where the source term is predominantly very long-lived (e.g. as in the case of naturally occurring radioactive material [NORM]), the remediation plan will have to account for the removal of institutional control at some point, unless the strategy is for long-term stewardship (see case study 10 and the US Department of Energy, 2001).

The potential exposure pathways may be well defined in the short to medium term; however, for longer-lived radionuclides, land use, local population and climate change may significantly affect the assessment of potential public exposure pathways, as extensively examined in the context of waste disposal in *Environmental Change in Post-Closure Safety Assessment of Solid Radioactive Waste Repositories* (IAEA, 2016). In addition, any engineered barrier systems will have a finite life, and thus effectiveness. The sustainability of the identified options should therefore be evaluated to provide assurance that radiological criteria are met over the applicable time frame.

The source term should also include any co-mixed chemicals, and especially chemotoxic contaminants. The requirement to undertake remediation and other site management activities may indeed be associated with the chemical toxicity of such contaminants, which could lead to remediation decisions that would not be warranted based solely on the radiological inventory. Other hazardous materials thus logically need to be considered in a holistic analysis of the source term.

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[3] www-ns.iaea.org/projects/modaria/modaria2.asp?s=8&l=129.

3.2.3. *Site characteristics*

The characteristics of the site itself will have a significant role in determining the nature and extent of any planned remedial actions. If the site is in a remote location, for example, facilitating extensive remediation will be more difficult, as will the removal of large quantities of contaminated material and the transport of clean backfill. At the same time, the number of people at risk may be relatively limited because it is a remote site. This aspect would need to be balanced against the potential contamination of otherwise pristine areas, and the protection of local flora and fauna.

For locations close to urban developments, the frequency in the change of use of such land is a key factor. Scenarios planning for future land use on, or adjacent to, legacy sites will need to account for potential rezoning for industrial or housing developments; recognising that these changes can happen over a short period.

For large sites, the scale of any remediation may introduce significant challenges in terms of managing the waste arisings, including characterisation, conditioning and transport to appropriate storage or disposal locations. These factors will have to be considered in the context of a sustainable remediation strategy. The size of the site will impact the scale of resources required and also the time needed to meet an appropriate endpoint. These factors will have to be clear to all stakeholders, including the local population and the organisation funding the remediation.

Large sites with extensive contamination may benefit from division into zones in order to manage characterisation and remedial activity. The geology and hydrology of the area may have a significant impact on the acceptable options for sustainable remediation. Suitable geology and hydrology may offer the opportunity for robust in situ disposal of contaminated material.

Surface and groundwater may be the predominant pathway for the mobilisation of residual contaminants on the site. As such, these pathways need to be well characterised and understood. The influence of rainfall events on the mobilisation of radioactive species on-site, as well as the potential impact that engineered barriers may have on existing water pathways will also need to be understood. The impact of landscape and environmental change should also be increasingly factored into decision making, where the planning horizon will extend into the period where such impacts may be felt (see for example, case studies 1 and 2; LLWR, 2011b; IAEA, 2016; and Lindborg et al., 2018).

The proximity of local populations and the ease of access to the legacy site will also influence the exposure pathways and dose estimates from the existing exposure situation. This point is highly relevant, for example, at the Little Forest Legacy Site (i.e. case study 1), which has seen significant urban development in an area that was semi-rural when the facility was established. The current use of surrounding land, and linkages between potentially contaminated ground and surface waters, for example, may also influence the current acceptability of existing exposures and selection of remedial actions. Such land use may also be subject to change, as a result of environmental factors, for example, or urban development (see case study 1; Seitz et al., 2016; IAEA, 2016).

3.2.4. *Historical knowledge*

The history of the site will provide useful input into the decision-making process regarding the level of remediation, priority areas for remediation and appropriate endpoints (see LLWR, 2011c and examples in Annexes 2 and 3). Key factors will be whether the site is currently under institutional control, and whether the institutional control has been continuous throughout the site's operation. If a site has a history of control, there may be historical monitoring records that support further understanding and site characterisation.

The status of the applicable regulatory framework governing both operation and subsequent management of legacy sites will also be a significant issue in assessing the level of control and supervision during the previous phases of site activities, and it will likely have an impact on the level of trust among local stakeholders. The framework, controls, regulatory inspections, investigation of incidents, etc. will assist in developing the history and standards of operation at the site. Knowledge about the history of the site can in turn inform the level of confidence associated with current knowledge and can direct the amount of environmental investigation required to adequately inform the decision-making process.

Previous ownership of the site can offer an indication of the types of activities conducted, while at the same time identifying companies or individuals with an enduring responsibility or obligation with regards to remediation and clean-up. Early records are unlikely to be complete. Interviews with employees, while useful, may be subjective or subject to the accuracy of individual recollections.

The above discussion suggests that future legacy site challenges may be mitigated by the collection and maintenance of relevant and accurate operational records. This collection and maintenance of records should be emphasised in the regulatory framework, in order to ensure that future end-of-life management activities can be based on adequate information.

3.2.5. *Decision-making process*

The decision-making process should be described in the regulatory framework for legacy management. Such a process should, as indicated above, be sufficiently flexible to accommodate a wide variety of legacy situations, some of which may not be readily foreseeable. It should also accommodate the likelihood of significant uncertainty, in particular at the early stages of remediation planning and implementation.

Decision-making processes will need significant technical and broader input. The regulatory framework should describe how remediation endpoints should be selected, including consideration of both radiological and chemical contamination levels and the wider, overall prevailing circumstances. The decision-making process should account for the concerns of affected populations and provide clarity on how they are to be addressed in reaching a decision.

With respect to decommissioning of nuclear facilities, remediation is typically assumed to be part of the decommissioning process (IAEA, 2014). However, as illustrated in several case studies in this report, decommissioning may involve managing significant hazards arising from operations carried out many years earlier, before modern standards were in place. There may also be a lack of necessary information about the source term in association with these old facilities.

In order to address the issues identified above and those outlined earlier in this report, the decision-making process should be consistent with a holistic and proportionate approach to risk management, considering both radiological and non-radiological hazards and impacts within the regulatory framework. It should also be compatible with the concept of sustainable remediation discussed above. A range of alternatives should be considered and the processes should include guidance on how to assess and select from the options. Examples of remedial approaches include the following (NEA, 2016a):

- immobilise the source and dispose in situ;
- separate contaminant from the source;
- implement long-term stewardship restricting access to the source;
- contain source to delay or prevent exposure of receptor;
- monitor natural attenuation of the source, and implement action as necessary;
- excavate the source and dispose off-site.

A number of remediation methods should be considered, and the best approach may consist of a combination of different remediation methods. Additionally, a staged approach to remediation may be necessary, especially for complex sites (e.g. risk prioritisation to determine what actions need to be taken in the short term so as to reduce higher risk areas and to determine what longer-term actions need to be taken to be compatible with selected end-states). Sellafield (site visit 1) and Andreeva Bay (site visit 2) provide good examples of complex sites with staged decision making and corresponding remediation.

The objectives of the overall plan and the individual stages need to be defined and clearly communicated in order to maintain stakeholder confidence. The decision on the nature of the interim and final end-states should be developed with concerned stakeholders, and should represent the objectives, values and priorities reflected in the national policy. It should, however, be kept in mind that responsibility for decision making lies with the designated organisation. In the development of environmental remediation policy, it is essential that the role of stakeholders, and their means of participation in the decision-making process, are defined and accepted from the beginning, for example, based on a set of working principles.

The SAFEGROUNDS programme, managing contaminated land at nuclear sites in the United Kingdom, followed this type of approach using principles developed within a learning network of stakeholders so that all players could buy in to the process from the start (Collier and Towler, 2009).

The long timescales involved in remediation of more complex sites may best be addressed using a phased (i.e. adaptive) approach. An adaptive approach allows for the end-state to change as time progresses, as a result of changes in stakeholder preferences, regulatory or policy requirements, or as further information on the contamination of a site is made available (NEA, 2016a). For the West Valley site, for example, a phased approach to decommissioning is being employed (see case study 10). The site has been divided into waste management units to facilitate decontamination and decommissioning. During the first phase of decommissioning, decisions were made on remediation of waste management units for which stakeholder agreement could be reached, while preserving decommissioning options for the remaining waste management units on the site. The final decommissioning decisions will be made in phase 2 of decommissioning. To inform phase 2 decisions, additional information is being collected to reduce technical and programmatic (e.g. waste disposal) uncertainties. This kind of phased approach provides a vehicle through which progress can be made on site clean-up while providing an opportunity for stakeholders to reach consensus on final remediation decisions for the site.

Long-term stewardship is an alternative to disposal, and it is important to answer the following questions in decision making on long-term stewardship:

- What constitutes a reasonable period during which time a society can expect institutional controls to be maintained: do the properties of the contaminant (e.g. differences between asbestos, organic solvents, “short-lived” radioactive substances) need to be considered in this case?
- Should controls be passive (e.g. the presence of markers or records as a reminder) or depend on active administration (e.g. monitoring, periodic review) by human institutions?
- Should safety considerations subsequent to the cessation of controls be predicated only based on passive measures that do not require any intervention, or even knowledge?
- What wider issues should be considered, such as funding and the availability of competent resources within the enforcing organisations, as well as governmental commitment to the long-term goals?
- What is the appropriate review period to be applied to institutional controls and what management arrangements are needed to ensure these controls?

An evaluation should be undertaken to determine whether removing the hazard or installing institutional controls will be the better option over the long term, in an effort to achieve the overall goal of reducing exposures to a level below defined reference levels (NEA, 2016a).

To inform the decision-making process, some type of risk or performance assessment is typically performed so as to determine to what extent various remedial alternatives can meet regulatory requirements. These types of assessments can also be conducted to determine to what extent a site needs to be remediated in order to be released for unrestricted or restricted use, or in order to optimise site clean-up. Typically, information about the site is collected to help develop a conceptual site model (CSM), which represents the key features of the site that are important in risk assessment and in reaching a decision. Information on the radiological inventory, and mechanisms controlling release of radioactivity to the environment, are also important to the CSM. The CSM may then be represented in the form of a mathematical model to evaluate the risk or dose in relation to members of the public. Information on the potential, future use of the land, and a description of the characteristics of potential critical groups or reference persons that may inhabit the land following decommissioning, is needed to inform the assessment.

Multi-criteria analysis that includes, but is not limited to, radiological protection criteria, may be a useful tool in the exploration and/or determination of remediation options. Weighting of individual attributes should be done in conjunction with key stakeholders, keeping in mind that major uncertainties in relevant parameters may complicate the analysis. Methods for addressing such difficulties have, however, been considered, for example in "An approach to multi-attribute utility analysis under parametric uncertainty" (Kelly and Thorne, 2001), in the context of uranium mine legacies in Eastern Europe. Making public the types of issues considered, such as those just mentioned, as well as the motivation of decision makers, is likely to result in better decisions.

Waste management will be a key factor in decisions about remediation. Most countries dispose of remediation waste in near-surface facilities (NEA, 2016a). Storage, transport and disposal typically contribute significant portions of the cost to remediate a site. Savings can be realised by minimising the volume of waste disposed of through characterisation, sorting, clearance and segregation, although it may not result in a minimisation of the risks, which is an additional factor to be taken into account in overall optimisation.

The range of disposal facilities includes conventional landfill sites and purpose built disposal sites, which may be regulated so that they can also be used for non-radioactive waste. If a disposal facility is not available, waste can be managed by an interim storage facility until disposal is available. Where available disposal space is sufficient, and the facilities accept a wide range of waste, with little need for segregation, the amount of waste segregation and handling can be reduced, resulting in greater worker safety and lower costs. The issues described above are informing the approach to the remediation of the Little Forest Legacy Site in Australia (see case study 1).

In the United Kingdom, regulatory authorities have provided guidance (SEPA et al., 2018) that provides flexibility in managing radioactive waste in a site-specific manner, recognising that sometimes it is not possible to remove all radioactivity from a site. The guidance considers various options for waste management to allow optimal solutions for site-specific problems. Among other options, in situ disposal of radioactive waste is available. In situ disposal could include use of engineered features and use of materials for specific purposes such as filling of structures, backfilling, and construction of bunds, barriers or screens, similar to those that might be used in purpose built disposal facilities. The disposals must meet numerical and other standards in all cases, and they require a demonstration of compliance using a waste management plan and site-wide environmental safety case.

Key factors that affect decision making, and ultimately sustainable remediation, will be the identification, recognition and management of uncertainty. Areas of uncertainty will include the inventory, distribution of contamination, release mechanisms, fate of contaminants and their transport in the environment, future uses of land, receptor characteristics and sustainability of institutional controls. Management of uncertainty will be important in obtaining support for the selected remedies. Stakeholder confidence can be increased through the reduction of uncertainty, and through the collection of information to support the analyses relied on for decision making.

Key uncertainties that are most likely to impact decision making can be identified through sensitivity and uncertainty analyses. The benefits of this type of analysis include identifying important features, events and processes (FEPs) most influential to the decision being made (e.g. the ability of the site to meet a particular end-state following remediation). After important FEPs are identified, additional data can be collected to reduce key uncertainties. The impact of remaining uncertainties that are difficult to reduce should be evaluated in order to inform the decision. For simpler problems, uncertainty can also be managed through the use of conservative assumptions, if the site can meet desired end-states without the collection of additional information. Use of overly conservative models or parameters should, however, be avoided because the use of such approaches could lead to less than optimal solutions.

3.2.6. *Monitoring*

Monitoring data are collected to characterise a site and support assessments of contaminant behaviour at a site, as well as to determine when remedial objectives have been met and when monitoring can be discontinued.

For sites undergoing remediation, the early detection of radiological contaminants in areas that were previously free of contamination can allow time for action to be taken so as to prevent the spread of contamination, and hence reduce the scale of the remediation. It is therefore important to think ahead and to have measures in place that will enable any contamination to be identified as early as possible (NEA, 2016a). Installing a strategic monitoring network on the site will facilitate the prompt implementation of remedial activities, if contamination is found.

"Scientific Opportunities for Monitoring at Environmental Remediation Sites (SOMERS)" (Bunn et al., 2012) discusses an integrated systems-based approach for monitoring that is focused on designing the monitoring programmes with site remediation processes in mind, where monitoring is tailored to the needs and objectives of each phase of the work. A site may transition through several characterisation and remedial iterative phases. The monitoring system configuration and monitoring objectives will thus evolve through these phases. At the same time, monitoring data can be used to guide and inform the transition. The monitoring programme should be designed to meet the specific needs of the selected end-state, and it may be very different for unrestricted use compared with restricted use.

In the CSM approach (see Section 3.2.5), monitoring programmes test or verify the CSM and provide insight into important transport processes and remediation system performance. Monitoring phases discussed in "Scientific Opportunities for Monitoring at Environmental Remediation Sites (SOMERS)" (Bunn et al., 2012) include the following:

- characterisation;
- process monitoring;
- performance monitoring;
- long-term monitoring.

As the CSM is refined, monitoring should also evolve with remedy adjustments, and help inform decision makers during the development planning process for the next monitoring phase.

Bunn et al. (2012) lists the various types and objectives of characterisation and monitoring activities, and discusses the importance of revising the monitoring programme as needed whenever a site transitions from one phase of remediation to the next. It is equally as important to revise the CSM as further information about the site is gained through each phase of the environmental remediation process.

Similar to Bunn et al. (2012), the US Nuclear Regulatory Commission (NRC) recommends an integrated and systematic approach for monitoring subsurface water flow and contaminant transport so as to test and confirm results of performance assessments (or similar analyses) used to facilitate decision making (NRC, 2007). This type of monitoring is referred to as performance confirmation monitoring. The objective of performance confirmation monitoring is to better understand site performance and to develop and support the performance assessment, rather than focus on compliance with ground water protection standards.

Decisions are made on what, how, where and when data should be collected through the evaluation of a performance assessment and the development of data quality objectives, as well as conceptual and computer modelling (NRC, 2007). A graded approach should be used in developing the monitoring strategy, in parallel with a graded assessment framework. The integrated monitoring approach can increase the efficiency of the monitoring system, both in terms of data quality and the savings realised by selecting the critical monitoring points, adequate frequency and time period. The results, if effectively communicated to stakeholders, may also increase confidence in the process.

One particular aspect of monitoring is the scope for contaminant migration in groundwater. Factors that influence the planning and level of investigation of the site include: i) source term inventory, ii) distance to receptors, iii) complexity of geology, and iv) the intended use of the data. Such monitoring can allow informed decisions to be made before wells are drilled or monitoring devices installed, leading to a more reliable, efficient and cost effective monitoring network design.

Long-term monitoring may also be required as a component of long-term stewardship to confirm that the controls are effective in allowing the end (or interim) use of the site, and this monitoring may last for many years, decades or more (NEA, 2016a). Monitoring may be used to demonstrate that contamination is behaving in a predictable manner, consistent with the CSM, and that additional risk is not created through changes over time in contaminant location, contaminant chemistry or receptor behaviours. Long-term monitoring may verify that the site continues to perform in line with the conceptual model or to provide early information to allow prompt preventative actions. It may also be used to support long-term remedial options such as "monitored natural attenuation" (IAEA, 2006b). Provisions for corrective actions in the case of deviation from the predicted behaviour of the site should be established (IAEA, 2006c).

In the case of deferred remediation, a site may be placed in long-term stewardship. In such cases, monitoring and maintenance will be important until more active remediation takes place.

3.3. Societal aspects

Stakeholder input is generally a significant aspect to be taken into account when making decisions regarding end-state status. The regulatory framework for legacy management will need to take societal aspects into account in order to be sufficiently flexible to achieve accepted and sustainable end-state decisions.

3.3.1. *Objective*

There are a number of legacy sites across the diverse membership of the NEA that have provided useful examples of experiences and lessons learnt concerning societal expectations. The ongoing objective is to build international guidance on practical, inclusive and transparent strategies that promote and take into account stakeholder engagement. Regular interactions with those who are affected and interested through all phases of remediation are a key feature of the overall process of reaching sustainable decisions/consensus among stakeholders in terms of the end-state/goals of the remediation actions. This may include involvement of stakeholders in the definition and management of protection strategies and not only the expression of their expectations.

3.3.2. *Societal expectations*

Many legacy sites will have existed for long periods, and the stakeholders, as well as the culture and makeup of the stakeholder population, may have changed or may continue to change over the duration of the remediation. There is a need to establish common expectations on the end-state and on the terminology for concepts such as optimisation and ALARA.

Economic considerations will shape how ALARA is implemented, but these considerations are not the only parameters to be taken into account. Large clean-up costs and trade-offs between jobs/income and the "not in my backyard" syndrome will influence societal views and acceptance. Public sentiment regarding how much they are individually willing to pay (in taxes) will also shape political realities across the globe. The remediation process can be largely influenced by public expectations and people's understanding of the situation. Sometimes, the stakeholders may not care about the costs, as they are relying on the polluter pays principle (OECD, 1992). However, the organisation that caused the pollution may no longer exist. In general, decisions will need to address a range of concerns that cannot all be fully satisfied.

Approaches to addressing societal challenges that could have a significant impact on the operator and regulator, as well as on stakeholder engagement, may include:

- Identifying stakeholders and understanding the basis for their interest.
- Selecting and achieving a sustainable end-state (see Section 3.4).
- Establishing a basis for leaving material contaminated with radionuclides on-site.
- Deciding if such contaminated material is waste or residual contamination.
- Ensuring the availability of coherent criteria that are credible to stakeholders.
- Addressing the implications of any site boundaries, and establishing different objectives on-site and off-site, noting the scope for population encroachment on areas adjacent to contaminated areas. (For example, in case study 1, encroachment on new suburbs adjacent to the Australian Nuclear Science and Technology Organisation's [ANSTO] buffer zone resulted in a new condition in its licence.)
- Indicating a possible continuation of uncertainty about responsibilities and changes in the future (e.g. history of the Ranstad site, case study 3).
- Highlighting the need for regulatory developments to address potentially unmet radiation safety protocols at legacy sites, as in the case of the Russian SevRAO facility (see site visit 2). Site-specific regulatory documents were developed by the Federal Medical Biological Agency (FMBA) and include: requirements for the radiological protection of workers and the public; personal dose monitoring; radioactive waste management, including very low-level radioactive waste; and implementation of environmental and radiation monitoring.
- Underlining that case studies suggest that a lack of criteria for site remediation and related management of radioactive waste arising in unplanned circumstances can delay and/or reduce the effectiveness of remediation projects, which in turn highlights the need for governments to put in place guidelines and criteria for decontamination of living areas, storage, treatment and the disposal of contaminated materials, as well as the reuse/recycling of contaminated materials in some cases.

3.3.3. *Emergency management, preparedness and response*

Emergency preparedness and response (EPR) must be addressed in an appropriately graded fashion, according to the current and potential risks of the addressed case, during the clean-up/remediation of legacy sites, for all of the typical reasons associated with risk management. This will also help to build trust, demonstrate that all hazards are addressed, and establish credibility with stakeholders. Application of a graded approach is illustrated as follows. The recovery of spent fuel and radioactive waste from poorly maintained stores, as discussed in site visits 1 and 2, will require more complex radiological emergency preparedness arrangements than for those sites with limited amounts of radioactivity (see case studies 3, 4 and 8). Emergency management planning, and development and implementation processes, should be clearly described in the regulatory framework for legacy management.

In general, the operator is responsible for establishing and managing an emergency management plan. The regulator is responsible for approving such a plan and for interfacing with the government organisations responsible for off-site emergency management. Emergency management plans should be developed according to existing international guidance, but should also take into account all relevant site-specific aspects. Relevant stakeholders and potentially affected populations should be involved in decision-making processes regarding emergency management plans, and they should be involved in discussions on emergency management planning evolution as remediation progresses.

Personnel involved in emergency communications should preferably be trained using real-life exercises/scenarios to ensure that they have appropriate public communication skills, as has been illustrated, for example, by the material presented concerning progress at Andreeva Bay (see site visit 2). A key aspect of public communications for emergency management is to ensure that relevant members of the public understand their emergency response systems, and in particular are encouraged to participate in preparedness measures, such as public involvement in training exercises and regular engagement in educational outreach endeavours.

3.3.4. *Communications and transparency*

Development of stakeholder trust is especially important with regard to legacy sites because it will typically have been degraded in the lead up to the creation and recognition of the site as a legacy site.

Because of the long time frames often involved in legacy remediation, and in the post-remediation presence of residual contamination, the need for effective communications with relevant stakeholders will be an ongoing process. The need for, and approaches to, such communications should be included as part of the process for legacy management. Decision processes related to communications between the regulatory authority and affected populations should be discussed and made clear to all regulatory and population stakeholders as an initial step in legacy management activities. Such communications can help to ensure that the decisions that are taken are accepted and sustainable.

Risk communication can prove to be challenging, but remains vital, as demonstrated in the case of impacted communities in the Marshall Islands (see Sneve and Strand, 2016). These communities desired certainty and finality in remediation decisions. However, in this instance, the principle of optimisation coupled with risk harmonisation did not easily translate into reaching mutually agreeable outcomes on resettlement. Risk communication has consequently emerged as one of the key issues and biggest challenges in attempting to forge a path forward.

3.3.5. *Safety culture*

Regulators, owners and operators must ensure that the safety and organisational culture at facilities promotes a questioning attitude among workers so as to be kept informed and to proactively and immediately take action where and when they see potential compromise in safety. Safe work performance, and the involvement of workers in all aspects of performance should be core values that are strongly and consistently held by managers and others involved in remediation. These core values should apply to safety during operations and also to ensuring that those operations are effectively implemented so as to achieve long-term objectives.

According to NEA studies *The Safety Culture of an Effective Nuclear Regulatory Body* (NEA, 2016c) and *Country-Specific Safety Culture Forum: Sweden* (NEA, 2018b), a healthy safety culture focuses on continuous improvement through leadership, employee/worker engagement and organisational learning. The importance of a healthy security culture should not be overlooked during remediation, and in some cases, should be considered in the long-term context of the post-remediation end-state. It is important for those working in safety and security to be aware of both aspects of protection Similarly, the IAEA suggests, "The principal shared objective of security and safety culture is to limit the risk resulting from radioactive material and associated facilities. This objective is based on common principles, e.g. a questioning attitude, rigorous and prudent approaches, and effective communication and open, two-way communication" (IAEA, 2008).

3.4. Deciding and achieving the desired end-state

In line with recommendations in *Strategic Considerations for the Sustainable Remediation of Nuclear Installations* (NEA, 2016a), the term "remediation", as used in the present report, refers to actions taken to reduce the impact from contamination in land areas and in the associated groundwater in order to leave the site in a state that is suitable for its next intended use.

Remediation does not necessarily imply complete removal of residual activity or returning the site to its previous or background conditions. Complete removal may not be practicable, necessary or in line with societal preferences, if for example it implies the destruction on amenities or resources. The focus should be to ensure that the site is left in a condition where the residual risks and hazards that comprise the existing exposure situation are sustainably acceptable to all stakeholders, in particular regulators and affected populations.

The term "end-state" (see NEA, 2017), with respect to a legacy site, may be seen in the context of environmental remediation, as well as deciding what may be left behind (e.g. infrastructure, in situ disposals, on-site disposals and residual activity) and what should be removed. The decision on "what to remove and what to leave" greatly affects the exposure pathways both prior to, during and following remediation. Therefore, the end-state concerns how the site/area can be used and its "destination of use". A general description for the purpose of explaining the concept has thus been suggested for this report as follows:

> An end-state is a set of site-specific conditions that are appropriately protective of people and the environment from a regulatory perspective,[4] taking into account the intended, continuing and future use of the site and the wider interests of people potentially impacted by the process of achieving the end-state and its future use.

End-states may be linked to unrestricted land use, so that any realistic mode of exposure can occur; or they can be restricted, so that some exposures are only possible if the restrictions are not applied in an effective manner. Typical, generic type uses include: residential, commercial/industrial, public recreational areas, and parkland and nature conservation. The first step is to determine the range of end use options that may be feasible, given national polices, regulatory requirements, location of the site, local natural resources, and local infrastructure. It is also important to recognise that the use of land can change significantly in relatively short spaces of time, particularly close to urban areas (see case study 1).

The decision maker should aim to be aware of and understand all the different stakeholder perspectives and to follow a process that most adequately balances those perspectives when coming to a decision. It is also very important to be ready to explain the decision in the context of those perspectives. The selected end-state may not please everyone; indeed every party should be prepared to compromise, especially if it leads to positive action in an acute set of circumstances. In addition, the selected end-state and the different aspects of the process to achieve it may require regulatory approval.

An important element of the end-state is the dose criterion for the unrestricted use of legacy sites; it should be selected taking into account radiological optimisation, including economic and social factors. It may be higher, for example, than the criterion for radiological clearance of material, provided that the degree of confidence about the potential uses of the land after its release from regulatory control is justified.

At more complex sites, a staged approach may be required (See NEA, 2016). Interim end-states can be defined to mark progress towards the final end-state. The prioritisation of the stages will depend on the drivers for change. If the driver is public health or environmental protection, the focus should be on reducing the hazard by remediating the areas that pose the highest risks. This may require short-, medium- and long-term actions, and it is important to ensure, as far as reasonably practicable, that actions undertaken in one stage do not preclude future options.

The international system of radiological protection recommends that human exposure be managed as a function of the situation that causes the exposure to occur. Three types of exposure situations are recommended (ICRP, 2007; IAEA, 2014): planned, existing and emergency. According to this approach, planned exposure situations are managed using dose limits and dose constraints. Emergency and existing exposure situations are managed using reference levels as per *Safety Fundamentals* (IAEA, 2006). *International Basic Safety Standards* (IAEA, 2014, para 1.21) suggests that descriptions of the three types of exposure situations are not always sufficient to determine unequivocally which type of exposure situation applies for particular circumstances. As the case studies and site visits suggest, some sites may exhibit more than one type of exposure situation at the same time on one site, as defined by the ICRP and IAEA.

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[4] This explanation is complementary to the description of a legacy site discussed in Section 1.3 of this report.

Table 3.1 illustrates how the distinction might be made for different legacy sites, between existing and planned exposures, and the relevant form of radiological criterion (dose limit and constraint or reference level). The table is provided for illustrative purposes and is not intended to be prescriptive. It does not respond to the question of how to explain to stakeholders why workers could, in some circumstances, have a lower dose criterion than the public. It should also be noted that a chemical toxicity standard is suggested in the case of the uranium mine legacy site (see example 6 in the table). In fact, chemical safety standards might typically be required for any legacy site (NRPA, 2015).

Table 3.1. **Illustrating the distinction between existing and planned exposure situations**

Example	Legacy site description	Exposed groups	Applicable exposure situation	Radiological criterion
1	Populated, **contaminated** land	Public	Existing	Reference level
		Public exposed as a result of remediation work	Planned	Dose limit and constraint
		Remediation worker	Planned	Dose limit and constraint
2	**Unpopulated,** contaminated land, restricted access because of past activities	Remediation worker	Planned	Dose limit and constraint
		Public	Existing	Reference levels
3	Contaminated facilities/ buildings, licensed in line with national regulations. Public living **nearby on uncontaminated** land	Workers	Planned	Dose limit and constraint
		Public, could be exposed from releases of the nearby facility	Planned	Dose limit and constraint
4	Contaminated facilities, un- or inappropriately licensed. Located on contaminated ground; public living nearby on uncontaminated land	Workers	Planned	Dose limits
		Public	Existing	Reference levels
5	Contaminated facilities/ building, located on contaminated ground; public living nearby on contaminated land	Workers	Planned	Dose limit and constraint
		Public exposed from radionuclides from past accidents or unregulated activities	Existing	Reference levels
		Public exposed from releases of the nearby facility	Planned	Dose limit and constraint
6	Drinking water affected by uranium mining or processing facility in operation	Public	Planned	Dose limit and constraint, chemical toxicity standard

As noted above, it would be misleading to suggest that it is possible to achieve an end-state that meets all of the interests of all stakeholders. Furthermore, it should be clear that the process of optimisation does not automatically minimise all impacts. As noted in *Management of Radioactive Waste after a Nuclear Power Plant Accident* (NEA, 2016b), the minimisation of one detrimental impact is always likely to result in something else detrimental not being minimised. In addition, it should be recognised that the removal of contamination may involve removal of other material, such as soil, or serious damage to forests. Such actions would normally be considered undesirable, or otherwise be thought of as degrading rather than improving the site.

The end-state should not be considered in isolation, but in the context of both remediation of on-site facilities (e.g. decommissioning) and environmental remediation. Both of these types of remediation may involve waste management, on- and/or off-site, and so legacy management should be clearly linked to waste management programmes, both for radioactive and other waste (NEA, 2014b and 2016a).

The above challenges should not be taken to mean that it is not possible to achieve a consensus on an acceptable and sustainable way forward. Noting the above working definition of an end-state and the examples presented in the Annex 2, as well as the current discussion alongside ongoing international discussions (e.g. in the IAEA DERES project[5]) the following aspects may need to be taken into consideration in the process of identifying an appropriate end-state, along with the implementing actions to achieve them:

- clarification of who is responsible for:
  - making the decision;
  - funding its implementation;
  - checking that it has been achieved.
- legal and regulatory frameworks and requirements, including:
  - land-use planning;
  - the local application of international standards, recommendations;
  - the scope for application of exemptions.
- holistic consideration of optimisation, taking into account factors such as:
  - radiological and non-radiological risks (chemical, physical, safety and security, present and future, workers, public and the environment);
  - proportionate and consistent criteria for legacy site management and assessment;
  - uncertainties in source terms, other features of the site description, assessment results, effectiveness of remediation and/or other methods for controlling the risks;
  - future site use(s) – including unrestricted and restricted use;
  - waste management;
  - financial constraints and life-cycle costs;
  - sustainability;
  - site knowledge and control;
  - technical implementation;
  - socio-economic aspects.
- input and acceptance from impacted persons (see NEA, 2015);
- coherence with regional or national radioactive waste management programmes.

The long time frames of some decommissioning and environmental remediation projects may lead to the need for interim end-states, for example initially involving full control of site access, then limited use (i.e. brown field, as in site visit 2) and then unrestricted use, as indicated in Figure 3.3 below.

Typical, generic type uses include: residential, commercial/industrial, public open space/park land and nature conservation. The identification of stages in reaching the end-state determine the range of interim end-states that may be feasible, given national polices, regulatory requirements, location of the site, local natural resources and local infrastructure, (i.e. similar factors to those relevant to achieving the final end-state). However, security and control measures in the interim period may have a higher profile. It may thus be appropriate to go through a process for each stage of a staged progression to the end-state, as shown in Figure 3.1 below.

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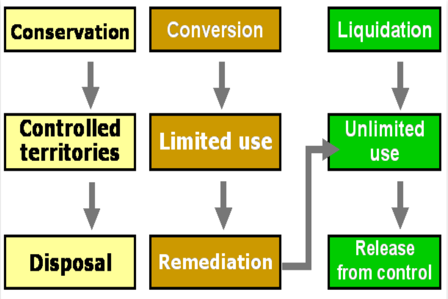
[5] www.iaea.org/ru/events/technical-meeting-on-the-definition-of-environmental-remediation-end-states-deres.

Figure 3.3. **Example of staged progress to end-state (Russian regulatory framework)**



Source: FMBA of Russia – Rosatom.

Whether the end-state decision is adopted using a once through or staged process, iteration such as that shown in the Figure 3.1 steps should be anticipated. While a simply presented linear process may enhance communication, in practice a multiple-interaction process between relevant organisations will generally be needed. Such complex processes will need strong management and leadership, and must be underpinned by clear definition of who is responsible for what, and what resources they have to meet those responsibilities (NRPA, 2018).

3.5. Long-term protection values

In general, remediation will not result in the removal of all contamination from a legacy site. This factor, in conjunction with what may be a long remediation process, suggests that the regulatory framework for legacy site management should address long-term protection values and criteria.

3.5.1. *Sustainable remediation*

The principle of "sustainability" (Weiss, 1990) emphasises the importance of taking an intra- and intergenerational perspective for environmental protection. Sustainability calls for a decent standard of living today for everyone without compromising the needs of future generations. This principle stresses the need to consider the social, economic and environmental implications of actions across locations and time. The objective is to maintain intergenerational equity; maintaining the balance between the benefits and detriments among the generations.

This particular topic is further discussed in the context of legacy sites in "An ethical dimension to sustainable restoration and long-term management of contaminated areas" (Oughton et al., 2004), where it is noted that the criteria by which countermeasures are evaluated need to be extended from simple cost-benefit effectiveness and radiological protection standards to a more integrated, holistic approach, including social and ethical aspects. In fact, social aspects have been recognised in radiological protection for a very long time. According to "An Approach to the Use of Risk Estimates in Setting and Using Radiation Protection Standards"(Dunster and McLean, 1970), published almost 50 years ago:

> In recent years, there has been an increasing emphasis on the quantitative assessment of risk following exposure to radiation. {…} It has generally been assumed that this trend will contribute to the formulation of policy and standards in the field of radiation protection. The difficulties of achieving this contribution have, perhaps, been underestimated because the problem has been seen too often as an exercise in science rather than as a combined operation involving, in addition, the skills of management, government and sociology.

This message remains valid today. To this effect, the ICRP has provided commentary on the ethical foundations of the system of radiological protection, which show that social issues have long been at the forefront of radiological protection thinking (ICRP, 2018). Intergenerational, distributive justice has been addressed through reference to the precautionary principle and sustainable development as a mechanism to preserve the health and environment of future generations. It is claimed that the participation of stakeholders in the decision-making process enables the adoption of more effective, sustainable and fair, protective actions promoting the empowerment and autonomy of stakeholders. However, such participation may also contribute to confusion about who is responsible for making a decision.

It is also been noted that:

> [N]either prudence nor the precautionary principle should be interpreted as demanding zero risk, choosing the least risky option, or requiring action just for the sake of action. The experience of over half a century of radiological risk management applying the optimisation principle can be considered as a reasoned and pragmatic application of prudence and/or the precautionary principle. (ICRP, 2018)

Further consideration of the application of the precautionary principle may be appropriate in future work, especially in cases where there are risks in taking action and risks in not doing so (see Section 3.1.7).

Sustainable remediation is defined by the UK Sustainable Remediation Forum (SURF) – an initiative set up to progress the UK understanding of sustainable remediation as: “the practice of demonstrating, in terms of environmental, economic and social factors, that the benefit of undertaking remediation is greater than its impact and that the optimum remediation solution is selected through the use of a balanced decision-making process” (SuRF, 2010). This is closely related to the US Environmental Protection Agency (EPA) concept of green remediation, which is defined as “the practice of considering all environmental effects of remedy implementation and incorporating options to maximize the net environmental benefit of clean-up action” (EPA, 2008).

Sustainable remediation represents actions and goals that are informed by an understanding of the overall impact of remediation activities NEA (2016a). Sustainable remediation is therefore informed by assessments of safety and environmental benefits and impacts, the social and economic benefits and drawbacks, and the impacts on natural resources and climate change, both in the short term and in the long term. Hence, sustainable remediation requires not only identification of a technical solution, but an element of social engagement in the form of an informed debate, discussion, negotiation and transparent decision making. Radiological protection principles and environmental principles provide the framework for this discussion, and the optimum (least bad) solution will be site specific.

Following a sustainable remediation approach will mean that it is not always optimal to remove all contamination, even if it were practicable, or to clean up sites to be fit for any use. The optimal remedial approach may be to include administrative controls (as a part of long-term stewardship) to break the pollutant linkage. As the US Department of Energy (DOE) has identified (DOE, 2001), the selection of the site remediation and its implementation process essentially determines how any residual hazard at a site will be managed for the long term and therefore establishes implicit or explicit long-term stewardship needs; “for example, a remedy that incorporates an assumption about anticipated future land use establishes the long-term stewardship needs to ensure that actual land uses remain consistent with this assumption”. Management arrangements therefore need to be made to ensure that these controls are reviewed periodically. This aspect of a staged approach is considered at the Little Forest Legacy Site in Australia (see case study 1, a s well as case studies 9 and 10).

3.5.2. *Radioactive waste management (including disposal)*

Radioactive waste may be generated during legacy site remediation, and include:

- Waste resulting from production activities, such mine tailings and residues from the processing of ores.

- Waste arising from dismantling, such as building materials and the equipment within them.
- Contaminated soil, sediments and other environmental material that is too contaminated to be left in situ.
- Secondary waste, which can arise during decommissioning and remediation, such as sludge from treatment of contaminated water, air filters, work overalls and personal, protective and other equipment that cannot be decontaminated.

International guidance already exists on predisposal management involving characterisation, sorting, packaging, treatment, temporary storage and final conditioning for disposal (IAEA, 2009a; NEA, 2014a and 2016b), as well as classification relevant to disposal (IAEA, 2009b). Some legacy sites present waste ranging, in the IAEA classification scheme (IAEA, 2009b), from high through to intermediate and low to very low-level radioactive waste, whereas others are much less complex, as shown in Annexes 2 and 3. In some cases, very low-level radioactive waste is classified and regulated within the structure for hazardous waste management, as in the case of Sites of Temporary Storage in the Kola Peninsula. (See the English version of the regulatory guidance in Sneve et al., 2008).

Some countries introduce additional and/or modified classification concepts. For example, in Czech legislation, described in (SÚJB, 2005), radioactive waste is classified as gaseous, liquid or solid, and temporary wastes are those whose radioactivity after up to five years is lower than clearance levels. The latter is just one example of how legacy planning and regulation and waste disposal arrangements are clearly linked, especially if on-site or in situ disposal is under consideration. Overall, radioactive waste processing, storage, pre-treatment for disposal and transport, packaging for transport and for disposal, as well as disposal itself may all take place on the legacy site, and would involve the integration of many safety and other issues and the broader integration of predisposal and disposal management, in the context of unplanned prevailing circumstances.

In Russia, the Federal Law "on the radioactive waste management recently established a new radioactive waste classification system according to which all radioactive wastes are divided into two groups: special and removable. Resolution of the Government of the Russian Federation No. 1069 specifies the criteria used to define radioactive waste as special or removable. They are distinguished according to the following criteria (see Sneve and Popic, 2018; Lavrinovich, 2017):

- Removable of radioactive waste – radioactive waste, for which the risks associated with radiation exposure or other risks, as well as the costs associated with the recovery of such radioactive waste from the radioactive waste storage facility, and subsequent management including disposal, do not exceed the risks and costs associated with disposal of such radioactive waste in the place of their location.
- Special radioactive waste – radioactive waste, for which the risks associated with radiation exposure or other risks, as well as the costs associated with the extraction of such radioactive waste from the radioactive waste storage facility, and subsequent management including disposal, exceed risks and costs associated with the burial of such radioactive waste at the site of their location.

The implication is that, unless it can be shown that there is a net benefit in removing radioactive waste and disposing of it somewhere else, it should stay where it is. This reflects the ICRP principle of justification (ICRP, 2007) and the utilitarian component of the ethical foundations of the system of radiological protection (ICRP, 2018). It also avoids creating an expectation that contaminated land should be remediated without first verifying that such work would generate a net benefit and that it would be in the interests of the affected people. It may not be straightforward to determine the net benefits, given conflicting views on how to value the different attributes of available options, but it is more productive to examine the issues than to ignore them. Such an examination would also support confidence in decisions if it is carried out in an open and transparent way.

3.5.3. *Post-remediation monitoring and control*

To ensure long-term protection during and after completion of remediation at legacy sites, long-term radiation monitoring should be organised and conducted as an integral part of institutional control (IAEA, 2006a, 2010, 2012a and 2012b).

An important goal of site monitoring is to demonstrate that the residual contamination on-site does not exceed the established criteria, or corresponding derived criteria, for the site end-state. To support this demonstration, and in parallel with demonstration activities (e.g. site monitoring and contamination measurements), the following activities may also be relevant:

- providing the public with information on the radiation situation;
- determining the trend in changing levels of radionuclides in the environment, and detecting any unpredicted changes in the parameters of the radiation situation;
- checking that the results of the assessment models used to support decisions are not exceeded, and where possible reduce the uncertainties in future assessments, for example, though model validation exercises.

Control of legacy sites once the end-state has been achieved gives rise to similar considerations to those at closed radioactive waste disposal sites, as discussed in the IAEA HIDRA project (Seitz et al., 2016). Apart from protecting the people who may venture onto a site, there is also a need to consider how their activities might disturb any residual activity, giving rise to new scenarios for radiation exposure. Such analysis should form part of the risk assessment used in support of option and end-state selection (see Section 3.4). Any necessary control measures identified in the assessment should be included in the long-term management plan, along with provisional, planned actions in the event that monitoring results indicate that established criteria have not been met. More broadly, planning of monitoring should include clear guidance on how the results will be used.

References

Balonov, M. et al. (2018), “Optimization of environmental remediation: How to select and use the Reference Levels”, *J. Radiol. Prot.*, Vol. 38, pp. 819-830.

Bunn, A.L. et al. (2012), “Scientific Opportunities for Monitoring at Environmental Remediation Sites (SOMERS)”, Integrated Systems-Based Approaches to Monitoring, PNNL-21379, www.pnnl.gov/main/publications/external/technical_reports/PNNL-21379.pdf.

Collier, D. and P. Towler (2009), “SAFEGROUNDS: Approach to Managing Contaminated Land on Nuclear-Licensed and Defence Sites – An Introduction”, CIRIA W27.

DOE (2001), “Long-Term Stewardship Study”, https://energy.gov/sites/prod/files/em/DOELongTermStewardshipStudy-VolumeI-FinalOctober2001.pdf.

Dunster, H.J. and A. McLean (1970), “An Approach to the Use of Risk Estimates in Setting and Using Radiation Protection Standards”, Proceedings of the Second International Congress of the International Radiation Protection Association, Brighton.

Environment Agency (2009), “Radioactive Substances Regulation – Environmental Principles”, EA/BR/E/STD/V1, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/296388/geho0709bqsb-e-e.pdf.

EPA (2008), “Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites”, US EPA, Office of Solid Waste and Emergency Response, EPA 542-R-08-002.

IAEA (2018), *Occupational Radiation Protection: International Basic Safety Standards*, General Safety Requirements Part 7, IAEA, Vienna.

IAEA (2016), *Environmental Change in Post-Closure Safety Assessment of Solid Radioactive Waste Repositories*, IAEA-TECDOC-1799, IAEA, Vienna.

IAEA (2014), *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, General Safety Requirements Part 3, IAEA, Vienna.

IAEA (2012a), *Monitoring for Compliance with Exemption and Clearance Levels*, Safety Reports Series No. 67, IAEA, Vienna.

IAEA (2012b), *Monitoring for Compliance with Remediation Criteria for Sites*, Safety Reports Series No. 72, IAEA, Vienna.

IAEA (2010), *Programmes and Systems for Source and Environmental Radiation Monitoring*, Safety Reports Series No. 64, IAEA, Vienna.

IAEA (2009a), *Predisposal Management of Radioactive Waste. General Safety Requirements Part* 5, IAEA, Vienna.

IAEA (2009b), *Classification of Radioactive Waste*, General Safety Guide GSG-1, IAEA, Vienna.

IAEA (2008), *Nuclear Security Culture, Implementing Guide*, IAEA Nuclear Security Series No. 7, IAEA, Vienna.

IAEA (2006a), *Release of Sites from Regulatory Control on Termination of Practices Safety Guide*, IAEA Safety Standards Series No.WS-G-5.1., IAEA, Vienna.

IAEA (2006b), *Remediation of Sites with Mixed Contamination of Radioactive and Other Hazardous Substances*, Technical Report Series No 442, IAEA, Vienna.

IAEA (2006c), *Management of Long-Term Radiological Liabilities: Stewardship Challenges*, IAEA, Vienna, www-pub.iaea.org/MTCD/publications/PDF/TRS450_web.pdf.

ICRP (2018), "Ethical Foundations of the System of Radiological Protection", ICRP Publication 138, *Annals of the ICRP*, Vol. 47(1), Elsevier.

ICRP (2007), "The 2007 Recommendations of the International Commission on Radiological Protection", ICRP Publication 103, *Annals of the ICRP*, Volume 37, Nos 2-4, Elsevier.

Ilyin, L. et al. (2005), *Initial Threat Assessment: Radiological Risks Associated with SevRAO Facilities Falling Within the Regulatory Supervision Responsibilities of FMBA*, Strålevern Rapport 17, NRPA, Østerås.

Kelly, M. and M.C. Thorne (2001), "An approach to multi-attribute utility analysis under parametric uncertainty", *Annals of Nuclear Energy*, Vol. 28, pp. 875-893.

Lavrinovich, A. (2017). "Regulatory Aspects of Safety for Legacy Sites in the Russian Federation", presentation to Lillehammer Workshop reported in Sneve and Popic (2018).

Lindborg, T. et al. (2018), "Climate change and landscape development in post-closure safety assessment of solid radioactive waste disposal: Results of an initiative of the IAEA", *Journal of Environmental Radioactivity*, Vol. 183, pp. 41-53.

LLWR (2011a), "The 2011 Environmental Safety Case: Inventory", LLWR/ESC/R(11)10019, LLWR, Holmbrook.

LLWR (2011b), "The 2011 Environmental Safety Case: Assessment of Long-term Radiological Impacts", LLWR/ESC/R(11)10028, LLWR, Holmbrook.

LLWR (2011c), "The 2011 Environmental Safety Case: Site History and Description", LLWR/ESC/R(11)10018, LLWR, Holmbrook.

Mrdakovic Popic, J., M.K. Sneve and H. Vandenhove (2018). "Radioecology as a Support to Regulatory Decision making on NORM and other Legacies, Related Waste Management and Disposal", report of an International Workshop, NRPA 2018:2.

NCRP (2018), *Management of Exposure to Ionizing Radiation: Radiation Protection Guidance for the United States*, NCRP, Bethesda.

NEA (2018a), *Towards an All-Hazards Approach to Emergency Preparedness and Response*. *Lessons Learnt from Non-Nuclear Events*, No. 7308, OECD Publishing , Paris.

NEA (2018b), *The Country-Specific Safety Culture Forum: Sweden*, OECD, Paris.

NEA (2017), *Radiological Characterisation from a Materials and Waste End-State Perspective – Experience from Decommissioning Nuclear Facilities*, No. 7373, OECD Publishing , Paris, www.oecd-nea.org/rwm/pubs/2017/7373-rad-char-pers.pdf.

NEA (2016a), *Strategic Considerations for the Sustainable Remediation of Nuclear Installations*, No. 7290, OECD Publishing , Paris.

NEA (2016b), *Management of Radioactive Waste after a Nuclear Power Plant Accident*, No. 7305, OECD Publishing , Paris.

NEA (2016c), *The Safety Culture of an Effective Nuclear Regulatory Body*, OECD Publishing, Paris.

NEA (2015), *Stakeholder Involvement in Decision Making: A Short Guide to Issues, Approaches and Resources*, No. 7189, OECD Publishing , Paris.

NEA (2014a), *Nuclear Site Remediation and Restoration during Decommissioning of Nuclear Installations*, No. 7192, OECD Publishing , Paris.

NEA (2014b), "Preservation of Records, Knowledge and Memory across Generations (RK&M): Monitoring of Geological Disposal Facilities: Technical and Societal Aspects", NEA/RWM/R(2014)2.

NRC (2007), "Integrated Ground-Water Monitoring Strategy for NRC-Licensed Facilities and Sites: Logic, Strategic Approach and Discussion", NUREG/CR-6948.

NRPA (2018), *Study of Issues Affecting the Assessment of Impacts of Disposal of Radioactive and Hazardous Waste*, NRPA, Østerås.

NRPA (2015), "Comparison of Safety and Environmental Impact Assessments for Disposal of Radioactive Waste and Hazardous Waste", report of a BIOPROTA workshop held on 10-12 February 2015, Asker, Norway.

OECD (1992), "The Polluter-Pays Principle: OECD Analyses and Recommendations", OCDE/GD(92)81, www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(92)81&docLanguage=En.

Oughton, D. et al. (2004), "An ethical dimension to sustainable restoration and long-term management of contaminated areas", *Journal of Environmental Radioactivity*, Vol. 74, pp. 171-183.

Seitz, R. et al. (2016), "Role of Human Intrusion in Decision-Making for Radioactive Waste Disposal – Results of the IAEA HIDRA Project", *Proceedings of 2016 Waste Management Conference*, Phoenix. American Nuclear Society.

SEPA, Environment Agency and Natural Resources Wales (2018), "Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation", Version 1.0, www.gov.uk/government/publications/decommissioning-of-nuclear-sites-and-release-from-regulation/decommissioning-of-nuclear-sites-and-release-from-regulation.

Shandala, N. (2008), "Radioecology and Regulation of Nuclear Legacy. Presentation to an International Workshop on the Application of Radioecology to Regulation of Nuclear Legacy Management", 14-15 June 2008, Bergen, Norway.

Sneve, M.K. et al. (2016), *Ukrainian Regulatory Threat Assessment: Identifying Priorities for Improving Supervision of Nuclear and Radiation Safety and Security*, NRPA, Østerås.

Sneve, M.K. et al. (2000), *Development of the Regulatory Guidance Documents within the Lepse Regulatory Project*, NRPA, Østerås.

Sneve, M.K. and J. Popic (Eds) (2018), *Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution: Report of an International Workshop held in Lillehammer, 21-23 November 2017*, NRPA, Østerås.

Sneve, M.K., M. Kiselev and O. Kochetkov (2008), *Regulatory Improvements Related to the Radiation and Environmental Protection during Remediation of the Nuclear and Radiological Legacy Sites in North West Russia*, NRPA, Østerås.

Sneve, M.K. and P. Strand (2016), *Regulatory Supervision of Legacy Sites: From Recognition to Resolution – Report of an International Workshop, Oslo, 17-19 November 2015*, NRPA, Østerås.

SÚJB (2005), "National Report under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management", Revision 2.3, State Office for Nuclear Safety, Czech Republic.

SuRF (2010), *A Framework for Assessing the Sustainability of Soil and Groundwater Remediation*, CL:AIRE, London.

Weiss, E.B. (1990), "In fairness to future generations", *Environment*, Vol. 32, No. 3, pp. 7-11.

Zhunussova, T. et al. (2013), *Norwegian Support to Regulatory Authorities in Central Asia in Radioactive Waste Management*, NRPA, Østerås.

Chapter 4. **Lessons learnt and conclusions**

Regulatory frameworks designed for nuclear or radiological sites and installations that are operational or in managed decommissioning in line with up to date recommendations, standards and guidance address radiological circumstances that are individual, but largely known and broadly common. In contrast, regulatory frameworks designed for legacies need to address circumstances that are generally unknown and uncertain, or not planned for, such that greater adaptability is needed relative to a framework developed for operational circumstances.

Legacies are so designated because they have been “unrecognised” (e.g. an old uranium mining/milling site, in a remote location and unused for decades), or “abandoned” (e.g. a building used long ago for making radium dials for watches and instruments), or are “long-term unused or redundant” (e.g. a hot cell facility not used for decades, on a regulated site with operating installations). A common characteristic of legacies, as described here, is that initially, in most cases their radiological characterisation is broadly unknown because records have been lost, former site operators with knowledge of the site are unavailable and/or site ownership has changed hands several times.

The absence of adequate records at many older sites strongly suggests the need to ensure knowledge management at currently operating and new sites. This is particularly true of facilities sites that are currently not considered legacies, to avoid creation of new legacies.

Since legacy circumstances are difficult to anticipate, it is not possible to provide regulations in advance that will be effective in all future cases. Some caution is needed to avoid prescription that could mitigate against the optimised solution in particular circumstances. However, it should be possible to set up in advance procedures and plans, including the role of regulators and all other stakeholders, to address legacies as they are recognised or arise. A similar lesson has been recognised with respect to planning for waste management after major accidents (NEA, 2016). This process should include how legacies can be recognised in a legal context, so that responsibilities can then be exercised within a proper regulatory framework.

Prescriptive regulations require a detailed knowledge and considerable experience of the activities being regulated. They are applicable to a clear and well-defined set of circumstances and need to be amended to keep pace with technological and other developments. In particular, they are best suited to widespread practices where the equipment and procedures do not vary significantly among users.

This is commonly not the case for legacies, suggesting the need for a goal-setting or performance-based approach. At the same time, there are advantages to having a precise set of rules available for application can have its advantages in terms of pre-planning, but this is merely moving the responsibility for adequate characterisation from the operator to the regulator, who is supposed to know the nature of all possible legacy situations. A balance has to be made between being prepared for every eventuality and not being prepared for any eventuality. In the end, that balance can only be achieved through development of an adequate understanding of the circumstances and the various stakeholder interests. This will normally require a staged and iterative process.

Experience from the case studies suggests that such a process is more likely to be successfully implemented when supported by close dialogue between operators, regulators and engineering and scientific support organisations, but also with other relevant stakeholders. The most relevant stakeholders are those directly affected by remediation decisions. These individuals are likely to have a very valuable input to selection of the most appropriate end-state, and the stages by which that end-state can be achieved.

Allocation of responsibilities is a key issue, but responsibilities cannot be effectively managed without corresponding adequate allocation of resources. In situations where there are very limited or inadequate resources, scheduling of a staged approach to the desired end-state and careful attention to optimisation might be especially useful, to identify what is truly feasible on a realistic timescale.

As part of the government's role, there is a substantial set of responsibilities that have to be allocated as part of, or within, a regulatory framework. Part of the strategy, has to be allocation of responsibility to investigate possible legacies. Thereafter, one of the challenges is that it can be difficult to implement responsibilities, until the legacy has been characterised. This might involve a need for urgent action, and hence be related to, emergency response, while not necessarily being related to accidents.

The steps to achieving an identified end-state should typically be supported by a radiological safety case, possibly supported by a wider environmental impact assessment. Development of a safety case is an iterative process, ongoing through the steps in remediation, with each step accounting for improved source term data, better understanding of the site, wider planning issues and stakeholder interests, and further refined design options.

Optimisation is a self-evidently good idea. Minimisation of a particular impact can be interesting to investigate, to see what is viable with respect to reduction of that impact. However, setting minimisation of a particular impact as a regulatory objective is likely to lead to the non-minimisation of another impact, and is contrary to optimisation. For example, minimisation of radiation risks may lead to increases in physical hazards, and focus on protection of the public may lead to an increase in risks to workers. A balance also needs to be made between the interests of safety and security.

As part of optimisation, it is recognised that there is a need for further consideration of how to select reference levels, or, in the case of legacies that are regulated as planned exposure situations, the appropriate dose constraints for both workers and the public. As part of that, further guidance is needed on how to address situations which are a mixture of planned and existing exposure situations. The preliminary view is that local regulatory authorities should decide the status of a site according to the prevailing circumstances, including the existing regulatory framework.

There is also a need to account for other environmental and human health risks arising alongside the radiological, as part of an overall optimisation process. It is noted that there is no chemical equivalent of an existing exposure situation or the reference level approach used in radiological protection. Absence of a coherent, proportionate and common approach to management of all risks could lead to miss-allocation of resources.

Radiological, other safety and wider technical assessments, including the assessment of stakeholder values, are subject to uncertainties. The transparent recognition of the uncertainties, and a documented approach to addressing them, is an important step in building confidence in the results of a safety assessment sufficient to support decisions. It is important to clarify whether an impact assessment is intended to identify the scale of the impact, or only intended to show that a particular impact related criterion has not been exceeded. The latter would usually be less data intensive, but may also be less informative if the objective is to find an appropriate balance among different options.

A proportionate and graded approach to environmental and human health risk assessment is likely to be most efficient. Proportionality, as used here, refers to the allocation of resources for risk assessment matching the scale of hazard and potential for harm. A graded approach can include using simple, less data and resource intensive assessment tools in a first iteration, and only progressing to more detailed analysis if the initial results suggest that this is appropriate or needed to support a robust decision. Confidence in the conclusions is likely to be enhanced by effective communication of the objectives, conduct and assumptions in the assessments. A common understanding of the assessment context is important from the very start of the assessment process, involving those commissioning the assessment, the intended audience and those carrying out the assessment.

Communication is of great importance throughout any addressing legacy situations. Reaching a common understanding of the locally relevant radiological protection issues, will involve what may be complex and lengthy discussions, tailored to the knowledge and understanding levels of the stakeholders involved. The radiological protection issues may include:

Radiological protection science issues:

- the difference between radioactivity and radiation dose;
- the difference between contamination and the presence of detectable radioactivity;
- the difference between hazards and risks.

Radiological protection system issues:

- the rationale behind the numeric level of radiological protection criteria;
- application of reference levels alongside dose limits and constraints at the same location.

Radiological protection implementation issues:

- the need to balance risks and resources;
- the need to take action now in order to avoid larger problems later.

Concerning the last bullet, an important issue is that, in some circumstances, if no action is taken, then eventually, the situation will deteriorate, leading to a significantly disruptive event, e.g. a large nuclear, radiological or chemical accident, or the collapse of a mine tailings pile onto occupied buildings. In order to improve the long-term management and to reduce the likelihood of such major events, some short-term increase in risks may be necessary, e.g. while waste is being recovered. Reasonable uncertainties should not, on the basis of precaution, delay action needed to mitigate a major hazard. A decision to delay may not be prudent. The key issue is to manage any temporary increase in risk effectively by understanding the uncertainties in the context of a holistic risk assessment. An adaptable regulatory framework is needed to address such circumstances.

Multi-criteria analyses may help in identifying a sustainable remediation option. Such studies should be recognised as informing a decision rather than making it. However, the systematic consideration of all the issues within a clearly scoped analysis can be very informative. Such an analysis may help to avoid creating an expectation that contaminated land should be remediated without first verifying that such work would generate a net benefit and is in the interests of affected people. It may not be straightforward to determine the net benefits, given conflicting views on how to value the different attributes of available options, but it is more productive to examine the issues than to ignore them. This approach would also support confidence in decisions if it is carried out in an open and transparent way. For example, such studies, if published, will help to make transparent the motivation of decision makers.

Experience shows that regulations and regulatory processes have to be applicable to a wide range of circumstances that typically differ from those arsing in planned situations. To assist in reaching agreements on complex decisions, there is a need for close involvement of all stakeholders, adoption of a holistic approach including all other hazards alongside the radiological, and greater adaptability of regulators and operators in finding appropriate responses to the challenges presented. Examples have shown the possibility of different approaches to exposure situation in the management of a single set of circumstances, e.g. workers protected as in a planned exposure situation and public protected as in an existing exposure situation. This can be complex to communicate to stakeholders; however, advanced planning may help alleviate some of these challenges.

Safety measures and security measures have the common aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The response to the at Fukushima Daiichi NPP accident required urgent development of legislation and standards to allow remediation activities to be undertaken, with the urgency being driven by the requirement to allow the local population to return to as close to their previous lives as possible. The actions taken by Fukushima Daiichi authorities prevented the situation from becoming a legacy.

While this report is focused on legacy sites, the above discussion suggests the prevention of current sites becoming legacy sites can be helped by the collection and maintenance of accurate operational records. This should be emphasised in the regulatory framework, in order to ensure that future end-of-life management activities can be based on adequate information.

Reference

NEA (2016), *Management of Radioactive Waste after a Nuclear Power Plant Accident*, No. 7305, OECD Publishing, Paris.

Chapter 5. Recommendations for the future, towards a common framework for the regulation of nuclear and radiological legacy sites and installations

This report has described experience from the application of regulatory frameworks coming from practical experience of management and regulatory oversight of sites and installations having not completed remediation, and which have radionuclides which give rise to regulatory authority safety concerns. The regulatory framework for the oversight of such sites and installations, aimed at appropriate protection of the public, workers and the environment, should be applicable to the remediation of contaminated land and of installations on that land where radiological circumstances are generally out of the ordinary, and often initially unknown and uncertain.

Practical challenges to meeting regulatory responsibilities include: absence of adequate regulatory framework to address unusual circumstances at legacy sites; lack of experience in regulation of such circumstances; and, availability of the corresponding resources. The regulatory framework should identify who holds the liability if a remediation project goes wrong, or fails to meet its objectives.

This, the first report of the NEA Expert Group on Legacy Management (EGLM), has identified many issues related to legacy management and regulation and presented a variety of case studies that illustrate the challenges and also potentially suitable approaches to their resolution.

5.1. Holistic optimisation

Value has been recognised in sharing experience in the application of optimisation, including, in a holistic sense, not only radiological but other aspects of protection and decision making. There is a need to describe, rather than define, what is meant by holistic optimisation. While holistic in this context leans towards inclusion, further examination is needed of what should be included, and recommendations provided for processes for how those aspects should be taken into account in an integrated and balanced manner. The development of a common set of protection objectives and, hence, assessment endpoints and methods is extremely challenging, but would be very beneficial. In parallel, regulatory development that makes the process for managing the chemical and radiological hazards and risks in a consistent and commensurate is worth further consideration.

Aspects to consider, alongside a wide range of economic and social factors, include:

- radiological protection of the public, workers and the environment;
- protection from non-radiological hazards, including psycho-social health detriment and well-being;
- protection of property, as well as human health and the environment, though they may be linked;
- protection of resources, such as groundwater, soil and forests;
- consideration of short-, medium-, and long-term aspects of all the above, as well as the number of people impacted;
- consideration of security alongside safety for all the above.

A holistic approach to optimisation is important. The aim is to balance all the issues in a transparent and proportionate manner and further work on how to achieve that is recommended, including interpretation of the precautionary principle in the face of competing protection objectives.

Corresponding assessments and safety cases designed to support optimisation should be as simple as possible but as complex as is necessary to be “fit for purpose”. Presenting complex issues in a simplistic manner should be avoided since will mislead rather than improve communication.

Overall optimisation of protection will need to concurrently address radiological, chemical, physical, and other hazards. However, there is no equivalent of radiological exposure situations for protection from chemically contaminated land, and balancing of mixtures of chemical, physical and radiological hazards presents regulatory challenges as well as challenges to societal understanding. To this end, positive results can be taken from the NEA study, *Towards an All-Hazards Approach to Emergency Preparedness and Response: Lessons Learnt from Non-Nuclear Events* (NEA, 2018).

5.2. Type of exposure situation

Although international recommendations, such as ICRP Publication 103, the international basic safety standards, and the European Union basic safety standards directive all describe the use of exposure situations, the case studies examined in this report suggest that the selection of the appropriate exposure situation is not straightforward. Several case studies illustrate that some sites present mixed exposure situations. It is recommended that consideration is given to preparing further guidance on sites presenting mixed exposure situations.

For example, reference levels may be used for members of the public living in areas affected by a legacy source. At the same time and place, remediation workers may be subject to dose limits, which are used in planned exposure situations. Although seemingly quite straightforward, such circumstances can cause confusion for regulators, workers, and members of the public. Another aspect is whether the selection of the reference level should be affected by the number of people exposed, and if so, how should that be taken into account? In this same context, detriment due to radiation exposure is a multidimensional concept that has a specialist meaning in radiological protection which may not be same as understood in common English. Risk communication, in order to develop common understanding of radiological circumstances, will be an important aspect of recovery management, and further work in this area is needed.

In parallel, regulatory development that makes the process for managing the chemical and radiological hazards and risks in a consistent and commensurate is worth further consideration.

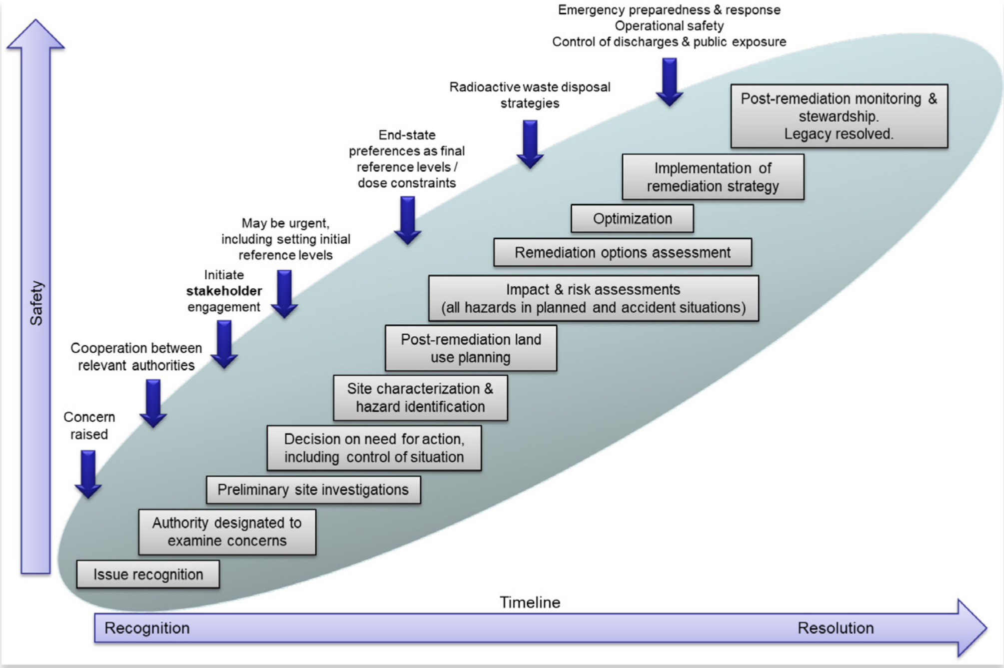
5.3. Prescriptive and performance-related regulations

Experience supports the need for a regulatory framework which is adaptable enough to support the identification and implementation of the optimum sustainable solution. Prescriptive regulations require a more detailed knowledge and considerable experience of the specific activity in question by the drafters of the regulations. They are narrowly applicable to a specific situation and may need to be amended frequently to keep pace with technological changes. In particular, they are best suited to widespread practices where the equipment and procedures do not vary significantly among users. This is commonly not the case for legacies. Further collaborative work to show how to find an appropriate balance would be useful.

While consideration of the above factors should facilitate effective regulatory and decisional processes, it should be noted that the responsibility for decisions rests with whichever organisation has been designated to make such decisions. If no organisation is so identified, the gap has to be filled by government. The emphasis is on developing an effective process from the very beginning so that impacted parties can see the direction being taken and their respective roles within it. Figure ES1 attempts to describe that process as a preliminary framework for a logical and linear progression to the appropriate and sustainable end-state.

Figure 5.1 supposes a linear step-by-step approach. Iterations may be needed at each step, and there may be stages of implementation of this process, i.e. staged progress from interim to final end-states. Note that anyone should feel empowered to raise a concern, but the regulatory authority needs to be empowered and prepared to address any such concern. Also it is the regulator who signs off on the resolution of the legacy. However, there may be no final end-state resolution in the case of long-term stewardship.

Figure 5.1. **Preliminary framework for a logical progression to the appropriate end-state**



Source: Norwegian Radiation and Nuclear Safety Authority.

The above type of illustration might be helpful in explaining the way forward to interested parties, but it does not recognise some of the real-life complications and interactions that experience from the case studies suggests would be needed in many significant legacy sites. For example, it does not show the connections and complex interactions that can be necessary in management of legacies.

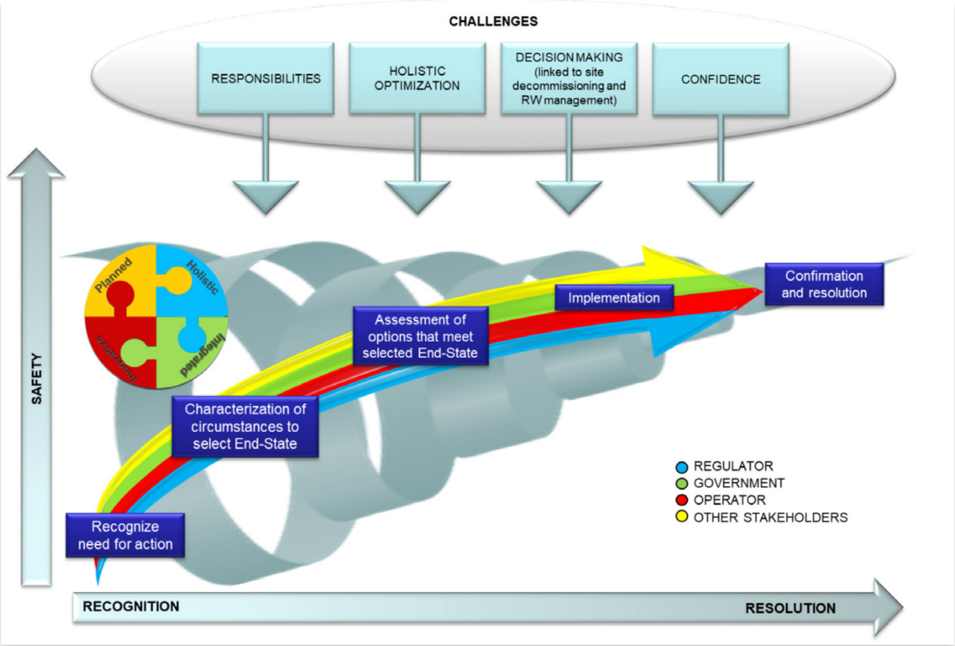
Figure 5.2 attempts to illustrate the challenges and interactions in progressing the linear steps in Figure 5.1. Note the emphasis on increasing confidence, as progress is made towards resolution, through a virtuous spiral of reduced uncertainties. Note also the simultaneous engagement among government (controlling policy), operators (delivering safe solutions), regulators (setting standards and monitoring compliance, and taking action if the operator falls short of the standards), and all other stakeholders who need to have confidence in the resolution.

To support the further development of the framework, accounting for the complex interactions and the value of a planned, innovative, integrated and holistic process, several additional recommendations for further work are given here:

- The usually separate communities engaged in assessments of radioactive waste management (including disposal) and legacy site management could usefully share information, and there is scope for partial model validation based on available data and monitoring experience. Both of these communities, also need to work with those involved in the technological and safety aspects of decommissioning.

- National strategies for decommissioning, legacy management and radioactive waste management, including disposal, all need to be developed in parallel and then updated in the knowledge of progress in all areas, including security management.

Figure 5.2. **Illustration of challenges and interactions in progressing the linear steps**



Source: Norwegian Radiation and Nuclear Safety Authority.

- This implies the need for long-term planning with political support, including action in case a plan fails, i.e. be aware of possible causes of failure and pre-plan to reduce risks of this happening, mitigate possible consequences, maintain responsibilities in the event of failure. Further study of long-term planning would be of value, to determine where pre-planning can be useful without prejudicing future decisions on as yet uncharacterised or unrecognised legacies.
- A review of historical events/incidents which may have led to the legacy contamination should be undertaken, to understand how legacies can be avoided in the future.
- It is considered beneficial in the next steps to reach out to the OECD Environment Directorate, the United Nations Environment Programme and the World Health Organization and to chemical regulators, with a view both to sharing experiences in legacy management and to work co-operatively to develop guidance on holistic optimisation.

References

ICRP (2007), "The 2007 Recommendations of the International Commission on Radiological Protection", ICRP Publication 103, *Annals of the ICRP*, Volume 37, Nos 2-4, Elsevier.

NEA (2018), *Towards an All-Hazards Approach to Emergency Preparedness and Response*. *Lessons Learnt from Non-Nuclear Events*, No. 7308, OECD Publishing, Paris.

Annex 1. Members of and NEA Support for the Expert Group on Legacy Management

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Annex 2. Site visits

A central approach of the NEA Expert Group on Legacy Management (EGLM) in preparing this report was the use of hands-on, practical experience as a basis for its conclusions and recommendations. In this context, the expert group had the opportunity to visit two legacy sites, and to hold detailed discussions with both operators and regulatory authorities, learning directly from experienced experts with site management responsibility. The two site visit reports listed here, for Sellafield in the United Kingdom, and for Andreeva Bay in Russia, provided significant examples of the regulatory and operational flexibility needed to effectively address such unusual and unforeseen circumstances.

These site visits are presented to provide site-specific contextual information and experience in the following areas:

a. site description;

b. regulatory framework;

c. characterisation of circumstances;

d. end-states, societal aspects and long-term protection values.

Conclusions and references are provided for each site visit, both of which involved old nuclear technology sites:

- Site visit 1: Sellafield, United Kingdom (A. Clark, Nuclear Decommissioning Authority [NDA]; R. Cowton, Sellafield Ltd; G. Smith, GMS Abingdon Ltd).
- Site visit 2: Andreeva Bay, site of temporary storage of spent nuclear fuel and radioactive waste at, Russia (N. Shandala, Federal Medical Biophysical Centre [FMBC]).

Site visit 1. Sellafield, United Kingdom

This case study summarises material presented at an EGLM site visit to Sellafield that took place on 16 and 17 May 2017, hosted by Roger Cowton and the staff of Sellafield Ltd with support from Anna Clark (NDA). The visit also included discussions with representatives from the Environment Agency, the Office of Nuclear Regulation and the Scottish Environment Protection Agency.

Site description

Sellafield is a nuclear fuel reprocessing and nuclear decommissioning site, close to the village of Seascale on the coast of the Irish Sea in Cumbria, North West England. The site occupies about 2 square miles, and there are about 200 nuclear facilities on the site.

Figure A2.1. **Aerial photograph of the Sellafield site**

Source: NDA.

Activities at the Sellafield site primarily support decommissioning of historic plants, and reprocessing fuel from UK and overseas nuclear reactors. Decommissioning projects include the Windscale Piles, the Calder Hall nuclear power station, historic reprocessing facilities, waste stores, as well as other clean-up projects on the site. Reprocessing plants include the THORP nuclear fuel reprocessing plant, the Magnox nuclear fuel reprocessing plant, and the Waste Vitrification Plant. The site contains several nuclear waste stores, and there are areas of contaminated land and legacy trenches used for low-level waste disposal in the 1950s. The Low Level Waste Repository, operated since 1959, is located 6 km to the south of the site (see case study 2).

Operations at the site continue to support nuclear generation; however, operations at the site began in the 1940s (see Figure A2.2), and some of the facilities have been in operation for many years. The operational history is summarised in Figure A2.3.

Figure A2.2. **The site with facilities under construction in 1948**

Source: NDA.

Figure A2.3. **Summary of the history of Sellafield operations**

1940s/50s	**1960s/70s**	**1980s**	**1990s**	**2000s**	**2010s**
• Nuclear build begins • Initially a military programme • Later civil programme begins	• Waste stored safely – pending treatment • Storage capacity extended incrementally • Coarse segregation of waste arising from process • Magnox reprocessing starts	• Main expansion of site • Major waste treatment focus • Environmental impact substantially reduced	• Commercialisation of reprocessing — Thorp comes online • Waste arising from processes treated in 'real time' • Product waste forms compatible with disposal concepts	• NDA formed • Stop start progress in Decommissioning • Calder Hall ceased generating power after 47 years in operation	• Decision taken to end Thorp reprocessing • Vitrification of all overseas highly active waste complete • Decommissioning gathering pace • First sludge exports from FGMSP

Source: NDA.

Regulatory framework

The Office for Nuclear Regulation (ONR) has responsibility for regulating safety and security at 36 sites in the United Kingdom that are licensed to operate under the Nuclear Installations Act.[1] Among the largest is the Sellafield site. ONR's strategy identifies three key outcomes, against which they will measure success:

- accelerated hazard and risk reduction across the Sellafield site;
- evidence-based confidence that the licensee is complying with its statutory obligations and that workers and the public are protected from the hazards of the site;
- stakeholder confidence that ONR's regulatory approach is appropriately targeted, risk-based, proportionate and effective.

The Environment Agency (EA) is responsible, under the Environmental Permitting (England and Wales) Regulations 2010[2] (EPR, 2010) for:

- issue and review of permits to hold radioactive material and for waste disposal, including discharges;
- inspection and audit for compliance;
- independent monitoring of discharges and environment;
- incident investigation and enforcement.

There is a Memorandum of Understanding between the ONR and the EA (see www.onr.org.uk/documents/2015/mou-onr-ea-180815.pdf). The objective is to ensure that:

- activities of the EA and ONR are consistent and co-ordinated;
- early engagement with those regulated is encouraged to minimise uncertainties and impact from potentially conflicting requirements;
- synergies are exploited and the appropriate balance of precautions is attained;
- duplication of activity is minimised;
- public confidence in the regulatory system is maintained.

A key aspect of nuclear-licensed site management is the process for delicensing. In particular, there is a requirement on the licensee to show that any residual radiological hazard will not pose a significant ongoing risk to any person, regardless of any foreseeable uses to which the site, or anything left on the site, may be put.[3]

In parallel, the EA, with others, has issued "Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation" (GRR), i.e. related to connected arrangements made under EPR 2010.[4]

The GRR requirements are very similar and use the same numerical standards as those developed for near-surface disposal of radioactive waste. The numerical standards are:

- dose constraint during the period of radioactive substances regulation 0.3 mSv/y per source, and 0.5 mSv/y for a whole sit;
- risk guidance level after releases from radioactive substances regulation 10^{-6} per year;

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1. www.legislation.gov.uk/ukpga/1965/57.
2. www.legislation.gov.uk/ukdsi/2010/9780111491423/contents.
3. www.onr.org.uk/delicensing.pdf.
4. www.gov.uk/government/consultations/guidance-on-requirements-for-release-of-nuclear-sites-from-radioactive-substances-regulation.

- human intrusion dose guidance level after releases of the site from radioactive substances regulation, in the range of 3 mSv/y to 20 mSv/y.

The GRR recognises:

- the need for flexibility to develop site-specific solutions by exercising control over the site for a period of up to the order of 300 years;
- that there are trade-offs to achieve release from radioactive substances regulation that need to be acknowledged and managed.

Characterisation of circumstances

The site is characterised by significant decommissioning challenges, especially in relation to the older facilities.

- inadequate storage facilities:
  - uncertain design;
  - ageing, up to 50 years or even longer;
  - current condition and future service life are unclear.
- large but uncertain inventories;
- uncertain material conditions, both originally and current;
- conditions of work in locations range from difficult to extremely challenging;
- extended time for hazard reduction:
  - complex tasks necessary in order to remove or recover wastes safely;
  - variable confidence in schedule.

Current legacy-related challenges include:

- legacy ponds and silos;
- radioactive particles found on the foreshore to the west of the site;
- land quality;
- the UK discharge strategy.

Among the most hazardous and challenging work is that related to decommissioning of the legacy ponds and silos described in Figure A2.4. Given the focus on risk reduction, these facilities are the UK government's highest priority in nuclear decommissioning. Retrieval operations are to be underway across all four ponds and silos by 2019. This represents a new era of getting legacy fuel and waste into a safer place.

An important feature of this progress is the recognition that leaving waste where it is indefinitely is not a safe option. However, interim increases in risk associated with retrieval operations have still to be adequately controlled. This requires an innovative and flexible approach to risk management, as illustrated in Figure A2.5.

Figure A2.4. **Legacy ponds and silos**

Legacy Ponds & Silos

Pile Fuel Storage Pond

- Constructed 1948-1952 to store Windscale fuel for reprocessing. Waste consists of sludge, fuel, intermediate and low level level waste.

First Generation Magnox Storage Pond

- Constructed in 1950s and 1960s to store Magnox fuel for reprocessing Waste consists of sludge, fuel, intermediate and low level level waste

Magnox Swarf Storage Silos

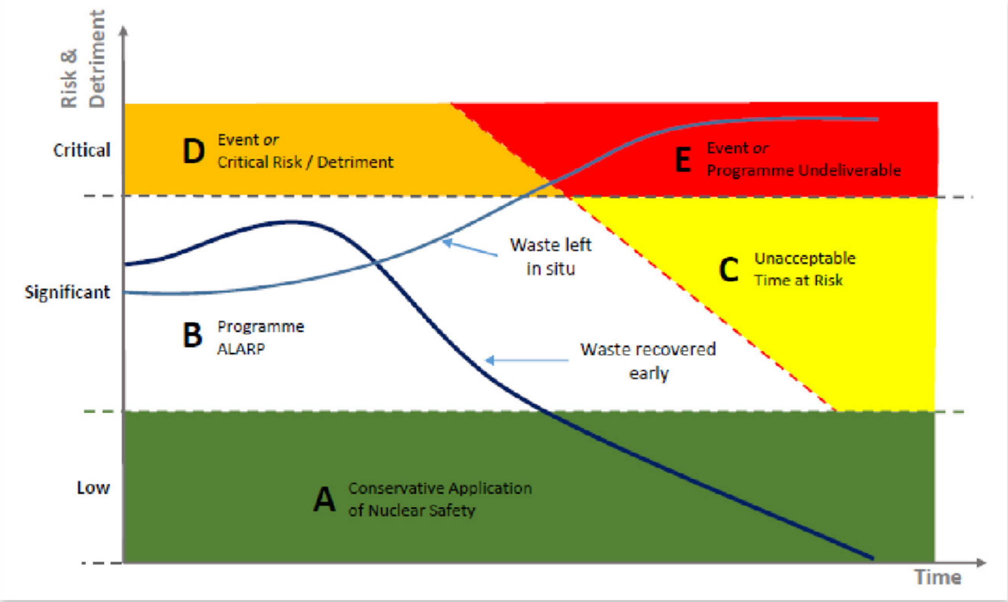
- Constructed 1960s-1980s to hold irradiated fuel canning waste. Received waste until 2000

Pile Fuel Cladding Silo

- Commissioned in 1952, 1st storage facility for intermediate level waste constructed at Sellafield. The silo was filled by 1964

Source: NDA.

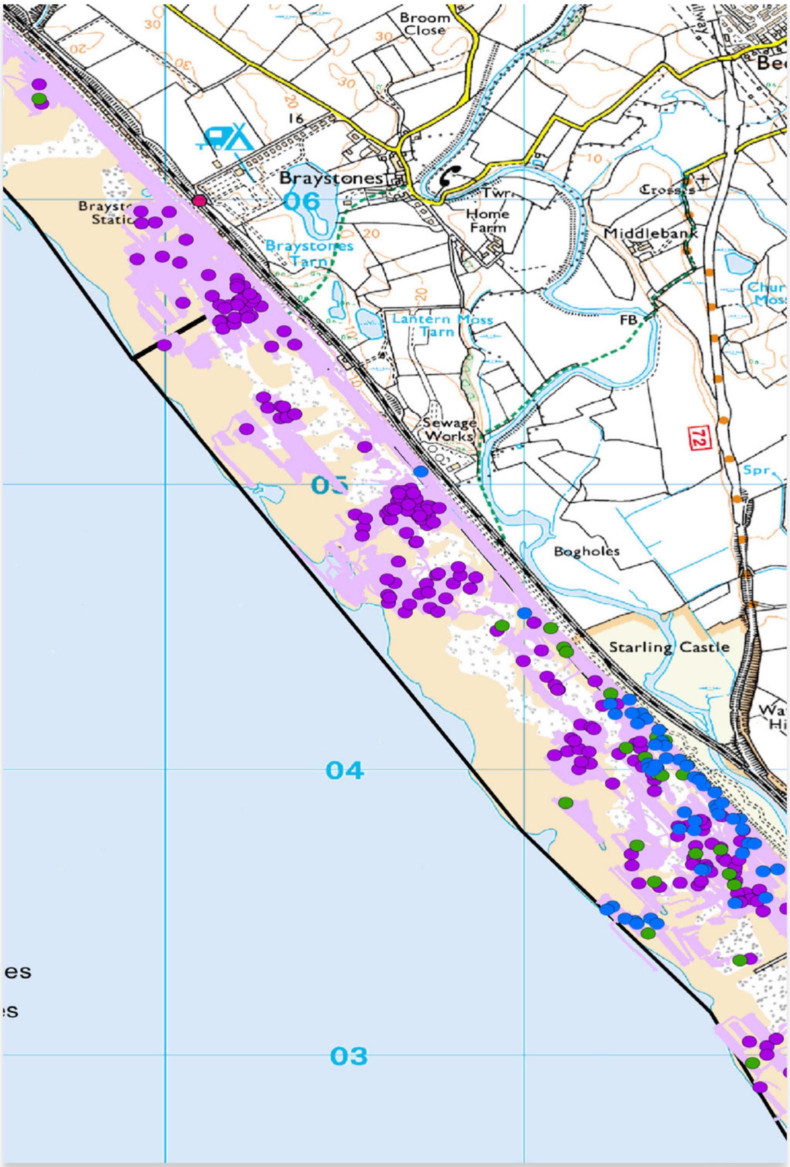
Figure A2.5. **Illustration of the risk management framework**



Source: Sellafield.

As of 30 June 2016, about 2 700 **radioactive particles** have been found since beach monitoring focusing on such particles began in 2006. Understanding the source of the particles and the nature of the hazard and risk associated with their presence is a significant challenge. Given the off-site location (see Figure A2.6), stakeholder management is another important issue.

Figure A2.6. **Sellafield beach monitoring area 2008-2009 and locations found from November 2006 to October 2008**



Source: Images reproduced courtesy of the NDA.

The **contaminated land legacy** arises following over 60 years of industrial site use, with a history of leaks, spills and burials resulting in contamination. The legacy is under active risk management to ensure protection of the workforce, the public and the environment prior to a final hazard reduction and remediation. The goal is to ensure that contaminated ground and groundwater are controlled to reduce risk.

An important contaminated feature arises from burial of waste, including LLW unlined trench excavations in the 1950s to bury lower-level wastes. Information on their contents is largely derived from indirect and anecdotal sources rather than contemporary records. Various estimates for the radionuclide inventory have been made, and consideration is also given to chemically hazardous materials in the waste. The trenches represent an accumulation of radioactive matter and are not managed to the current standards for waste disposal to ground. Tritium in groundwater is also an issue, particularly near to the trenches.

The objectives of interim management include: preventing inadvertent disturbance or exposure of the trench contents, minimising the potential mobility of contaminants in the trenches via leaching into groundwater, and developing techniques for a final remediation solution. Any decision to remediate needs to consider the balance between risk reduction to off-site receptors and the dose received by remediation workers. Excavation is possibly the least attractive option because of dose to the workforce. Groundwater pumping involves greater costs and produces effluent that has to be managed but could also reduce the risks posed by some other sources on-site.

This last point makes the link between solid waste management and discharge strategy. For example, solid waste arisings might be minimised by decontamination processes, but give rise to liquid effluents. Minimisation in one area may not lead to an overall optimised result. Integrated site management is very important. As part of that, completing reprocessing at Sellafield is key to meeting UK discharge targets.

Societal aspects

Sellafield supports a public interest group, one of the largest in the United Kingdom, through which to maintain constant communications with local stakeholders.

Recognising that there are several stakeholders with an interest in accelerating hazard and risk reduction on the site, a new working group has been established. The group, informally known as the "G6", facilitates a co-ordinated approach to complex issues, where input may be required from a broad range of decision makers. The group incorporates six key organisations: the Department for Business, Energy & Industrial Strategy, NDA, Sellafield Limited, Environment Agency, UK Government Investments (UKGI) and ONR. All members work through a constructive approach towards the common objective of facilitating hazard reduction, for example by enhancing opportunities for, or removing barriers to progress.

End-states and long-term protection values

The strategic aims for land quality management at Sellafield are to:

- provide stakeholder confidence and reassurance in the near-term management of land quality;
- enable high hazard reduction and the development of decommissioning and waste facilities;
- set the agenda for optimising the site end-state in order to realise safety, environmental and long-term cost benefits.

To support these aims the NDA has developed a value framework, shown in Figure A2.7. With the intention to ensure transparency in decision making, the NDA established factors that are considered when assessing options. The factors are tiered and the seven top tier factors are:

- health and safety;
- security;
- environment;
- risk/hazard reduction;
- socio-economic impacts;
- cost;
- enabling the mission.

Further information is provided at www.gov.uk/government/publications/nda-value-framework-how-we-make-decisions/explaining-the-value-framework.

Figure A2.7. **NDA value framework**

Source: NDA.

Conclusions

The management needed to secure a suitable end-state for a complex site such as Sellafield involves long-term strategic thinking supported by long-term commitment to deliver to that strategy.

Progress can best be made in a staged process that best meets the developing needs of all stakeholders and takes account of changing circumstances.

For sites presenting major nuclear and radiation safety legacies, an important focus should be on hazard reduction. Such reduction can be supported by innovative approaches to regulatory supervision that support identification of the appropriate balance between present and future risks, and between risks to workers, the public and the environment. Early and close co-ordination between regulators responsible for different areas of safety and protection is important to achieving that balance. Nuclear and radiation safety also need to be coupled with the management of other hazards.

Decommissioning and remediation at Sellafield is producing a significant amount of radioactive waste that will require comprehensive management leading to final disposal. Therefore, collaboration with waste management organisations is crucial. Thus, for example, material characterisation needs to address not only issues relevant to safety on-site and support achieving the site end-state, but it also has to fit the needs of the national radioactive waste management programme, to allow, as appropriate, the movement of radioactive waste off-site. Account also needs to be made of the chemically hazardous content of wastes.

Some additional areas for continued consideration include:

- greater focus and priority on near-term management and long-term planning;
- clarity on regulatory status areas within the site;
- better record keeping and sample management;
- development of remote sensing, investigation and remediation technologies;
- information sharing;
- development of recognised risk assessment techniques and acceptance criteria for in situ management.

Site visit 2. **Andreeva Bay, site of temporary storage of spent nuclear fuel and radioactive waste, Russia**

This case study presents materials on temporary storage of spent nuclear fuel and radioactive waste at Andreeva Bay. The EGLM meeting and the site visit were organised by the SC Rosatom jointly with the Burnasyan Federal Medical Biophysical Center (SRC-FMBC) and hosted by NWC SevRAO on 5-7 June 2018. The objective of the meeting was to familiarise international experts with the Russian experience in remediation of nuclear legacy sites using the case study of the Andreeva Bay site for temporary storage (STS) of spent fuel and radioactive waste.

Site description

In the early 1960s, the Coastal Technical Base of the Navy was established in north-west Russia at Andreeva Bay, in the Murmansk region. The Coastal Technical Base was used to support the reloading of nuclear reactors of nuclear submarines, temporary storage and subsequent sending of any spent fuel for recycling. Liquid radioactive waste (LRW) and solid radioactive waste (SRW) was borne out of the activities of nuclear submarines, above-water ships with nuclear powered installations and nuclear service ships that were stored at the Coastal Technical Base.

To support the operation of submarines, it was necessary to provide special conditions for spent fuel management, namely cooling and storage of unloaded spent fuel assemblies in protected areas. For this purpose, onshore facilities were constructed to store spent fuel in the maintenance bases of nuclear power installations. The construction of the first stage of the storage facility ended in 1962. Because of the high rate of accumulation of spent fuel assemblies discharged from nuclear reactors, it was necessary to expand their storage volumes. In 1973, the construction of the second stage was terminated. Total storage volume was 80 cores. At the same time, the spent fuel removal from the north-west region for reprocessing began.

Figure A2.8. **General view of the technical territory of the Andreeva Bay site**

Source: FMBA of Russia – Rosatom.

The radiation accident in the spent fuel storage facility in 1982 was a key event in the history of Andreeva Bay. This accident took place because of the loss of tightness of the storage pools. The emergency situation at Andreeva Bay required making some management decisions, which changed significantly the destiny of the facility. These decisions included: the accelerated removal of spent fuel for processing, the creation of new storage facilities in Andreeva Bay and the transport of spent fuel to the facility, the mitigation of the consequences of the accident in the old spent fuel storage facility and the comprehensive modernisation of facilities for spent fuel and radioactive waste management.

Operation of the Coastal Technical Base was discontinued in 1993, including the acceptance of spent fuel and radioactive waste. The lack of appropriate maintenance of the infrastructure of spent fuel and radioactive waste storage facilities after termination of the operations resulted in degradation of the protective barriers. This caused release of radioactivity into the soil, as well as unevenly distributed man-made contamination of the environment. The site belongs to Category I for potential radiological hazards.[1]

In 1999, the Coastal Technical Base was transferred to the State Atomic Energy Corporation Rosatom for the purpose of its remediation, and it was renamed the site for spent fuel and radioactive waste temporary storage (STS) (further – Andreeva Bay STS). Andreeva Bay STS is one of the branches of the north-west Center for Radioactive Waste Management (NWC SevRAO). The plan for environmental remediation of the Andreeva Bay STS was established in 2002. The consistent implementation of this plan involves the restoration of the area up to "brown field" status (see Figure 3.3).

Figure A2.9. **Areal categorisation of Andreeva Bay STS**

Source: FMBA of Russia – Rosatom.

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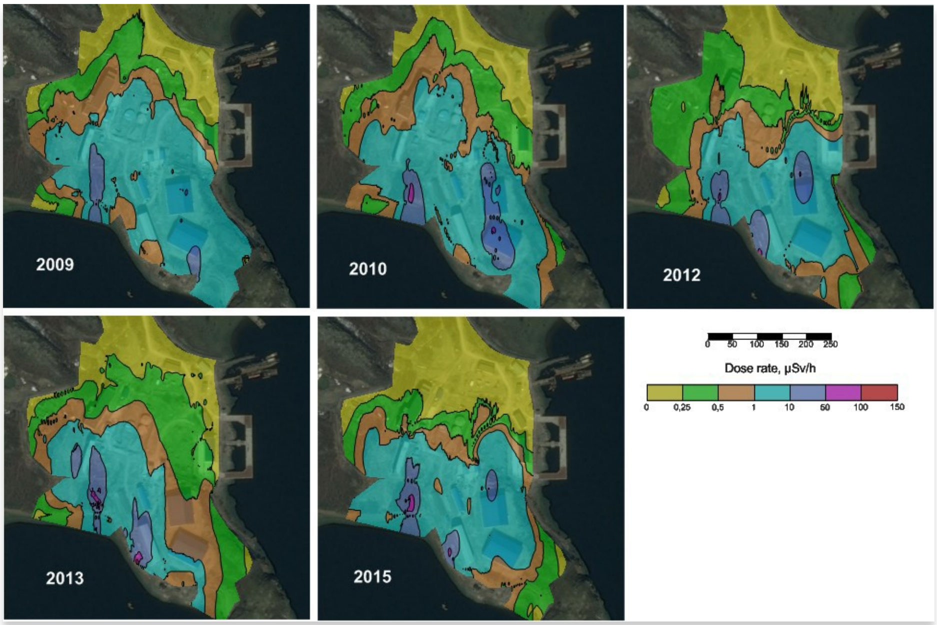
[1] Classification of a radiation hazardous facility by potential hazard is determined by its potential radiation exposure to the population and personnel in case of a radiation accident (Basic OSPORB-99.2010). There are four categories of potential radiation hazard. A health protection zone is established around radiation facilities of categories I-III, while a supervision area (where people live) is also established around radiation facilities of category I. Category I includes radiation facilities, in case of an accident at which their radiation exposure to the population living in the supervision area is possible and protective measures may be required. Category II – radiation exposure in case of an accident is limited by the area of the health protection zone. Category III – radiation exposure in case of an accident is limited by the industrial site (Guidelines 2.6.1.2005-05).

At the Andreeva Bay STS, the gamma dose rate in the controlled access area varies over a wide range from 0.5 to 150 µSv/h and also over time as work progresses. Taking into account the special features of this exposure component (buildings and constructions, contaminated machines and radioactive waste located in containers make the most contribution to radiation), redistribution of areas with increased gamma dose rates results from remedial operations including radioactive waste management on-site (Figure A2.10) (Sneve et al., 2014).

There are 18 000 m^3 of SRW of up to 2×10^{16} Bq activity; and 3 400 m^3 of LRW of up to 2×10^{15} Bq activity at the site. There are about 20 000 spent fuel assemblies in the dry storage facilities (DSF), including abnormal or irregular ones. For the purpose of radiological protection of workers and the public, the following areas are specified on-site and around the STS site:

- Controlled access area (CAA) – spent fuel and radioactive waste storage facilities are situated here, and radiation hazardous operations are performed.
- Uncontrolled (free access) area (UAA) – Facilities intended for to support work carried out in the CAA.
- Health protection zone (HPZ) – This is an area related to administrative and technical provisions of the STS.
- Supervision area (SA) – This is an area surrounding the STS, where radiological monitoring is being carried out to ensure radiation safety and protection for the public. The city of Zaozersk (15 000 residents) is included in the SA (8 km from the STS).

Figure A2.10. **Dynamics of gamma dose rate at the industrial site between 2009-2015**



Source: FMBA of Russia – Rosatom.

Regulatory framework

The Federal Medical Biological Agency (FMBA) is the official regulatory body at Rosatom facilities. It is responsible for radiation safety regulation (i.e. introduction and control of norms, implementation of supervision and independent monitoring). The Burnasyan Federal Medical Biophysical Center (SRC-FMBC) implements the technical support of the FMBA in this activity. The Norwegian Radiation Protection Authority (NRPA) participates in this work under the Plan of Actions of the Norwegian government.

The lack of maintenance of the infrastructure after termination of the active operation of the Coastal Technical Base resulted in significant degradation of the spent fuel and radioactive waste, and of the storage facilities. The DSFs and basin-type storage facilities (building 5) are the most radiation problematic areas at the Andreeva Bay STS. The degradation of infrastructure of radioactive waste storage resulted in abnormal radiation conditions in these buildings. Because of the lack of information about the condition of the spent fuel, and the complexity of technology for spent fuel and radioactive waste management applied for the first time in these abnormal circumstances, these facilities required improved methods of radiation monitoring and radiological protection of workers.

The potential for additional release of contamination due to acute and/or continued prolonged further degradation of the stored spent fuel, and the spreading of contamination, in addition to irregular and extreme radiation conditions at the Andreeva Bay STS, generated the main radiological risks to workers, the population and the environment.

In order to develop a thorough overview of the most important issues requiring enhanced supervision and regulation, in 2005, the radiological threats[2] connected with the activity of the site falling in the scope of the regulatory responsibility of FMBA were assessed (Ilyin et al., 2005). According to this assessment, the following threats were identified:

- poor condition of the infrastructure for spent fuel and radioactive waste storage, complicating subsequent decommissioning;
- insufficient, available methodological framework for radiation safety regulation under the irregular conditions of spent fuel and radioactive waste management during remediation;
- lack of sufficient information on the existing exposure situation and radiation conditions around the facility and, hence, uncertainties in the assessment of doses to the public;
- insufficient organisation of interactions between the operator, regulator and ambulance agencies in case of emergencies during remedial operations.

The FMBA took these circumstances into account when planning and carrying out regulatory activities at Andreeva Bay STS during 2003-2013 (Shandala et al., 2008b and 2015; and Sneve et al., 2015). Within collaboration between the FMBA and NRPA, between 2004 and 2016, 25 regulatory projects have been completed and are ongoing today (Siegien-Iwaniuk et al., 2016; Shandala and Seregin, 2013).

The results of the threat assessment, conducted by FMBA with the support of NRPA at the initial stage of the STS remediation, created the background for the three key areas for improving regulation in the field of radiation safety and protection of:

- workers;
- the public and the environment;
- emergency preparedness and response (Ilyin et al., 2005).

Based on the received results of monitoring and assessment of current risks, site-specific regulatory documents have been developed for the bodies and institutions under the FMBA, which were involved in activities to control the facility. Those documents include the requirements for:

- radiological protection of workers and population;
- personal dose monitoring;
- radioactive waste management, including low-level radioactive waste;
- implementation of environmental monitoring;
- radiation monitoring nearby the Andreeva Bay STS;
- remediation of the sites as remediation criteria and regulations (Sneve and Strand, 2016; Shandala et al., 2008a).

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[2] "Threat assessment" implies the preliminary, qualitative review of risks and hazards, which describes details of additional efforts and additional sources in place and in the areas requiring more attention.

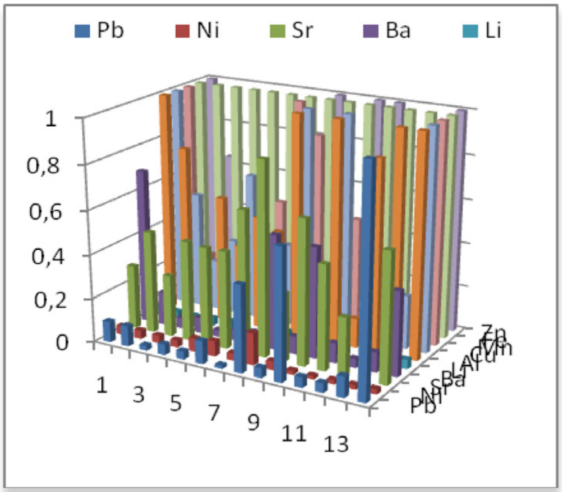
Site characterisation

Within the HPZ, where the STS supporting facilities are located, the dose rate varies over the comparatively narrow range of 0.08-0.25 µSv/h and its mean values do not exceed significantly the mean value of ambient background over the whole region. Gamma dose rate at the SA (beyond the STS area) varies over the range of 0.12-0.17 µSv/h and is within variations of the natural background typical of the region.

Cs-137 and Sr-90 are the main contaminating radionuclides in the groundwater. The specific concentration of Cs-137 in the majority of water samples significantly exceeds the intervention level for drinking water established by the Russian standards. The presence of Sr-90 in the studied water samples is negligible, except for two wells of water where concentrations of Sr-90 are two orders of a magnitude higher than the intervention level for drinking water. This can be induced by the presence of the local source of contamination in the area of these sampling points.

Compared to the radioactive contamination, chemical contamination of groundwater is more dispersed both by localisation and quantitative and qualitative factors. Concentrations in the Class I hazard chemicals mercury and beryllium (found in the majority of studied samples) are much lower than the established standards. In some samples, the contents of mercury and beryllium reach the maximum permissible concentrations (MPC); in others, double the MPC excess of beryllium content has been registered. For Class II hazard chemicals, multiple violations of health physics standards have been recorded. Lead and nickel concentrations in all monitoring wells are higher than MPC. Also, multiple measurements exceeding established radiological and chemical criteria have been recorded for strontium, lithium and barium. MPC for Class III hazard chemicals have been exceeded in many cases. The highest levels in some samples are observed for iron. For other chemicals, in some samples, the standards for drinking water and economic activities have been exceeded by three to four times.

Figure A2.11. **Concentration of chemicals of the 2nd and 3rd class hazard in water samples**



Source: FMBA of Russia – Rosatom.

During the studies, some local contamination of the offshore marine water area was found. The key dose-forming radionuclide is Cs-137. The dose rate in bottom sediments varies over the range 0.05-3.5 µSv/h. The density of the bottom sediment contamination with Cs-137 varies over the range 100-200 kBq/m^2. In the remainder of the water area, the density of contamination with Cs-137 varies over the range from 0.1 to 100 Bq/m^2.

In general, the radiation situation in the coastal sea area shows the stable decrease of man-made nuclides in the marine environment. Contents of Cs-137 and Sr-90 in sea water were reduced by a magnitude of 10 in the CAA. However, the contents of radionuclides exceed the typical regional background by 1.5-2 times on average. These parts of the sea area require more in-depth research.

The radiation situation around the STS has typical background values of the dose rate and Cs-137 and Sr-90 environmental content (water, soil, vegetation). The monitoring studies analysis did not reveal any increase (as of 2005-2015). The Cs-137 specific activity in mushrooms was 43 Bq/kg in 2013, which is similar to the data obtained in 2005 (20-30 Bq/kg), and significantly below the permissible content (500 Bq/kg), established for Russia. In moss samples the content of the radionuclides (to the south of the site) was: 12-51 Bq/kg for Cs-137 and 6-14 Bq/kg for Sr-90.

The mean values of the gamma dose rate in the open and inside the houses of the city of Zaozersk are 0.106 µSv/h and 0.110 µSv/h, respectively. The external effective dose for the city residents is 0.95 µSv/y. Man-made radionuclide contribution in the external dose is less than one percent. The assessment of the internal effective dose due to ingestion of the man-made radionuclides for the population living in the STS supervision area is 65 µSv/y. The contribution of the wild-growing component of the food ration into internal dose does not exceed 5.3%. The internal dose due to inhalation of man-made radionuclides is about 6.5 nSv/y. Doses to the population of the STS supervision area are consistent with the NRB-99 parameters and do not exceed 1 µSv/y due to the facility operation.

Thus, the public doses do not exceed the dose limits for populations recommended by the BSS for the planned activities. Overall, the data available point to no contamination of the studied parts of the supervision area, and the levels of man-made radionuclides are consistent with the global fallout.

To ensure the safe unloading of the spent fuel, infrastructure facilities and a complex for spent fuel management (Building of the DSU sheltering – Building 153) are used. Building 153 is intended to ensure the safe spent fuel unloading from the DSU cells, and spent fuel loading to the transport radiation shield containers, at any time of year irrespective of weather.

Building 153 is divided into 2 areas for radiation safety of the personnel and environmental media against potential contamination: a periodically serviced area intended for unloading spent fuel assemblies and for the collection and unloading of radioactive waste, and a personnel area so that shift workers can remain on-site and in low-dose areas throughout the whole shift. A decontamination/transfer unit connects these two areas.

Actions taken

To monitor the dynamics of the radiation situation, mapping computer databases were developed, including integrated computer images of facilities for spent fuel and radioactive waste management (Chizhov et al., 2014). The analytical capabilities of the DOSEMAP software, developed in the framework of Russian-Norwegian co-operation, through the input of the initial radiation monitoring data, and frequent prompt updating, helps all parties to obtain information on the occupational radiation situation inside the premises and, based on the site working routes and locations of workers established by the operator, automatically calculates prospective doses to workers at the planning stage of particular work activities.

In the course of the spent fuel and radioactive waste management, radiological threats relating to the exposure to workers are increased significantly. To reduce the probability of the radiological risk implementation, Andreeva Planner software has been developed. This software helps to generate and simulate various scenarios of radiation hazardous operations. It serves as a virtual simulator, which, in very visual form, helps the operator to reveal negative consequences resulting from various deviations from the optimal option.

The developed software is considered as a working tool to make management decisions to prevent potential threats relating to the personnel overexposure. This helps, at the preliminary stage of radiation hazardous operations, to generate a list of different options for technological procedures including sets of individual doses for all performers in each scenario and collective doses for each option and time dependencies of the dose rate for any participant.

Measures for optimisation of radiological protection of the environment and the local population at all stages of facility remediation are based on reliable information about the radiation situation parameters and prognostic assessments of changes in the radiation situation. Structuring radioecological data, systematisation and analysis are implemented in the information analytical system (IAS) DATAMAP. The developed analytical apparatus enables detailed analyses of the current radioecological situation at the STS, supports prognostic assessment of a potential future radiation situation, and facilitates optimisation of the continuing radiation monitoring programme. It also provides support to the overall optimisation programme for the site remediation, for example, by providing input data for the software for radiation situation visualisation and comparison with established criteria for remediation of sites and facilities.

With international participation of the United Kingdom, Norway and others, preliminary work has been done for the remediation of the spent fuel storage facility. Inside the building, a comprehensive engineering and radiation survey of all basins was carried out. It was found that at the bottom of the right-hand pool there are six spent fuel assemblies that fell out of the storage cases during the unloading of the building, and other radiation hazardous objects. For the purpose of better understanding, various remediation options have been developed. The work project and design was submitted to the regulatory bodies for review.

Societal aspects

In order to work out the components of the response to radiological accidents and emergencies, emergency trainings were performed at the Andreeva Bay STS (2006, 2016). The main focus was on medical tasks of the response – emergency assistance to victims. Taking into account the plans (Grigoriev, 2016) for remediation, topics of training were devoted to working out the issues of radiation safety regulation during removal of radioactive materials from facilities and subsequent transport of these materials, including the current risks of traffic accidents and potential radiation effects. A list of scenario tasks related to emergencies and covering the loss of control over the sources of ionising radiation during transport has been prepared. Based on the list, the experience of practical activities and the results of discussions, a compendium of educational scenario tasks (tests) has been developed, which can be used for further training and testing the regulators.

Under the Project of 2006, the emergency training at the Andreeva Bay STS has been performed. The training was focused on medical tasks of the response – emergency treatment of victims. Based on findings of the event, the methodical recommendations have been developed and introduces in the practice of the regulatory bodies. These recommendations deal with operational radiological and medical criteria for initiating the emergency plans of NWC "SevRAO" facilities.

In 2009, the emergency training was arranged and conducted, devoted to radiological protection of workers of the NWC "SevRAO" "Ostrovnoy" Facility and population of the Gremikha village. More than 100 representatives of 17 companies from various ministries and agencies attended the training. At different levels, teams and units were involved representing the executive authorities of the Murmansk region, the State Corporation Rosatom, FMBA, Emercom, and some technical supporting centres under the State Corporation Rosatom (Roshydromet and the Nuclear Safety Institute [IBRAE RAN]). Mass media described the preliminary work and the course of the training in detail.

Over 2010-2012, a series of practical events were performed by working groups and expert groups of regulators, in order to: exercise the making of consolidated assessment of emergency consequences, develop recommendations on measures for the protection of workers and the population; and work out the issues of organisation of interaction between the units under FMBA and the State Corporation Rosatom.

To enhance the progressive improvement of emergency preparedness and response, the developed strategy should be strengthened by practical activities through organisation of the training process for the personnel of the FMBA's of Russia territorial units and testing interagency interaction and co-operation with stakeholder-agencies (State Corporation Rosatom, Roshydromet, RAS) within the joint exercise.

Accordingly, in 2016, a research emergency exercise was conducted at the premises of the NWC SevRAO Andreeva Bay site. During the research emergency exercise, the effectiveness of participants was assessed using the advanced methods of the radiation situation simulation, and measures were taken to enhance psychological training of the personnel and medical staff for the radiological accident aftermath operations.

More than 150 people were involved in the exercise including Russian and foreign observers from 19 organisations. A total of 13 responding institutions participated in the exercise: the State Corporation Rosatom (NRS Department of SC Rosatom, Rosatom's SCC, ETC SPb etc.), FSUE RosRAO (Andreeva Bay NWC SevRAO facility), medical units under FMBA (SRC-FMBC, IRM-120, CMSU-120, CH&E-120, NWREMDC etc.), Roshydromet (SRA Typhoon), RAS (IBRAE RAN), the Government of the Murmansk region, the Headquarter of the Emercom over the Murmansk region.

Within the framework of the Early Warning Convention and in accordance with the current agreements of the State Corporation Rosatom, information notification forms were prepared and sent in real time to the International Atomic Energy Agency (IAEA) and the Scandinavian countries: Nuclear and Radiation Safety Agency (STUK) Finland, NRPA, and the Swedish Radiation Safety Agency (SSE).

Special attention was paid to the participation of the public in the implementation of remediation projects at Andreeva Bay, including public hearings, stationary and remote meetings of the Public Council under SC Rosatom, regional and international forum-dialogues, and organising and conducting technical tours of the sites in the Murmansk region.

Lessons learnt

In order to assess environmental threats realistically, comprehensive radiation and chemical monitoring shall be organised. Practical implementation of a comprehensive radiation monitoring methodology based on an integrated assessment of factors of radiation and chemical impacts on the environment is the basis for the development of the principles of environmental regulation in the context of radiation safety regulation during remediation of the nuclear legacy in north-west Russia.

The practical activities performed during implementation of emergency preparedness have revealed the necessity to work out the organisation of co-operation and response both at the local level (within FMBA) and with the external, responsible authorities (SC "Rosatom" etc.).

To improve emergency planning and response, a list should be specified of potential emergencies in terms of the development and introduction of new technologies of spent fuel and radioactive waste and perform regular emergency drills and exercises to improve the procedure of interaction of territorial bodies, hygiene and epidemiology centres and health units of FMBA.

In the course of operations, management of a large volume of industrial waste is planned. Qualitative support of radiation monitoring of this type of industrial waste at the stages of waste collection and sorting, and planned use in economic activities with a view to assuring radiation protection, is an important aspect of radiological protection of the public and environment at each stage of the site remediation. An urgent requirement for regulatory activities in this area stems from the need to prevent the creation of a new existing exposure situation.

Conclusions

The issues of necessary improvement of regulatory supervision at the Andreeva Bay STS are directly connected to the results achieved in the course of the remediation works. The initial period was notable for some peculiarities. There were no reliable data on spent fuel and radioactive waste status, nor was there the necessary infrastructure for doing the work. There were no reliable data on the radiation situation in the buildings located around the STS nor on environmental radiation contamination.

Taking these peculiarities into consideration, the decision was made to conduct a few projects (including the threat assessment project), which involved the development of an emergency preparedness and response programme with the purpose of improving the regulatory infrastructure in the field of occupational and public protection. The programme was successfully implemented, which allowed Rosatom to realise numerous emergency measures (in certain cases accident-prevention) in the sphere of regulatory supervision over spent fuel and radioactive waste temporary storage facilities and adjacent territories.

Clear evidence of the success of the regulator may be found in the results of the first stage of remedial activities conducted between 2008 and 2012, when the first lots of spent fuel were removed using a special tanker. During that period, the real occupational doses were a bit higher than 1 per cent of the predicted values and did not exceed the reference levels. Such operations did not impact on the population and environment with respect to additional doses.

According to the plan for Andreeva Bay site remediation, preliminary work is being carried out and infrastructure is being generated for the safe removal of spent fuel and SRW as well as for site remediation. Today, the improvement of infrastructure at STS is almost completed and a new stage of remediation projects began, including the direct management of spent fuel and radioactive waste.

Designed software tools (Chizhov et al., 2014), lessons learnt and regulator decisions will help to reduce the uncertainty in assessment of radiation exposure during radiation hazardous operations and to protect the public and environment.

References

Chizhov, K. et al. (2014), "3D simulation as a tool for improving the safety culture during remediation at Andreeva Bay", *Journal of Radiological Protection*, Vol. 34, No. 4, pp. 755-773.

Grigoriev, A. (2016), "The history, current status and prospects of remediation of nuclear and radiation hazardous facilities of Andreeva Bay (north-west of Russia)", presentation at the 5th Information Workshop, www.atomic-energy.ru/news/2016/11/01/70008.

Ilyin, L. et al. (2005), *Initial Threat Assessment: Radiological Risks Associated with SevRAO Facilities Falling Within the Regulatory Supervision Responsibilities of FMBA*, NRPA, Østerås.

Shandala, N.K. and V.A. Seregin (2013), "Russian-Norwegian Cooperation in Regulation of Public Radiation Protection in Northwest Russia", *Proc. Conf. WM2012*, ANS.

Shandala, N.K. et al. (2008a), "Radiological criteria for the remediation of sites for spent fuel and radioactive waste storage in the Russian Northwest". *J. of Radiological Protection*, Vol. 28, pp. 479-497.

Shandala, N.K. et al. (2008b), "Regulatory supervision of sites for spent fuel and radioactive waste storage in the Russian Northwest", *J. of Radiological Protection*, Vol. 28, pp. 453-465.

Shandala, N.K. et al. (2015), "Status of Regulatory Issues in Personnel, Public and Environmental Radiation Safety at Legacy Nuclear Sites in Russia", 10 year FMBA-NRPA collaboration, printed at Burnasyan FMBC, FMBA.

Siegien-Iwaniuk, K. et al. (2016). *Regulatory Cooperation Program between Norwegian Radiation Protection Authority and Russian Federation: Results of Projects Completed from 2010 to 2015*, NRPA, Østerås.

Sneve, M.K. and P. Strand (2018), *Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution – Report of an International Workshop held in Lillehammer, 21-23 November 2017*, NRPA, Østerås.

Sneve, M.K., M. Kiselev and N.K. Shandala (2014), “Radio-ecological characterization and radiological assessment in support of regulatory supervision of legacy sites in northwest Russia”, *Journal of Environmental Radioactivity*, Vol. 131, pp. 110-118.

Sneve, M.K. et al. (2015), “Radiation safety during remediation of the SevRAO facilities: 10 years of regulatory experience”, *Journal of Radiological Protection*, Vol. 35, No. 3, pp. 571-596.

Annex 3. Case studies

Another significant contributor to the practical-experience used as a bases for this report's conclusions and recommendations were the 11 case studies summarised by the NEA Expert Group on Legacy Management (EGLM) members. Although these case studies did not involve first-hand experience by a delegation of expert group members, the contributing members built the case studies based on their own experience, and importantly, using the same format of site-specific contextual information and experience in the following areas:

1. site description;
2. regulatory framework;
3. characterisation of circumstances;
4. end-states, societal aspects and long-term protection values;

Conclusions and references are provided for each case study.

The case studies include examples from a wide variety of different sites that illustrate a range of prevailing circumstances. They have been provided as listed below so as to outline the perspectives of those managing and/or regulating the sites, reflecting the real, historic, current and planned future legacy activities. They are presented as shared examples of actual practice and experience in applying safety measures to address legacy sites, and to inform the development of international guidance specific to the regulation of nuclear and radiological legacy sites.

Case studies

Old radioactive waste disposal facilities

- Case study 1: Little Forest Legacy Site, Australia (H. Griffiths, Australian Nuclear Science and Technology Organisation [ANSTO]);
- Case study 2: The Low Level Radioactive Waste Repository, United Kingdom (G. Smith, GMS Abingdon).

Facilities for long-term storage and or disposal of naturally occurring radioactive material (NORM), uranium and other ore mining and milling facilities

- Case study 3: Ranstad uranium milling plant, Sweden (H. Wijk, Swedish Radiation Safety Authority [SSM]);
- Case study 4: Søve: A former Niobium mine, Norway (M. Sneve, Norwegian Radiation Protection Authority [NRPA]);
- Case study 5: Stráž Pod Ralskem and Rožná legacy sites, Czech Republic (M. Jurda, SUJB);
- Case study 6: Shiprock Disposal Site in New Mexico, United States (C. Barr, US Nuclear Regulatory Commission [NRC]).

Radium affected areas

- Case study 7: Radium Action Plan 2015 to 2019, Switzerland (E. Christen, Swiss Federal Office of Public Health).

Disposal sites found to have emplaced, unplanned radioactive waste

- Case study 8: Capriano Del Colle special waste dump, Italy (M. Altavilla, Ispra).

Old nuclear technology facilities

- Case study 9: Hanford, United States (P. Worthington, US Department of Energy [DOE]);
- Case study 10: Western New York Nuclear Service Center and West Valley Demonstration Project, United States (C. Barr, NRC).

The case studies provide the perspectives of those involved in managing and/or regulating the sites, reflecting the real, historic, current and planned future legacy context and activities. They are presented as shared examples of actual practice and experience in applying safety measures to address legacy sites, and to inform the development of international guidance specific to the regulation of nuclear and radiological legacy sites. They have not been edited to correspond to international preconceptions but are the perspectives of those producing them. Part of the intention in examining historic legacy site experiences is to avoid having current installations and sites evolve into new legacy sites. To this end, a further case study has been provided, as follows:

- Case study 11: The Challenges of preventing the development of a legacy situation at Fukushima, Japan (S. Takeda and T. Tanaka, Japan Atomic Energy Agency [JAEA]).

Case study 1. **Little Forest Legacy Site, Australia**

Site description

From 1960 to 1968, the former Australian Atomic Energy Commission (AAEC) disposed of radioactive waste in trenches at Little Forest, near its research facility on the southern periphery of Sydney (now a campus of the Australian Nuclear Science and Technology Organisation [ANSTO]). The waste was disposed of in a series of trenches, following the international practices which were used at that time for the disposal of low-level solid and liquid wastes.

The Little Forest Legacy Site (LFLS) is situated inside the ANSTO buffer zone. It occupies a section of land where the buffer zone juts out from the 1.6 km radius circle around the former HIFAR reactor at Lucas Heights (Figure A3.1). The nearest residential area to the LFLS is the suburb of Barden Ridge, located 2.5 km to the east. The western parts of the suburb of Menai are about 3 km north-east of the LFLS. The LFLS consisted originally of a rectangular area approximately 350 m long and 115 m wide surrounded by a cyclone wire fence, which on the eastern side was close to the trenches.

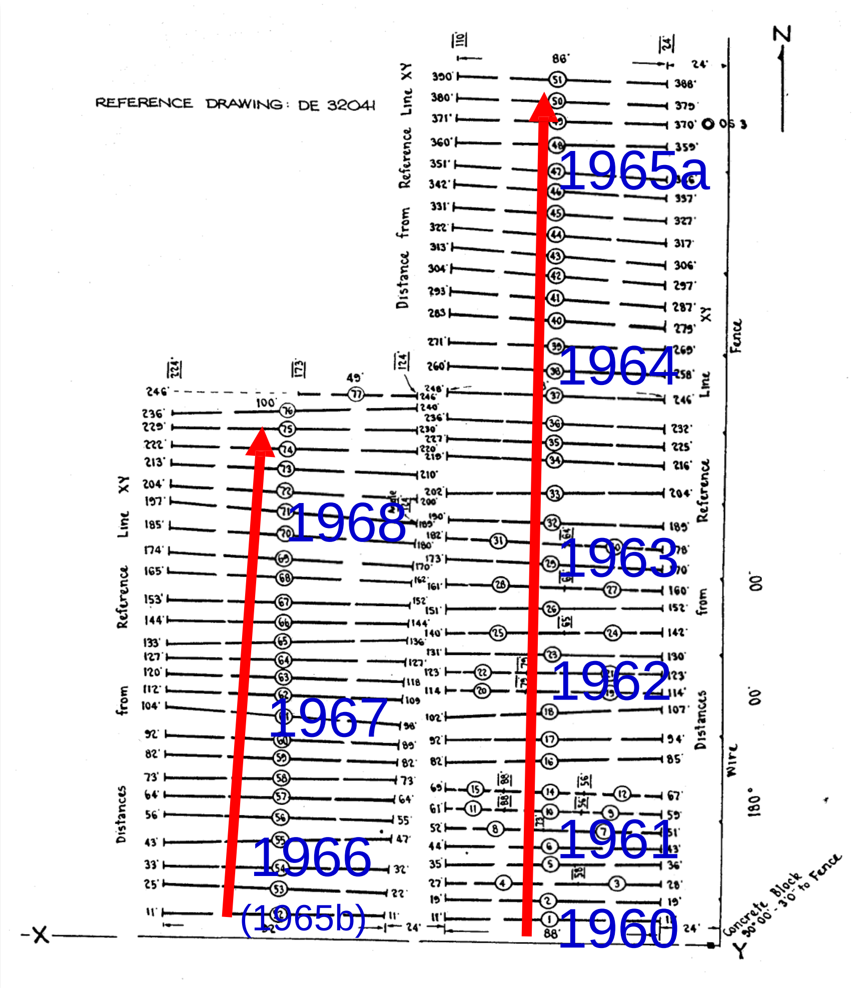
Figure A3.1. **General location map for the Little Forest Legacy Site**

Source: ANSTO.

The site was cleared of its original native shale forest vegetation and is now covered predominantly by grass, which is mown on a regular basis. The site slopes gently to the north and to the southeast, with a surface drainage line developed towards the south-eastern corner of the site. Two adjacent sets of trenches containing the wastes are located on the higher part of the site. In addition, two trenches (S1 and S2) are positioned about 50 m to the south of the main trenched areas. The trenches were filled in a sequential order as shown in Figure A3.2. The trenches were nominally 25 m long, 0.6 m wide and 3 m deep, and spaced 2.7 m apart. The waste was covered by about 1 m of the local clay soil. Records were kept of the disposal operations and these records provide an indication of the materials disposed in each trench.

The LFLS is adjacent on three sides to other waste disposal sites. On the western boundary is a former municipal waste disposal site known as Harrington's quarry. To the west of this site is the Lucas Heights Waste Management Centre, which currently includes a major municipal landfill operation. Immediately to the east of the LFLS is an area formerly used by the Sutherland Shire Council to dispose of night soil (human excreta). To the north-west lies a former industrial liquid waste site used for the disposal of grease, paints, solvents, tannery wastes, etc., as well as specific hazardous industrial chemicals including dioxin-contaminated materials and residues from herbicide production (Coffey Partners, 1991).

Figure A3.2. **The sequence of filling of trenches at the LFLS from 1960 to 1968**



Source: ANSTO.

Regulatory framework

The successor to the AAEC, ANSTO, controls and manages the site. Since the cessation of disposal operations, the AAEC/ANSTO has undertaken continuous care, maintenance, surveillance, monitoring and research activities at the site, through which ANSTO has contributed to international research on such legacy disposal sites.

Australia is a federation of states and territories, overlaid by a federal (Commonwealth) government. ANSTO is a Commonwealth government agency and is subject to Commonwealth, rather than state, legislation. The relevant legislation is the Australian Radiation Protection and Nuclear Safety (ARPANS) Act 1998 and supporting regulations. The Act is regulated by the ARPANS, an independent Commonwealth Authority.

In July 2016, following amendments to the ARPANS Act, the LFLS became the first site to be licensed as a legacy site under that act. A condition was attached to this licence to develop a plan to address the arrangements for managing the wastes and the facility over the medium term (several years to one to two decades) and management over the long term (beyond one to two decades). The medium and long-term management plan needs to be sufficiently well developed, with contingency plans identified, to cope with foreseeable changes in Australia's radioactive waste management policy.

Any remedial action may trigger the threshold for a "Nuclear Action" under the Environmental Protection and Biodiversity Conservation Act 1999 and require the referral of the action to the Department of Environment for assessment.

Characterisation of circumstances

Over the years of disposal at LFLS, the wastes consisted of waste drums (including 760 drums of solidified sludge from the AAEC's effluent treatment plant), chemicals, disused equipment, laboratory trash and contaminated items, contaminated equipment, waste packages consigned from other organisations, and beryllium/beryllium oxide scrap (AAEC, 1985). These included fissile isotopes in gram quantities (plutonium, U-233 and U-235) as well as around 100 kg of the long-lived natural actinides (uranium and thorium). Numerous containers of liquid waste were also disposed and a few items were incinerated on the site.

Figure A3.3. **Excavation and filling of trenches at LFLS**

Source: ANSTO.

The waste is known to have contained various radionuclides including fission products (Cs-137 and Sr-90), tritium, activation products such as Co-60 (used in an irradiation facility at the site), U-238, U-235 and Th-232 (with their radioactive progeny), and small (several gram) amounts of Pu-239, Pu-240 and U-233 derived from the research into power reactor design. This latter activity also resulted in significant amounts of non-radioactive Be (~1 100 kg) being present (AAEC, 1985). Types of information available include Waste Disposal Cards (pink cards), aggregated waste books, waste burial books and photographs.

Since disposal operations ceased, a minor but measurable plume of tritium in groundwater has developed, although this also includes additional contributions from adjacent waste sites. There has been intermittent subsidence of the soil covering the trenches. This subsidence is attributed to voids developing in the buried wastes, due to deterioration of containers and disposed objects. This has led to a mobilising effect known as the "bathtub effect" (or "bathtubbing"), which has been seen at other legacy trench sites.

This process has been described as one in which the waste material has degraded producing voids within a disposal trench, followed by subsidence of the overlying soil and the entry of surface water into the trench. In cases where the soil surrounding the trenches was sufficiently impermeable, the trenches filled with water. Any overflow of water from this "bathtub" would have the potential to distribute radionuclides and other contaminants derived from the wastes directly across the surrounding ground surface. Following such events, which have led to low levels of surface contamination, further soil cover has been added, which has proved to be an effective remediation, at least in the short term.

Societal aspects

The LFLS is contained within ANSTO's current buffer zone, which precludes activities or development without ANSTO's consent. The buffer zone is currently used for a number of recreational activities such as mountain-bike riding and bush-walking (hiking). The site is defined by a security fence with appropriate signage and is currently bounded by several existing or closed waste disposal facilities. As such there is no current societal impact specifically due to the presence of the LFLS. Some adjacent land is owned by the Gandangara traditional owners who are exploring the potential to develop the land for dwellings.

The presence of LFLS has been well known within the local community, and ANSTO is transparent in its communication with the local Council, with which it has developed a strong trust-based relationship. As future remedial plans are developed, these will be shared as part of an ongoing process of consultation with the local community.

End-states and long-term protection values

As noted above, the licence covering the site requires ANSTO, as the licence holder, to develop both medium and long-term management plans for consideration by ARPANSA. ANSTO has commenced a research project at LFLS to enable the assessment of possible management options including continuing the current regime of maintenance and monitoring, in situ remediation or exhumation. The final end-states and long-term protection values will be determined in conjunction with the regulator and local community and will depend on the conclusions of the research-based safety case and assumptions regarding the medium and long-term usage of the land.

The project plan covers a range of potential options including:

- non-intervention and maintenance of the current state, which will serve as the reference case;
- full exhumation of the waste, followed by characterisation and conditioning for interim storage and final disposal at the proposed National Radioactive Waste Management Facility;
- in situ remediation to provide additional engineered barriers for isolation and containment of the current waste inventory.

The potential remediation options under consideration are:

- engineered covers over the trenches to prevent water ingress;
- provision of surface bunds/interceptors to mitigate the spread of radionuclide release;
- subsurface barriers;
- "pump and treat" for water retained within the trenches;
- injecting a suitable grout material, either directly into the trenches or surrounding the trenches, and using a near-surface bentonite clay barrier.

As part of the project, the answers to the following key questions are being sought:

- What was put in the trenches?
- What has come out of the trenches?
- How can the input and export of water to/from the trenches be controlled?
- What chemical and physical processes are occurring?
- Can the trench contents be stabilised and if so, how?
- What are the environmental and human impacts under various scenarios?
- What are the most sustainable remediation options?

The project has been divided into six key sub-projects, which are resourced by experts from within ANSTO and key partners including the University of New South Wales, the University of Newcastle and The University of Strathclyde.

Sub-project 1: In situ grouting options

In situ grouting is considered to be beneficial because it would stabilise the waste; filling the pore spaces within the trenches would decrease volume available for water residing within the trenches and further subsidence may be minimised.

Working with the University of Strathclyde, ANSTO is assessing the potential to utilise colloidal silica as a grouting or barrier medium. Colloidal silica provides a very effective barrier against water transfer and has many physical and chemical properties that make it suitable as a barrier or grouting material. Colloidal silica has a low viscosity, allowing pumping at low pressures. The set time can be chemically increased to allow long-pumping times, increasing the potential to fill all voids within the trench system. The decision whether to inject directly into the trenches or to utilise colloidal silica as a barrier to ground water ingress or egress is yet to be made.

Sub-project 2: Integrated engineering design and test trench

The project involves the assessment of several engineering options, broadly aimed at preventing, minimising or mitigating the effects of water ingress into the trenches and the stabilisation of trench content. The sub-project looks at the individual options and also an integrated study of the combination of engineering options.

Working with the University of New South Wales, ANSTO is assessing the optimum design of engineered cover to prevent surface water ingress into the trenches.

In order to test the engineered options and to better understand the processes occurring within the proximity of the trenches, a series of test trenches is being constructed within the LFLS boundary, but at a distance from the disposal trenches. Test trenches will enable rainfall events to be simulated, improve hydrologic models and enable study of relevant processes (e.g. compaction, subsidence). Crucially, the effectiveness of proposed engineering solutions can be assessed, both initially and, if implemented, over a period of decades.

An important consideration of proposed in situ remediation options is that they should not inhibit any future exhumation of waste if this is deemed necessary.

Sub-project 3: Dose modelling/beryllium assessment

The output of the research project will include a detailed safety case substantiating effectiveness of the selected remediation option in terms of isolation and containment. In order to demonstrate the safety case, a comprehensive approach to assessing impacts on the biosphere from the site under various remediation scenarios is required (more specifically, comparison of in situ and exhumation scenarios). This would inform any comparative cost-benefit analysis and address the sustainability of the selected option.

The presence of a significant inventory of beryllium is a major hazard driver, and any selected remediation options will have to assess the current and residual hazards and risks holistically. Exposure to beryllium and mitigation of the inhalation pathway would be a major consideration if exhumation is undertaken.

Sub-project 4: Records and trench inventory

Detailed compilation of information on radionuclide inventory/trench contents is essential in assessing the status of the site and best remediation strategy. Having a reference inventory is essential in assessing the consequences of fault scenarios identified in the safety case.

The available disposal records have been collected from a number of different locations. The quality of disposal records is variable, although this is a common feature for legacy sites. The disposal records have been collated into a searchable electronic format. This is important given that the records have been dispersed (and in some cases deteriorated). There is a strong driver that the current study should result in a high-quality document archive and records for perpetuity.

The analysis of the disposal records has been used to derive a reference inventory for use in the safety analysis. While it is recognised that there is uncertainty in the reference inventory, this will be managed by the use of conservative assumptions and sensitivity analysis to test the final conclusions.

Sub-project 5: Radiochemistry

Distribution and mobility of radionuclides is a key aspect of the study. This [study?] is very data intensive.

Most of the residual radionuclides at LFLS are either alpha emitters (e.g. Pu-239; Pu-240) or beta emitters (e.g. Sr-90). Analyses for these radionuclides is difficult and time-consuming. Due to the large number of analyses required in the proposed study, additional analytical effort was identified and suitable resources obtained.

Sub-project 6: Benchmarking against international, UK and Australian best-practices

It is important to have expert and objective advice, as well as an external perspective on the project. Specific aspects of Australian regulatory requirements specifically require international best practice to be taken into account.

The participation in the EGLM and similar IAEA working groups, and the input of specialist consultants are considered invaluable in developing an informed, evidence-based option selection and in supporting the substantiation required by external stakeholders.

Conclusions

Little Forest is recognised as a legacy site under legislation, the first of its kind in Australia. Since disposal activities ceased in 1968, the site has been managed and monitored effectively. While there is evidence of minor periodic mobilisation of contaminants, short-term remedial actions have been effective at mitigating any public and environmental risk.

ANSTO, as the entity with management obligation for the site, and ARPANSA, the independent regulatory body, recognise that appropriate remedial actions will be required to secure the facility in the medium and long term. ANSTO has commenced a project to identify the appropriate actions required to secure the site for the medium and long term. The options will be based on the best available techniques and underpinned by a safety case based on robust scientific investigation.

References

AAEC (1985), “The Little Forest Burial Ground: An Information Paper”, AAEC/DR19.

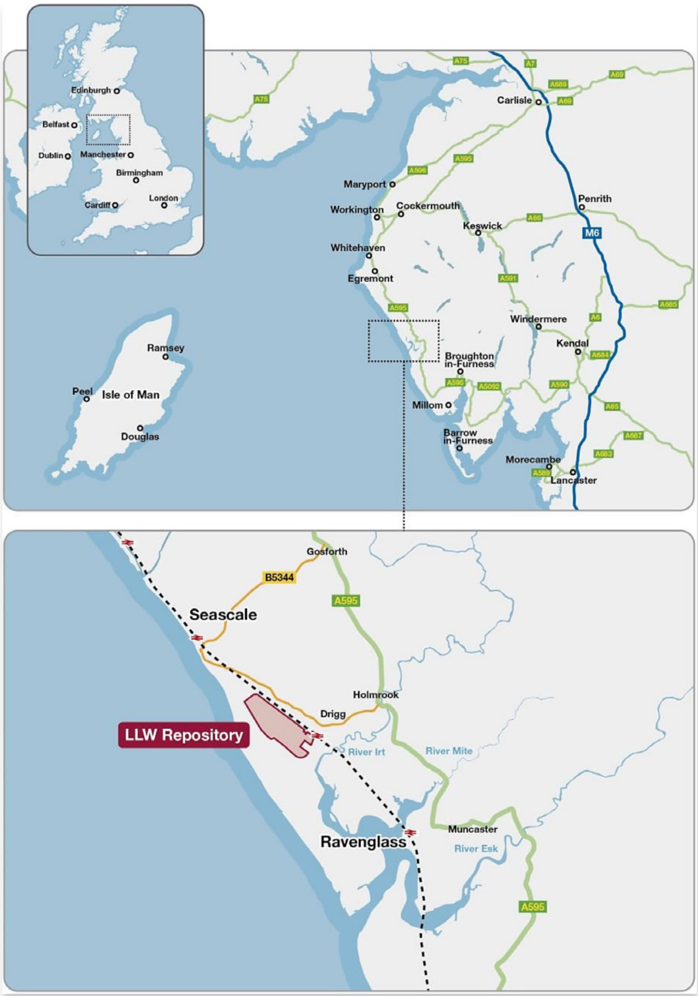
Coffey Partners (1991), *Little Forest: Potential Contaminated Lands Investigation*, West Menai, a report prepared for and published by the New South Wales Department of Planning.

Case Study 2. **The Low Level Radioactive Waste Repository (LLWR), United Kingdom**

Site description

The Low Level Radioactive Waste Repository (LLWR) is located on the coastal plain of West Cumbria about 0.5 km from the Irish Sea coast (see Figure A3.4). It is about 3 km from the Ravenglass Estuary where the Rivers Irt, Mite and Esk join. The Rivers Irt and Mite flow roughly south-west from the hills inland in the Lake District. The River Esk is separated from the other rivers by the prominent bedrock ridge of Muncaster Fell. To the east, the site is bounded by the Carlisle to Barrow-in-Furness railway line.

Figure A3.4. **LLWR site location**



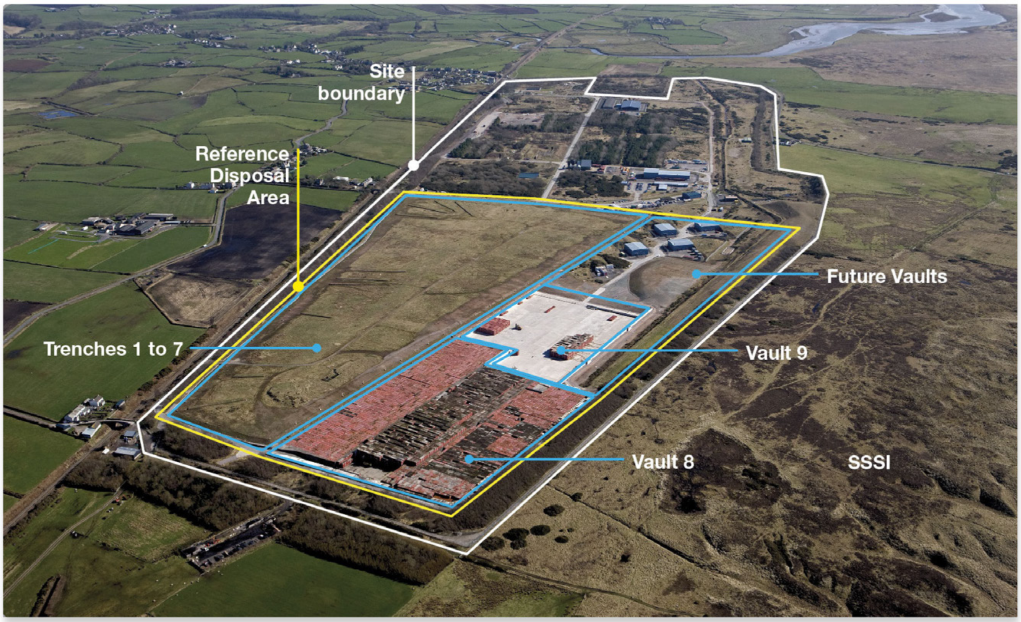
Source: LLWR, 2011.

The site now operated by LLW Repository Ltd on behalf of the Nuclear Decommissioning Authority (NDA) was originally developed as a Royal Ordnance Factory (ROF) during World War II. Prior to that, records suggest that the site was agricultural land. Construction of the ROF was essentially complete at the end of 1941 when it achieved its target production of 400 tonnes per week. During this period the site was connected to the Carlisle to Barrow-in-Furness railway line by two sidings. Trench disposals of LLW commenced in July 1959, starting in one of the former ROF railway cuttings re-engineered for the purpose.

Approximately 1 million m^3 of LLW has been disposed there, initially as loose tipped waste in trenches (1-7) excavated into the ground, and latterly as treated wastes, grouted into steel ISO containers placed within specially built concrete lined vaults. The gross alpha and pure beta activity limits were 20 millicuries per cubic yard and 60 millicuries per cubic yard respectively (approximately 0.97 GBq/m^3 and 2.9 GBq/m^3 respectively), both values being the averages not to be exceeded for the whole of the wastes being buried in one day. The dose rate at the surface of substantially unshielded beta-gamma waste was not to exceed 0.75 rads per hour (0.0075 Gy per hour in SI units). Trench leachate was collected and discharged to the sea.

The main site features as of circa 2011 are shown in Figure 5.1-5.2. Note the now covered trench disposal area and the circa 2011 operational working areas involving a new style of waste emplacement. Trench disposal began to be phased out in 1988 when Vault 8 commenced operation. Disposals to Trench 7 were completed in 1995 and this was then capped.

Figure A3.5. **Aerial photograph of the LLWR site**



Source: LLWR, 2011.

Regulatory developments, and site characterisation and developments

Since 1959, several important developments have occurred, reflecting changing LLW disposal needs, closer consideration of post-disposal impacts, substantially improved site characterisation and corresponding understanding of the surface and subsurface environments, improved safety assessment methods, and updates of regulatory requirements related to the grant of authorisation for disposal. Key features include:

- early 1960s: storage of plutonium contaminated material (PCM) in ten old wartime magazines previously used for storing explosives;

- 1971: revised authorisation issued under the Radioactive Substances Act, 1960;
- 1979: government policy of review of control of radioactive wastes;
- early 1980s: five PCM storage magazines decommissioned;
- 1987: commencement of major upgrade programme and revised authorisation, involving:
  - annual activity disposal limits for certain, individual radionuclides and groups of radionuclides, and limits on concentrations in individual waste consignments of 4 GBq per tonne alpha emitters and 12 GBq per tonne for other radionuclides;
  - a limit on radioactive content of discharges from the LLWR site;
  - an agreed environmental monitoring programme.

The upgrading activities were undertaken with the principal aims of:

- improving management practices;
- utilising the space efficiently;
- reducing the visual impact of the disposal operations;
- implementing a variety of improvements to the barrier system for containment.

The above changes were supported by new safety assessments, accounting for new site information and updated safety criteria and regulatory guidance.

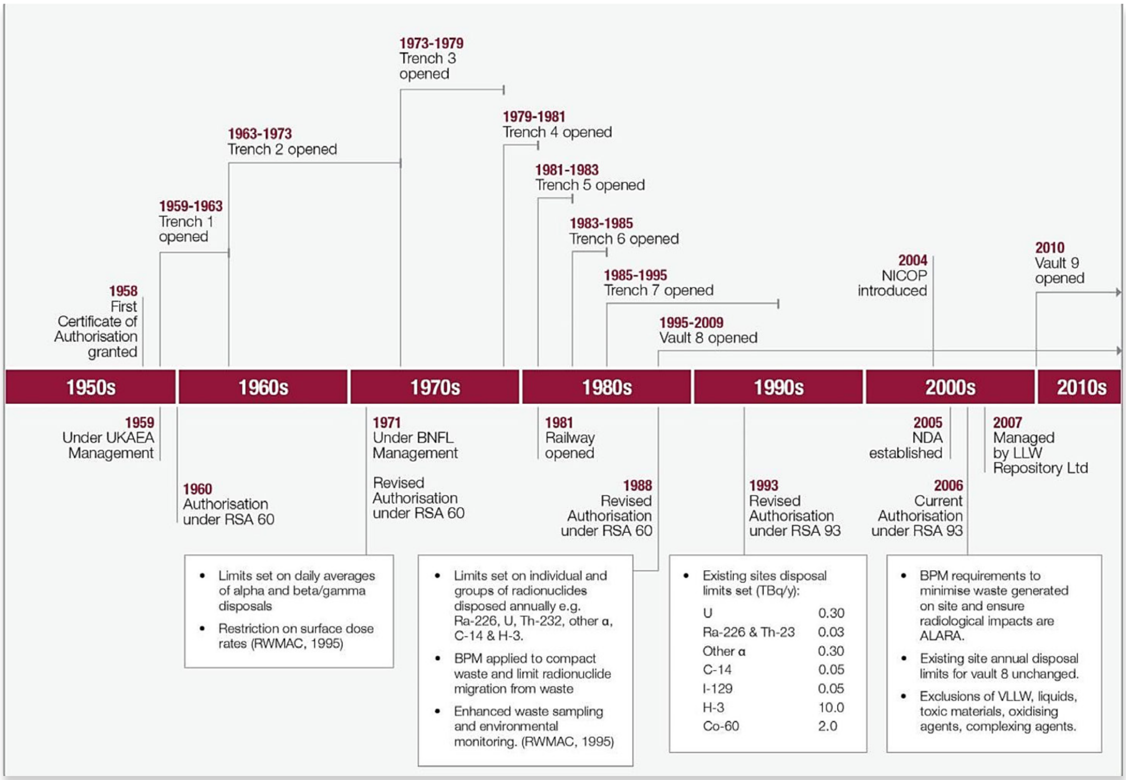
- 1988: commencement of vault disposal operations;
- 1991: commissioning of the Marine Holding Tanks and a new marine discharge pipeline;
- 1993: revised Authorisation issued under the Radioactive Substances Act 1993;
- 1995: completion of Trench 7 cap and extension of cut-off wall to limit underground release of leachate from the trench disposal area;
- mid-1990s: installation of temporary on-site waste treatment capabilities and LLWR waste grouting facility;
- new programme for management of PCM at LLWR from 1997;
- 2002 updated safety case (more than just safety assessment);
- 2006-2010 a range of regulatory developments and revised guidance on near-surface waste disposal;
- from 2010: latest engineering developments;
- 2011: Updated Environmental Safety Case (ESC) and regulatory review.

The above sequence is illustrated in Figure A3.6 with some additional details.

Conclusions, end-states and societal aspects

The above material comes from the LLWR (2011). It illustrates the range of possible changes that can occur through the history of management of waste disposal sites that were commissioned well before present day standards were developed. It shows clearly that the development of a safety case is an iterative process, ongoing through the life of the facility, involving progressive development with focused improvement of data, understanding, design options and assessments.

Figure A3.6. **Timeline of radioactive waste management operations at the LLWR and related developments**



- Limits set on daily averages of alpha and beta/gamma disposals
- Restriction on surface dose rates (RWMAC, 1995)

- Limits set on individual and groups of radionuclides disposed annually e.g. Ra-226, U, Th-232, other α, C-14 & H-3.
- BPM applied to compact waste and limit radionuclide migration from waste
- Enhanced waste sampling and environmental monitoring. (RWMAC, 1995)

- Existing sites disposal limits set (TBq/y):

U	0.30
Ra-226 & Th-23	0.03
Other α	0.30
C-14	0.05
I-129	0.05
H-3	10.0
Co-60	2.0

- BPM requirements to minimise waste generated on site and ensure radiological impacts are ALARA.
- Existing site annual disposal limits for vault 8 unchanged.
- Exclusions of VLLW, liquids, toxic materials, oxidising agents, complexing agents.

Source: LLWR, 2011.

This document and the entire set of 2011 ESC documents is available at: http://llwrsite.com/national-repository/esc-permit-approval. This includes an extensive range of technical reports supporting the demonstration of safety, the set of regulatory review documents and operational permits. The strategic approach taken in managing the radiological capacity of the site takes account of key stakeholder perspectives regarding the implications of alternative options. This process and post-closure management controls and engineering design (end-state issues) have been described in "The 2011 Environmental Safety Case: Site History and Description" (LLWR, 2011).

Apart from radiological safety, a variety of other performance attributes consistent with those used in stakeholder engagement on site end-states have been taken into account in examining factors that potentially differentiate between options.

Reference

LLWR (2011), "The 2011 Environmental Safety Case: Site History and Description", LLWR/ESC/R(11)10018, LLW Repository Limited.

Case study 3: **Ranstad uranium milling plant, Sweden**

Site description

The Ranstad uranium mining and milling plant ("Ranstadverket" in Swedish) was established as a pilot plant in 1960 under the state-owned company AB Atomenergi. It has changed ownership a couple of times through the years, and since 1987 it belongs to RanstadIndustricentrum AB (RIC). The plant was originally licensed under the Coal Mining Law (from 1886) and the Atomic Energy Law (from 1956) and during its main operational phase 1965-1969, about 200 tonnes of uranium were produced from the surrounding alum shale ore. The tails were deposited close to the Ranstad industrial area. Due to the low uranium content in the ore (0.03%), combined with the then low uranium market price, all major operations were terminated in 1969.

During the 1970s, the Ranstad facility was used for R&D projects. Apart from uranium extraction, there were also studies for production of other substances (e.g. molybdenum, vanadium, phosphate, oil and sulphur); however, this work was phased out in 1982 due to low industry interest. The same year, uranium recovery was initiated from waste from nuclear fuel fabrication. Additional requirements from the authorities forced this work to be sized down significantly from 2000-2003 and the facility finally closed down at the end of 2009, in conjunction with the end-date for the operational licence.

The Ranstad site is contaminated with uranium and other heavy metals originating from alum shale and operation of the plant. In 1990, the County Administration Board approved some remediation plans proposed by Studsvik Nuclear AB,[1] the original owner, which still had a responsibility for remediation. Between 1990 and 1994, these remediation actions comprised dismantling/demolition of several buildings, isolating and covering the mill tailings and water filling of the open quarry.

There were no actions for a period of time. Then, in 2006, the County Administration Board, with support from the Environmental Code, issued an injunction requiring further remediation of the site, which was understood to pose a hazard for human and environmental health. Therefore, between 2007 and 2009, further remediation of soil, equipment and facilities (only loose material) was performed by SVAFO AB.[2]

Regulatory framework

The regulatory framework for radiological protection and nuclear safety in Sweden is built on international laws and guidance and it could be used in the Ranstad case even though there were problems connected to rather high concentrations of natural uranium located at the site.

In 2008, according to conditions in the original licence from 1960, the government concluded that RanstadIndustricentrum AB (RIC) was responsible for the ultimate decommissioning of the Ranstad site. The County Administration Board also issued a new injunction, this time to RIC, requesting the full demolition of buildings and facilities in the industrial area. Any waste was required to be sorted and managed according to a waste management plan and the

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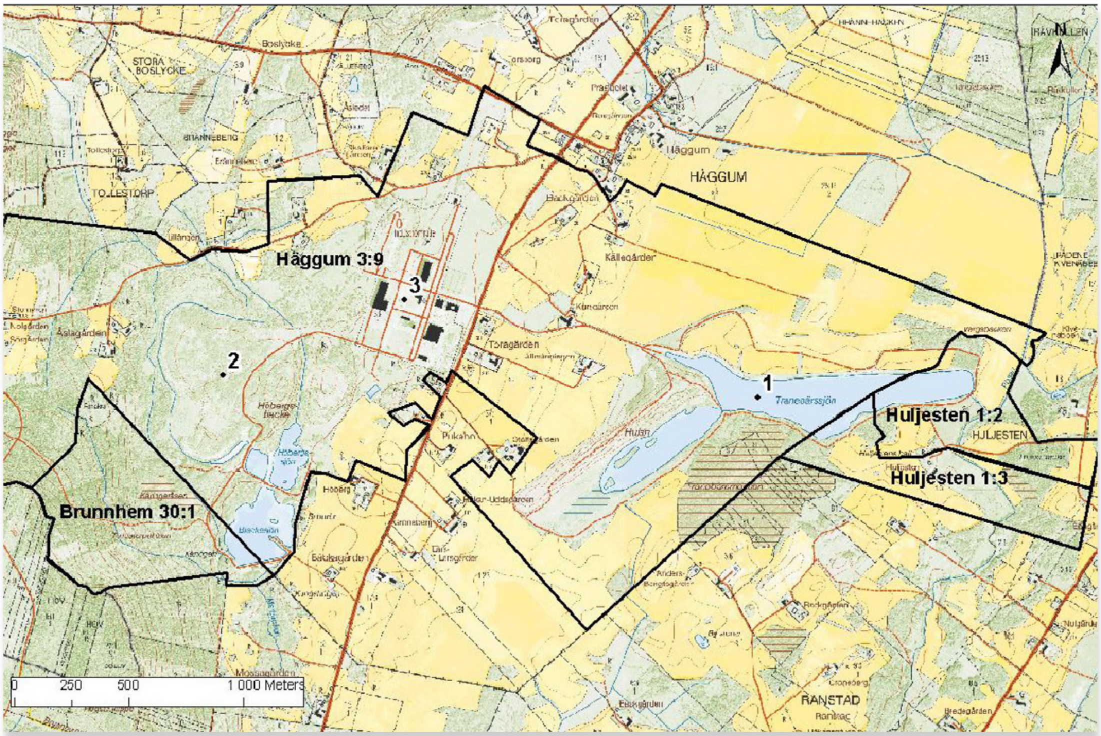
1. Studsvik Nuclear AB is the same company as AB Atomenergi mentioned above.
2. SVAFO AB took over the responsibility to remediate the site from Studsvik Nuclear AB.

corresponding waste ordinance. According to regulations issued by the Swedish Radiation Safety Authority (SSM), RIC developed a decommissioning plan for the entire site.

In 2008, when RIC began to consider decommissioning the site, the party responsible for the decommissioning, both from a practical and financial perspective, was not clear. In 2010, the SSM initiated an investigation and concluded that the earlier radiological protection and nuclear safety authorities should have had more involvement and oversight over the distribution of responsibilities throughout the life cycle of the facility. Some issues are still not resolved, in particular the long-term responsibility for the tailings area.

Figure A3.7. **Ranstadverket overview**



Note: 1. Mining site, now pond. 2. Tailings. 3. Industrial area.

Source: SSM.

Characterisation of circumstances

Regarding radiological contamination, the leaching/extraction facility and the sorting facility were considered to be contaminated, with only minor contamination found in other parts of the plant. The highest amounts of radioactivity were present in the leaching/extraction plant and consisted of:

- natural uranium in alum shale;
- leached shale (tailings);
- uranium concentrates, both natural and low-enriched;
- contaminated equipment, spots of uranium at walls and floors;
- sludge and contaminated materials from the leaching pools.

This contamination originates from the processing of both alum shale and waste from nuclear fuel fabrication and is represented almost only by natural uranium (i.e. U-235, U-238 and their decay chains). The leaching hall was assessed to contain approximately 400 kg of uranium and the total amount of waste to be handled was estimated at approximately 5 000 tonnes.

Significant portions of demolition waste have either been cleared from regulatory control, considered for management as hazardous waste or have been approved to be left in the ground. Some nuclear material has been transferred to other licensees for use as nuclear fuel for light water reactors.

Figure A3.8. **Ranstad site (facilities remaining, 2008)**

Note: 7. Extraction facility; 8. Office building; 10. Waste water treatment facilities; 11. Garage; 12. Workshop; 13. Staff building; 14. Leaching facility; 15. Waste water processing facility; 16. Lime silo; 17. Heating facility; 18. Transformer building; 19. Ore milling (sorting) facility.

Source: SSM.

The following alternative waste routes were proposed by the licensee, based on a 10 μSv/y dose criterion:

- B1: clearance for recycling or reuse of equipment, materials, buildings and offices;
- B4: clearance of offices and buildings for demolition – demolition waste to be used inside the industrial site of Ranstad;

- B7: clearance of materials and equipment for disposal at a disposal site for hazardous waste;
- B8: final disposal of radioactive materials (nuclear waste) in a repository for long-lived radioactive waste (SFL), for waste that could not be cleared.

B1 was enabled by application of SSM regulations on clearance of materials, buildings and land (SSMFS 2011:2[3]). Only minor amounts could be cleared in this way. B4 was enabled in case-by-case decisions by the SSM, based on dose calculations presented by RIC. B7 was enabled by several case-by-case decisions by the SSM, based on dose calculations presented by RIC. The direct disposal waste route was complemented by incineration of both hazardous waste and acid water contaminated with low levels of uranium, since the water treatment facility in Ranstad was no longer in use.

Regarding B8, it was suggested that the waste route include interim storage on another site and final disposal of radioactive materials (nuclear waste) in a planned future repository. This route was anticipated for a few waste units with elevated levels of uranium (1-10%). The SFL is currently planned to start operation in 2045. As there are still no waste acceptance criteria developed, this presented a challenge. However, it turned out that this waste should be classified as material that could be transferred to the fuel fabrication plant owned by Westinghouse Electric Sweden AB.

In 2011, the SSM issued an injunction requiring specific documents and actions to be developed prior to the decommissioning of the Ranstad site. These include:

- a safety analysis report, including descriptions of management of nuclear materials and waste, management systems, radiological protection, physical protection, safety analysis.;
- an established radioactive waste management plan;
- an established management system;
- plans for each stage of decontamination and dismantling of the sorting and leaching/extraction facilities;
- applications for exemptions from requirements that RIC did not consider necessary.

As a result of this and other discussions with the SSM, RIC has also submitted, and the SSM has approved:

- a general decommissioning plan for the Ranstad site (2014);
- a decommissioning waste management plan (2013);
- mapping of radioactive contamination and dose assessment for workers and the population (2012);
- exemptions from some requirements for decommissioning and dismantling of the leaching plant and sorting facility (2012 and 2013; note, special conditions were set for these activities);
- clearance of wastes to be deposited in a facility for disposal of hazardous waste (loose materials, dismantled components, remainders of alum shale, floors, etc.; 2012);
- clearance of uranium-contaminated waste for incineration in a facility for treatment and disposal of hazardous waste (2015);
- decisions on clearance of buildings, with subsequent use of building rubble as filling material within the Ranstad industrial area (2013 and 2016).

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[3] www.stralsakerhetsmyndigheten.se/publikationer/foreskrifter/ssmfs-engelska/ssmfs-20112.

Societal aspects

The supervision by the County Administration Board and by the SSM is well documented and to a large extent open for insight of other organisations and members of the public. No concerns from the public have been raised during the decommissioning project.

End-states and long-term protection values

The end-state of the Ranstad decommissioning project is to enable future industrial use of the industrial area. The mill tailings will probably be declared as a closed disposal site, with conditions concerning monitoring, surveillance and restrictions on future use. Discussions are ongoing between the County Administration Board and the SSM regarding how to solve the problem of long-term protection and monitoring of the mill tailings area. The ongoing control performed by SVAFO AB will soon be finished and there are questions needing to be answered as to who should have the responsibility for monitoring and for the financing of a monitoring programme.

Conclusions

The Ranstad facility has had several owners under shifting legislation and regulatory supervision. Regarding decommissioning, it was not performed properly between 1984 and 2008. As a result, uncertainty of responsibility remains, especially for certain wastes and for the mill tailings disposal area. The small-scale operator from the beginning of the 1980s did not have the personnel and technical resources necessary for a modern approach to decommissioning, but the situation was solved by the use of external consultants, contractors and regulatory advice.

The heavy administration of such a project may not seem commensurate with the involved radiological risks, but it is necessary to achieve public confidence and to justify security in other matters. Importantly, it has provided valuable experience from the application of existing regulations and development of procedures for decommissioning.

Reference

There are no references on this subject available in English. Readers are recommended to contact the SSM for further information on matters of particular interest. However, a description of the history of uranium recovery in Sweden is available in English:

Hultgren, Å. and G. Olsson (1993), “Uranium recovery in Sweden – History and perspective”, SKB Arbetsrapport 93-42, SKB.

Case study 4. **Søve, a former Niobium mine, Norway**

Site description

The state-owned mining company NorskBergverk was responsible for Søve, a niobium (Nb) mine, between 1953 and 1965 in the Norwegian county of Telemark (N 59°16.902’ E 009°17.162’), in the geologically well-known Fen complex. Here, rock compositions include considerable quantities of thorium (Th-232) ore as well as enhanced quantities of rare earth elements and iron (Fe).

In the western part of the Fen complex, where the Søve mine is located, the predominant bedrock is søvite, which consists of calcium carbonate and minerals such as pyrochlore, columbite and fersmite rich in Nb and naturally occurring radionuclides, specifically Th-232 and uranium (U-238) (though to a lesser degree than Nb). The main Nb-bearing mineral, pyrochlore, was identified early and vastly exploited commercially. In total, it is estimated that 1.15 million tonnes of søvite were extracted and then passed though subsequent extraction processes.

The former Søve mining site was decommissioned in the 1960s. Waste from the Søve mine, as both crushed stone and slag, was left in an area just outside of the processing plant. Primary hazard areas, identified as a sludge disposal site, a wash-house and a slagheap, are now accessible to the public in a local recreation area close to Nordsjø Lake. Additionally, a mechanical engineering shop is located on part of the prior mine site. When the mine was active, worker protection was regulated at the site, but waste management and discharge of radioactive materials was not. After decommissioning the site for economic reasons, remediation began in the form of overlaying numerous parts of the site with sand.

Regulatory framework

Environmental concerns relating to mining in Norway are addressed under the Mining Act, Pollution Control Act and the Planning and Building Act. In January 2011, revised legislation for radiological protection came into force with the Pollution Control Act, which is enacted through regulations on radioactive pollution and waste, and regulations related to the recycling of waste. Radioactive substances have been included into the law as environmental contaminants in the same line as other, previously listed contaminants, such as heavy metals and hazardous organic substances, and a graded approach for waste classification and consequently further disposal has been developed. The act applies to all activities, including existing, planned and legacy mining sites, to provide the same level of regulation and protection for humans and the environment, irrespective of the source.

In accordance with the revised Pollution Control Act and EU BSS Directive from 2009, the Norwegian Radiation Protection Authority (NRPA) has been working on mapping all mining sites (existing and legacy) where radiological protection and radioactive pollution to the environment could be issues of concern. Søve mine was identified as the site most vital for clean-up. No active mines are known to have radioactive pollution or radioactive waste. The amount of radioactive nuclides in the waste at site Søve was considered high enough to damage or cause significant inconvenience to the environment or public, according to the above-mentioned regulations set out within the Pollution Control Act on Radioactive Pollution and Radioactive Waste §2b.

In 2000, Telemark County asked the NRPA whether the radioactive mine residue was safe for the public. The Directorate for Mining, in co-operation with NRPA, initiated renewed investigations into the radioactive residues. Based on these investigations the decision was made to completely recover the area.

The role of the NRPA in this case study can be summarised as:

- the main regulatory authority;
- offering guidance and support to the ministry concerning radiological protection and environmental-related questions or doubts;
- the co-ordinator between the regulator, operators and organisations of concern to achieve best results, through a positive mutual understanding and sharing of responsibilities in a transparent and open way.

The key challenge in regulating this legacy site has been to identify the responsible party to investigate the existing residues and carry out possible recovery options for the area. The old mine site and the radioactive residues were sold by the state-owned mining company, which used to run Søve mine, and are now owned by the local county. When the contract for sale was established, it emphasised that "…property is transferred in the condition it is in, and with the concomitant rights and obligations belonging to the seller…"

After lengthy discussions between the county and the Ministry of Trade, Industry and Fisheries (MTIF), the latter agreed to take fiscal responsibility, but made sure to point out that they are not the sole party responsible for the area. The NRPA instructed the MTIF to first survey the radioactive pollution at the former Søve mining site and then to identify the necessary steps to counteract the pollution. Based on the MTIF's proposed plan, the NRPA then asked the MTIF to perform those preventative measures that they had proposed to counter radioactive pollution.

The MTIF also proposed to remove the waste classified as radioactive and send it to a repository. While there currently are four repositories in Norway with a licence to accept this waste, it has been difficult to find a repository that will accept it. This is primarily because of a concerned public, especially neighbours with homesteads and businesses within the vicinity of the repositories. The removal of radioactive waste was nonetheless planned for 2017-2018.

Characterisation of the circumstances

The question of waste management and radiological protection at Søve became a focal point in the last decades and the MTIF took responsibility for the Søve site in 2011. The NRPA has also completed several joint field expeditions to Søve mine (such as the aforementioned mid-2000 investigation in co-operation with the NRPA and the Directorate for Mining) and has measured enhanced gamma dose rates, as well as soil, water and sludge naturally occurring radioactive material (NORM) activity over the past ten years.

Measurements over the last decade have consistently confirmed the presence of NORM pollution in this area. High gamma dose rates and hot spots of U-238 and Th-232 and their progeny contamination have been identified (Table A3.1). More recently, new site characterisation efforts have been undertaken, along with impact and risk assessments and an evaluation of options for waste management.

The current estimated amount of slag is 825 tonnes or 236 m^3. Estimated amounts of crushed stone are close to 23 000 m^3. The highest level of radiological activity is typically found in the slag. The maximum measured gamma dose rate in the air was most recently 20 µGy/h. Maximum values of Rn-220 were also high (1.200 Bq/m^3).

NORM activity concentrations in soil and waste material at different sub-sites were also found to be higher than exemption levels provided by legislation for radioactive waste (Table A3.1). The majority of NORM concentrations in waste were in excess of 1 Bq/g.

However, only a limited transfer to biota of Th-232 and U-238 series radionuclides was observed; this was not a sufficient amount to induce population-level effects. Still, effects from multiple stressors on other organisational levels could not be excluded. For humans, terrestrial gamma radiation was the main contributor to outdoor exposure with annual doses of up to 30 mSv, being estimated in "worst case" scenarios. The difficulty and significant uncertainty associated with the inclusion of high Rn-220 in the dose assessment was seen.

Table A3.1. **NORM concentrations in soil and solid waste material; summarised ratio to exemption levels**

Area	Sample	Activity (Bq/kg)						Σ activity/ exemption level
		U-238	Ra-226	Pb-210	Th-232	Ra-228	Th-228	
Exemption levels		1	1	1	1	1	1	
1a	Wash-house 1	10.9	12.5	13.6	15.4	18.8	19.5	103.0
1b	Wash-house2	5.2	3.3	2.7	7.7	8.7	8.3	39.2
1c	Wash-house 3	1	8.8	8.9	1	9.9	1.1	39.5
1d	P1-0m	Na	5.4	Na	Na	5.2	Na	16.0
1d	P2-0m	Na	5	Na	Na	5.2	Na	15.2
1d	P3-0m	Na	0.04	Na	Na	0.02	Na	0.12

In the same year, state responsibility for this site was made clear (2011); the NRPA officially ordered the MTIF to deliver full site characterisation and proposals for clean-up solutions. This decision was taken in order to stop further contamination to the environment and to diminish the risk to both human populations and biota in the area. An action plan with clean-up measures, proposed by the MTIF was approved by the NRPA in 2013 and the deadline for action was set for the end of 2014. However, to be able to deposit the radioactive masses from Søve mine, additional investigations of behaviours of radionuclides Th-232, U-238 and their progeny are required from the proposed disposal sites. Leaking tests are currently ongoing to show the mobility potential of radionuclides through soil phases and into the water. This kind of information will help to estimate the stability of radioactive waste in future and will support a decision concerning where the waste should be disposed. Therefore, the NRPA prolonged the time requirements allotted for final clean-up of the Søve site.

Societal aspects

On the topic of the public, risk communications with those living near the site has also been somewhat difficult. This is partly due to insufficient information on the existing exposure situation, but is coupled with increasing negative media and public attention, with speculation over the magnitude of doses at and around the site. In the last decade, in addition to the MTIF and the NRPA, municipalities and universities have also begun to become involve. This further complicates matters as, with the mix of organisations involved, it has been difficult to communicate clear messages to the myriad stakeholders, including local people. This negative media coverage has even led to further problems regarding final waste disposal, since the local community and politicians from the district of the best potential repository were clearly against receiving the waste. Finally, the state has to be involved in finding the solution for Søve waste disposal.

Several aspects of this case study – especially the determination of the responsible party for this legacy site, as well as risk communication to the public, several investigation studies done by different actors and a lack of clarity in some messages about dose magnitudes – have made the radiological protection and waste management process at Søve complicated.

In this case, it has been seen that early identification of the roles of all involved parties and clearly defined tasks and deadlines is important for proper waste management and thus minimisation of the risk to humans and the environment. Further, radioecological investigations are a necessary step in radioactive waste management, and the dependence of repository choice on radioecological leach test results is clear.

With respect to regulation, close co-ordination and frequent contact between the different parties involved in this case have been highly necessary and beneficial. However, the NRPA and the MTIF should continue working on established communications and available information for exposure risks to the public, and especially keep working with local and regional media outlets, universities and businesses to improve reporting about the site and region.

End-states and long-term protection values

The end-state of the former mining site Søve is to enable common unlimited use of the area that is now partly a mechanic-engineering shop and partly on the shores of the lake and near a settlement area. The main objective, currently, is to finish clean-up of the area according to the agreed solution to dispose the waste in the proper repository with complete recover that will be monitored with pre-defined environmental requirements to ensure long-term protection. Collaboration of the state's authorities and deposition sites to find the best solution for management of this legacy waste will continue.

Conclusion

Since decommissioning the Søve site, enhanced radiation levels such as gamma dose rates, radon levels in the air, activity concentrations of Th, U and progeny have continued to be observed on and around the site. It is clear that remedial activities and continued clean-up at Søve will assist in decreasing further seepage of radioactive contamination into the environment. The MTIF will continue to monitor environmental conditions around the site to prove that after remediation the waste is not a continuing source of contamination.

Estimated waste at Søve consists of 236 m^3 of slag and around 23 000 m^3 of crushed radioactive stone. The Ministry of Trade, Industry and Fisheries has proposed to completely remove the waste and deposit it at a licensed repository that is in compliance with NRPA regulations for storage of such waste. The NRPA confirmed this to be a suitable solution for the radioactive material. Final waste removal is now planned to be finished in 2017. Collaboration of the state's authorities and deposition sites to find the best solution for the management of this legacy waste will continue.

Legacy waste management from the Søve mine has been complex due to unclear responsibilities for the site and waste, unclear roles and duties and negative public perception, even though remediation and waste management is not difficult. To be able to continue to solve problems that arise, close collaboration between the regulator, responsible ministry, county and repository should continue.

Case study 5. Stráž Pod Ralskem and Rožná legacy sites, Czech Republic

Site description

The Czech Republic was the birthplace of wide-scale uranium mining, which started in the 1890s on an industrial scale in and near the town of Jáchymov, in particular to produce the colours requested by glass and porcelain manufacturers. In the early 1900s, Marie Curie discovered radium within the uranium at the Jáchymov mines and until World War I this was the only known source of radium production in the world. Pre-Cold War uranium production has been estimated to be around 1 000 tonnes, but starting from 1947 the Czech Republic produced uranium for the former Soviet Union.

Including the early mining sites, such as Jáchymov, HorníSlavkov and Příbram, the Czech Republic is estimated to have produced 110 000 tonnes of uranium from 64 uranium deposits. This case study focuses on two of these sites, Stráž pod Ralskem and Rožná.

Mining took place at the Stráž pod Ralskem site in the Liberec region from 1967 until 1996, by which 15 562 tonnes of uranium has been extracted. The site's mining area covers 24.1 km^2 and reaches a depth of 220 m beneath the surface. Even though mining has stopped in the traditional sense, uranium has continued to be exploited as a by-product of the remediation of the Stráž uranium deposit. More than 2 200 research boreholes and almost 7 700 mining boreholes have been drilled into this deposit. The majority of activity up to today has been chemical uranium mining using in situ acid leaching processes with H_2SO_4 and HNO_3. Thirty-five leaching fields were established, covering an area of 700 hectares.

Fifty-five kilometres north-west of Brno, is the Rožná underground facility in the Vysočina region, where a uranium mine operated since 1958. A chemical processing plant and two tailings impoundments have been in operation there since 1968, where 11 shafts and approximately 580 km of mine tunnels have been dug over 8.76 km^2. Mining is conducted to a depth of between 950-1 100 m beneath the surface. Annual uranium extraction at Rožná was around 200 tonnes between 2000 and 2016, with around 18 370 tonnes of extracted material over the life of the site. Specific activities at Rožná have consisted of gradual wall slicing under a man-made ceiling, with backfill, the selective method for multi-level tunnels. There also exists a chemical uranium ore processing plant (alkaline leaching) and storage of sludge at the tailings impoundments. Extraction of uranium ore ceased in April 2017.

Regulatory framework

The regulatory framework for radiological protection and nuclear safety in the Czech Republic is built on international laws and guidance. The new nuclear law system of the Czech Republic has entered into force on 1 January 2017. Act No.263/2016 Cool. – Atomic Act and implementing Decrees No. 422 on Radiation Protection and Security of a Radioactive Source, No. 377 on the requirements for the safe management of radioactive waste and on the decommissioning of nuclear installations or category III or IV workplaces, No. 360/2016 Coll. on radiation situation monitoring and others.

The state enterprise DIAMO, based at Stráž pod Ralskem, is an organisation dealing with the elimination of consequences of mining and ore processing activities. The attenuation and remediation programme is in compliance with the state policy for progressive improvement of the quality of environment and elimination of old environmental burdens with state funding.

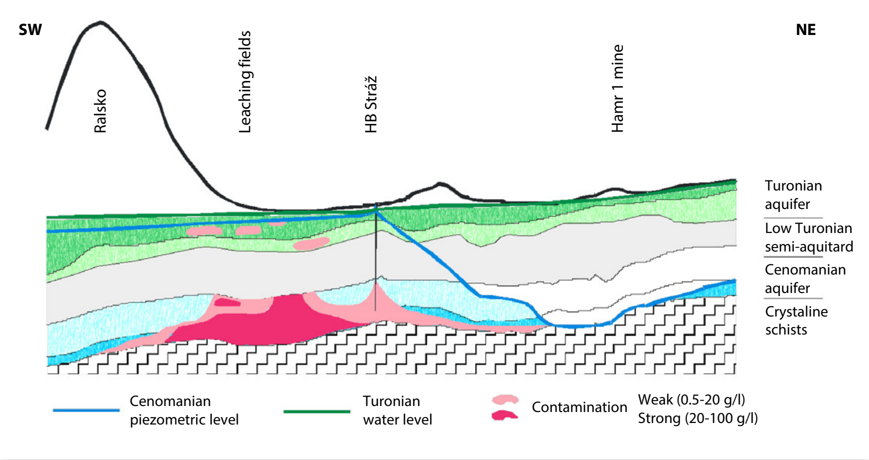
The programme commenced in 1989 and consists of the implementation of a liquidation programme to eliminate the consequences of survey, mining, treatment and processing of uranium from uranium deposits.

The concept of the performed liquidation and remediation work is based on individual resolutions of the government of the Czech Republic; for the individual localities, the concept is described in technical projects of liquidation and rehabilitation. Removal of the consequences of the survey, mining and processing of the above-mentioned raw materials is performed in compliance with strict requirements for environmental protection and development.

Characterisation of circumstances

Due to chemical processing of uranium at Stráž approximately 186 million m^3 of contaminated groundwater exists in the Cenomanian aquifer, and another 80 million m^3 in the Turonian aquifer. There are additional challenges with the soil surrounding both aquifers. The groundwater contamination at Cenomanian and Turonian leaves residual technological fluids in the ground. During mining operations, the underground was subject to 4 100 kt of H_2SO_4 (of this, 80% reacted with the ore and 800 kt remained in the form of loose H_2SO_4), as well as 312 kt HNO_3, 112 kt NH_3, 26 kt HF and 1.5 ktHCl.

Figure A3.9. **Schematic cross section of the area of in situ leaching**



Source: SÚJB.

At the Rožná site, there has been continuous outflow of contaminated mine water. This water undergoes regulated out-pumping and treatment, and the treated water is later released into the Nedvědička stream. This treatment of mine water was specifically carried out in localities where mining activities had been discontinued under the framework of reducing such activities. Since the end of mining, close to 6.5 million m^3 of water has been released to streams from the mine and mining facility through the main outputs (where cleaned water is released to the stream), including already-treated additional sludge water from the Rožná deposit. A higher level of treatment is required for runoff from the tailings impoundments.

Liquidation and rehabilitation of the extraction fields at Stráž are underway, as well as a broader remediation of the mining area with an aim to: i) remove the uranium enriched solutions from underground water; and ii) revitalise the district's environment wherever affected by chemical mining. The remediation activities include pumping out and treating the water at both the desalination plant and the neutralisation and decontamination plant. This evaporation technology works at a capacity of 5.5 m^3.min-1 and is followed by crystallisation, re-crystallisation (crystal sulphate of ammonium aluminate) and the removal of salts and metals at an operational capacity of 5.5 m^3 per minute, the results of which are further processed into both usable and non-usable products. The treated water is released into the Ploučnice River.

Societal aspects

An integral part of the remediation of mining activity consequences is represented by payment of social and health benefits to the former and current employees of the DIAMO, state enterprise, including all organisations for which DIAMO, state enterprise, became their successor company.

The supervision is well documented and to a large extent open for insight of other organisations and members of the public. No concerns from the public have been raised during the decommissioning project.

Several meetings have taken place between the local committee to illustrate possible interventions and monitoring of the contaminated leachate flow.

The outlets of the main abandoned mines managed by branch and closed in the past after completion of survey and mining of uranium are periodically inspected. The landscaped piles are used for planting of the damaged forest cultures and fence repairs. The mining, liquidation and remediation works include monitoring of their effects on the environment.

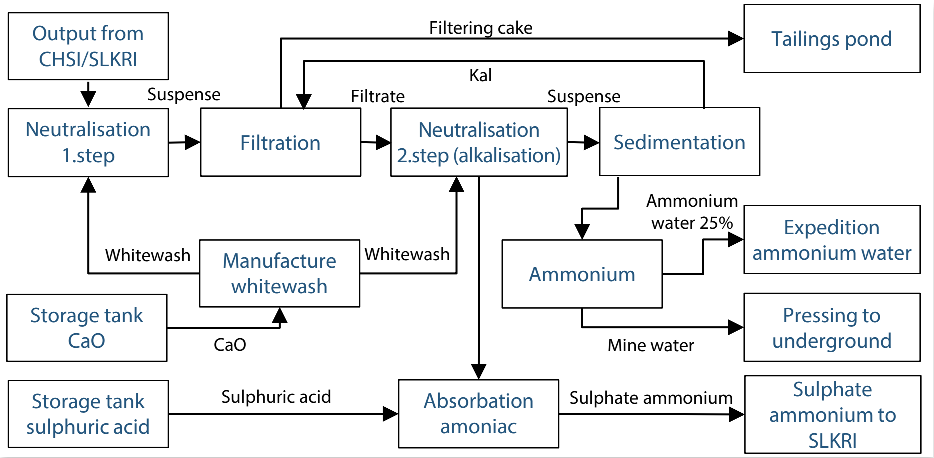
The remediation and reclamation work in both areas is very well received by local authorities and by the population, because both areas and especially the Stráž area want to focus in the future on the development of tourism and its infrastructure.

End-states and long-term protection values

A number of milestones have been important throughout the remediation process. In 2011, target values for remedial parameters (TVRP) were set on the basis of an original risk analysis and the TVRP was subsequently approved by the Czech authorities (Ministry of Environment, Ministry of Industry, State Office for Nuclear Safety) with a final goal to reach TVRP by 2037.

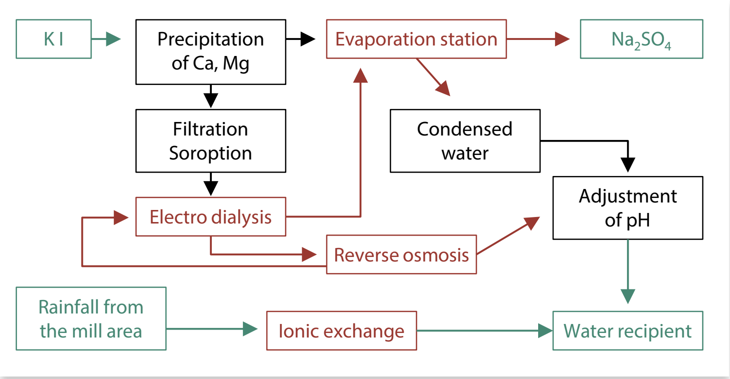
In 2012, all necessary remedial surface technologies (neutralisation stations) were completed and the necessary storage was secured for residual materials from technological processes. In 2014, the TVRP risk analysis was updated and the first steps of the TVRP were confirmed as completed. It was decided (Ministry of Environment) then that this confirmation and update process will be performed every five years. The ultimate objective is to achieve liquidation of the in-situ leaching area, evaporators and other surface objects, designated as CHSI and SLKRI in Figure A3.10, and full landscape revitalisation by 2042. The total costs for remediation process are expected to be on the level of EUR 2 billion.

Figure A3.10. **Chart of technologies for remediation ISL**



Source: Adapted from SÚJB.

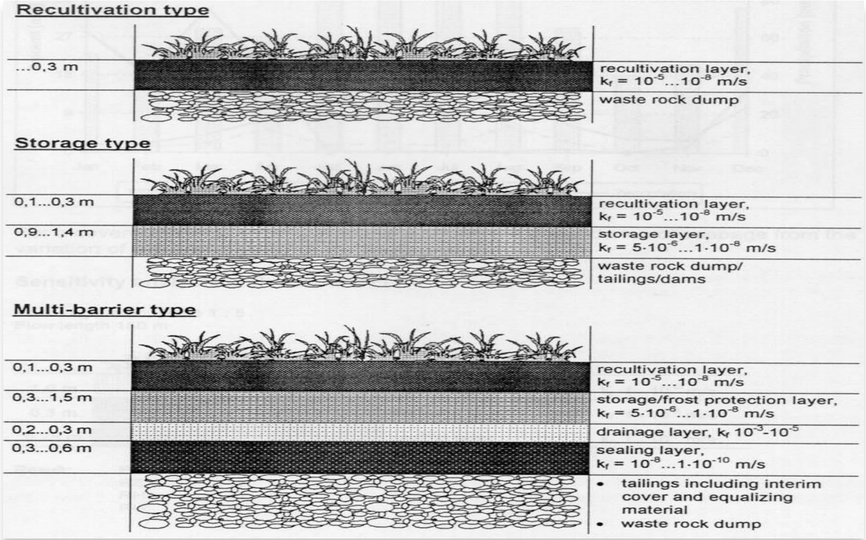
Figure A3.11. **Chart of water treatment at Rožná**



Source: Adapted from SÚJB.

At the Rožná site, site dismantling and gradual rehabilitation are underway (mine tunnels, dumps, the tailings impoundment, unusable structures). Based on a decision by the State Office for Nuclear Safety, the entry points of deserted major mines, dismantled after the completion of prospecting and/or uranium mining, are regularly monitored by the organisation that will oversee the site's remediation. Restoration works include planting of forest trees, and replacement of damaged forest trees on reclaimed dumps, as well as specific fence repairs. An important part of the mining, dismantling and clean-up processes is continuous monitoring of environmental impacts, for which conditions are currently under review as part of a national monitoring plan. A number of conclusions were drawn and practical implementations carried out based on a specific investigation programme for disposal and remediation at Rožná (approved by the Czech authorities). Primarily, these include the construction of new separators for inner dams and the deposition of sludge under the water level reaching the centre of the tailing pond. As a preliminary step of technical restoration, methods should be considered for covering (with non-sorted fresh tailings) the finest tailings that have been deposited in the centre of the tailing pond.

Figure A3.12. **Ending overlap sludge beds (tailing ponds)**



Source: SÚJB.

Further needs for remediation have been concluded based on mathematical modelling of the tailings ponds. These include a reduction of i) overall water salinity; ii) concentration of uranium in seepage water to one-third within 50 years; and iii) concentration of sulphates from 16 g/l to 4 g/l within 50 years. The necessary capacity for water treatment equipment should handle 400 000 m^3/year. Additionally, the central parts of the tailings pond (which is the deepest area of the pond, where fine-grained sludge is deposited) should be filled with coarse materials for better stability and better conditions for land reclamation, especially with regard to a building up of internal dams.

Conclusions

Authorities and operators discovered the need to specifically ensure that in situ leaching mining did not happen within the vicinity of drinking water reservoirs or in the same areas for underground mining. Additionally, it was found that early securing of long-term financing, as well as clear definition of environmental goals and end-states, are necessary prior to starting any remediation process.

Case study 6. **Shiprock disposal site in New Mexico, United States**

The Shiprock disposal site is a former uranium- and vanadium-ore processing facility located within the Navajo Nation in the north-west corner of New Mexico, near the town of Shiprock. The former Navajo Mill at the Shiprock site was constructed and operated from 1954 to 1963 by Kerr-McGee Oil Industries, Inc., and from 1963 to 1968 by Vanadium Corporation of America, which merged with Foote Mineral Company in 1967. Former milling operations at the site created process-related wastes and radioactive tailings.

Most of the waste generated during operation of the mill is managed on-site. The site is managed by the US Department of Energy (DOE) Office of Legacy Management. In 1983, the DOE and the Navajo Nation entered into an agreement for site clean-up. By September 1986, all tailings and associated materials (including contaminated materials from off-site vicinity properties) were encapsulated in a disposal cell (see Figure A3.13). Remediation of contaminated groundwater from past milling operations is ongoing.

Site description

The Shiprock site consists of two distinct, hydrogeologic systems: the terrace and floodplain systems. In general, the geologic profile of the region consists of alluvial deposits of Quaternary age, which overlie Cretaceous age Mancos Shale. Underlying the Mancos Shale is the Cretaceous age Dakota Sandstone and the Jurassic age Morrison Formation. Groundwater occurs under confined conditions in the Dakota Sandstone and Morrison Formation. A free-flowing artesian well, constructed near the site approximately 460 to 580 m below land surface, discharges at a rate of 200 L/min into Bob Lee Wash, a drainage dissecting the terrace northwest of the disposal cell (see Figure A3.14).

Contaminated groundwater, from milling operations, exists in terrace alluvium and weathered Mancos Shale near the former mill site. During mill operations, an estimated $3.2 \times 10^{+09}$ L of water was discharged into the terrace system, producing a significant groundwater mound above the alluvium-Mancos Shale interface. Impacted water is not expected to migrate to the lower aquifer given confinement of the deeper aquifer and upward gradient.

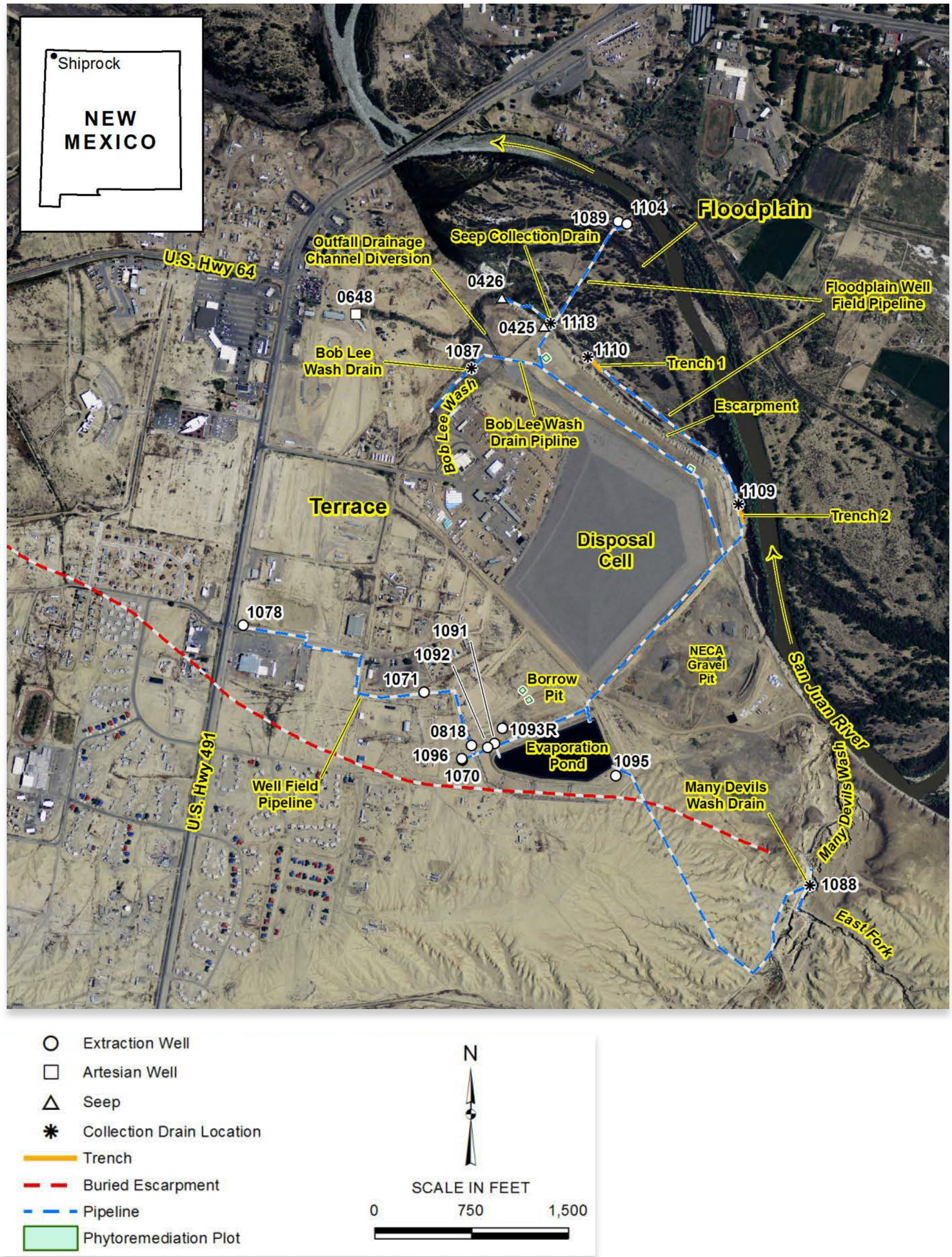
In addition to losses from the San Juan River, seepage and discharge of groundwater from the terrace groundwater system are sources of groundwater to the floodplain (see Figures A3.13 and A3.14). At the north-east edge of the terrace, a steep escarpment 15 to 20 m high forms the boundary between the San Juan River floodplain and the terrace area. Seeps at the edge of the escarpment and on Bob Lee Wash were activated and contributed to the lingering contamination of the floodplain.

Regulatory framework

From 1943 to 1970, much of the uranium ore mined in the United States was processed by private companies (DOE, 1996). After fulfilling their contracts, many of the uranium mills closed and left large quantities of waste, such as uranium mill tailings and abandoned mill buildings, at the mill sites. Beginning in the late 1960s and 1970s, direct gamma radiation, radon gas and uranium decay became regulatory concerns.

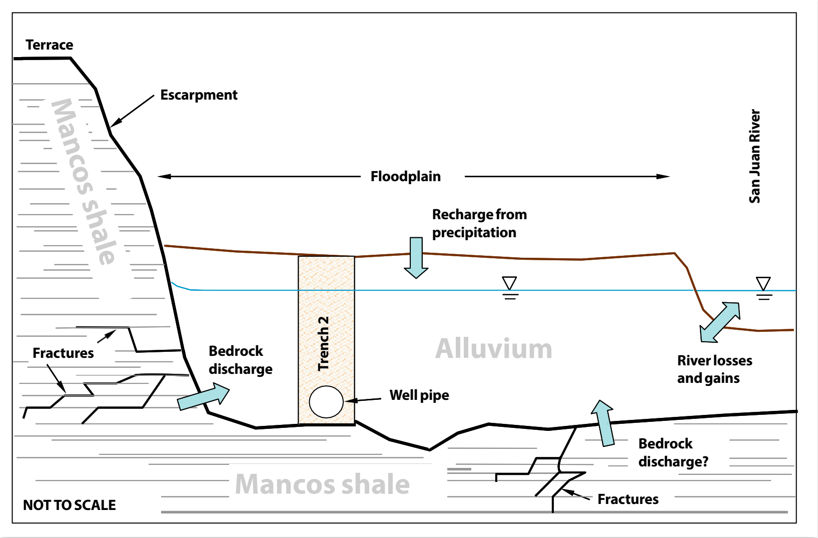
The conceptual model for the terrace groundwater system assumes vertical movement of contaminated groundwater from the terrace alluvium through the weathered Mancos Shale into fractures and bedding surfaces of the unweathered Mancos Shale and finally to discharge into the floodplain alluvium.

Figure A3.13. **Features of the Shiprock site and remediation system**



Source: Adapted from Figure 1 in DOE, 2016.

Figure A3.14. **Conceptual model depicting flow to San Juan River Floodplain**



Source: DOE, 2009.

Products at the abandoned mill sites were determined to be potential health hazards. In 1972, concern for the potential long-term adverse health effects from uranium mill tailings used as fill material in construction projects led the United States Congress to pass a law funding clean-up of the contaminated buildings. Public concern about other abandoned uranium mill sites led to engineering and radiological studies to identify mill sites in need of clean-up. As a result of these studies, the United States Congress passed the Uranium Mill Tailings Radiation Control Act (UMTRCA)[1] in 1978, establishing programmes for the stabilisation and control of mill tailings at uranium and thorium processing sites.

The Shiprock disposal site is managed by the DOE Office of Legacy Management. In 1983, the DOE entered into an agreement for clean-up of the site with the Navajo Nation, resulting in the encapsulation of tailings piles, which was completed in September 1986. A long-term surveillance plan was prepared for the disposal site in 1994. After the long-term surveillance plan was approved, the US Nuclear Regulatory Commission (NRC) included Shiprock under a general licence[2] in September 1996. Site ground water clean-up was deferred to the UMTRA Ground Water Project. Ongoing groundwater restoration activities include active groundwater extraction, as well as use of Environmental Protection Agency's (EPA) supplemental standard provisions provided in 40 CFR 192.

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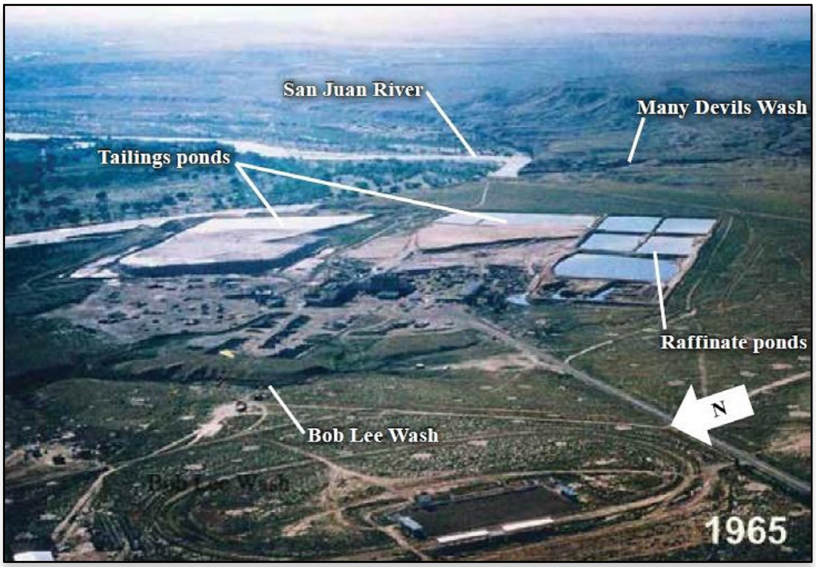
1. Title I of the act addressed the remediation of legacy/unlicensed sites (Title I sites) and Title II created a framework for regulating wastes at NRC-licensed sites (Title II sites). Three primary parties, the US DOE, US EPA and the NRC, have responsibilities under the act. The EPA is responsible for setting standards for remedial action criteria (surface clean-up standards), disposal cell (tailings pile) performance, and air and groundwater quality at Title I and Title II sites. With respect to Title I sites, the DOE is responsible for both remediation and long-term care and maintenance of the sites, stabilising, disposing of, and controlling, in a safe and environmentally sound manner, uranium mill tailings. To this end, the DOE established the Uranium Mill Tailings Remedial Action (UMTRA) Project to address surface contamination (including uranium mill tailings and abandoned mill buildings) and ensure related EPA standards are met. The UMTRA Ground Water Project addresses any groundwater contamination and ensures sites meet EPA-established groundwater standards. Although the DOE also has long-term management responsibility at Title II sites, the DOE was not made responsible for remediation of the privately licensed sites.
2. After remediation is complete, the NRC [will?] oversee[s] the DOE in its role as a licensee and long-term custodian of UMTRCA sites. NRC regulations in 10 CFR 40.27 and 10 CFR 40.28 provide general licence requirements for custody and long-term care of Title I and II sites, respectively.

Characterisation of circumstances

The former mill reportedly processed approximately 1.4 x 10^{+06} tonnes of ore along with smaller quantities of bulk precipitates from heap leach operations from the Monument Valley area and from purchased vanadium liquor. Ore processing consisted of crushing, leaching with sulphuric acid, washing and extracting uranium and vanadium with organic solvents. Both nitrate and ammonium complexes were used as ion exchange strippers to concentrate the uranium, and ammonia was used to adjust the pH of the slurry during the milling process. Tailings from the washing circuit and yellow cake filtrates were pumped to tailings disposal areas. Fluid remaining after the uranium was removed from the process water, also known as raffinate, was allowed to evaporate in ponds located to the west and south-east of the tailings piles (see Figure A3.15). Water in the unlined ponds was able to percolate into the underlying soil and rock.[3] A 1960 report (AEC, 1960) estimated that approximately 600 L of water seeped out of the bottom of the ponds per minute.

By September 1986, all tailings and associated materials were encapsulated in a disposal cell; however, remediation of contaminated groundwater continued after construction of the disposal cell. A Final Ground Water Compliance Action Plan for Remediation at the Shiprock, New Mexico, UMTRA Site was developed to address groundwater contamination (DOE, 2002). Contaminants of concern monitored at the Shiprock disposal site include ammonium, manganese, nitrate, selenium, strontium, sulphate and uranium. Water quality parameters include calcium, chloride, magnesium, potassium and sodium. In March 2003, the DOE initiated active remediation of groundwater using extraction wells and interceptor drains (see Figure A3.13).

Figure A3.15. **Features of the former mill during operations in 1965**



Source: Adapted from Figure 2 in USGS, 2016.

The compliance standards for nitrate, selenium and uranium are listed in the EPA's 40 CFR 192 (Table A3.2). An alternative Safe Drinking Water Act limit of 0.05 mg/L for selenium has been proposed. Regulatory standards are not available for ammonia, manganese, sulphate and

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[3] Water for the mill and plant operation was taken from the San Juan River just upstream of the mill. For the acid leach process, water use was about 2 700 to 4 500 L of water per tonne of ore processed with approximately 360 to 450 tonnes of ore processed daily, and 1.5 x 10 + 06 L of water used per day.

strontium. A clean-up goal of 2.74 mg/L was established for manganese based on measured background concentrations at the time, although recent background measurements have been as high as 7.2 mg/L. Historically, sulphate concentrations have been elevated in groundwater entering the floodplain from the flowing artesian well, where levels have ranged from 1 810 to 2 340 mg/L (average of 2019 mg/L). Because of these elevated levels from a natural source, the DOE (2002) proposed a clean-up goal for sulphate of 2 000 mg/L for the floodplain, which is conservative as nearly half (46%) of the 68 samples collected were above this level (e.g. in background well 0797, sulphate concentrations have ranged from 2 690 to 5 000 mg/L since 2010). No standards are available for strontium, a constituent not typically associated with uranium milling sites, though it was selected as a constituent of concern in the DOE's Baseline Risk Assessment (DOE, 1994). The EPA's Regional Screening Level for stable strontium in drinking (tap) water is 12 mg/L (EPA, 2016).

Table A3.2. **Maximum concentrations, clean-up goals and floodplain groundwater background levels**

Contaminant	40 CFR 192 maximum concentration of constituents (mg/L)	Clean-up goal (mg/L)	Historical range in floodplain background wells (mg/L)	Comments
Ammonia as N	--	--	<0.074-0.20	Most (94%) of ammonia results for floodplain background wells have been non-detects <0.1 mg/L
Manganese	--	2.74	0.016-7.2	2.74 mg/L clean-up goal was the maximum background concentration when the groundwater corrective action plan was developed (DOE, 2002)
Nitrate as N	10	--	0.004-5.7	10 mg/L is equivalent to 44 mg/L nitrate as NO_3
Selenium	0.01	0.05	0.0001-0.02	The 0.05 mg/L clean-up goal is the US EPA Safe Drinking Water Act maximum contaminant level
Strontium	--	--	0.18-10	EPA's Regional Screening Level for tap water is 12 mg/L
Sulphate	--	2 000	210-5 200	Because of elevated sulphate levels in artesian well 0648 (1 810-2 340 mg/L), a clean-up goal of 2 000 mg/L was proposed
Uranium	0.044	--	0.004-0.12	Uranium levels measured in background well 0850 have varied widely and have exceeded the maximum concentration at times – in five of the last six samples collected (0.05 to 0.07)

Source: Adapted from Table 1 in DOE, 2016.

The aforementioned standards and background levels apply only to the floodplain and not to the terrace groundwater. The strategy for remediation of the terrace is to eliminate exposure to groundwater at the washes and seeps and apply supplemental standards to the west. Terrace groundwater is not expected to be a reliable source of groundwater, nor a quality source of drinking water.

Results of the DOE's groundwater monitoring efforts at Shiprock are documented in annual performance reports. In 2016, contaminant distributions of nitrate, sulphate and uranium were stated to be generally the same as those observed in previous years. In general, contaminant concentrations have decreased in several floodplain wells over time in response to pumping – most notably in the Trench 1 area. Contaminant concentrations in the easternmost Trench 2 area wells (closest to the San Juan River) are also lower than those nearer the escarpment, demonstrating the effectiveness of the Trench 2 remediation system.

Remediation of the site was initially hampered by an incomplete understanding of the hydrogeological system and sources of contaminants in groundwater. Reducing hydrogeological conceptual model uncertainties has led to better informed remedial decision making and increased effectiveness of selected technologies.

A significant challenge for remediation of the Shiprock disposal site has been determining the source of elevated concentrations of constituents of concern in groundwater, and determining whether those sources are naturally occurring. A study conducted by the US Geological Survey (USGS) for the Navajo Nation presented multiple lines of evidence to support a conclusion that the source of water beneath Many Devils Wash is likely focused recharge of precipitation, and is not likely sourced from groundwater impacted by former milling operations or from the disposal cell (USGS, 2016). This evidence includes:

i. the lack of a hydraulic gradient from the disposal cell to Many Devils Wash;

ii. visible observations of near-surface, erosion processes such as piping and sapping in and near the channel;

iii. review of geochemical data to differentiate between terrace impacted and naturally occurring waters, including sodium-sulphate, nitrate and selenium concentrations; as well as uranium activity ratios;

iv. concentration data providing information on the potential age of recharging ground waters (due to differences in atmospheric concentrations of certain constituents over time) including tritium and chlorofluorocarbon concentration data.

Societal aspects

Regarding social and public concerns, collaboration on studies with the Navajo Nation, which values scarce water supplies in this arid region, has been beneficial to build trust and confidence in remedial decision making. For example, due to early scepticism about the results of the DOE's investigations of constituents of concern in the water beneath Many Devils Wash, the DOE agreed to provide funding to the Navajo Nation to do parallel, independent investigations, which were performed by the USGS. The results of these studies support DOE conclusions that constituents in the water beneath Many Devils Wash are naturally occurring. Furthermore, the DOE developed a Communications and Outreach Plan for the Navajo Nation UMTRCA sites[4] to describe how the DOE will i) support stakeholder participation and community relations with the Navajo Nation, ii) support public awareness and understanding about the long-term management of the four Navajo Nation UMTRCA sites, and iii) foster communication with stakeholders (DOE, 2013).

Communication with stakeholders, including members of the public surrounding the disposal facility, has been important to the success of the project. The DOE formed a working group and organised Navajo Nation Chapter House meetings to inform local stakeholders about groundwater restoration activities and the risks of living next to a uranium mill tailings disposal facility. Enhanced communication efforts with the Navajo Nation has increased public confidence and led to better decision making. One lesson learnt with respect to communication is the importance of considering socio-economic factors and cultural differences when planning and executing public outreach efforts. For example, certain forums and methods of communication (e.g. one-on-one and verbal communication) with the Navajo Nation seem to be more effective than other methods.

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[4] UMTRCA sites on Navajo Nation land in Utah, Arizona, and New Mexico include the Mexican Hat, Shiprock, and Tuba City disposal sites; and the Monument Valley processing site.

End-states

Due to the long-term risks posed by uranium and thorium wastes, uranium recovery sites are under long-term care by the DOE, under an NRC licence. NRC regulations in 10 CFR Part 40, Appendix A, implement statutory requirements of the UMTRCA of 1978. The rule reflects prescriptive elements of the statute including the requirement for state or federal government ownership and control of the sites under an NRC licence. The NRC determined that a general licence approach would be efficient for the over 40 UMTRCA Title I and II sites expected to be included under the licence. Long-term stewardship is one element of a defence-in-depth approach to long-term protection consisting of government ownership/control, NRC licensing that provides independent oversight, robust engineered barriers that provide long-term stability, and financial assurance. Engineered barriers must be designed to provide stability for up to 1 000 years, and a minimum of 200 years, without reliance on active ongoing maintenance.

A summary of potential human health risks associated with site-related groundwater and surface water for the various pathways were evaluated by the DOE either quantitatively or qualitatively and a number of observations were made based on the analyses (DOE, 2000). The main unacceptable human health risks associated with the Shiprock site are for use of floodplain and terrace groundwater systems for drinking water in a residential setting. For a compliance strategy for the Shiprock site to be protective of human health, only a few restrictions on water use or access were identified (DOE, 2000).

Long-term protection values

Shiprock is a disposal facility and most of the waste generated during operation of the mill is managed on-site. Waste that may be managed off-site includes contaminated sediments from the evaporation pond when the evaporation pond is decommissioned. The DOE will manage the site indefinitely and will monitor the site consistent with the long-term surveillance plan.

Long-term custodial care of the site helps ensure public health and safety long into the future, but also requires constant input and effort by the DOE and regulators and can therefore be resource intensive.

Conclusions

Remedial activities have led to a decrease in seepage rates to the floodplain and reduced water levels and contaminant levels in terrace wells. Groundwater remediation has also led to significant mass reductions of legacy groundwater contamination in the floodplain alluvial aquifer. The DOE plans to remove the ageing liner in the evaporation pond once groundwater extraction in the floodplain is terminated and monitor ensuing groundwater concentrations to determine whether to reline the evaporation pond and resume extraction, or decommission the evaporation pond and allow natural flushing to proceed. At that time, the DOE will also monitor groundwater conditions around the disposal cell to better understand if it is a continuing source of contamination to the floodplain aquifer.

Alternatives in groundwater compliance strategies have allowed the DOE to focus on mill-related groundwater contamination, rather than areas with widespread ambient contamination where groundwater restoration efforts are ineffective. The DOE continues geochemical investigations in the area surrounding the disposal cell to better define mill-related versus non-mill-related groundwater contamination to support use of supplemental standards for terrace groundwater.

The DOE and NRC UMTRCA programmes are well defined and have matured over the 40 years since the promulgation of the UMTRCA, providing a stable and predictable regulatory environment for the long-term care and oversight of the uranium mill sites. Requirements in 40 CFR Part 192, including a design for effective control of radioactive material for up to 1 000 years, to the extent reasonably achievable, and in any case, for at least 200 years; and the "authority of the Secretary (of Energy) to perform groundwater restoration activities under

40 CFR 192"…" without limitation" (FR Vol 60, No. 7, pp. 2855) ensures that there will be a government agency with authority to perform long-term care into the future.

References

AEC (1960), "AEC Radiation Control Program for Uranium Mill Operations", May 1960.

DOE (1994), "Long-Term Surveillance Plan for the Shiprock Disposal Site, Shiprock, New Mexico", Revision 1, UMTRA-DOE/Al/62350-60F, prepared by Jacobs Engineering Group Inc., Albuquerque.

DOE (1996), "Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Ground Water Project", October 1996.

DOE (2000), "Final Site Observational Work Plan for the Shiprock, New Mexico, UMTRA Project Site", GJO-2000-169-TAR, Rev. 2, Grand Junction, Colorado.

DOE (2002), "Final Groundwater Compliance Action Plan for Remediation at the Shiprock, New Mexico", UMTRA Project Site, GJO-2001-297-TAR, Grand Junction, Colorado.

DOE (2009), "Evaluation of the Trench 2 Groundwater Remediation System at the Shiprock, New Mexico, Legacy Management Site", LMS/SHP/S05037, Office of Legacy Management, Grand Junction, Colorado.

DOE (2013), "Communications and Outreach Plan for the Navajo Nation Uranium Mill Tailings Radiation Control Act Sites", LMS/S09372, November 2013.

DOE (2016), "Annual Performance Report April 2015 Through March 2016 for the Shiprock, New Mexico, Disposal Site", LMS/SHP/S14467, October 2016.

US EPA (2016), "Regional Screening Levels for Chemical Contaminants at Superfund Sites", www.epa.gov/risk/regional-screening-levels-rsls.

USGS (2016), "The Source of Groundwater and Solutes to Many Devils Wash at a Former Uranium Mill Site in Shiprock".

Case study 7. Radium Action Plan 2015 to 2019, Switzerland

Site description

In June 2014, the problem of radiological legacies linked to radium resurfaced following the discovery of radium-contaminated waste at a former landfill site in Bienne (A5 motorway construction site). The Federal Office of Public Health (FOPH) carried out a complete analysis of the site in order to evaluate the health risk to the local population. The results of the analysis confirmed the absence of any health risk to persons living in the areas constructed on this old landfill site. Nevertheless, protective measures were put in place for the workers on the construction site.

Radium was used to produce luminescent paint in the watchmaking industry between 1920 and 1960. In spite of the precautions taken to misplace as little radium as possible, given its cost, employees were exposed and surface contamination occurred in the workshops or in the private apartments or buildings where work was carried out. At the time, given the limited management of the waste resulting from the use of radium, radium residues were found in household waste and, in the absence of any particular precautions, this waste was sent to ordinary landfill sites.

With the action plan, the Federal Council wishes to settle this problem definitively.

Figure A3.16. **Watchmaking workshop in Mont Lucelle (formally Canton of Bern) in the 1950s**

Source: Swiss Federal Office of Public Health.

Regulatory framework

The regulatory framework for radiological protection and nuclear safety in Switzerland is built on international laws and guidance. Having considered the elements presented above, the Federal Department of Home Affairs (FDHA) has requested the FOPH to prepare an action plan to resolve the problem of radium. Its implementation is based on art. 9 of the Radiological Protection Act of 22 March 1991 (RAP; RS 814.50) and on the IAEA International Basic Safety Standards for Protection (GSR part 3). These standards and the recommendations of the International Commission on Radiological Protection (ICRP) define the strategy for the management of radiological legacies such as existing exposure situations. The action plan provides for the search for possible radium-contaminated sites, the diagnosis of its presence in buildings and surrounding land, the assessment of the resulting annual exposure for the residents and, in the case that the exposure to the public exceeds the annual limit of 1 mSv, remediation work. Finally, a particular section of the action plan concerns the monitoring of potentially contaminated landfill sites. The overall process has been approved by the Federal Commission for Radiological Protection.

The radium action plan 2015-2019 is made up of **four axes having** the aim to account for the sites where radium was handled, to diagnose its presence or absence, to plan and to carry out remediation justified from the viewpoint of radiological protection, and to put in place monitoring of the landfill sites in which radioactive waste of this substance was placed.

Searching for potentially contaminated sites: The search for radium-contaminated sites will involve the use of the following different information sources:

- historical information (federal, cantonal and municipal archives);
- contacting the professionals concerned (watchmaking industry, radium suppliers);
- contacting individuals (information requests).

Survey of the potentially contaminated buildings, accompanying measures: A measurements plan has been established with a time line, based on the list of the potential radium-contaminated sites, the results of the pilot survey and the procedures drawn up in the preparatory phase.

The following actions were carried out for each potentially contaminated site:

- contact with the residents of the site (tenants and owners) and definition of the conditions for the survey (timing, duration, implications for the residents);
- carrying out the measurements according to the established procedure;
- first information to the residents at the end of the measurements; when needed, propose immediate arrangements in the case of significant contamination;
- prepare the radium assessment report with proposals on the follow-up (acceptable or remediation);

The measurements of the potentially contaminated sites have been made at the priority affected cities of Bienne and La Chaux-de-Fonds. It is hoped that the process will be terminated by 2020.

Remediation of the contaminated buildings: Remediation is a very specific procedure at the site in question and requires good collaboration between the occupants of the site and the owner. The remediation procedure is preceded by a campaign of complementary measurements in order to determine the extent and the nature of the contamination. This partially invasive process (moving furniture, carpets, floor coverings) is carried out in close collaboration with the inhabitants. Figure A3.17 and Figure A3.18 show examples of indoor and outdoor remediation.

Figure A3.17. **Photo of the remediation of a contaminated room with partial removal of floor coverings**

Source: Swiss Federal Office of Public Health.

Figure A3.18. **Excavation of radium-contaminated part of a garden**

Source: Swiss Federal Office of Public Health.

Based on these measurements, and with the support of a construction specialist, a remediation plan is established. The aim is to reduce the contamination to a minimum and to guarantee the habitability of the premises without unacceptable risk.

A final check of the remediation is made by the FOPH at the end of the work. The report of this inspection contains a proposal for future actions.

Surveillance of the landfill sites and other contaminated sites: In the landfill sites and other sites identified as being contaminated with radium, the FOPH is in charge of implementing an appropriate radiological surveillance and of guaranteeing a monitoring of the situation. This action, which has the principal aim of guaranteeing the protection of the workers and the environment during the work, may lead to a remobilisation and a dispersal of the contamination, and will be done in close collaboration with the Federal Office for the Environment (FOEN) and the relevant municipalities and cantons.

With regard to the potentially contaminated public landfill sites, it is not envisaged to search and eliminate radioactive traces present in the mass of waste. Involvement will simply consist of a visit to each site concerned, measurement of the exposure exterior to the site and measurement of the radioactive concentration of the leachates from the site. On this basis, an approach that enables the site workers to avoid exposure and to monitor the activity of the leachates could be implemented as needed.

Characterisation of circumstances

The specific problem of radium resulting from watchmaking mainly concerns the Jurassic Arc. After having examined the steps taken abroad, principally in France, the lessons learnt demonstrate that:

- the operation is necessary because legacy situations from the past can involve health issues and have an environmental impact;
- the inventory phase, the identification of the sites and the initial contact with the owners concerned is indispensable for the operation to run smoothly;
- the radium survey phase is essential to confirm the absence of health issues;
- the remediation phase involves decontamination and waste management, as well as the rehabilitation of the concerned premises and lands.

All these steps require resources for planning, co-ordination, radium survey, detailed confirmatory protocols, assessments of the health risk, contacts with individuals, owners and local authorities, the press, the companies involved in the remediation, etc.

The key objective of the radium action plan is to guarantee that the annual exposure of the population from residual radium contamination does not exceed the limit of 1 mSv, and to ensure the protection of workers and the environment against risks associated with the remobilisation of the radium present in the buildings, ground and landfill sites.

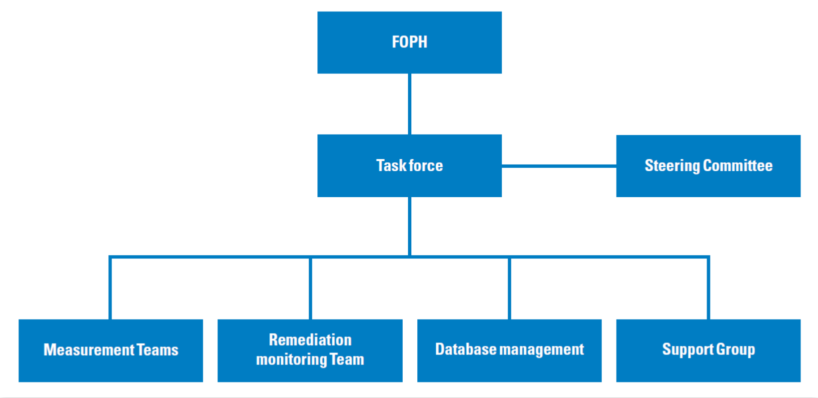
In parallel with the measures to dispel any doubt by excluding the presence of radium, or in cases of traces, to be certain that urgent measures are unnecessary, it was indispensable to develop measurements and remediation tools that precisely assess the health risks and, when needed, to intervene effectively to reduce them. The radium task force therefore decided to develop and implement the procedures and methodologies in a pilot phase that was carried out in Bienne. Not less than 160 apartments located in 26 buildings were thus checked by carrying out systematic measurements on the floors and walls of each room. External areas of the buildings were also examined. One case of contamination immediately justified a remediation that was carried out as a pilot project.

This phase made it possible to address the problem of contacting the residents and to develop the diagnostic methods. Lessons were also learnt from accomplishing the first remediation. The tools that were developed and the acquired experience can now be used for the extension of these actions to all the buildings in question by prioritising the establishment of a review of the radium situation by the end of 2015 in all buildings whose addresses were published. In parallel, a search has been carried out to find other potential radium-contaminated sites. At the present stage, about 1 000 properties (buildings including several apartments and gardens) will be examined. The experience shows that 20% of those properties need decontamination and rehabilitation. In these cases, an appropriate case management represents a major challenge.

Moreover, cases that require an immediate intervention, together with unforeseen problems during the remediation, cannot be excluded. To this must be added the question of potentially contaminated landfill sites, a question which has to be planned together with the Federal Office for the Environment (FEON), the relevant municipalities and the cantons.

The action plan was drawn up under the auspices of the FDHA. The organisation of the project (see Figure A3.19) enables co-ordination of the internal actions of the administration and the accompanying actions (initial contact, radium survey, planning and implementation of remediation, disposal of waste), as well as the presentation of findings to the various representatives and stakeholders (occupants, owners, cantons, municipalities).

Figure A3.19. **Organisation of the action plan**



Source: Swiss Federal Office of Public Health.

The strategic guidance of the project is entrusted to a steering committee that comprises representatives from the FOPH, FOEN, Suva and the Federal Radiation Protection Commission. This committee is called upon to give an opinion on the implementation of the action plan, principally in the context of the decision for and planning of remediation, oversight of the effectiveness of the work and of the control of associated costs. With regard to the landfill sites, sampling seeking to address the radium problem will be co-ordinated when possible with those required for the analysis of other contaminants, analysis carried out in the context of the preliminary investigation pursuant to the Contaminated Sites Ordinance of 26 August 1988 (CSO; RS 814.680).

In the various areas of the action plan, the information needed for the co-ordination and implementation of practical measures must be integrated right from the start. In this capacity, a project support group comprising representatives of the cantons and the municipalities concerned, a representative of the watchmaking industry, as well as a foreign expert follow the procedure from start to finish. Other partners may be co-opted to the project as needed.

Societal aspects

Informing on the one hand the general population, and on the other hand, those persons directly concerned is a very delicate step that is decisive for the success of the programme. Ensuring that administrative bodies are informed at the cantonal and local level is also important, as their trusting collaboration is necessary for the success of the process. This information must be open and transparent. Neither systematic assurances nor scaremongering are needed. The problem must be recognised, but the possibility of an effective solution must be underlined. This is the sole attitude able to ensure the adhesion of all the involved parties.

Current legislation does not allow intervention in the private sphere without the explicit agreement of the individuals concerned. Thus, the success of the action plan depends on the collaboration of the residents of the potentially contaminated sites (owners and tenants). Just as for the procedures of the radon action plan, an effort must be made to convince the individuals. This requires collaboration at all administrative, federal, cantonal and municipal levels. A wide-ranging debate must be initiated to put forward arguments that justify the radium survey and any subsequent remediation work, and which define the roles and responsibilities of each and every player. In this respect, the actors of the action plan and their role are defined as:

- The **tenants** of the potentially contaminated sites are the leading actors of the plan. They have to agree to allow the survey procedures in their private sphere. In the context of a possible subsequent remediation, they have to agree to the proposed solution, bearing in mind the possible implications that this can have on their private life (for example, the need for temporary rehousing). The financial aspect, see above, must be very clear so as to avoid from the outset any misunderstanding. It should be noted that the procedure is implemented for their benefit.
- The **owners** are also beneficiaries of the programme. However, one can imagine their initial reticence with regard to the potential loss in value of their property. Their possible refusal of the survey process is hardly imaginable. On the other hand, their agreement in the phase of a possible remediation may be necessary given that this procedure implies interventions on the property (for example replacing the wastewater discharge pipes).
- The **representatives of the municipal authority and administration** play the role of facilitators in the procedure. Their closeness to the persons concerned and the trust that they enjoy must contribute to a positive and transparent passage of information to the inhabitants of the sites concerned. They can be called to participate in information sessions and to serve as intermediates to individuals. They also have to intervene in the context of managing the potentially contaminated municipal landfill sites.

In this context, the apprehension felt by the residents of the sites in question must be taken into account. In a climate of confidence, this will actually serve as a driving force for the programme. The second argument that may make people suspicious is the potential loss in value of the properties in question. Here again, effective communication will make the plan attractive due to the increase in value brought about by assessing of a site as being non-polluted or by its remediation.

End-states and long-term protection values

The proposed course of action consists in searching for potentially contaminated sites, and initially establishing a radium assessment of each site. A strategy for action has been established based on experience gained in the pilot phase and specifying, depending on the measured parameters, the follow-up. Although most cases show no trace of radium, the assessment provides reassurance for concerned inhabitants. In the case that traces are detected, the following options have to be considered:

- the removal of the radioactive sources or contaminated objects (e.g. the soil from contaminated gardens);
- mechanical or chemical decontamination of the contaminated parts of the housing (floors, walls, water discharge pipes);
- the installation of other means of protection on a case-by-case basis.

With regard to the potentially contaminated public landfill sites, monitoring the concentration of radium in the landfill leachate is the chosen option.

The final objective is to guarantee the habitability of the premises without any unacceptable risk to the population from exposure to remaining contaminants, and to ensure the protection of workers and the population faced with the risks involved with contaminated landfill sites. It should be emphasised that this does not mean the achievement of zero residual activity from radium. Such an objective could involve disproportionate interventions and unacceptable costs. Thus, it is important that each decision for remediation be justified in an optimisation approach that draws a comparison between its advantages and disadvantages.

Conclusions

The objective of the radium action plan is to eliminate the radiological legacies associated with the use of radium in the watchmaking industry. The organisation and the applied technical procedures ensure the progress of the four axes of the radium action plan.

Reference

There are no references on this subject available in English. Readers are recommended to contact the FOPH for further information in German, French or Italian on matters of particular interest.

www.bag.admin.ch/bag/de/home/themen/mensch-gesundheit/strahlung-radioaktivitaet-schall/radioaktive-materialien-abfaelle/radium-altlasten.html.

Case study 8. Capriano Del Colle special waste dump, Italy

Site description

The Caprianodel Colle special waste dump is located in the Italian province of Brescia, in Lombardy. It is bounded by other communes of AzzanoMella, BagnoloMella, Flero, Poncarale, Castel Mella and Dello. It is situated on the eastern slopes of Monte Netto, occupying a total of about three hectares. It is structured in seven tanks placed in two parallel rows for a total disposable volume of approximately 370 000 m^3. The contaminated material is collocated only in tank 3, 4, 5 and 6 for a total volume of 200 000 m^3.

The special waste dump was used only for the disposal of foundry wastes coming from the production of a metal refinery. The municipality of Capriano del Colle is located in a rich and lush countryside with vineyards dotting the hills and the plain, which are part of the ancient tradition of this natural area.

In the second half of 1990, three sites were investigated for radioactive contaminants, namely Ex-Fermeco 80, RaffineriaMetalli Capra and the dump in Caprianodel Colle (BS). Radiological characterisation was performed of the entire special waste dump and Cs-137 discovered, probably due to a melted radioactive source in aluminium scrap metal coming from Eastern Europe. The same investigations revealed the acknowledgement of Cs-137 contamination within company records. After a first evaluation by special committee, including local governments, these three sites were closed, along with Caprianodel Colle (BS) special waste dump.

Regulatory framework

Article 126 of Legislative Decree No. 230/1995, concerns prolonged exposure situations coming from nuclear or radiological emergency or contamination events, such as the one at Caprianodel Colle, or past practices or working activities with natural radiation sources. The same article is applied under Act No. 225/1992, which provides for taking appropriate actions through general principles set out in article 115, especially in relation to exposure risk. Also, in view of the wide variety of situations that may arise in practice, it should be noted that for such situations the legislator did not establish possible actions or reference levels in terms of effective dose, or derived quantities, to individuals of the public reference groups.

Reference levels are adopted in accordance with the general principles of justification and optimisation of intervention referred to in article 115-bis and can be identified on the basis of claims and technical guidelines provided by the European Union and at international level. According to article 126-bis of Legislative Decree No. 230/1995, the responsibility for the establishment and adoption of protection strategies are within the exclusive jurisdiction of the state, namely the National Department of Civil Protection or prefectures (territorial offices of government) depending on the extent and urgency of the intervention or emergency.

The authorities responsible for operations under the Act 25 No. 225/1992 are therefore permitted to take appropriate actions, and then ensure that remedial and protective actions are justified and that protection and safety are optimised. Generally, as soon as an existing exposure situation is identified, according to paragraph one of article 126, restrictions to the access and use of the contaminated areas are required by the prefecture. The duration of the restrictions depends on the type of remediation, and they can also be applied after remediation.

Usually prefectures set up a technical commission which includes local, regional and national technical services. Then, supported by the technical commission, the prefectures define site-specific safety criteria and remediation levels. Interested parties (operators, local community representatives, etc.) are typically involved in technical meetings set up by the prefectures in order to analyse the specific site situation and help to define remediation plans.

Article 126 of Legislative Decree 230/95 refers directly to article 115, setting general principles concerning interventions, in particular:

a. intervention is undertaken only if the reduction in detriment due to radiation is sufficient to justify the harm and costs, including any social costs of the intervention;
b. the form, scale and duration of the intervention is optimised so that the benefit of the reduction in health detriment, less the detriment associated with the intervention, is maximised.

In particular, paragraph two of article 126 states that "provisions of Chapter VIII apply to workers involved in interventions related to prolonged exposure situations." Generally, persons or organisations responsible for areas with residual radioactive material are identified during the reconstruction of the site history and in most cases they are the site or plant owner(s).

In all those cases in which the owner(s) or operator(s) cannot be identified, the national authority is held responsible. When organisations or persons responsible for the contamination cannot be found, the government is held responsible for providing a funding source for site remediation activities on or around a site. Unfortunately, the legal framework does not ensure such a funding mechanism.

Characterisation of circumstances

In July 1990, the Lombardy region prefecture required ENEA[1] to commence what safety and remediation actions were necessary for a contaminated landfill in the Montenetto area, in the municipality of Capriano del Colle. This was connected to investigations that found Cs-137 contamination due to its presence in aluminium scrap. At one recycling plant, a second category landfill (type B[2], though technical solutions configure it as a type C[3]) , was the disposal site of waste coming from two aluminium refineries, Castel Capra Mella and Fermeco of Montirone, which produce aluminium recycled from scrap metal.

The first decision needed from the Lombardy region's specific Technical Committee related to relocating the wastes or having a safe intervention in situ. The results of the radiometric measurements carried out on the landfill surface and within the vast amount of material, as well as the awareness that its removal would have resulted in a dangerous ambient diffusion of the Cs-137 present in the waste, convinced the Technical Committee to operate in situ, unless other decisions were imposed by the results of further investigations.

The ENEA was faced with a number of new safety requirements with a target for full containment of radioactive Cs-137. The solution that the ENEA presented was based on the following:

a. immediate containment of radioactive contamination of the special waste dump with a physical barrier, to allow for worker safety on-site, to allow collecting of samples, to quantify the contamination level and to manage the landfill;
b. a realisation of the final sealing with a physical barrier, adapted to prevent dispersal of any radioactive contamination for the next 25-50 years.

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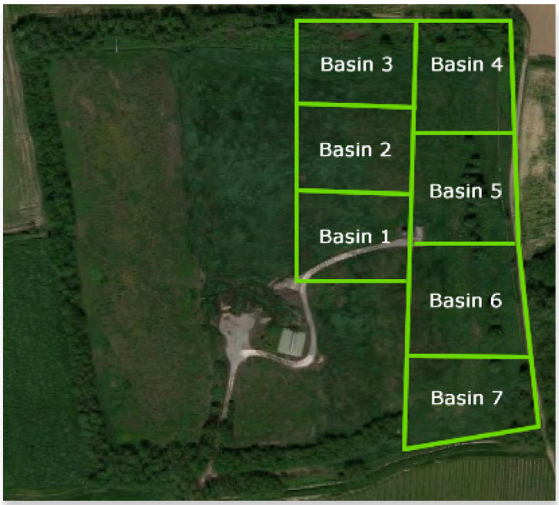
[1] The ENEA is the name for the Italian National Agency for New Technologies, Energy and Sustainable Economic Development. The agency's activities are mainly focused on energy efficiency, renewable energy sources, nuclear energy, climate and the environment, safety and health, new technologies and electric system research.

[2] Landfill for non-hazardous waste, Legislative Decree 36/2003.

[3] Hazardous waste landfill, Point 4.2. of Resolution 27 July 1984 also included a category of type C landfills, where it was allowed to dispose of particular categories of hazardous waste. Type C landfill has been repealed by Ministerial Decree 26 June 2000 n. 219.

Further to this, a number of important actions were put into place. One important step has been periodic monitoring of the amount of Cs-137 present in the water leaching into the landfill body and into the groundwater.

Figure A3.20. **Special waste dump map with relative basins into which radioactive contamination was deposited**



Source: ISIN.

Radiometric characterisation of the waste disposal, performed by collecting surface and subsurface samples, concluded that most of the radioactive contamination (around 1 x 10^{12} Bq) was confined to a limited area of the landfill. The total mass of wastes contaminated by Cs-137 was found to be in the range of 200 000 m3, covering an area of about 30 000 m2. The largest amount of contaminated waste, containing around 1.1 TBq, was found in basin three. Into basins five and six, an average Cs-137 radioactive content was estimated to be much lower than that of basin three (for example, 12 GBq of Cs-137 for basin 5). These activity estimates were based on averaged values and in some samples collected from basin three, Cs-137 values were measured at 20 times higher (196 033 Bq/kg) than the averaged values (9 819 Bq/kg), implying a conservative total Cs-137 radioactive inventory of about 20 TBq.

Cs-137 contaminated wastes that were constituted as dust were mixed with soil to around 30% of volume to avoid any air dispersion. As necessary, the basins were waterproofed through layering 40 cm of clay linings throughout the excavation area, and covering the excavation walls and bottoms with a geomembrane. Both upper and lower draining systems were installed with the upper linked to a piping system and tank for collecting the percolate.

After several years, additional groundwater investigations were carried out using piezometers, revealing some further Cs-137 contamination. Local authorities declared that only a portion of the landfill had been filled in a controlled manner, while another portion had been filled without confinement barriers. Therefore, both controlled and uncontrolled landfill liquid was present in the network. Monitoring under the first seal revealed chemical-physical characteristics similar to the top leachate (Cs-137 radioactive concentration of about 0.30 Bq/g); but the water samples, collected from environmental piezometers, found some Cs-137 radioactive contamination greater than minimum detectable concentration values.

Only in recent years, the National Institute for Environmental Protection and Research (Ispra – the competent national regulatory authority in the field of nuclear safety and radiological protection) was requested to participate in a local committee established by the prefecture to assist with the problem of radioactive contamination. Values of Cs-137 radioactive contamination in percolate were found to be below 1 Bq/g.

The local committee (previously established by the prefecture and Ispra) requested that the owner of the Caprianodel Colle site provide specific radiological scenarios for the leachate that is sent to the local purifier. This would demonstrate compliance with the criterion for radioactive discharge of no radiological concern of 10 µSv/y and activity concentrations of the Cs-137 discharge ≤ 1 Bq/g. For compliance with the above criteria, the following information was specifically requested by the prefecture:

a. identification of all possible exposure routes for members of the population (critical group), and possibly for workers, also in relation to the leachate destination;

b. any conservative assumptions used in the evaluations;

c. the reference mathematical models used for evaluating individual doses to the population.

The operator of the Caprianodel Colle site demonstrated compliance with the radiological concern criteria of 10 µSv/year. All radiological scenarios were verified independently by the local committee.

Societal aspects

Several meetings have taken place between the local committee, established by the prefecture and the mayors of the relevant municipalities, to illustrate possible interventions and monitoring of the contaminated leachate flow. The monitoring of the contamination concentration of Cs-137 has been conducted on behalf of the regional environmental agency, which is familiar with the local situation.

End-states and long-term protection values

The management of radioactive waste in the past, without a consolidated solution, has intensified the situation today, especially since some radioactive traces of Cs-137 have been found in the groundwater. There is no longer a possibility of waste recovery for disposal. Instead, intensive control of the groundwater is ongoing in order to understand the radioactive concentration of Cs-137 and the concentration of other chemical substances.

In general, the removal of radioactive contamination due to Cs-137 seems to be quite difficult because in the past the disposal of radioactive metal scrap involved mixing the same contaminated metal scrap (dust) within the dumping ground. The contaminated powder was mixed with soil at around 30% of the volume in order to prevent wind transport of the same. The stored material in the plant is configured as earthy powder in a matrix, with whole or fragmented salt blocks placed mainly at the edges of the tanks. Deep monitoring and evaluation of contaminated percolate has to be performed regularly through the environmental monitoring network established around the whole area of the special waste dump.

Conclusions

It was recently decided that a specific geomembrane will be put on the main basins (basin 3, and basins 5 and 6) to avoid the production of percolate. The special waste dump will continue to be monitored by the environmental monitoring network.

An appropriate decision-making process was available and applied at the time contamination was confirmed. It was then concluded that the best solution, given the risks in movement, was to leave it where it was and provide containment. However, the provided containment was not fully effective.

Ongoing monitoring is maintained in co-operation with local stakeholders.

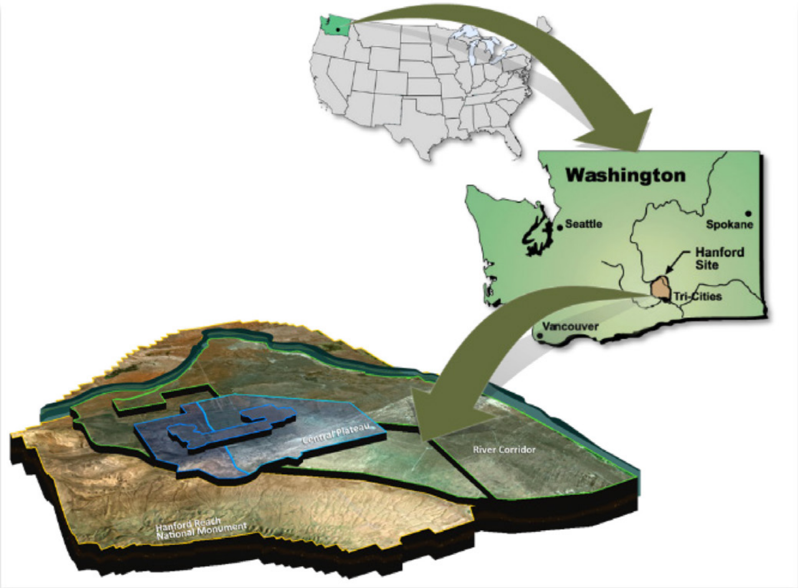
Case study 9. **Clean-up approaches and strategies for public engagement and participation at Hanford, United States**

Site description

Hanford is primarily known for its plutonium production over the years from World War II through the Cold War. Since 1989, the site has focused on clean-up resulting from plutonium production. In fact, Hanford is known as the largest nuclear clean-up project in the United States.

The Hanford Site in Richland, Washington, United States, was chosen due to: i) its abundant source of cold water from the Columbia River; ii) its proximity to a massive power source of the Grand Coulee Dam; and iii) its isolation from large cities while being far enough inland from the Pacific Ocean. Construction of the site was rapid, from 1943 to 1945 (the time frame from design to start-up was only 13 months) with 50 000 workers at its peak.

Figure A3.21. **Location of the Hanford site**

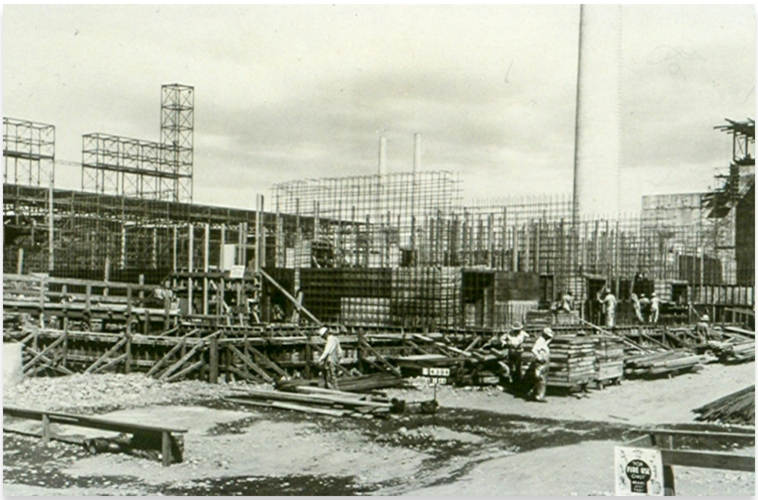


Source: US DOE.

Construction of the B Reactor (the world's first plutonium producing reactor) was one of the largest projects ever undertaken by the US government. Designer, engineers and constructors had to deal with many complexities in this first of its kind design.

Reactor construction included the dual-purposed N-Reactor. Plutonium Production ended at Hanford in 1989 and its mission changed to clean up of legacy waste.

Figure A3.22. **Construction of the B reactor**



Source: US DOE.

As Hanford seeks to protect the public, workers and the environment, near-term priorities are to:

- complete demolition of the Plutonium Finishing Plant;
- clean-up research waste burial ground (618-10) and nearby waste site (316-4);
- move highly radioactive sludge from storage near river for future treatment/disposal;
- upgrade/replace and optimise Cold-War-era systems to support Central Plateau clean-up;
- complete design of the low-activity waste pre-treatment system, to provide near-term waste feed for treatment at the Waste Treatment Plant (WTP);
- retrieve, manage and treat 56 million gallons of radioactive waste, currently stored in 177 ageing underground tanks to protect the Columbia River.

Recent successes include:

- completion of the vast majority of clean-up in 220-square-mile area near Columbia River (428 facilities demolished, 984 waste sites cleaned up and 6 reactors cocooned);
- near-completion of remediation of highly radioactive waste site near river (618-10 Burial Ground).

Opportunities exist to increase efficiencies and accelerate clean-up. The US Department of Energy (DOE) is working with US Environmental Protection Agency (EPA) and states to streamline clean-up regulations so as to get work done more efficiently.

Efficiencies are also being sought by replacing a 70-year-old water reservoir system needing multiple repairs with smaller reservoirs in the centre of Hanford. Also, portions of the decades-old electrical distribution system are being updated for long-term mission needs through 2060.

Also, the DOE Office of River Protection is assessing opportunities to further accelerate the tank waste treatment mission by aligning tank space management, operational efficiencies and waste treatment – including the opportunity to direct feed high-level tank waste to the WTP High-Level Waste Facility, and assessing benefits such as providing additional needed tank space, earlier treatment of the high-level waste, and additional waste treatment capabilities.

Figure A3.23. **Legacy reservoir (left) and illustration of scale of building works (right)**

Source: US DOE.

Source: US DOE.

Regulatory framework

In 1989, Hanford's mission shifted from plutonium production to clean-up of nuclear and hazardous facilities. Clean-up is governed by federal and state laws, and is overseen by numerous regulatory agencies. Advisory groups also provide input to the clean-up of the site.

The US Department of Energy, the US Environmental Protection Agency, and the State of Washington Department of Ecology signed a comprehensive clean-up and compliance agreement on 15 May 1989. The Hanford Federal Facility Agreement and Consent Order, or Tri-Party Agreement, is an agreement for achieving compliance with the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) remedial action provisions and with the Resource Conservation and Recovery Act (RCRA) treatment, storage, and disposal unit regulations and corrective action provisions. More specifically, the Tri-Party Agreement i) defines and ranks CERCLA and RCRA clean-up commitments, ii) establishes responsibilities, iii) provides a basis for budgeting, and iv) reflects a concerted goal of achieving full regulatory compliance and remediation, with enforceable milestones.

The Tri-Party Agreement is a legally binding agreement consisting of two main documents.

1. The "legal agreement" itself which describes the roles, responsibilities and authority of the three agencies, or "parties", in the clean-up, compliance and permitting processes. It also sets up dispute resolution processes and describes how the agreement will be enforced.
2. The "action plan" to implement the clean-up and permit efforts which include milestones (in Appendix D) for initiating and completing specific work and procedures the three agencies will follow.

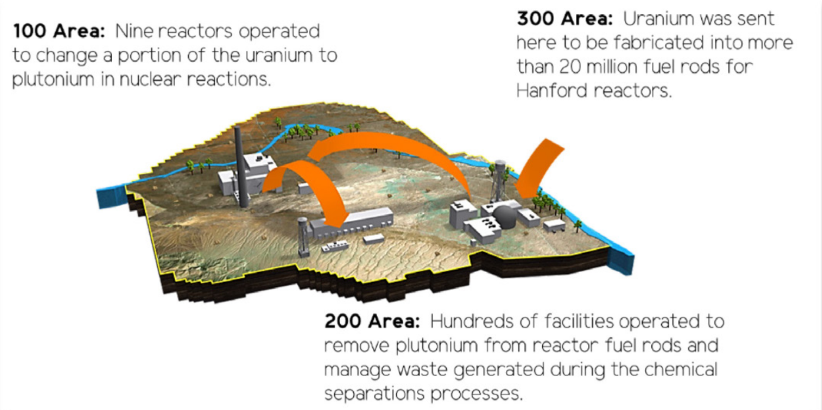
Additionally, an associated plan called the "public involvement plan", describes how the public will be informed and involved throughout the clean-up process.

Characterisation of circumstances

The primary mission at Hanford was plutonium production. Most of the uranium metal shipped to Hanford was prepared at Fernald, Ohio and Weldon Spring, Missouri. Further milling, metal cladding and final fuel preparation were complete in the southern part of Hanford in the 300 area. Nearly 20 million uranium fuel slugs were prepared at Hanford.

The Columbia River was critical to Hanford during its plutonium production mission because river water was used to cool the reactors when operating. Thus all nine reactors were built within close proximity to the Columbia River. All of the above processes left a legacy footprint with clean-up that workers are dealing with today.

Figure A3.24. **Areas of operation**



Source: US DOE.

As of April 2017, 879 of 1 715 facilities have been demolished since clean-up began. The Plutonium Finishing Plant, which began operation in 1949 and was the last facility to stop plutonium production was among the highest hazard facilities in the DOE waste management inventory. The plant was scheduled to be torn down in 2018.

In the Building 324 Disposition Project, remotely-operated equipment is used to remove highly radioactive soil from beneath the building. The soil removal will allow for eventual building demolition. A critical aspect of this project is that Building 324 is located within 300 yards of the Columbia River. A mock-up is used to improve safety and reduce project risk.

Figure A3.25. **Facility for decommissioning near the Columbia River (left) and underground storage site (right)**

Source: US DOE.

Source: US DOE.

The Sludge Treatment Project focused on clean-up of 35 cubic yards of radioactive sludge located near the Columbia River. Acceptance testing on equipment used for treatment and retrieval of the sludge is underway. Mockup technologies and procedures were effectively applied to the Sludge Treatment Project.

In May 2017, a partial collapse of a 20 foot by 20 foot section of a dirt cap occurred over a tunnel storing equipment. No contamination release occurred and crews were able to refill the hole with dirt and sand and cover the entire tunnel area with a large plastic cover. The plan was to fill this tunnel (Tunnel 1) with engineered grout. Tunnel 2 is similarly at risk for potential collapse. The contractor stabilisation options were discussed with stakeholders.

Groundwater remediation, or "pump and treat" is conducted by pumping ground water to the surface, treating it using specialised processes to remove the contaminants, and then returning the water to the subsurface. Further, clean-up workers are using several methods in the ground itself to stop or slow the movement of contaminants towards groundwater. As of April 2017, 16 billion gallons of groundwater have been treated, with 343 tonnes of contaminants removed.

A significant portion of the radioactivity at the Hanford site is contained in 1 936 capsules of caesium and strontium that are stored in pools of water. The plan is to relocate these capsules into dry storage casks.

Figure A3.26. **Underground storage site (left), groundwater remediation (middle) and storage for caesium and strontium capsules (right)**

Source: US DOE.

Source: US DOE.

Source: US DOE.

Societal aspects

All Hanford site clean-up is governed by federal and state laws, and is overseen by a number of regulatory agencies with involvement of advisory boards.

The Hanford Advisory Board (HAB) comprises 32 seats, with members providing advice and recommendations to the Tri-Party agencies (State of Washington, the US EPA, and the US DOE) on selected major policy issues. These issues include clean-up standards, environmental restoration and waste management and disposition, as well as stabilisation and disposition of non-stockpile nuclear materials and future land use and long-term stewardship. Members of the public are engaged through comment periods, public meetings and the Hanford Speakers Bureau.

The Hanford site also has considerable regional and national support from elected leaders, including the Washington State Governor, federal senators and representatives, as well as four separate Tribal Nations. Three of the four Tribal Nations have Treaty Rights to Hanford lands, however, the US DOE engages in regular consultation with all four.

End-state and long-term protection values

Remedial activities are ongoing at the Hanford site as discussed above. These activities are being conducted with the objective of reducing environmental risk, protecting the Columbia River, and eventually making the land available for other uses. To date over 1 600 acres of land have been transferred for redevelopment, over 800 facilities have been demolished and over 1 300 waste sites have been remediated. The DOE intends to continue to manage the site to ensure protection of public health and safety into the indefinite future.

Figure A3.27. **Typical environmental scene**

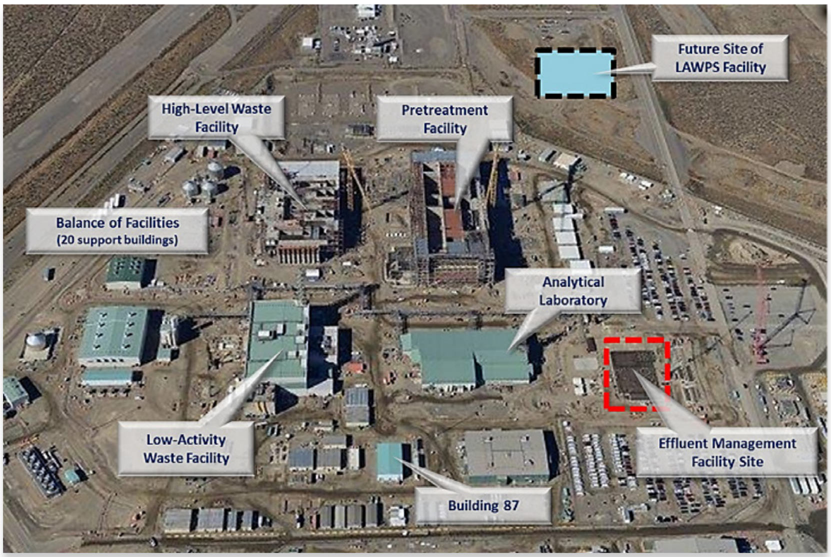
Source: US DOE.

With respect to waste management, solid low-level waste is taken to the Environmental Restoration Disposal Facility (ERDF) on the Hanford site. The ERDF accepts low-level radioactive, hazardous and mixed wastes that are generated during site clean-up activities. Over 1 300 of 2 032 waste sites have been remediated since clean-up began.

One other important aspect of the Hanford clean-up effort is the management of its 56 million gallons of liquid chemical and radioactive waste, currently stored in 177 large, ageing underground tanks.

The Waste Treatment Project has been tasked with the mission of immobilising tank waste in glass for environmental protection and long-term storage. Low-activity waste treatment could begin as soon as 2022. Technical issues are still being resolved for the pre-treatment facility.

Figure A3.28. **Example waste management facilities**



Source: US DOE.

Conclusions

Clean-up is comprised of many types of activities. All are governed by federal and state laws, and are overseen by numerous regulatory agencies. Clean-up is important to stakeholders to reduce environmental risks, to protect the Columbia River, to eventually make the land available for other uses and to meet federal obligations.

Case study 10. Western New York Nuclear Service Center and West Valley Demonstration Project, United States

The Western New York Nuclear Service Center (WNYNSC) is a complex decommissioning site located in western New York State, about 50 km (30 miles) south of Buffalo. The New York State Energy Research and Development Authority (NYSERDA) holds the licence and title to the 13 km^2 WNYNSC site. The WNYNSC is the former location of the only commercial spent fuel reprocessing plant to operate in the United States. Nuclear Fuel Services (NFS) operated the spent fuel reprocessing plant and associated waste disposal areas from the years 1966 to 1975.

In 1972, the plant permanently ceased reprocessing operations after NFS determined that it would not be economically viable to continue reprocessing operations. In 1976, the NFS informed New York State that it would not resume reprocessing and would transfer the facility to NYSERDA when the lease expired in 1980. At the time, the NFS said it would withdrawal from West Valley, the site contained 750 spent fuel assemblies that had not been reprocessed, $2.3 \times 10^{+06}$ litre of liquid high-level radioactive waste stored in two steel tanks, a highly contaminated main plant process building, and almost $8.5 \times 10^{+04}$ m^3 of radioactive waste buried in the two disposal areas. New York State refused to accept the facilities and the waste, and in 1980 the West Valley Demonstration Project (WVDP) Act was passed. The WVDP Act allowed the US Department of Energy (DOE) to take exclusive possession of about 0.8 km^2 of the WNYNSC in order to complete the high-level waste (HLW) solidification and decommissioning activities at the site.

Site description

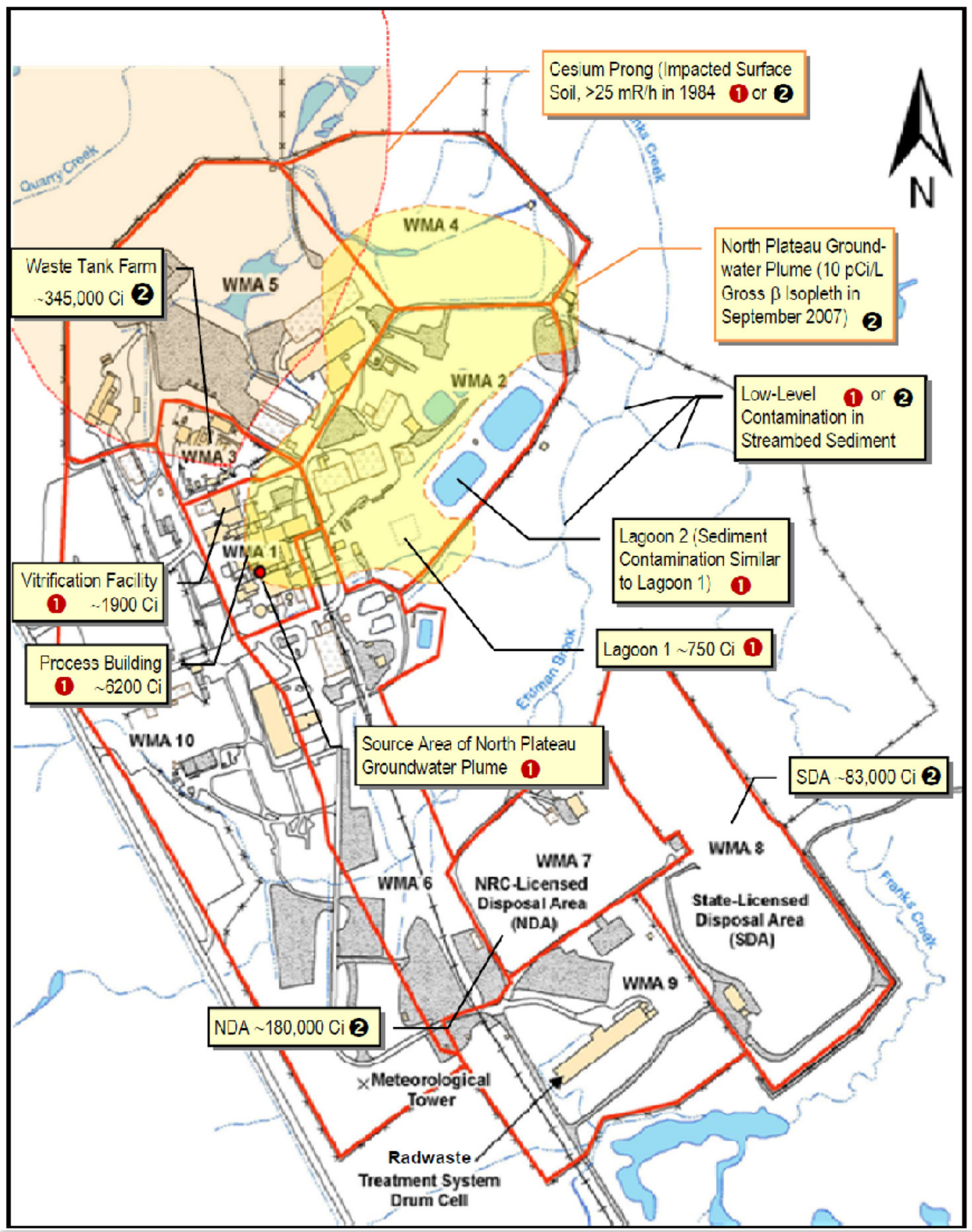
The WNYNSC is located on the west shoulder of a steep-sided, glacially-scoured bedrock valley that is filled with a sequence of glacial sediments. These glacial deposits are comprised primarily of clays and silts separated by coarser-grained layers created during periods of glacial retreat. WVDP is bordered by two streams, Franks Creek to the east and Quarry Creek to the north. The WVDP is bisected by Erdman Brook that divides the site into the North Plateau and South Plateau. Franks Creek is a tributary of Buttermilk Creek. Figure A3.29 shows major site facilities and features, as well as source areas to be addressed in two phases, referred to as Phase 1 and Phase 2 Decommissioning.

Regulatory framework

A number of federal and state entities are currently involved with long-term management and oversight of the former spent fuel reprocessing facility, including the US Nuclear Regulatory Commission (NRC), the US Environmental Protection Agency (EPA), the NYSDEC and the New York State Department of Health (NYSDOH).

The DOE has completed some of the requirements of the Act, including vitrifying the liquid high-level radioactive waste in borosilicate glass and placing it in 275 canisters suitable for permanent disposal. The DOE will remain on-site until its responsibilities under the WVDP Act are completed, and will then return the WVDP portion of the WNYNSC back to NYSERDA, at which time NYSERDA will be responsible for meeting the decommissioning criteria for the entire WNYNSC.

Figure A3.29. **Layout of West Valley Site and source areas to be addressed in two phases of decommissioning: Phase 1 and phase 2**



Note: Areas to be addressed in Phase 1 are marked with a red symbol. Areas to be addressed in Phase 2 are marked with a black symbol. 1 Ci = 3.7 x 1 010 Bq.

Source: Adapted from Figure ES-5, DOE, 2009.

The NRC's responsibilities under the WVDP Act include informal review and consultation, as well as monitoring of DOE activities, and defining the clean-up criteria for the site. While a majority of the site activities have focused on the management of radioactive waste and contamination, there are also hazardous chemicals and hazardous wastes on-site that are being managed in accordance with the EPA, and New York State regulations. The EPA, NYSDEC, and NYSDOH also review documents developed by the DOE and NYSERDA related to site decommissioning, and serves as a co-operating agency on preparation of the decommissioning environmental impact statement (EIS).[1]

The NRC established decommissioning criteria for the WVDP in a final Policy Statement (67 Federal Register [FR] 5003) in February 2002. The final West Valley Policy Statement prescribes the NRC's licence termination rule as the decommissioning criteria for the WVDP, recognising that the NRC licensee, NYSERDA, will also have to meet the licence termination rule when the DOE relinquishes control of the project premises back to the state. The licence termination rule provides for release with and without restrictions.[2] The final Policy Statement also provides flexibility to consider other alternatives (e.g. perpetual licence for some parts of the site or exemptions from the rule) to the decommissioning criteria provided in the License Termination Rule, if justified, after considering health and safety, as well as the costs-benefits of the various alternatives.

Characterisation of circumstances

Most of the residual inventory at the site is stored in the HLW tanks and disposal areas. Liquid HLW from spent fuel reprocessing was stored in two tanks, Tank 8D-2, a 2 800 m^3 carbon steel tank, and Tank 8D-4, a 57 m^3 stainless steel tank. Table A3.3 includes estimates for the total quantity (in Ci) of the inventories i) in the tank farm following reprocessing, ii) the NRC-Licensed Disposal Area (NDA), and iii) the State-Licensed Disposal Area (SDA) (DOE, 2009).

As a result of operations, site soils, groundwater and surface water/sediments are radiologically contaminated. In 1968, leaks of radioactive nitric acid recovered from spent fuel reprocessing operations migrated into soils beneath the south-west corner of the main plant process building creating what is referred to as the North Plateau Groundwater Plume. This plume contains high concentrations of relatively mobile and short-lived Sr-90 (see Figure A3.29). The DOE is remediating the groundwater plume with a permeable reactive barrier wall utilising natural zeolite to remove Sr-90 from groundwater prior to its seepage to surface water.

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1. In conjunction with NYSERDA, the DOE issued a draft EIS in 2008 evaluating various alternatives to decommissioning and long-term stewardship. The DOE and NYSERDA selected the Phased Decision making alternative as the preferred alternative in the final EIS issued in 2010 (DOE and NYSERDA, 2010).
2. The License Termination Rule applies various options for decommissioning, including unrestricted and restricted release. A dose criterion limit of 0.25 mSv/y total effective dose equivalent (TEDE) to the average member of the critical group and at residual radioactivity levels that are as low as is reasonably achievable (ALARA) is required for unrestricted release. For restricted release, the License Termination Rule specifies a dose limit of 0.25 mSv/y TEDE with legally enforceable institutional controls in effect, and residual radioactivity levels that are ALARA. In the event that institutional controls are no longer in effect, dose to the average member of the critical group should not exceed 1 mSv/y TEDE. If it is demonstrated that the 1 mSv/y TEDE criterion is technically not achievable, would be prohibitively expensive, or would result in net public or environmental harm, dose to the average member of the critical group may be as high as 5 mSv/y TEDE when institutional controls are no longer in effect.

Table A3.3. **Estimated radiological inventory (MBq) in (i) HLW tanks, (ii) NDA, and (iii) SDA of radionuclides of interest listed in the DOE's Decommissioning Plan**

Radionuclide	Half-life (years)	Estimated activity in HLW tanks	NDA	SDA
C-14	5 700	1.3E+03	1.9E+07	1.1E+07
Sr-90	29	1.3E+09	8.1E+08	5.2E+06
Tc-99	2.1E+05	4.4E+05	3.7E+05	5.6E+04
I-129	1.6E+07	6.7E+02	8.1E+02	1.2E+05
Cs-137	30	1.1E+10	1.1E+09	4.1E+08
U-232	72	3.3E+04	--	--
U-233	1.6E+05	1.3E+04	4.1E+05	9.3E+04
U-234	2.5E+05	5.2E+03	2.2E+04	3.6E+06
U-235	7.0E+08	1.9E+02	4.4E+03	1.3E+05
U-238	4.5E+09	1.4E+03	5.6E+04	7.0E+06
Np-237	2.1E+06	2.0E+04	6.3E+03	6.3E+01
Pu-238	88	5.9E+06	1.3E+07	8.9E+08
Pu-239	24 000	1.4E+06	2.1E+07	6.7E+06
Pu-240	6 600	1.0E+06	1.5E+07	4.1E+06
Pu-241	14	2.1E+07	3.4E+08	8.5E+07
Am-241	430	1.4E+07	7.4E+07	1.8E+07
Cm-243	29	1.3E+05	--	--
Cm-244	18	3.0E+06	--	--

Notes: This information was mainly taken from various tables in the DOE's Phase 1 Decommissioning Plan (DOE, 2009) and only includes radionuclides of interest listed in the Plan. The Sr-90 value for the SDA was recently updated to 2.8E+08 MBq by the Exhumation Working Group (ExWG, 2016).

Source: DOE, 2009.

The DOE performs routine on-site and off-site monitoring (air, surface water, groundwater, storm water, soil, sediment and biological samples) to evaluate any impacts from DOE operations and issues an Annual Site Environmental Report documenting the results of the monitoring. The 2015 calculated dose to the hypothetical critical receptor from airborne radiological emissions was estimated to be <4.7% of the 0.10 mSv EPA limit (DOE, 2016). The 2015 dose from combined airborne and waterborne radiological releases was estimated by the DOE to be <0.49% of the 1 mSv DOE limit.

Societal aspects

The Seneca Nation, a Native American tribe, is also a key stakeholder keenly interested in timing and extent of remediation of the site. The Seneca Nation has three reservations: i) Cattaraugus Reservation, ii) Allegany Indian Reservation, and iii) the mostly unpopulated Oil Springs Reservation. The 8 000 members of the Seneca Nation of Indians reside within 30 miles of the West Valley site.

Regulatory Roundtable meetings have been instrumental in bringing key players to the table with the common goal of reducing risk from the site and cleaning up the site to the extent practical. The initiation of these regulatory meetings has helped facilitate decision making and has led to real progress on clean-up of the site. The DOE and NYSERDA continue to work collaboratively to reach final decisions regarding decommissioning of the site in Phase 2.

Additionally, following the preparation and issuance of the 2010 FEIS, the DOE and NYSERDA developed processes for the equal funding and management of the analyses necessary to inform the Phase 2 decommissioning decisions. This approach was developed to ensure that the DOE and NYSERDA have equal input on the development of these critically important analyses with the goal of facilitating interagency consensus on the Phase 2 decommissioning decisions.

In 2015 and 2016, NYSERDA conducted a radiological survey, collected soil/sediment samples, and prepared a dose assessment to assess the risk associated with off-site residual radioactivity "slightly" above background identified in a 2014 aerial survey. To complete this work, NYSERDA contacted affected members of the public to obtain access to their lands for sampling and to conduct a land-use survey to better understand activities being conducted around the site. Additionally, NYSERDA developed culturally specific exposure scenarios with input from the Seneca Nation for the areas identified by the 2014 areal radiation survey on Seneca Nation land. These serve as good examples of co-operation and communication with public stakeholders.

Throughout the development of the decommissioning EIS further stakeholder interactions have included public hearings, a public comment period on the draft EIS, and consultations with federal and state partners on the EIS. A supplemental EIS planned to be issued in 2020 is expected to have a similar public participation process.

Additionally, in the late 1990s, NYSERDA worked with the DOE to initiate the formation of the West Valley Citizen Task Force (CTF) to provide input on the decommissioning process. The CTF held its first meeting in January 1997, and in July 1998 submitted a Recommendations Report to NYSERDA and the DOE, on policies, priorities and guidelines for the clean-up, closure or long-term management of the West Valley site, which were summarised in Guiding Principles adopted by the organisation. The CTF meets regularly and remains actively involved in decommissioning and Phase 1 study activities. Furthermore, the DOE holds quarterly meetings to inform members of the public on progress made on WVDP decommissioning. Recent topics have included work on decontamination of the main plant process building and Vitrification facility, work planning for demolition of the Vitrification facility, as well as the transfer of HLW canisters to an on-site interim HLW storage pad.

End-states

The final decommissioning EIS for WVDP and WNYNSC evaluated the following alternatives i) site-wide removal, ii) site-wide close-in-place, iii) phased decision making, and iv) a no action alternative. The preferred alternative selected was phased decision making, or remediation of certain portions of the site in Phase 1 of decommissioning, along with the collection of additional information to inform decisions regarding remaining portions of the site in Phase 2 of decommissioning. The option for unrestricted release of the site was preserved under Phase 1 (the DOE is cleaning up areas of the site to unrestricted release standards in the event that the final Phase 2 decision is unrestricted release of the WVDP and WNYNSC).

As indicated above, the final West Valley Policy Statement prescribes the NRC's licence termination rule as the decommissioning criteria for the WVDP, recognising that the NRC licensee, NYSERDA, will also have to meet the licence termination rule, which has provisions for release with and without restrictions, when the DOE relinquishes control of the Project Premises back to the state. The final Policy Statement also provides flexibility to consider alternatives (e.g. perpetual licence for some parts of the site or exemptions from the rule) to the decommissioning criteria provided in the License Termination Rule, if justified, after considering health and safety, as well as the costs-benefits of the various alternatives.

Long-term protection values

The categories of waste that currently exist at the site include non-hazardous waste, hazardous waste, LLW, mixed LLW, mixed transuranic, transuranic waste and HLW. Much of the Class A LLW is slightly contaminated, low-specific-activity waste that would be expected to have no adverse impact on the capacities of the DOE or commercial disposal facilities. The DOE is currently disposing of LLW and mixed LLW waste at commercial sites, the Nevada National Security Site near Mercury, Nevada, or a combination of commercial and DOE sites. Disposal paths for higher risk wastes are less clear. Until issues related to disposal of commercial Class B and C low-level radioactive waste, Greater-Than-Class C waste, and non-defence transuranic waste are resolved, these potentially orphan wastes will be stored on-site.

The DOE is currently storing 275 canisters vitrified HLW in stainless steel multipurpose canisters placed within a vertical reinforced concrete storage cask. In 2016, these storage casks were transported to a concrete storage pad located on-site and await shipment to a HLW repository. Development of a geological repository (Yucca Mountain) for spent fuel and HLW disposal is currently on hold.

Although the final disposition path of certain WVDP wastes is unclear, the DOE and NYSERDA are actively managing the WVDP and the remaining portions of the WNYNSC, respectively, and will continue to do so until a record of decision is made regarding final disposition of the site. The DOE will continue to monitor the WVDP site and surrounding environs to ensure that public health and safety are protected. The DOE and NYSERDA have also commissioned work to reduce technical uncertainties associated with the long-term risks associated with residual radioactivity remaining following decommissioning to facilitate sound decision making.

Conclusions

The DOE has completed a number of activities in Phase 1, including decontamination of i) the vitrification facility where liquid HLW from spent fuel reprocessing was solidified, and ii) the main plant process building, where spent fuel was reprocessed. The DOE is in the process of dismantling and demolishing these buildings and expects to have the buildings removed by Fiscal Year 2020. The DOE has disposed more than 265 000 ft^3 (7 500 m^3) of LLW and is actively managing the HLW tanks. Recent accomplishments include the permanent disposal of three vitrification components by loading and transporting the low-level waste packages, mostly by rail, to a permanent disposal site in Andrews, Texas.

NYSERDA and the DOE have actively managed the SDA and NDA disposal areas, including installation of hydraulic barriers and low-permeability geomembrane covers to reduce infiltration of precipitation into the disposal trenches and reduce the volume of water that accumulates in the disposal holes and trenches. A large portion of the SDA geomembrane cover, installed in 1995, is reaching the end of its effective life. NYSERDA will replace this portion of the cover in 2017. Additionally, NYSERDA is investigating water elevation increases in two SDA disposal trenches; a recommendation for mitigation of these increases will be developed in 2017. The total volume of water extracted from the NDA interceptor trench has been reduced to one-sixth of pre-existing volumes since a geosynthetic cap and low-permeability up-gradient barrier (slurry wall) were installed in 2008.

The DOE and NYSERDA have commissioned various working groups and studies, including terrain analyses, and evaluation of recent erosion and depositional processes, to facilitate interagency consensus in Phase 2 decision making and to provide key data for updated erosion modelling, and model calibration and validation (EWG, 2012a; EWG, 2012b). They are also actively managing a contract to develop a probabilistic performance assessment that rigorously evaluates features, events and processes important to site performance, and uncertainty in dose modelling predictions.

Enhanced communications through the regulatory roundtable process and the equal management and funding of the Phase 2 analyses by the DOE and NYSERDA have led to a more collaborative and productive process to reach common goals for the site and significant decommissioning progress.

The NRC's establishment of clear decommissioning goals in the West Valley Policy Statement has made it possible for the DOE and NYSERDA to establish clean-up goals or evaluate the ability of various decommissioning alternatives to meet radiological criteria for licence termination. Flexibility provided in the West Valley Policy Statement with respect to decommissioning options is expected to lead to optimal solutions to the problem.

The DOE and NYSERDA's effective use of risk and performance assessment tools have made it possible to evaluate risks associated with various decommissioning options for the site, and identify areas where additional data collection would be beneficial to decision making. For example, the DOE was able to successfully derive clean-up levels to guide remediation of surface and subsurface soils to be addressed in Phase 1 decommissioning. NYSERDA used a qualitative risk assessment to better understand the risks associated with continued management of the SDA over a 30-year management period (Garrick et al., 2009). The results of the EIS were used to identify key parameters and processes to help focus data collection efforts in Phase 1 studies. State-of-the-art performance assessment methods and data collection efforts continue to be used to help ensure a fully risk-informed Phase 2 decision.

References

DOE (2016), "West Valley Demonstration Project Annual Site Environmental Report Calendar Year 2015", prepared by CH2M HILL BWXT West Valley, LLC, September 2016.

DOE (2009), "Phase 1 Decommissioning Plan for the West Valley Demonstration Project", Revision 2, December 2009.

DOE/NYSERDA (2010), "Decommissioning and/or Long-Term Stewardship at the West Valley Demonstration Project and Western New York Nuclear Service Center", DOE/EIS-0226, January 2010.

EWG (2012a), "Recommendations for Phase 1 Erosion Studies", prepared for the US Department of Energy and New York State Energy Research and Development Authority, 20 July 2012, ADAMS Accession No. ML13072B210.

EWG (2012b), "Erosion Working Group Recommendations for Phase 1 Studies", 22 August 2012.

ExWG (2016), "Task 1.2: Technical Memorandum – Update Waste Inventories to Account for Radiological Decay", Revision 1, Prepared by the ExWG for Department of Energy and New York State Energy Research and Development Authority", August 2016.

Garrick, B.J. et al. (2009), "Quantitative Risk Assessment of the State-Licensed Radioactive Waste Disposal Area", prepared for New York State Energy Research and Development Authority", 11 August 2009.

Case study 11. The challenges of preventing the development of a legacy situation at Fukushima, Japan

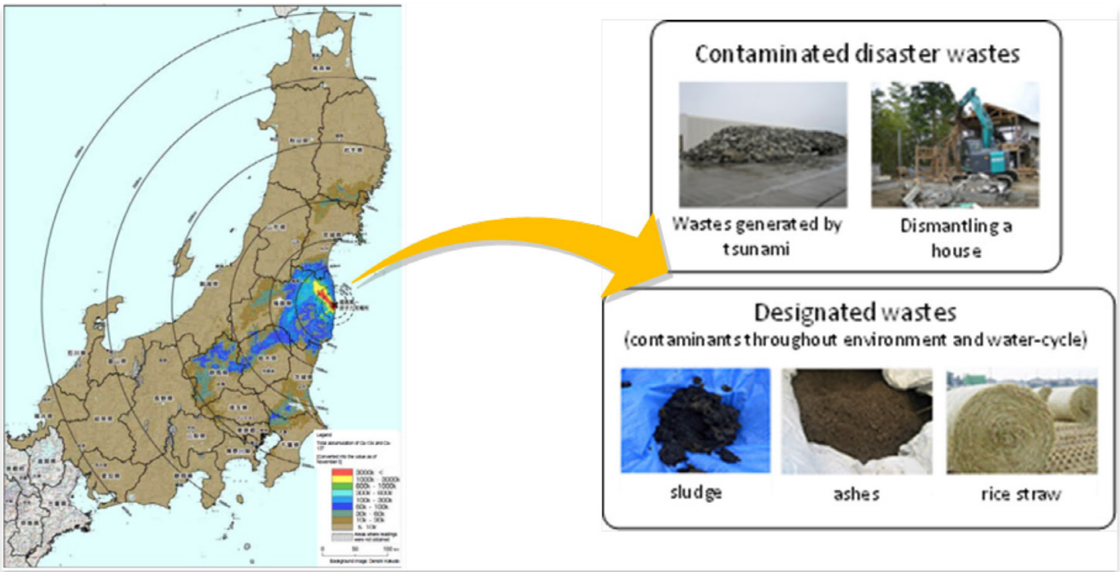
Site description

This case study elaborates the initial response, in particular to waste management, for off-site areas that were affected by the major nuclear accident that occurred at the Fukushima Daiichi nuclear power plant (NPP). It focuses only on contamination by radioactive Cs (Cs-134 and Cs-137), which are the dominant radionuclides. The off-site situation of the Fukushima Daiichi NPP was formed as follows.

The Fukushima Daiichi NPP incurred a major nuclear accident in conjunction with a great earthquake and tsunami in Japan in March 2011. Despite various emergency procedures having been initiated and carried out, the Fukushima Daiichi NPP was not spared from a hydrogen explosion. Fukushima Daiichi NPP surface-levels, along with surrounding land, were widely contaminated by radioactive Cs released from the accident.

A great deal of disaster-related waste was also generated by the earthquake and the tsunami, a portion of which was also contaminated by released radioactive Cs (Figure A3.30). High radioactivity was detected as early as April 2011 in designed wastes existing before the accident, such as sewage sludge, rice straw and incinerated ashes, because radioactive Cs had been concentrated through the environmental and water cycle.

Figure A3.30. **Radioactive Cs deposition and contaminated wastes following the Fukushima NPP accident**



Source: MEXT, 2011.

Regulatory framework

Prior to the accident at the Fukushima Daiichi NPP, there were no laws or criteria for the remediation of a radioactively polluted environment. These missing pieces within the legislation and guidance spheres also created challenges related to appropriately handling radioactively-contaminated materials in Japan. It was therefore necessary to immediately prepare and establish a legal framework covering occurrences of radioactive pollution, especially to ensure public safety. Guidelines and criteria for the implementation of decontamination and the handling of the contaminated materials, in particular for human population zones, were also required.

The Japanese government demonstrated urgency in those measures taken for the management of radioactivity on-site and immediately off-site. Within several months, they were able to construct a legal framework for their regulatory system, while also establishing required guidelines and criteria. The institutional responses for rapidly and effectively managing environmental pollution, as well as sourcing the required technical information, were identified as good examples of required measures for oversight of similar legacy situations that could occur in the future.

The institutional response process for environmental contaminants that occurred following the Fukushima accident is summarised as follows:

i. The Ministry of the Environment (MOE) demanded urgent measures be taken for restrictions on handling disaster wastes in the Fukushima prefecture beginning 2 May 2011.[1] The Nuclear Emergency Response Headquarters (NERH) and Ministry of Land, Infrastructure, Transport and Tourism (MLITT) demanded urgent measures be taken for restrictions on handling sewage sludge in the Fukushima prefecture beginning 12 May 2011.[2] These measures were installed to ensure the safety of both the worker in sewage treatment plants and the public.

ii. On 3 June 2011, the Nuclear Safety Commission of Japan (NSC) indicated a "Near-term policy to ensure the safety for treating and disposing contaminated waste around the site of Fukushima Daiichi NPP" (NSC, 2011). The policy established dosimetric criteria for both the protection of workers treating the materials and the public within the vicinity of treatment facilities and disposal sites, and for the recycle and reuse of the contaminated materials. The dosimetric criteria proposed in the policy were such that the dose for workers should not exceed 1 mSv/y, and that for residents during the period of waste treatment was under 1 mSv/y. Additionally, criteria for residents after termination of institutional control of the waste must remain under 10 μ Sv/y; recycling of any contaminants is also controlled at lower than 10 μSv/y. Based on this policy, guidelines for radioactive Cs concentration and handling were also discussed and agreed.

iii. In order to provide the technical information for establishing guidelines and criteria, dose estimation was conducted for specific scenarios related to remediation activities, as well as the treatment, disposal and recycling of contaminated materials. Examples of scenarios and exposure pathways for dose estimation are illustrated in Figure A3.31. Based on these, the ministries announced temporary instructions. On 13 June 2011, for example, the NERH and MLITT instituted guidelines for the handling of contaminated sludge.[3] The MOE then instituted guidelines for the treatment and disposal of contaminated disaster waste on 23 June 2011;[4] and on 15 July 2011 the NERH established the basic policy for decontamination activities in population areas.[5]

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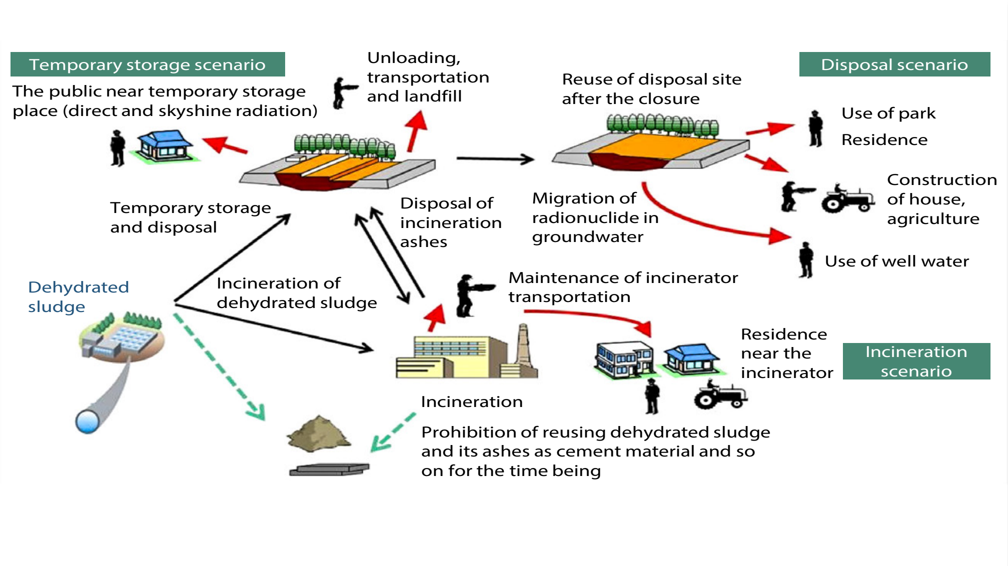
1. www.env.go.jp/jishin/saigaihaikibutsu.pdf (in Japanese).
2. www.mlit.go.jp/common/000144244.pdf (in Japanese).
3. www.mlit.go.jp/common/000147621.pdf (in Japanese).
4. www.env.go.jp/jishin/attach/fukushima_hoshin110623.pdf (in Japanese).
5. www.mext.go.jp/b_menu/shingi/chousa/kaihatu/016/shiryo/__icsFiles/afieldfile/2011/09/21/1311103_10_2.pdf (in Japanese).

Figure A3.31. **Example of scenarios considered in dose estimation for sludge management**



Source: Japan Health Physics Society.

iv. The Japanese government enacted "The Act on Special Measures concerning the Handling of Environment Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District –Off the Pacific Ocean Earthquake that Occurred on March 11, 2011", on 26 August 2011 (MOE, 2011). This act became the primary legal instrument for decision making related to remediation activities and the management of various radioactive wastes, including contaminated soils resulting from remediation activities and related contaminated materials. The treatment flow for contaminants, including recycling removed soil and disaster wastes based on the act is described in Figure A3.32.

v. Based on the Act referenced in point IV, important guidelines were instituted for environmental remediation and restoration of inhabited areas. On 27 December 2011, the MOE established "Decontamination guidelines", constructed in four parts (MOE, 2013).

   a. Part 1: Guidelines for Methods for Investigating and Measuring the Status of Environmental Pollution in Intensive Contamination Survey Areas

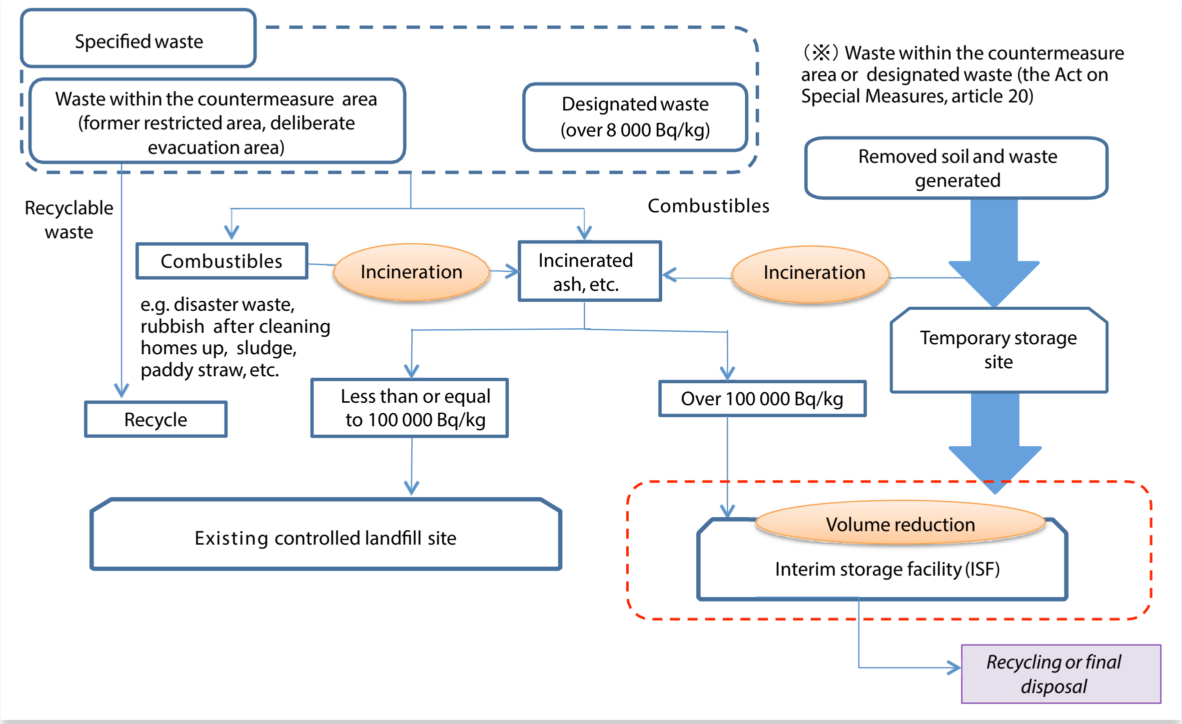
   b. Part 2: Guidelines Pertaining to Decontamination and Other Measures

   c. Part 3: Guidelines Pertaining to the Collection and Transfer of Removed Soil

   d. Part 4: Guidelines Pertaining to the Storage of Removed Soil

vi. On 22 December 2011, the Ministry of Health, Labour and Welfare (MHLW) issued an "Ordinance on Prevention of Ionizing Radiation Hazards at Works to Decontaminate Soil and Waste Contaminated by Radioactive Materials Resulting from the Great East Japan Earthquake and Related Works" (MHLW, 2013), and announced "Guidelines on Prevention of Radiation Hazards for Workers Engaged in Decontamination and Related Works" (MHLW, 2011), to ensure the safety of workers handling contaminated materials.

Figure A3.32. **Treatment flow for contaminants, including recycling removed soil and disaster wastes**[6]



Notes: Waste other than specified waste less than or equal to 8 000 Bq/kg is basically processed as conventional waste. The interim storage facility shall be planned to receive such waste, the amount of which is difficult to estimate at present.

Source: Japan Ministry of the Environment.

Characterisation of circumstances

Currently, based on the new Act and Decontamination Guidelines, as the planning and implementation phases of decontamination work have been carried out, the site's administration is aiming to reduce additional exposure doses to less than 1 mSv/y as a long-term goal. In addition to the above Decontamination Guidelines, the MOE established "Guidelines for Waste" on 27 December 2011, in six parts to manage various kinds of wastes.[7]

- Part 1: Guidelines for Survey on Pollution Status;
- Part 2: Guidelines for Specified Municipal Solid Waste/Specified Industrial Waste, etc.;
- Part 3: Guidelines for Designated Waste;
- Part 4: Guidelines for Waste from Decontamination Work;
- Part 5: Guidelines for Method of Measurement of Radioactive Concentration;
- Part 6: Guidelines for Specified Waste (added in 2013).

As regards recycling, and according to the near-term policy issued by the NSC on 3 June 2011, prior to the recycled materials being put on the market, it is now necessary to check that radioactivity concentrations are controlled at lower than 10 μSv/y. Dose estimations were

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6. http://josen.env.go.jp/en/news/pdf/news_160600_02.pdf.
7. www.env.go.jp/en/focus/docs/files/20140725-87-0.p (in Japanese).

carried out for recycling of disaster wastes into pavements, which is public-enterprise controllable and expected to reduce waste volume. The calculated results concluded that concrete wastes less than around 3 000 Bq/kg can be reused as sub-base course material for pavements under controlled conditions. Based on the results, the MOE established "Guidelines to reuse the contaminated disaster waste (concrete debris) under the controlled conditions" on 27 December 2011.[8]

Establishment of new guidelines are also undergoing implementation at this time for the recycle and reuse of various contaminants, revision of previous guidelines on decontamination and waste management, and maintenance of many implementation manuals.

Conclusion

During the initial stages of environmental polluting caused by the Fukushima Daiichi NPP accident, rapid supply of technical information was important to establish the guidelines and criteria concerning radiological protection. For unpredictable beyond-design basis accidents, the government should prepare beforehand, to the extent possible, the regulatory system and the legal frameworks needed to consider phenomena outside assumptions.

This case study presented a situation where effects from an NPP accident are deeply felt off-site. Areas affected by the accident releases from the Fukushima Daiichi NPP are not considered to be a legacy site. This has been avoided through the process of institutional response(s) concerning radioactivity and associated pollution in and around the Fukushima NPP, including during the initial stages of the accident. The experience is offered as referable practices for supervising both sites affected by future nuclear or radiological accidents and sites undergoing states of emergency.

References

Kuroda, H. (2016), "Lesson Learned from the Implementation on of Decontamination in Japan", http://josen.env.go.jp/en/news/pdf/news_160600_02.pdf.

MEXT (2011), "Results of the Fourth Airborne Monitoring Survey by MEXT", http://radioactivity.nsr.go.jp/en/contents/4000/3179/24/1270_1216.pdf.

MHLW (2013), "Ordinance on Prevention of Ionizing Radiation Hazards at Works to Decontaminate Soil and Waste Contaminated by Radioactive Materials Resulting from the Great East Japan Earthquake and Related Works", Amendment of Ordinance of the Ministry of Health, Labour and Welfare No. 89 of 2013, www.japaneselawtranslation.go.jp/law/detail/?id=2714&vm=04&re=02.

MHLW (2011), "Guidelines on Prevention of Radiation Hazards for Workers Engaged in Decontamination Works", www.mhlw.go.jp/english/topics/2011eq/workers/dr/dr/pr_120615_a03.pdf.

MOE (2013), "Decontamination Guidelines", 2nd Edition, http://josen.env.go.jp/en/framework/pdf/decontamination_guidelines_2nd.pdf.

MOE (2011), "Act on Special Measures concerning the Handling of Environment Pollution by Radioactive Materials Discharged by the NPS Accident Associated with the Tohoku District – Off the Pacific Ocean Earthquake That Occurred on March 11, 2011", http://josen.env.go.jp/en/framework/pdf/special_act.pdf.

NSC (2011), "Near-term Policy to Ensure the Safety for Treating and Disposing Contaminated Waste around the Site of Fukushima Dai-ichi Nuclear Power Plants", http://warp.da.ndl.go.jp/info:ndljp/pid/9483636/www.nsr.go.jp/archive/nsc/NSCenglish/geje/20110603suggest_2.pdf.

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[8] www.env.go.jp/jishin/attach/concrete-waste111227.pdf (in Japanese).

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Challenges in Nuclear and Radiological Legacy Site Management

Many countries are dealing with challenges stemming from nuclear and radiological legacy sites. In particular, managing these sites in an open and transparent fashion while taking into account the views of all relevant stakeholders and building confidence in the solutions adopted is an ongoing challenge.

This report provides information on the challenges and lessons learnt in legacy management and regulation based on practical experience documented in 13 case studies and site visits conducted by the OECD Nuclear Energy Agency. A preliminary framework for a stepwise process to help reach an accepted and sustainable end-state is proposed based on this experience. The complex challenges and interactions among stakeholders in progressing in a harmonised, step-by-step manner are also examined in depth. The report concludes with recommendations for future international collaborative work to improve and test the preliminary framework, and to examine and address the complexity of the relevant interactions.

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