

Nuclear Site Remediation and Restoration during Decommissioning of Nuclear Installations

A Report by the NEA
Co-operative Programme
on Decommissioning



Radioactive Waste Management

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NEA No. 7192

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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- 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 friendly and economical use of nuclear energy for peaceful purposes;
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Foreword

The Nuclear Energy Agency (NEA) Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking among NEA member country organisations actively executing or planning the decommissioning of nuclear facilities. The objective of the CPD is to acquire and share information from operational experience in conducting specific decommissioning projects that would be useful for future endeavours. Its working method is based on the exchange of knowledge currently drawn from over 60 participating reactor and fuel cycle decommissioning projects.

Although some of the information exchanged within the CPD is confidential in nature and is restricted to programme participants, experience of general interest gained under the auspices of the programme is released for public use. Such information is brought to the attention of all NEA member countries through regular reports to the NEA Radioactive Waste Management Committee (RWMC), as well as through published studies. The Working Party on Decommissioning and Dismantling (WPDD) of the RWMC would like to thank the CPD for sharing experiences from its important work.

The information exchange within the CPD includes biannual meetings of the Technical Advisory Group (TAG) and supporting projects on diverse topics. The TAG formed a Task Group on Nuclear Site Restoration (TGNSR) made up of nuclear operators, experts and regulators to review nuclear site restoration. This task group produced the present report, which summarises work carried out between March 2012 and April 2014, providing observations and recommendations to consider in the development of strategies and plans for land quality management at nuclear sites. The task group was supported by the International Atomic Energy Agency (IAEA).

Acknowledgements

The NEA is grateful to the members of the Task Group on Nuclear Site Restoration (TGNSR) for their contributions to this report and to the respondents to the national and project-specific questionnaires. The task group members are: Mr Peter Orr (Chair, United Kingdom, Environment Agency), Mr Nick Mitchell (Co-editor, United Kingdom, Eden NE), Ms Shelly Mobbs (Co-editor, United Kingdom, Eden NE), Mr Terry Bennest (Secretary, United Kingdom, NEA/CPD), Dr Rateb (Boby) Abu-Eid (United States, US NRC), Ms Marie-Anne Berton (France, CEA), Ms Catherine Ollivier Dehaye (France, EDF), Mr Julian Cruikshank (United Kingdom, Sellafield Limited), Dr Paloma Diaz Arocas (Spain, CIEMAT), Ms Ester Garcia Tapias (Spain, Enresa), Mr Norbert Hess (Germany, AVR Jülich), Mr Sam-Bung Hong (Republic of Korea, KAERI), Ms Susan Miller (Canada, AECL), Dr Horst Monken-Fernandes (IAEA), Mr John Morse (United States, US DOE EM), Mr Olaf Nitzsche (Germany, Brenk Systemplanung), Mr Bart Ooms (Belgium, Belgoprocess), Dr Celso Osimani (Italy, SOGIN), Mr Gilles Pellenz (France, EDF) and Mr Stuart Walker (United States, US EPA).

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Executive summary

Decommissioning of nuclear facilities and related remedial actions are currently being undertaken around the world to enable sites or parts of sites to be reused for other purposes. The term remediation is used here to refer 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 use. Other terms that are sometimes used include site clean-up, decommissioning and restoration. Long-term stewardship may also be considered as a remediation action.

Remediation has usually been considered as the last step in a sequence of decommissioning steps but the values of long-term planning and parallel remediation are also increasingly being recognised as important steps in the process. This report by the OECD Nuclear Energy Agency (NEA) highlights lessons learnt from the remediation experiences of NEA member countries that may be helpful to practitioners of nuclear site remediation.

The report was prepared by the Task Group on Nuclear Site Restoration (TGNSR) which was formed through nominations from members participating in the Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD), following a proposal submitted to the NEA Working Party on Decommissioning and Dismantling (WPDD). The task group gathered information at selected nuclear sites on experiences, approaches and techniques for remediation that minimise risks to workers and the environment, as well as costs and disruptions to decommissioning programmes. This was achieved using national level and project level questionnaires, detailed case studies and the experiences of task group members.

The aim of the national and project level questionnaires was to collect data on strategic and regulatory aspects across different NEA member countries so as to gain a common understanding of the current status of site remediation, good practices and any issues or gaps at the national level, as well as an understanding of practices and approaches at site and project level of all the activities necessary to achieve successful site remediation. The purpose of the case studies was to enable a more in-depth understanding of the remediation practices used and the issues encountered during remediation than can be obtained from questionnaires.

Environmental remediation is a multi-phased activity consisting of identifying environmental problems, gathering information in order to develop a range of solutions to solve problems, evaluating the options and selecting the preferred solution, carrying out the remediation project that will resolve the problem, and then verifying and documenting that the solution was successful. The lifecycle of a nuclear site remediation project is divided into several phases: problem definition, remedial investigation, remedial planning, remedial action, project closeout, and potentially, institutional control.

The responses to the national questionnaires indicate that national level policy, regulation or guidance is provided in each of the ten countries where a questionnaire was completed. Nine countries have national policies that deal with site remediation. Six of these countries have specific regulations, three have overarching legislation that is applicable to facility decommissioning and site remediation and one has national guidance on the remediation of contaminated areas. Experience with remediation of nuclear sites is estimated to be low or moderate, except in the United States and Germany. In these countries, a large number of contractors are available to perform characterisation and remediation of environmental media, including contaminated soils, surface water and groundwater. In other countries, there are fewer contractors, and in a few cases, resources and best practice guidance are generally obtained from other countries. Although many facility decommissioning projects have been completed, there are only a few major sites where the entire remediation process has been completed. The timescale for finishing projects varies widely. The three most important barriers and obstacles to remediation are other site priorities (such as operations), regulations and lack of disposal routes.

The experiences of the task group members and the 12 case studies obtained as part of this report were combined to offer an in-depth understanding of remediation practices used and key issues encountered. Key issues surrounding site remediation include poor problem definition, lack of stakeholder engagement (including regulatory bodies) and inadequate characterisation. Without a well-defined problem and associated conceptual model, the site end state and clean-up goals may not be explicit. A clear consensus on clean-up goals is essential in order for every action taken to be directed towards this goal. When developing an end use, comprehensive stakeholder engagement is also essential. If end states will not be met for a very long time, or if a consensus cannot be reached on what that end state should be, it may be necessary to develop interim solutions, in addition to final end states. Identifying and achieving clean-up criteria are key issues for many countries, where national policies often inhibit cost-effective remediation.

Good conceptual models, based on adequate characterisation, are important and necessary. Since they should be rigorous and thorough, conceptual models can take time to develop and may go through many iterations, underlining the importance of initiating them as soon as possible in the remediation process. Conceptual models are a representation of the real world, and thus the need for ongoing verification must be emphasised. Robust decision-making methods are essential as well and do exist in some countries. Such methods enable decisions to become transparent and defensible. Alternative concepts should be considered with stakeholders to increase confidence in the chosen remediation approach, and open and honest communication with stakeholders should remain of utmost importance.

Sustainability is another key issue for many countries. Remediation need not take the site back to past or pre-operational conditions: social and economic factors need to be considered, as well as the burden to future generations. Using a risk-based approach to remediation can help take into account sustainability and remediation costs and can help countries with significant legacy clean-up challenges and budgetary constraints to better manage their remediation projects. Remediation activities should strive to be safe and cost-effective, but any number of technical issues may arise along the way. The size and complexity of the site to be remediated can be a significant factor in determining how and when to remediate. Another factor to be considered is national regulations and policies, which can vary significantly from country to country. Ongoing interventions should be avoided, if practical, to ensure that clean-up responsibilities are not passed on to the next generation. A lack of waste disposal facilities can also affect remediation plans. Without disposal facilities, interim storage may be required, often at a significant cost. If suitable storage facilities are not available, the projects could then be delayed. An efficient methodology for the classification of waste for disposal is also required to make the most efficient use of waste management facilities. In addition, a holistic approach to onsite disposals and residual contamination left on the site needs to be considered.

The long timescales associated with remediation projects can entail challenges for records management. Information management technology issues have occurred at sites transitioning to a long-term institutional control regime. Benchmarking and information sharing are important to avoid repeating mistakes. Lessons learnt from other countries can improve safety, cost-effectiveness and environmental protection effectiveness. When implementing changes, basic differences and similarities between countries regarding the scale of remediation, approaches and policies need to be considered. Lessons learnt can be in the form of what not to do again, as well as what went well and should be repeated. Learning from other countries' experiences can also lead to prevention of contamination in the first place, eliminating the need for remediation later.

Finally, recommendations for further research and development are proposed, based on the experiences of member countries. Opportunities for further investigation include the prevention of contamination in the environment from the beginning, suggestions for better characterisation results, ways to improve decision-making processes and methods to obtain more successful stakeholder engagement. Other opportunities for technical development include phyto-remediation, groundwater protection and clean-up, remediation techniques for soils underneath buildings and the reduction of waste volumes. Knowledge sharing and communication between countries engaged in environmental remediation is also an important area for further development.

1. A report on the experiences of NEA member countries in nuclear site remediation

This report describes the experience of NEA member countries in nuclear site remediation and draws on this experience to make recommendations for good practice and further research. The project has focused on legacy and operational nuclear sites (and excludes uranium mining sites and contamination following a major accident).

Around the world, nuclear sites are being decommissioned and remedial actions are being undertaken to enable the site or parts of sites to be reused. The term *remediation* is used here to refer 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 use. In line with the IAEA definition of remediation [1], remediation does not imply complete removal of the contamination or returning the site to its background conditions, something that may be neither achievable nor necessary. Other terms that are sometimes used include site clean-up, decommissioning and restoration. Long-term stewardship may also be considered as a remediation action.

Remediation has usually been considered as the last step in a sequence of decommissioning steps but increasingly the value of parallel decommissioning and remediation is being recognised [2]. One of the planning drivers is that regulators wish to know that liabilities are well understood and that adequate financial resources will be available. Recognising the potential issues with uncertainties in final site remediation costs, operators are now undertaking early site land and groundwater characterisation. Operators are also learning the importance of prevention and minimisation of leaks of radioactivity in the design phase of the facility as well as in the operating phase, and the value of early intervention if a leak was to occur to reduce contamination in the soil and groundwater. This will reduce overall liabilities and ensure protection of the environment. However, in some cases early intervention may not be considered value for money or beneficial for technical or logistical reasons e.g. ease of access to the contamination. Early intervention and final site remediation both need to be guided by good characterisation, reliable conceptual models, quantified clean-up goals and good knowledge management. For both early and final remediation, clarity and agreement on interim and end states for the land and groundwater is important.

Whilst the focus of remediation is often about the suitable management of contaminated land and groundwater, the scope of this report is wider to encompass steps that can be taken to avoid the need for remediation in the first place (prevention is better than cure). The aim is also to help ensure that site operators are well positioned to respond promptly and effectively to any contamination event that may occur. The overall goal is to take a lifecycle approach to protecting land and groundwater. This approach is called land quality management in the United Kingdom [3] or sustainable remediation [4]. Sustainable remediation considers the environmental, social and economic impacts of a project to ensure an optimal outcome, while being protective of human and environmental health, both at a local level and for the wider community.

Currently most nuclear site remediation work takes place at the legacy nuclear sites. This work has emphasised the need for better clarity in terms of the regulatory expectations for clean-up to enable de-licensing to occur. At other nuclear sites the drivers are less evident and there is a risk that remediation issues are overlooked. In 2013, there were about 150 nuclear power reactors that were undergoing decommissioning [5].

This report highlights the successes and lessons learnt from selected case studies that may be helpful to remediation situations on other nuclear sites.

1.1. Summary of the Task Group on Nuclear Site Restoration (TGNSR) approach

This report was prepared by a task group that was formed by nominations from the participating CPD members following a proposal submitted to the NEA WPDD. In recognition of the significant interaction of regulatory bodies with site remediation programmes the task group included representatives from the UK Office for Nuclear Regulation, the Environment Agency of England and the US Environment Protection Agency. The NEA also provided secretarial support. The task group shared information on experiences, approaches and techniques for land quality management at selected nuclear sites with the aim of ensuring risks to workers and the environment, costs and disruption to decommissioning programmes are minimised. This was achieved using questionnaires, case studies and personal experiences of task group members.

Consideration was given to any project leading to a nuclear site being released for re-use, but excluded decommissioning of site facilities, clearance of buildings and non-nuclear sites contaminated with Naturally Occurring Radioactive Material (NORM). The selected projects are predominantly concerned with land quality and include nuclear sites that have been restored, sites where early remediation has occurred and sites where early remediation is being considered. Projects relating to uranium mining sites have not been considered.

Information was gathered on current practice at two levels:

- National level (a questionnaire)
- Site and project level using:
 - a site and project level questionnaire targeted at project managers through CPD member contacts;
 - detailed case studies produced by members of the task group based on their experience or that of their organisations using a standard template.

The aim of the national level questionnaire was to gather information on strategic and regulatory aspects across different NEA countries to gain a common understanding of the current status of site remediation, good practice and any issues or gaps at a national level. The task group worked very closely with the IAEA to ensure that the data that was collected would also support the IAEA work on decommissioning and environmental remediation barriers (the CIDER Project www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/IDN/announcements.html). The questionnaire was targeted to only one or two people within each country with a senior role, setting or delivering national policy, strategy or relevant legislation. Task group members identified the individuals in advance and gained their support before sending out the questionnaire. Completed national questionnaires were received from ten NEA countries.

The aim of the Site and project questionnaire was to gain an understanding of practice and approaches at site and project level for all the activities necessary to achieve successful site remediation. The task group members approached members of the NEA WPDD and CPD, other CPD contacts and personal connections and asked them to target project managers known to them to complete the questionnaire, and provided assistance and support. Completed questionnaires were received from 30 projects.

The purpose of undertaking case studies was to obtain a more in-depth understanding of the remediation practices used and the issues encountered than can be obtained from the questionnaires. Task group members selected sites/projects for case studies from their own experience or from inside their parent organisation where it was expected that they could access detailed information. The case studies consider all activities and stages necessary to achieve successful remediation and not just those sites where work has been completed. A total of twelve case studies were received.

1.2. Remediation

Remediation is part of the land quality management lifecycle which is implemented throughout the site and facility lifetime. The flowchart below identifies the main land quality management lifecycle phases and activities (Figure 1.1).

Figure 1.1: Land quality management lifecycle

Conceptual phase



Operation phase



Decommissioning phase

- Physical, chemical and radiological background survey.
- Identifying sources and processes that could lead to land or groundwater pollution – ensuring elimination or mitigation of risk by design.
- Develop initial conceptual model.
- Defence-in-depth to prevent pollution (includes both plant systems/components and arrangements) = containment.
- Ground and groundwater quality monitoring programme, taking into account normal and incidental situations (wells, monitoring systems) – includes concentration levels of concern or trigger values that may trigger investigation or mitigating actions.
- Contingency arrangements in response to events (safety cases).

Stakeholder involvement on final end state through the decommissioning plan (public enquiry) before operation start

- Ground and groundwater quality management programme.
- Barriers control and asset management programme (liner, leaks detectors).
- Procedures to prevent pollution and to manage events or failure of barriers.
- When possible, immediate ground or groundwater remediation; compliance with decommissioning plan final end state, or ALARP/ALARA.
- Data quality and records management => conceptual model refining.
- Stakeholder information (incidents, regular discharges, end state evolution).
- Same or updated procedures and control and asset management programmes during building dismantling.

- If new facilities needed (waste disposal, workshops), see conceptual and operation phases => could lead to updated land quality management plans.
- In-depth characterisation adapted to historical records and knowledge.
- Check final end state of the decommissioning plan is practicable. If not, new end state to be negotiated with regulators and stakeholders.
- Refining conceptual model.
- Defining and implementing site remediation programme.
- Final measurements (final status survey/verification survey).

- Site release, with or without restrictions.

The first objective is therefore to prevent contamination occurring and in doing so avoid the need for remediation.

In principle remediation should only be considered if there is a source-pathway-receptor linkage, an approach that is used for both radioactive and other hazardous substances. Should remediation be necessary it could be carried out at different times at different parts of the site (partial site remediation or phased site remediation) or as one single project, depending on what is the optimum approach for the site.

Remediation is itself a multi-phased activity consisting of identifying the environmental problems, gathering information in order to make decisions about how to solve the problems, carrying out the remediation project that will solve the problem, and verifying and documenting that the solution has in fact been achieved. Many solutions may not have a defined end time as they may require monitoring or care and maintenance for an extended period of time, or even in perpetuity. Remediation can be broken down into the following six phases (see Figure 1.2).

Problem definition

Initially, one has to determine whether a condition exists that needs remediation considering factors such as the actual and/or foreseeable future use of the site, and regulatory advice or requirements (e.g. dose and risk criteria). In other words, is there a problem, and does it need fixing? There will be a need to compare with appropriate criteria, e.g. activity concentrations, and these will be established on a case by case basis. A conceptual model should be developed to assist in the development of the problem definition. The Conceptual Site Model (CSM) is an iterative, living representation of a site and its environment that helps to visualise and understand available information about a site. Some characterisation may be required to determine the exact nature of the problem or if a response is even required. Levels of contaminants in soil or groundwater may be below clean-up criteria, so no clean-up action may be required at all. The problem definition phase is an appropriate time to identify relevant stakeholders.

Remedial investigation

While initial characterisation and comparison to screening levels may indicate a problem may exist, further characterisation may be required to refine the problem definition and develop remedial action options. Site conceptual models may be updated at this point to better clarify or predict future clean-up scenarios. This is an iterative process where the CSM develops as understanding increases.

Remedy planning (options evaluation and selection)

Remedial options that will solve the problem should be identified and developed, after which the feasibility of each should be assessed. The feasible options are then evaluated so the optimal remedial action is implemented. Alternative options are evaluated against criteria and goals or objectives. Stakeholder involvement is critical in determining the optimal solution.

Planning for remediation requires careful consideration of financial, technical and human resources. Activities that need to be performed by different organisations need to be integrated. Remedy planning further includes a set of specific plans and specifications prepared to conduct the remedial action selected for site clean-up.

Remedial action

Once a remediation path forward has been chosen and planned, the action must be implemented. Implementation involves many challenges, including technological and safety challenges as well as disposal issues.

Project closeout

Once the Remediation fieldwork has been completed, project closeout work begins. Verification that the project objectives have been met must be undertaken. A project closeout report must be written to

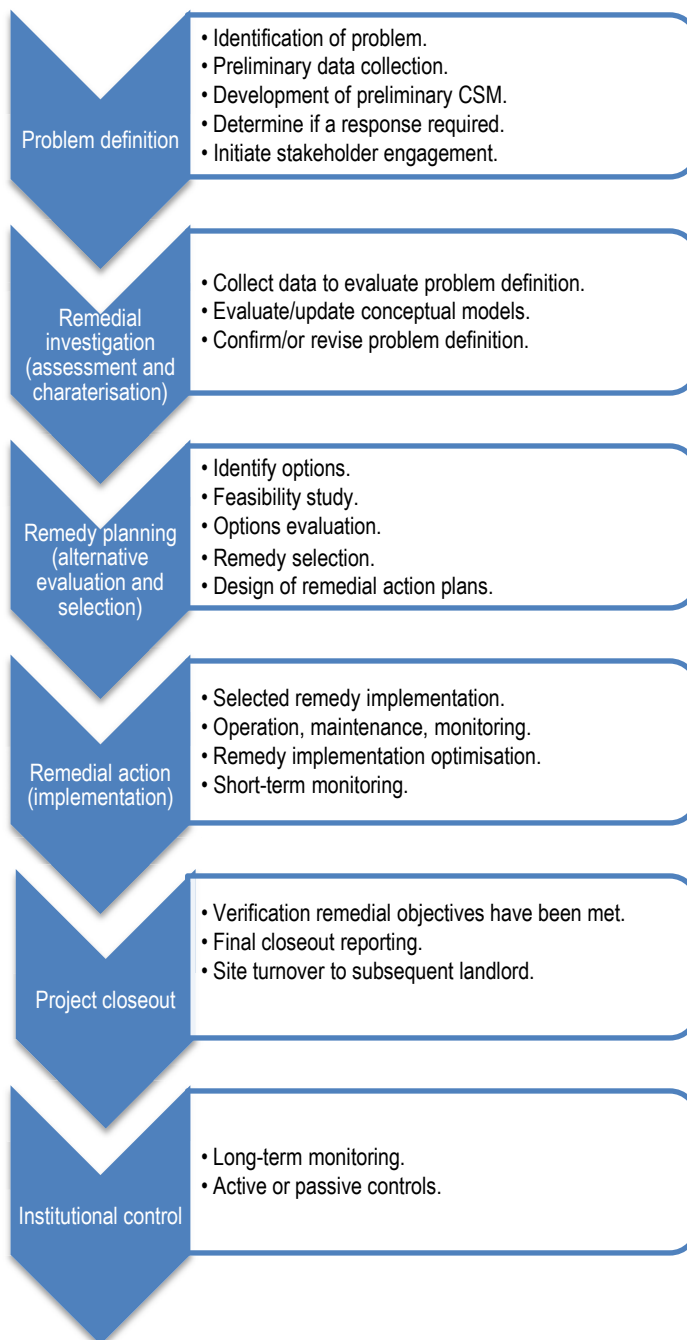
document the work that was done and that the project objectives have been met. Records should be maintained for future reference.

Institutional control

If a project site is not remediated to meet an unrestricted or greenfield state, some form of passive (e.g. land use control, archived records) or active (e.g. fencing) institutional controls may be required.

Monitoring of contaminants may also last well beyond the end of the formal remediation project. Groundwater may need to be treated for many decades beyond the installation of a groundwater treatment system [6].

Figure 1.2: Nuclear site remediation project phases



1.3. Report structure

The responses to the questionnaires are considered in Section 2 of the report, drawing on an analysis which is included in Annex 4. The six phases of site remediation are then used to highlight issues raised by the case studies and the experiences of the task group members (Section 3). Section 4 draws together findings in the previous sections to present the recommendations of the task group, highlights efforts to share knowledge and considers research and development priorities. References are given in Section 5. A glossary and bibliography are included in Annexes 1 and 2, respectively, the blank questionnaires are reproduced in Annex 3 and the case studies are given in Annex 5.

References

- [1] IAEA (2007), *IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection*, 2007 Edition. Vienna.
- [2] IAEA (2009), *Integrated Approach to Planning the Remediation of Sites Undergoing Decommissioning*. IAEA Nuclear Energy Series No NW-T-3.3 www.pub.iaea.org/MTCD/Publications/PDF/Pub1385_web.pdf.
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- [4] Interstate Technology and Regulatory Council (ITRC) (2011) *Green and Sustainable Remediation: A Practical Framework*, www.itrcweb.org/GuidanceDocuments/GSR-2.pdf.
- [5] IAEA PRIS (Power Reactor Information System), Database on nuclear power reactors maintained by International Atomic Energy Agency, www.iaea.org/pris/.
- [6] IAEA (2006), *Management of Long Term Radiological Liabilities: Stewardship Challenges*. Technical Reports Series 450, www-pub.iaea.org/MTCD/Publications/PDF/TRS450_web.pdf.

2. Data collected through questionnaires

This section describes the information received in the responses to the questionnaires. As stated in the introduction, the task group distributed two questionnaires: a national questionnaire, aimed at assessing the regulatory framework, policy drivers and constraints; and a site and project questionnaire on remediation. The questionnaire templates are reproduced in Annex 3. The aim of these questionnaires was to gather experiences in all aspects of site remediation, ranging from legal to technical and administrative aspects, and to gain an understanding where additional work is still required. The questionnaires were distributed in September 2012 and the final responses received by June 2013. A summary of the responses is given here and a more detailed evaluation of the responses is given in Annex 4.

The response coverage by country is shown in Table 2.1. In the case of France different responses to the national questionnaire were received from both *L'Institut de Radioprotection et de Sûreté Nucléaire* (IRSN) and *Électricité de France* (EDF) and in this section we summarise these responses.

Table 2.1: Questionnaire responses by country

Country	National questionnaire	Project questionnaire	Case studies
Belgium	1	1	
Canada	1	2	2
France	2	5	2
Germany	1	1	1
Italy	1	1	
Japan		5	
Netherlands	1		
Republic of Korea	1	1	1
Slovak Republic		2	
Spain	1	1	2
Sweden		1	
United Kingdom	1	5	1
United States	1	3	3
Total number of responses	11	28	12

The countries listed in Table 2.1 encompass the major regions using nuclear technologies in the Organisation for Economic Co-operation and Development (OECD) and account for about 70% of operating reactors, about 90% of those permanently shut down and about 20% of those under construction [1]. In particular, experiences from the restoration of sites used in the 1940s (United States and Canada) and early pioneering work on nuclear technologies (Canada, France, United Kingdom and United States) are covered. These countries are therefore representative of current remediation practice and provide a broad evidence base for this study.

2.1 Information from national questionnaires

The responses to the national questionnaires indicate that national level policy, regulation or guidance is provided in each of the ten countries for which a questionnaire was completed. There are national policies dealing with site remediation in nine countries, of these six countries have

specific regulations and the others have over-arching legislation that is applicable to facility decommissioning and site remediation (Belgium, Canada and United Kingdom). In France, there is national guidance on the remediation of contaminated areas.

National level principles that drive site restoration are described in nearly all the responses. These all fall under four broad headings: the polluter pays, as low as reasonably achievable, triviality of dose and restoration to a green field site. Notably respondents did not specifically mention inter-generational equity (lifetime costs, timing of remediation) or the precautionary principle, although minimising burden on future generations was considered a significant driver (see below).

The goal of nuclear site remediation varies from cost effective risk reduction and protection of soil and groundwater, restoration to a green field site, to clearance for unrestricted use (see Table 2.2). In half of the countries the goal for a specific site restoration is based on a case-by-case decision. In many cases this case specific goal is industrial use and this implies the need for certain restrictions on land use to be applied for the future.

Table 2.2: Goal of nuclear site remediation

Country	Remark
Belgium	Final remediation objectives, case by case.
Canada	Case by case, depends on site use.
France	Remove all the contamination; authority prefers the operator to remain the owner; effort depends on site use.
Germany	Release for unrestricted use (using clearance criteria).
Italy	"Green field", site use not defined yet, 10 µSv/y criteria.
Netherlands	Green field, reuse of land (scarce in the Netherlands) but special permits for restrictions on site use possible 10 µSv/y criteria.
Spain	Case by case, depends on site use.
United Kingdom	Reducing safety risk (1 in 10 ⁶ ; 10 µSv/y criteria), reducing the number of sites and reuse of land.
United States	Cost effective risk reduction and protection of soil and groundwater.

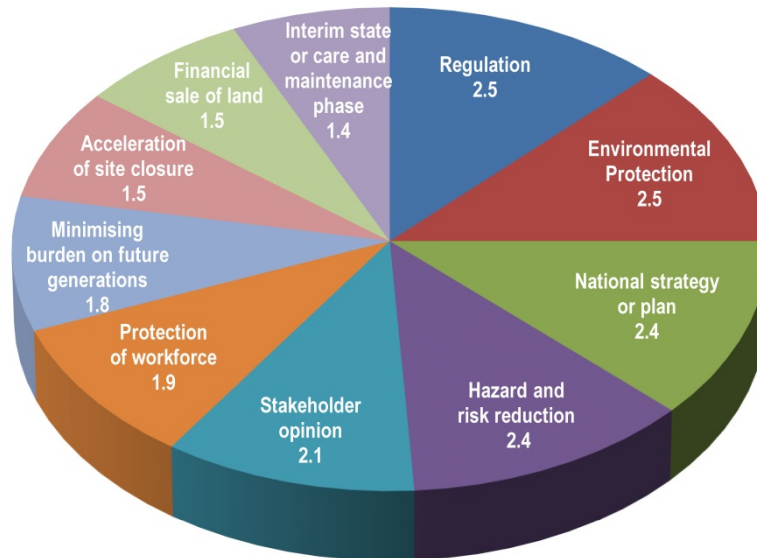
Decommissioning is funded either by the public (legacy sites, state-owned facilities) or by private organisations (polluter pays principle for commercial sites) through direct payment or compulsory financial provision from commercial activities (see Table 2.3).

Table 2.3: Funding of nuclear site remediation

Country	Remark
Belgium	Funding by government (if Belgian waste agency approves the decommissioning plan).
Canada	Regulatory requirement defined in Canadian Nuclear Safety Commission (CNSC0 regulatory document G-219). Funding arrangements vary depending on the site. Nuclear power plant: decommissioning fee. Laboratories: by government.
France	Decommissioning costs including site remediation have to be included within financial provision. Legacy sites: site remediation by ANDRA, funding by government (2011: EUR 3.3 M; 2012: EUR 2 M). Sites polluted by ²²⁶ Ra: special funding by government (2010: EUR 8 M; 2011: EUR 2.2 M; 2012: EUR 1.8 M).
Germany	Power utilities: polluter-pays principle. Public ownership: state budget..
Italy	Funds provided by ENEL (transferred funds, component of the kWh price).
Netherlands	Polluter-pays principle, approved by regulatory body. After accident: legislation is based on the Paris Convention. No specific requirements for legacy sites.
Spain	Case by case (national agency, own budget).
United Kingdom	Private companies: own commercial activities. Commercial (AGR fleet, Sizewell PWR): Nuclear Liability Fund (set up from the sale of British Energy to EDF Energy). MOD sites: Government and commercial activities, decommissioning by NDA: Government and NDA's commercial activities.
United States	Legacy sites: funding authorisations from congress. For commercial sites: polluter pays principle.

In most countries, the regulators and stakeholders participate in the development of site remediation plans. Licence applications and permits from a regulatory authority are necessary in most countries. The factors influencing timing and progress of site remediation were ranked by each respondent and the overall score is shown in Figure 2.1.

Figure 2.1: Ranking of drivers of remediation



The top four criteria affecting the timing and progress of site remediation were:

- regulation;
- environmental protection;
- hazard and risk reduction;
- national strategy or plan.

Stakeholder opinion ranked fifth as a driver to remediation.

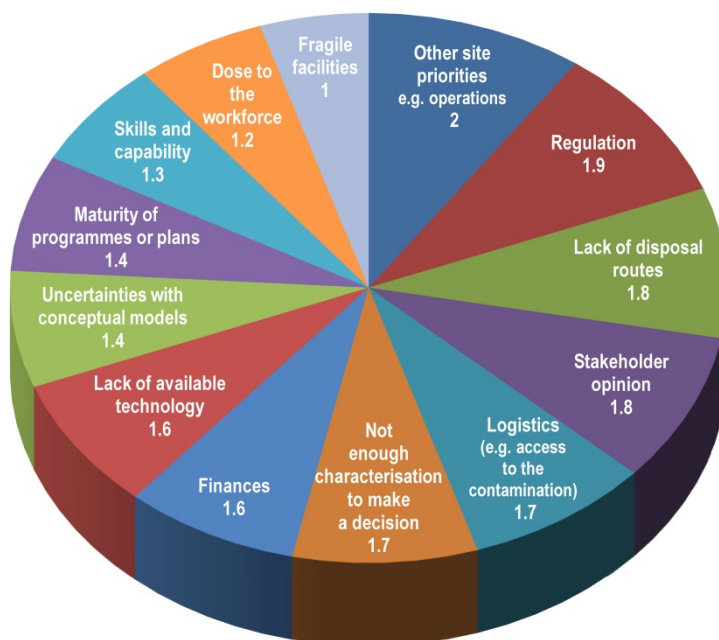
The IAEA CIDER survey [2] asked about factors that facilitated or promoted remediation. The main factors identified were:

- decommissioning programme;
- national policy;
- risks to the public/environment;
- local stakeholder expectations and demands.

Clearly the respondents did not think of the fate of the site in terms of reaching the end state, land value or interim phase management as important drivers compared to other factors. When asked which factors had the greatest impact on timing, the answers were diverse. The most important was the local site decommissioning strategy and plan (40% of responses).

The selection of barriers and obstacles to remediation were scored (see Appendix 4 for further information) and the rankings are shown in Figure 2.2 below.

Figure 2.2: Ranking of barriers to remediation



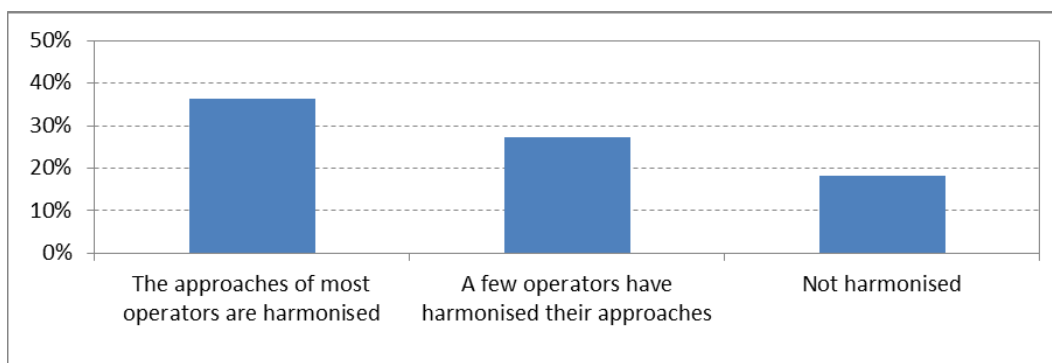
The four most important barriers to remediation were other site priorities, regulation, a lack of disposal routes and stakeholder opinion. The barriers and risks within each country were described in more detail, the responses varied but there were three dominant themes:

- agreement on site release levels;
- financial resources;
- a lack of either disposal routes (including conditioning/pre-treatment technology) or a repository.

The CIDER survey [2] identified the same themes as the top three barriers to site remediation.

The level of harmonisation of approaches within the ten countries is illustrated in Figure 2.3 (excluding two answers “don’t know”).

Figure 2.3: Harmonisation of approaches within countries

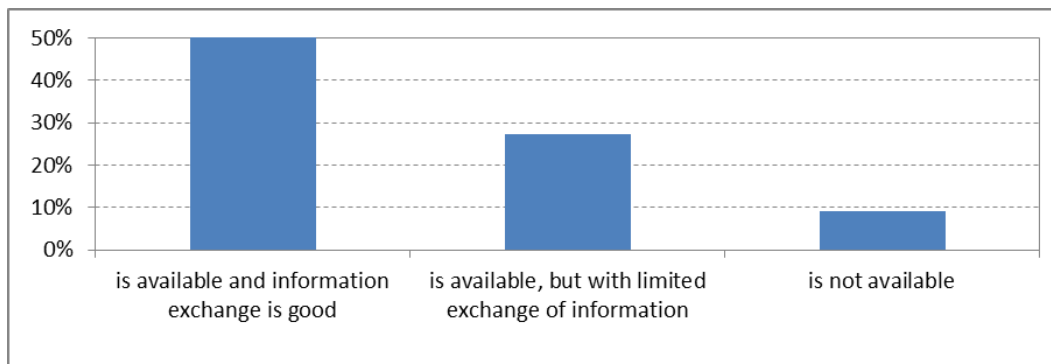


Experience with site remediation (management of contaminated land and groundwater) on nuclear sites is estimated to be low or moderate, except in the United States and Germany. In these countries there are a large number of available contractors to perform characterisation and

remediation of ground and contaminated groundwater. In other countries, there are fewer contractors and in a few cases, resources as well as best practice guidance are obtained from other countries.

The information exchange between owners, operators, regulators and stakeholders in different countries is described as shown in Figure 2.4. One country answered that information exchange is not available as the number of operators planning for site restoration is small; none of the countries answered that information exchange is not available because of lack of interest or opportunity, or is based only on international networks.

Figure 2.4: Network for information exchange between owners, operators, regulators and stakeholders on nuclear site restoration



In response to qualitative questions on the scale of contaminated land or contaminated ground water issues, the high or very high responses were given by Canada, United Kingdom and United States. All other responses given were low, except for the scale of contaminated land in Germany and Spain which was moderate.

In eight of the national questionnaires further research and development requirements are suggested and summarised as follows:

- remediation of mixed contaminants;
- estimating the uncertainties of characterisation including the use of the ratio between easy and hard to detect radionuclides;
- discrimination of weapon testing and Chernobyl fallout to take account of background radioactivity;
- remediating large volumes of lightly contaminated groundwater;
- volume reduction of contaminated soils (supercompaction/cementation);
- the characterisation of inaccessible areas;
- natural attenuation and bioremediation;
- treatment of Iodine 129 and Tritium;
- techniques for significantly reducing the migration velocity of nuclides.

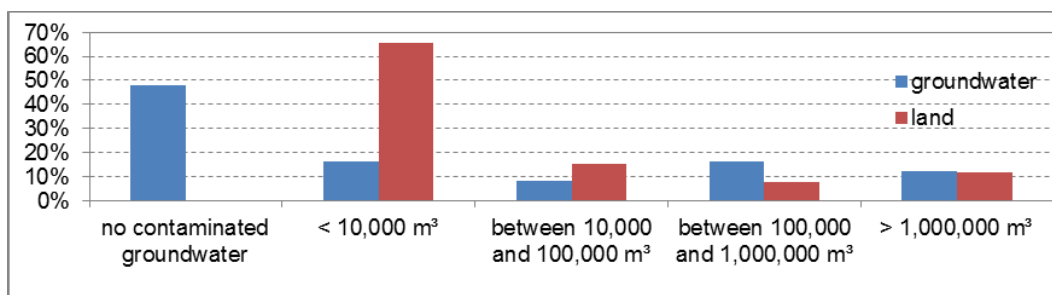
2.2 Information from site and project questionnaires

There were 28 site and project questionnaires to evaluate from 12 countries. Not all respondents gave an answer to all questions and this is highlighted where relevant.

The partial or complete removal of buildings from the site will occur on the majority of sites, in many cases buildings are demolished only to ground level (57%). Building re-use for non-nuclear purposes was indicated in 10% of responses.

An estimate of the scale and distribution of contaminated land and contaminated groundwater for the sites and projects in the questionnaires is shown in Figure 2.5.

Figure 2.5: Estimated scale of contaminated land and contaminated groundwater

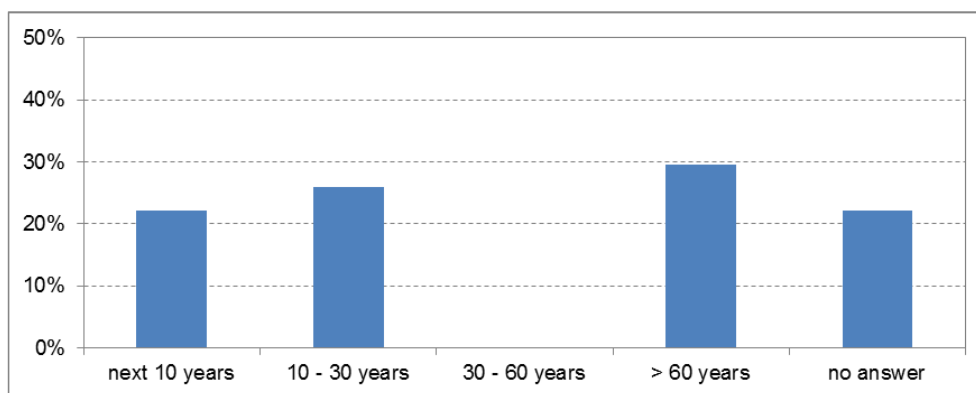


The sites with the largest volumes of contaminated material are Hanford and Fernald (both in the United States) and Sellafield (United Kingdom). The United States has several other large sites including Idaho National Laboratory, Savannah River Site, Oak Ridge and West Valley. Hanford was presented in the questionnaires because it is the largest clean-up, and Fernald was presented because it is a medium-sized site in which the clean-up had been completed and is in long-term monitoring. While for most sites, the number of separate remediation projects is small (one or less than five), the Hanford (United States), Dounreay and Sellafield (United Kingdom), and Chalk River (Canada) sites each have more than ten separate remediation projects; the number of separate remediation projects is related to the size, complexity and organisational approach of the nuclear site.

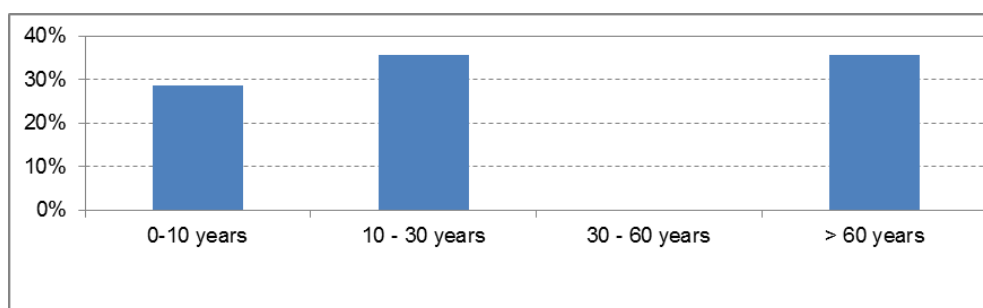
It was also found that at 26% of the sites the contamination had spread beyond controlled areas with the potential to affect groundwater users. At one site, contamination was stated as affecting a salmon population. The extent of groundwater contamination is expected to remain constant or decrease at 90% of these sites.

Although many facility decommissioning projects have been completed, there are only a few major sites where the entire remediation process has been completed (see [3]) or is nearly completed (e. g. Hanau case study). The time scale for finishing projects is very widely spread (see Figure 2.6). For about 22% of the projects the decommissioning and remediation work is expected to finish within the next ten years; for about 26% of the projects finishing is expected within 30 years. In 30% of the project cases, the end state will not be reached within 60 years. The remaining 22% of projects do not have a timescale for the proposed end state. The reason for this is postulated as being the challenge of decommissioning legacy sites; this is an intergenerational issue.

Figure 2.6: Timescales for reaching the end state



There appears to be a link between the timescale over which the end state is expected to be reached and planned groundwater monitoring (see Figure 2.7).

Figure 2.7: Expected time for further groundwater monitoring

In response to the question on the long-term monitoring undertaken at sites, 36% of the cases, groundwater monitoring will be done solely by the site owner, in 29% of the cases by an external contractor and in the remaining 31% of the cases by both site owner and an external contractor.

The radionuclide which is found to be detected at the most sites is ^{137}Cs (half-life 30.5 y), mostly detected in soil. The nuclides ^{90}Sr (half-life 28.8 y) and uranium nuclides (half-life 2.5×10^5 y for ^{234}U , 4.7×10^9 y for ^{238}U) are also detected on several sites, both in soil and the groundwater. ^3H (half-life 12.3 y) is found mainly in the groundwater. ^{14}C (half-life 5,730 y), ^{60}Co (half-life 5.3 y), ^{99}Tc (half-life 2.1×10^5 y), ^{129}I (half-life 1.6×10^7 y), ^{226}Ra (half-life 1,601 y) and transuranic nuclides (longest half-life 2.4×10^4 y for ^{239}Pu) are mentioned at two sites in the questionnaire.

Those elements showing high environmental mobility, such as C, Sr, Tc and I, are observed in both soil and groundwater, while the very mobile ^3H is found mainly in groundwater. Uranium is also observed in both media, indicating that it is rather mobile in certain chemical environments.

The questionnaire did not determine whether the levels of radionuclides detected required remediation of the environmental compartments due to their presence.

Radioactive contamination is connected with a large variety of non-radiological contaminants at 50% of the sites. These contaminants are typical of industrial sites and include building materials such as asbestos. Chemical contaminants include those that were originally gas (fluorine), liquid solvents (chlorinated) and hydrocarbons (oil, petroleum), as well as metals (arsenic, boron, cadmium, chromium, copper, lead, mercury and zinc) and compounds such as nitrates. The same contaminants were found in both soil and groundwater at 23% of the sites.

Cost estimates for site remediation projects can reach a million EUR for a small project rising to more than 40 billion EUR for the largest remediation project in the United States.

Table 2.4: Site and project costs

Site	EUR M	USD M
Hanford	> 37 500	> 50 000
Fernald	3 216	4 400
Downreay	1 795	2 456
EDF United Kingdom sites	~78	~106
Chalk River	<6.5	<9
Bohunice V1	23	32
Hunterston A	6	8
AREVA	<5	< 6.8
EDF France – Brennilis	2.5	3.4
EDF France – SLA	2	2.7
KAERI	1.8	2.5
CIEMAT	1.5	2.1

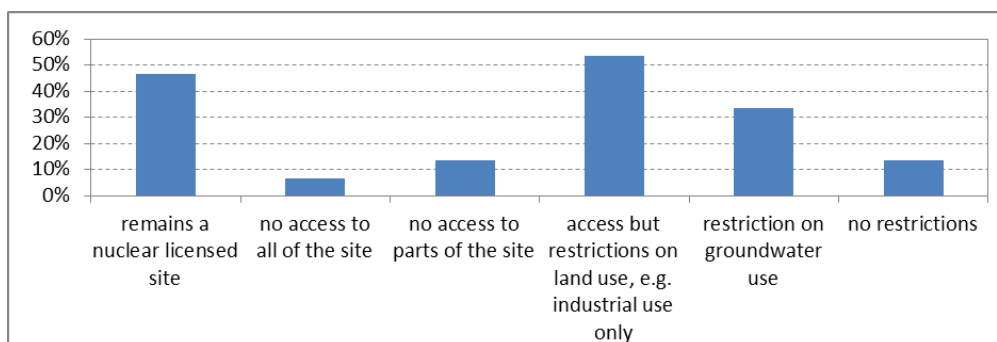
Table 2.5 shows the different techniques which are used or are planned to be used for soil and groundwater remediation. In many cases remediation of radioactive contamination and non-radioactive contamination is dealt with using the same technique. In a few cases, different techniques will be used (in-ground barrier, e.g. permeable reactive barrier, is a favourite method for remediation of radiological contamination).

Table 2.5: Techniques for land and groundwater remediation

Answer	Radiological contamination		Non-radiological contamination	
	Number of sites	Percentage (%)	Number of sites	Percentage (%)
Soil				
Dig and dispose	12	92	8	80
In-situ stabilisation	1	8	1	10
Capping	2	15	1	10
Other	3	23	3	30
Groundwater				
Pump and treat	4	50	3	50
In-ground barrier	4	50	1	17
Pump and re-inject	0	0	3	50
Monitoring	4	50	4	67
Other	2	25	2	33

The intended land use after completing remediation varies. About 47% of sites will remain nuclear licensed sites. In other cases, different restrictions are to be imposed and they will depend on the expected end use of the site (see Figure 2.8). Very few projects expect to limit access to the site, and about 13% expect no restrictions on subsequent use.

Figure 2.8: Expected land use after remediation



The questionnaire allowed multiple responses on expected land use. The option followed in 53% of cases is to place restrictions on land use and the same respondents similarly marked restrictions on groundwater use. There was some debate over the scope for remaining a nuclear licensed site and the timescale over which this would apply before allowing access with land use restrictions in place.

The management of information to produce a record of site remediation for future reference is an important consideration. Table 2.6 summarises the answers from sites regarding information management.

Table 2.6: Information management

Answer	Number of responses	Percentage (%)
Kind of data management		
Spread sheets	14	67
Off-the-shelf package	2	10
Site-specific database	15	71
Information storage place		
Centrally within site records management process	5	19
Locally within the project team	6	23
Both	15	58
Kind of information storage		
Electronically	3	12
Paper records	2	8
Both paper and electronic	21	81

References

- [1] IAEA PRIS (Power Reactor Information System), Database on nuclear power reactors maintained by International Atomic Energy Agency, www.iaea.org/pris/.
- [2] IAEA (2011), Global Constraints to Implementing Decommissioning and Environmental Remediation Projects (CIDER), www.iaea.org/newscenter/news/2012/overcoming-barriers.htmlIAEA.
- [3] IAEA (2011) *Redevelopment and Reuse of Nuclear Facilities and Sites: Case History and Lessons Learned*. IAEA Nuclear Energy Series, No. NW-T-2.2, Vienna.

3. Key Issues and experiences from the case studies

3.1 Introduction

This section describes the key issues and experiences that were derived from the twelve case studies obtained as part of this project, and from the remediation experience and understanding of the task group members. The case studies are summarised in Table 3.1 and further details are given in Annex 5.

Table 3.1: Summary of case studies

Case Study Number	Case Study Title	Country	Brief Description
1	CEA's Grenoble STED facility	France	Remediation of contaminated soil around and under redundant solid and liquid waste processing buildings.
2	Monts d'Arree, Brennilis	France	Clean-up of a waste water channel on the Brennilis site.
3	PIMIC rehabilitation project, CIEMAT	Spain	Remediation and waste management activities following decommissioning of a nuclear research facility.
4	Windscale Trenches, Sellafield	United Kingdom	Remediation of historical unlined low level waste disposal trenches. Enhanced capping selected as the remedial option for interim management.
5	Uranium Conversion Facility, Daejeon	Republic of Korea	Remediation following decommissioning of a uranium conversion facility.
6	Fuel Assembly Plant, Hanau	Germany	Uranium contaminated soil and sediment under a fuel assembly plant was excavated.
7	618-10 Burial Ground, Hanford	United States	Removal of contaminated soil and debris from waste trenches is currently underway.
8	Site groundwater, Hanford	United States	A pump-and-treat system and natural attenuation are being used to treat contaminated groundwater at Hanford.
9	In-Situ Permeable Treatment Wall, West Valley	United States	A permeable treatment wall system replaced a pump-and-treat system that was not adequately treating ⁹⁰ Sr at a former fuel reprocessing plant at West Valley.
10	Laboratory building decommissioning at Chalk River Laboratories	Canada	Unplanned contamination in soil found under building during decommissioning.
11	"Lenteja" area remediation (PIMIC decommissioning project), CIEMAT	Spain	Site remediation of a contaminated area in CIEMAT.
12	Caustic cells, Chalk River Laboratories	Canada	Retrieval of historical buried radioactive wastes in waste management area.

The starting premise on all projects is that implementing site remediation (to an agreed end state) *may* require clean-up actions and hence it is important to have an open mind. An understanding of the status of the site is usually required prior to end state consultation. Remediation actions need to be justified, in other words the actions to be implemented to reduce existing or potential doses to people and biota should do more good than harm. It must be understood by the relevant stakeholders that returning the site to background conditions may not be necessary and may not even be achievable – at least under a reasonable economic perspective. The choice of the course of action will depend on a series of factors and will in many situations encompass technical (objective) and social (subjective) factors. The IAEA *International Basic Safety Standards* [1], [2] – a document that is endorsed by different member states of the Agency – defines a series of requirements that should be taken into account when considering the implementation of remediation works. The important aspect here is that the removal of all contamination is not a universal requirement.

When examining the need and timing of remediation, practitioners will take both a site and a project specific perspective using the CSM and the phased approach described in Section 1. In reality, where there are uncertainties, practitioners and site owners are expected to be flexible when considering both the scale and timing of the remediation projects. Site history (events, historical records, expert knowledge), critical appraisal of asset management (particularly sub-surface systems and components and therefore suspects for leaks), local hydrogeology, artificial groundwater recharge or flow rate adjustment (from services leaks etc.), informs the initial conceptual site model and agreed end state. Addressing important information gaps ensures prompt remedial action to prevent or mitigate leaks that have gone undetected or to provide reassurance that land earmarked for redevelopment is well understood before dismantling commences. The case studies illustrate the potential impacts of unknown contamination being discovered and halting and delaying decommissioning.

Stakeholder engagement is an essential component of each of the remediation phases identified in Figure 1.2. Stakeholders are people, groups of people or organisations that have an interest in the remediation project. Stakeholders can be active (directly involved in the project) or passive (affected by or interested in the project). A remediation project should implement a stakeholder participation programme to ensure stakeholders are adequately engaged, thereby avoiding the negative consequences of not getting stakeholder input at appropriate times.

A stakeholder participation plan may incorporate:

- stakeholder management plan (goals and ways to reach them);
- ways to integrate the stakeholders into the remediation project plan;
- planning and implementation of processes to engage stakeholders;
- determination of responsibilities within the project organisation;
- determination of communication methods.

Stakeholder communication should:

- be open, honest, respectful and transparent in both directions;
- provide understandable information (technical and scientific information has to be translated into non-technical language);
- evaluate all attitudes and expectations;
- provide objective evaluation of stakeholder proposals for modification;
- involve independent facilitators if required.

The relevant stakeholders may change as the project progresses.

The experience and key issues associated with each remediation stage are addressed in turn in the following sections.

3.2 Problem definition

3.2.1 General description

A problem is defined as a site condition which stakeholders or team member subject matter experts determine poses a real or potential level of risk to humans or the environment that requires a response. The risk is defined in relation to a specific use (present or future) of the site.

Problem definition includes the identification of the nature, cause, location, dimensions, origin, time frame and importance of the problem, as well as an indication of who considers it to be a problem.

The root cause of the problem must be well established. If the underlying causes of a problem are not identified and addressed, the solutions can end up being superficial and unsuccessful and may not solve the problem at all.

Stakeholders and decision makers must be identified and involved early in the problem definition phase. The core team and stakeholders should all agree on a written definition of the problem to be solved before proceeding further.

The problem definition process should also establish the data that is needed (necessary data, sufficient data) to complete the problem definition and reflect current conceptual site models (modified as information is obtained).

A key part of the problem definition is determining whether or not the problem requires a response or solution. After a problem has been initially brought forward, uncertainty may exist as to whether the problem requires a solution or response. This uncertainty usually results from insufficient data. More information may be required to fill the gap or the initial problem definition may need to be modified.

A problem definition should include:

- a clear, concise problem statement, usually expressed in one or two sentences.
- a demonstration that a response or action is required.
- supporting information, including:
 - definition of the initial state;
 - current conditions;
 - symptoms pertinent to the problem;
 - potential causes of the condition;
 - who or what is affected;
 - assumptions appropriate for the analysis;
 - data needed to support decisions;
 - consequences if the problem is not solved;
 - historical barriers important to option development;
 - expected characteristics of the system after the problem is properly solved;
 - problem/system boundary;
 - environmental medium, geographic feature, types of waste present or suspected.
- project success criteria (what does the solved problem look like?).

3.2.2 Issues and experiences

Poor problem definition leads to poor project focus, overly extensive or ineffective site investigations (e.g. trying to remove all uncertainties) and extended processes to decide on the remedy. Poor problem definition also leads to poor project execution, not fixing the problem, fixing the wrong problem or fixing the problem at a greater cost than needed, prolonged site closeout or inappropriate exit strategy.

Factors leading to poor problem definition are:

- inadequate or insufficient information leading to inaccurate or incomplete conceptual site-models;
- lack of stakeholder (including regulatory bodies) involvement in defining the problem.

It is important to consider the land use in the foreseen future under unrestricted and restricted land use as this will impact on the level of remediation, cost and schedule. Examples of land use scenarios are: recreation, parkland, industrial use, residential use.

Risk-based approach

In some cases, an accurate final end state is required by regulation (safety report or other regulatory document), for example a maximum residual activity in soil, whatever the level of risk. This can lead to remedial work being undertaken even if the risk is already acceptable.

A risk-based approach is more relevant as it allows the remedial work effort to be adapted to the actual risk to humans and the environment.

Stakeholder input

Although Rocky Flats in the United States has a long history of stakeholder engagement, issues still arose when the site changed from an operating site to a clean-up site. Challenges were overcome, but not before learning many lessons, and some of the lessons learnt at Rocky Flats are listed here [3], [4].

- Developing and communicating a clear, simple and consistent site message.
- Providing greater stakeholder access to clean-up documents during the early stages of development creates significantly more work for the federal and contractor staff, but ultimately leads to better decisions and achieves greater community ownership of the clean-up.
- Having regulators agree with the site's message that the clean-up would be comprehensive, and meet or exceed all regulatory requirements. The DOE was not asking the public to trust the DOE, but rather to trust site regulators.
- Advising stakeholders of legitimate government constraints early in the decision-making process.
- Consulting stakeholders early in the decision-making process and, to the extent practical, empowering them to affect the decision that is ultimately made. At Rocky Flats, the best example of this "openness" was the funding of a citizen's panel by DOE to determine a plutonium soil clean-up level that would be generally acceptable to the community.
- Developing relationships with elected representatives (e.g. Congress) and the press. Almost inevitably, unhappy stakeholders will seek assistance from elected representatives and the media for issues of concern.
- Explaining the technology and to achieve good understanding before the results are presented, especially with new and unfamiliar technology and protocols. You cannot over-communicate with an interested and engaged stakeholder group.

The importance of extensive communication was learnt at the Brennilis site in France as well. Over a year after the remediation project started, two local ecological associations became concerned over whether EDF was adequately protecting certain wildlife species. Additional meetings with stakeholder groups, to inform them of the remediation plans and the precautions that would be taken, were required before approval to proceed was obtained. Stakeholder issues should be anticipated, as far as possible, before they arise and the site should be prepared to address those issues.

It should be noted that involvement of stakeholders and regulators can sometimes lead to the wrong decision due to outside pressures. An example of implementing an expensive remedy that did not solve the problem is the use of a pump-and-treat system for a strontium plume at the Hanford Site [5]. Under a 1999 regulatory decision, the site was required to install and operate a pump-and-treat system to try and remediate a ^{90}Sr plume adjacent to the Columbia River. There was considerable pressure by stakeholders and regulators to implement this remedy even though the site scientists said it would not be effective. The system was operated for approximately eight years, cost 20 million USD and removed only 1.8 Ci (66.6 GBq) of ^{90}Sr . At the same time 320 Ci (11,840 GBq) were removed by radioactive decay. The system has been replaced by a permeable reactive barrier to reduce flux to the river and the ^{90}Sr is being allowed to decay away (natural attenuation).

Naturally occurring radioactivity and other artificial sources

In some countries, clean-up criteria for some radionuclides may be lower than the levels that exist naturally at the site, making remediation a challenging task.

Radioactivity occurs naturally in soils and groundwater. This natural radioactivity is generally at a low level and results from uranium and thorium and their decay chains. This radioactivity is natural and is not considered to be contamination. There will also be low levels of anthropogenic radioactivity in soils and groundwater from nuclear weapons testing fallout, nuclear accidents (e.g. Fukushima and Chernobyl) and routine authorised releases to the environment. This is considered to be contamination but is either outside the control of the operator or is authorised by the regulator. It is good practice to disregard this radioactivity in any remediation considerations. Natural levels of non-radioactive elements or compounds will also need to be considered.

Often, a great deal of naturally occurring activity is contained in radioactive waste. National policies or regulations that allow for high natural background levels when developing clean-up criteria, e.g. in terms of Bq/g, result in less material being stored or disposed as waste.

3.3 Remedial investigation (characterisation and assessment)

3.3.1 General description

A remedial investigation is an in-depth study of the physical, radiological and chemical condition of a site in order to determine the nature and extent of contamination at a site; it involves characterisation and assessment of the contamination. Characterisation is performed for three main reasons: to understand the contamination pattern at the site and assess impacts and risks to the environmental or public, to have sufficient knowledge to ensure worker safety during remediation activities and to determine waste disposition pathways prior to retrieval.

Existing information is first assessed to determine what additional data is required to confirm (or not) the definition of the problem and to create or update conceptual models. Historical records (reports, memos, photographs, logbooks, and anecdotes from past or current employees) can often provide a fairly detailed inventory of the contamination.

Depending on the type of remediation being performed, different types of information and models may be required. The CSM helps to visualise and understand available information about a site. It allows project teams to access and interpret data throughout the clean-up process, from project planning to final clean-up completion. It captures existing information, focuses future data collection to fill data gaps and reduce key uncertainties, and serves as a framework for incorporating new data as it becomes available.

Data collection and refinement of the CSM is an iterative process, during which the CSM can be viewed as gaining in maturity as understanding increases.

Technologies used to characterise sites in terms of the lateral and vertical extent of contamination vary according to complexity and robustness. Simple characterisation techniques include test pits and grab samples. More complex techniques may include geophysical imaging or radiochemical or spectroscopic techniques.

Because characterisation, particularly intrusive characterisation, may involve some risk to workers or the environment, every effort should be made to minimise this risk by preplanning. An assessment should be made of exactly what information will be required and what purpose that information will serve, prior to any fieldwork being undertaken.

The US Environmental Protection Agency (EPA) has produced detailed guidance documents on site characterisation, including the Data Quality Objectives (DQO) process, see www.epa.gov/quality/dqos.html. Overall, the process for assessing exposures to radionuclides and consequently radiation risks that is presented in EPA risk and dose models and in EPA guidance documents parallels the process for assessing risks from chemical exposures (exposure assessment, toxicity assessment, and risk characterisation). Both types of assessments follow the same evaluation process, consider similar exposure scenarios and pathways, determine exposure point concentrations and provide estimates of cancer risks to humans. However, several aspects of risk assessment for radioactive contaminants differ substantially from those considered for chemical contaminants. Occasionally these differences – in measurement units, exposure terms and concepts (particularly the external exposure pathway), field and laboratory procedures and detection limits, and toxicity criteria, among others – have led to questions concerning the recommended approach for addressing radionuclide contamination and risk and this is also explained in EPA guidance.

A characterisation plan should be developed and agreed with pertinent stakeholders prior to implementation. This will avoid costly, time-consuming trips back into the field to collect data that could have been collected in a previous trip.

Real time measurements may provide important indications of radiological risks and doses at a site, particularly during early investigations, when these may be the first data available. These may also be important for radiological safety of workers. Real time measurements provide other benefits since they can provide feedback, which then allows the operator to focus on what they are doing and enable greater understanding of variability. They are also cheaper, and ideally suited to initial screening. Examples of circumstances where it may be appropriate to use real time measurements include:

- During early site assessment efforts when the site manager is attempting to communicate the relative risk or dose posed by areas containing elevated levels of radiation.
- As a real-time method for indicating that remedial objectives are being met during the conduct of the response action. This does not replace the need for a final status survey.

Using real time in-situ data collection methodologies can also help minimise repeat field trips.

3.3.2 Issues and experiences

Remedial investigations can be time consuming, expensive and lack focus if not carefully planned. Too little information or the wrong kind of information can make remedial planning difficult. If insufficient historical information is available, additional characterisation data may need to be acquired. Alternatively, the additional data may not be worth the additional time, dose and money needed to acquire it.

Natural background and other artificial sources

In some countries, clean-up criteria for some radionuclides may be lower than the levels that exist naturally at the site, making remediation a challenging task.

Radioactivity occurs naturally in soils and groundwater. This natural radioactivity is generally at a low level and results mainly from uranium and thorium and their decay chains for soils, and ^3H and ^{14}C for groundwater. This radioactivity is natural and is not considered to be contamination. There will also be low levels of anthropogenic radioactivity in soils and groundwater from nuclear weapons testing (most important for soils: ^{137}Cs , ^{90}Sr , $^{239/240}\text{Pu}$, ^{241}Am ; most important for groundwater: ^3H and ^{14}C) fallout, nuclear incidents (e.g. Fukushima and Chernobyl, most important: ^{137}Cs) and routine authorised releases to the environment. This is considered to be contamination but is either outside the control of the operator or is authorised by the regulator. It is good practice to agree a scheme to allow this radioactivity to be disregarded in any remediation considerations. There are also natural levels of non-radioactive elements or compounds that will also need to be considered.

Often, a great deal of naturally occurring activity is contained in radioactive waste. National policies or regulations that allow for high natural background levels when developing clean-up criteria result in less material being stored or disposed of as waste.

Experience shows that background radionuclide levels can be very heterogeneous, varying over very small distances, due to geological/hydrogeological characteristics. Hence it is necessary to develop methodologies to characterise the background taking into account this variability.

Incomplete historical records

Remediation of contaminated areas often occurs long after the contamination has occurred. Consequently, records of the contamination are frequently lost, damaged (e.g. by fire or water) or never existed in the first place. Employees who may have worked in a particular facility may have changed jobs, retired and relocated, or perhaps are deceased.

One way to get an insight into the nature of contaminated sites if historical inventories are not available is to search out indirect operational knowledge. Inventories can be estimated from analyses of site processes and other related reports pertaining to the time period of the contamination events, anecdotal evidence and logical reasoning. As many of the case studies indicate (including the United Kingdom and the Republic of Korea case studies), if a site process can be reasonably tied to a contamination event, then reports describing the process may give an indication of associated hazards. As a Canadian case study shows, unexpected contamination may appear during decommissioning, and contingency plans should be in place for unknown historical contamination events, to save time and money on remediation projects.

In France, all the historical assessments conducted at EDF decommissioning power plants were reassessed and revised because they were not detailed enough to be able to prioritise the different areas of a site and to plan for further characterisation campaigns.

Incomplete characterisation data

Incomplete characterisation data can lead to remobilisation back to the field to get better/more data, or to an inaccurate CSM, which in turn leads to inappropriate decisions and solutions being implemented. The German case study (Hanau) illustrates a case where the first estimations of the amount of soil to be excavated were too low.

Further characterisation almost tripled the known extent of contaminated soil when waste water channels were shown as major contamination sources. Consequently, the original plans for disposal of excavated material at the site were not achievable.

Experience in France (CEA Grenoble) is also that the initial characterisation underestimated the extent of contaminated soil. The high background levels from an operating interim waste disposal facility were one reason. In this case, clean-up levels negotiated for the site were very low so a high background severely interfered in the detection of the low levels of soil contamination that were required. In this situation, due to the difficulty in demonstrating the residual levels of soil contamination, the risk of promising an overly ambitious end state is very possible.

Another lesson learnt is that it is quite difficult to characterise the contamination sufficiently in one site visit. EDF had to go back to field once or twice to get characterisation information that would enable a decision to be made. So EDF has now included in its contracts the fact that when a contamination is found there will be an extension of the contract in order to go back to the field at least once to define the extent of the contamination.

The main advantage of in-situ techniques for site characterisation based on gamma radiation measurement is to achieve an overall understanding of the contamination distribution pattern, with an indication of the key areas where contamination can be found that will lead to further detailed examination. However, real time data may reflect only a subset of the radionuclides and exposure pathways of potential concern (for example, only external exposure from gamma-emitting radionuclides in near-surface soil), and may therefore present an incomplete picture of site risks and doses (such as risk or dose from internal exposures, or potential increased future risks or doses from radionuclides in subsurface soils). In most cases, more accurate estimation of radiation risks or doses will require additional site characterisation data, including the determination of activity concentrations of all radionuclides of concern in all pertinent environmental media. The principal benefit of using real time measurements is the speed and convenience of analysis, and reducing the potential for missing areas of contamination. However, skill is required to interpret it correctly. Real time measurements scanned in the field should be correlated with samples analysed in a laboratory by collocating them, to ensure that modelled assumptions about the correlation between exposure rate and sample concentrations are accurate. In the United States, the state led consortium ITRC has provided the *Real-Time Measurement of Radionuclides in Soil: Technology and Case Studies* report [6] and the online training course *Real-Time Measurement of Radionuclides in Soil* [7].

Also contributing to the difficulty in obtaining contamination information is obstruction by nearby buildings. Once the buildings are removed, additional soil could be assessed resulting in the discovery of new areas requiring clean-up. If possible, all surfaces should be clear when performing characterisation work, even though it may delay the start of the clean-up activities for that area.

An additional characterisation issue is the stratification of contaminants with depth below the surface, resulting from different sorption and transport characteristics of the contaminants and the soil. Surface characterisation data may not represent contamination levels at different points below the surface. A project in Spain carried out by *Empresa Nacional de Residuos Radiactivos, S.A. (Enresa)* has overcome this complication by using vertical and horizontal test wells to obtain radiometric data that allowed development of detailed 3-D contamination models. A decommissioning project at a Uranium Conversion Facility (UCF) in the Republic of Korea investigated contaminant diffusion at the site using core boring samples. Soil under the building was contaminated through a sump and trench during facility operation. Site remediation was planned using 3-D visualisation and all contaminated soil was removed using an excavator.

Collecting unnecessary data that is never used, accruing unnecessary costs and exposing workers to unnecessary risks.

In some cases, remediation workers may encounter significant hazards in the course of collecting field data. At Sellafield, potential risks to workers associated with intrusive characterisation of wastes in the trenches were calculated and as a result it was found that actinides and fission products presented an unacceptable radiological risk. Conventional safety hazards were also associated with the trench contents (e.g. asbestos, solvents) and altogether, these components of the inventory were thought to represent a substantial hazard to workers should they be encountered by drilling activities. Site safety authorities considered that the benefits of further characterisation would not outweigh the potentially significant health and safety risks and the decision was made to not perform intrusive characterisation in the waste trenches at the Sellafield site.

Technology and techniques for site characterisation

Occasionally, characterisation methods that are commonly used may not include the appropriate technology to be used under the particular circumstances. Therefore, other methods must be found to obtain contamination data. As it has been observed from site

characterisation efforts in the United Kingdom, geophysical surveys can only be useful if the contamination or contaminated wastes are distinct from the surrounding soil. If wastes or contaminated soil are too compact, and neighbouring soils are quite consolidated, the wastes may be geophysically indistinguishable from the neighbouring soils. Alternatively, in loose sandy soil, disturbed areas such as waste trenches may also be indistinguishable.

Geophysical surveys may also produce inconclusive results that may be misleading in other ways. Such surveying of waste trenches at Hanford in the United States led to assumptions that the trenches contained metal drums. These drums, of course, could potentially contain all types of radioactive materials. Upon excavation, however, the source of the significant metal anomalies turned out to be “page wire” fencing.

Even test pits can have limitations. An important consideration in deciding whether to carry out further characterisation is the potential level of benefit that could be realised were intrusive characterisation to be undertaken. At Sellafield, the contents of the waste trenches are believed to be very heterogeneous and their boundaries are not clearly known. Consequently, any single investigation will only build confidence in the understanding of the trench contents in the immediate vicinity of the test pit. Little benefit from such investigation can be anticipated unless significant excavation is involved. Moreover, as the wastes are often highly compacted, test pit intrusions might actually create contaminant migration pathways in the subsurface.

A test pit sampling plan was developed at Hanford in the United States using a biased, non-statistical design, based on previous geophysical studies and historical records. The results of trench sampling had similar limitations. The results of the sampling were valuable to note “hot spots”, but without knowledge of densities and potential interferences, the data did not provide further useful information. Beyond a radius of approximately one metre, even high activity waste was difficult to detect.

At Fernald, also in the United States, the same lesson was learnt when using Geoprobe sampling of subsurface soil contamination. Point sampling can provide very useful information, but cannot be expected to identify all the hot spots of contamination.

In addition, complex and multi-hazard site investigations for remediation require more sophisticated integrated multi-disciplinary (e.g. hydrogeological, health physics, environmental) analytical tools to correctly model complex environmental interactions. Systematic integration of characterisation and assessment for non-radioactive and radioactive contaminants is required.

Geostatistical methods are important analysis tools, especially when the contamination is reasonably homogeneous, and they produce useful maps. They can complement conventional statistical methods, particularly when subsurface contamination is present. Integration of geostatistics with survey and sample planning tools is required to take full advantage of the new geostatistical modelling capabilities.

The relevance of the geostatistical methodology relies on the presence of the spatial continuity for the radiological contamination. The phenomenon variability is analysed through the variogram, kriging and simulation processes,¹ which provide reliable methods for activity estimation with uncertainty. Geostatistical cartographies have been successfully performed using ISATIS software. These tools have also been used to optimise the final site remediation and site survey design. Conventional statistical (e.g. EURSSEM, MARSSIM) and geostatistical data processing are complementary rather than in opposition to one another when applied to the radiological characterisation stage of a decommissioning and dismantling project. Development of guidance documents, such as NUREG/CR-7021 [8], is required, incorporating geostatistical methods into the overall MARSSIM method.

1. Statistical techniques used to interpolate the value of a random field at an unobserved location from observations of its value at nearby locations.

Risk assessment

In order to assess the consequences of the contamination risk assessments are usually conducted to evaluate the current and future risk to humans and environment. A risk assessment is an essential part of the remediation process, and numerous guidance documents have been produced on this topic (see bibliography for background materials). Different countries sometimes use different terminology in their guidance documents. The environmental risk assessment is discussed here in more detail but it should be remembered that an operational risk assessment (describing the risks to workers implementing the remedial option) is also required.

The risk assessment considers regulatory requirements, foreseeable land use scenarios (e.g. recreation, industrial, residential) and the potential contamination of surface and ground water. The period of time considered in the risk assessment depends on the national regulations and guidance. In many cases release criteria (derived concentration guideline levels, DCGLs) can be obtained from regulatory agency guidance that is based on default modelling input parameters, while other users may elect to take into account site-specific parameters to determine site-specific DCGLs.

Clean-up objectives for radioactive and non-radioactive contaminants are not always the same and therefore the remediation of sites containing both radioactive and non-radioactive contaminants needs to address both sets of objectives.

Risk is a complex concept and this means that communication of risks to stakeholders is not straightforward and it is important that it is addressed in a proactive manner.

3.4 Remedial planning (alternative evaluation and selection)

3.4.1 General description

Remedial planning should consider both the spatial extent of remediation required and the timescales over which it is implemented. Interim states may be specified or the remediation may be carried out piecemeal as opportunities arise on an operating site. A smaller site may have pressures to remediate within a short period of time whereas larger sites may have longer clean-up timescales, or even plan to just put a fence round it.

It is often useful to divide potential options into those that act close to the source of contamination (near field) and those that are implemented at a greater distance (far field). Similarly, short-term and long-term options should be identified. Evaluation of the options considers many attributes, including sustainability, and the balance between the cost of remediating over long timescales (delayed remediation) in terms of extended surveillance and the higher short-term cost of cleaning up in a short period of time. Practical issues such as location, access, waste routes and how to decommission the facilities that were used to perform the remediation are also relevant attributes to be considered in the evaluation of the options and selection of the preferred option.

The kick-off to remedial planning could involve an initial session where all appropriate stakeholders identify potential solutions or remediation methods to the identified problem.

Feasibility study

The feasibility study evaluates different methods to remediate, or clean-up, the contamination problems found during the remedial investigation. It may start as soon as the remedial investigation is underway.

The feasibility study is a risk management tool carried out to evaluate the likely success of a solution or a selected number of solutions. It identifies the risks, increases financial certainty and provides evidence as to whether an option is workable and realistic from a technical, cost or other perspective. It is equally valuable if it demonstrates that an option is not viable as it helps avoid the expensive mistake of undertaking a project which is later cancelled.

The feasibility study identifies requirements and goals that all viable options should meet. Requirements are used to screen inadequate options from future evaluation. They are conditions that any

acceptable solution to the problem must meet and may contain both strategic and functional elements. Cost effectiveness, cost benefit and other tangible and intangible benefits should be addressed.

Options evaluation

Decisions often have to be made between equally good options as well as needing to satisfy various competing goals and objectives. When the consequences of the decision are great, optioneering is a process that enables clear and structured decisions to be reached. If none of the options satisfy all the objectives and specifications, the requirements and goals need to be reassessed.

Project requirements and goals are considered for each alternative potential solution to the problem in a quantitative or qualitative manner. A final solution is selected from various alternatives. That solution should fulfil the desired state, meet the requirements and best achieve the goals according to the values of the stakeholders and decision makers.

Different countries use different forms of a Multi-Attribute Decision Analysis (MADA) process to evaluate the options. At its simplest, a pros and cons type of comparison can be used to evaluate options. At its most formal, a Best Practical Environmental Option (BPEO), Best Available Technique (BAT) or similar type of evaluation can be used. Generally, the more complex the issue or the more options one has, the more complex the evaluation.

3.4.2 Issues and experiences

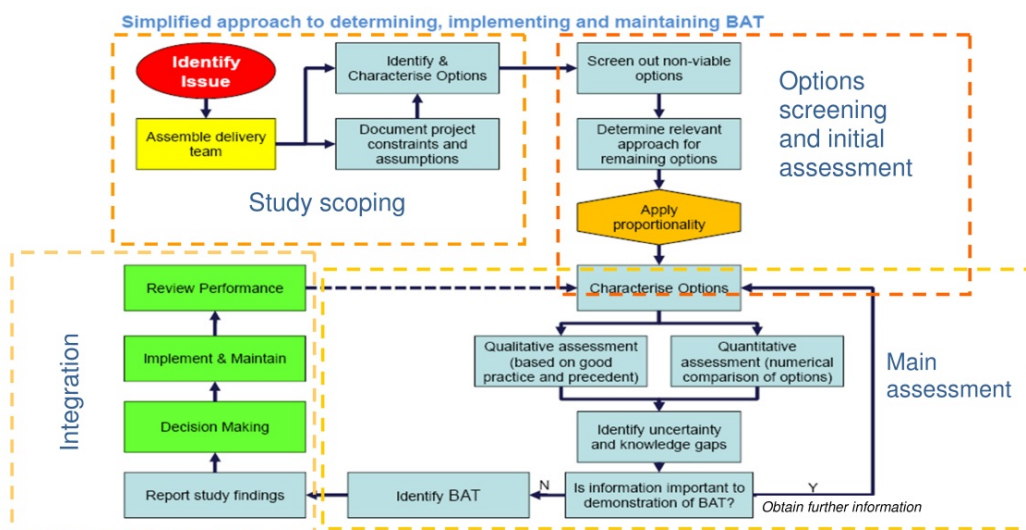
The robustness of any decision is a reflection of the decision-making process that was used. Many countries have developed a formal process to avoid the pitfalls of decision-making. These processes usually include guidance on the inclusion of stakeholders, the incorporation of national (or other) policies, accommodation of end (or interim) states or other factors.

Decision-making processes

The United Kingdom used a formal process to evaluate the remediation of the waste trenches at Sellafield. Guidance from United Kingdom regulators applies optimisation concepts, for example the as low as reasonably achievable (ALARA) concept to contaminated land. The assessment process is therefore designed to demonstrate optimisation through both Best Available Techniques (BAT) and proportionality arguments.

An annotated version of the BAT diagram developed for the Nuclear Industry Safety Directors Forum [9] BAT “code of practice” is presented in Figure 3.1 to illustrate the key phases of the BAT assessment process followed for the United Kingdom case study.

Figure 3.1: BAT Code of Practice (United Kingdom)



At project initiation a series of activities are identified as necessary to complete the study scoping and options screening/initial assessment phases of the process. The assessment phase of the process is centred on a main assessment workshop involving all key stakeholders. At this workshop, the attributes of the different options are evaluated and compared with performance criteria. The proceedings and outcomes of this workshop are documented in a report together with the documentation/evidence collected and compiled during the preceding phases. The outcomes of the workshop and the associated report provide direct support to subsequent processes that integrate the outcomes into wider site decision-making and planning processes.

Uncertainties both in conceptual site model understanding and the effectiveness of remediation technologies have inhibited the decision-making process in the past. Whereas previously this has resulted in a tendency to continue with the status quo, there is recognition that such uncertainties must not be allowed to dominate decisions regarding land quality management going forward.

In the Sellafield case study, the decision-affecting uncertainties are almost certain to remain if undue focus is given to specific remediation technologies. The decision has therefore been taken during the scoping study to identify a strategic, “direction of travel” management option representing BAT for the interim period, i.e. to control the contents of the trenches until widespread Sellafield site remediation takes place to meet the site final end state. As such, further detailed evaluation of specific aspects of the identified strategic BAT management option will be required before integration with other Sellafield Ltd. strategies and plans can be considered. The overall goal for the Sellafield site is to ensure that contaminated ground and groundwater on site are controlled such that the risks associated with them are acceptable and commensurate with the agreed use of the land. The assessment criteria in the BAT assessment workshop included preventing inadvertent disturbance or exposure of the contents of the trenches and minimising the potential mobility of contaminants in the trenches via leaching into groundwater.

A United States Department of Energy (US DOE) decision-making process is shown, in Figure 3.2 [10]. As with the United Kingdom process, it begins with the problem definition. Step two is defining the requirements that any solution must meet. Once the requirements are established, the goals or objectives of the solution are established (Step 3). These goals will be used to determine which solutions are better than others. Step four is identifying all possible solution alternatives. This may consist of brainstorming sessions with stakeholders. Once the remediation alternatives have been established, the evaluation criteria can be developed, based on the remedial objectives. A decision-making software tool can be used to evaluate the alternatives with respect to the criteria, resulting in the selection of a preferred, or optimal remedial solution.

Sensitivity analyses can help distinguish between alternatives if information is lacking for some options or if evaluation criteria do not point to a clear preferred solution.

The final step is to verify that the selected remedial option does, indeed, solve the problem as defined in step one.

Atomic Energy of Canada Limited (AECL) in Canada has a similar decision-making process shown in Figure 3.3 [11]. Like other countries, the process begins with problem definition. Stakeholder involvement is critical at this stage. Once the problem has been adequately defined and agreed to, the next steps are executed using a graded approach, e.g. smaller projects use completion of forms rather than the fully reviewed formal documents that are used for larger projects. Additionally, strategic requirements are identified separately from project level requirements to assure any remediation projects are aligned with the overall site clean-up strategy.

Because feasibility studies can be very expensive, a proposal for the work involved in the feasibility study must be approved before proceeding with the feasibility work. When the proposal is approved, the feasibility study and options evaluation can proceed. Once an option is selected, a business case is prepared for the option. Once that is approved, a project concept report is prepared and then the project can proceed.

Figure 3.2: US DOE decision-making process

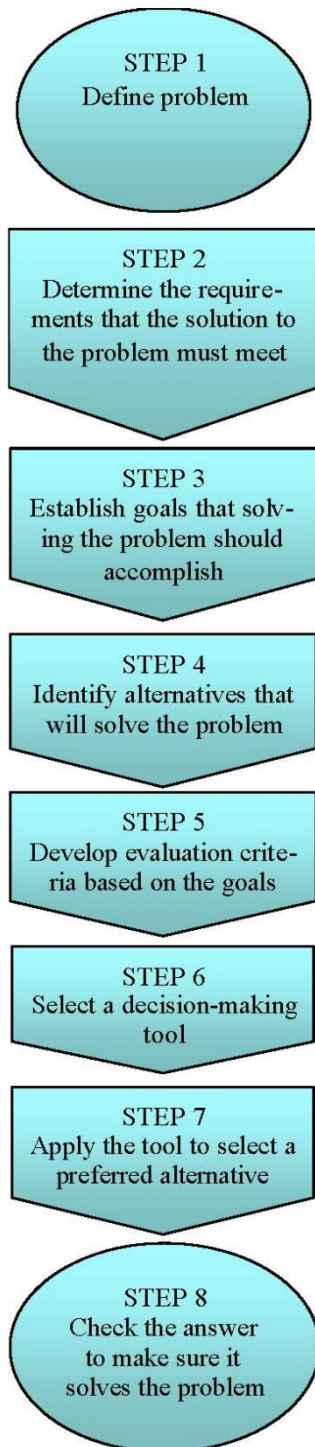
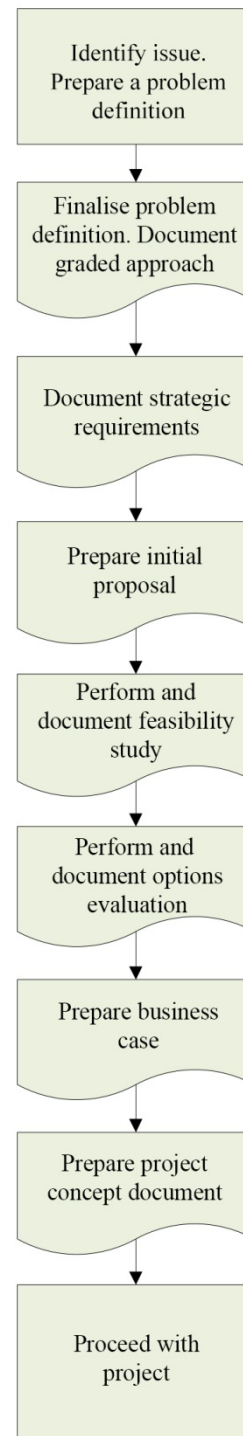


Figure 3.3: Canadian AECL decision-making process



The IAEA Safety Guide No. WS-G-3.1 *Remediation Process for Areas Affected by Past Activities and Accidents* [12] considers an iterative process. If, after remedial actions have been carried out, the criteria for unrestricted release have not been met, the responsible party should determine whether further remediation is feasible or whether the area should be released with restrictions, and should submit a proposal to the regulatory body for approval. If conditions have changed or additional information has been collected, and further remediation is justified, the optimisation process starts again at the stage at which the options are identified.

Failure to include a key stakeholder can lead to an unacceptable remedial solution

Fernald initially had limited stakeholder communication and limited public participation in the decision-making process. This led to an adversarial relationship between the facility and the public. Eventually, Fernald expanded public communication beyond the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements to develop a participatory relationship with citizen groups. Feedback pathways were expanded to collect input from a larger cross section of the public. The public eventually participated as a fully engaged member of the Fernald planning and development team. They advocated for site future use and contributed to the solution of major issues in the Fernald site clean-up [13], [14].

In Spain (CIEMAT site), the clean-up objectives and final verification criteria were discussed with the regulator as part of the options evaluation. Three end use scenarios (residential, industrial and educational) were discussed. The discussions were useful and positive and allowed for the definition of realistic release values. In United Kingdom the regulators were observers at the BAT workshop but also contributed to the discussion if they had an important point to make.

End state versus interim state

On a multi-purpose site with an ongoing operational mission, the end state for the site may not need to be achieved for many years or decades. However, if contamination on the site is prohibiting other uses or is impacting humans or the environment, clean-up activities may still be required some time before final decommissioning. As is the case in Canada and the United Kingdom, an interim state may be developed so risk can be reduced and the land can be reused for another purpose in the meantime, while the final clean-up to meet the end state can be deferred until a later time. One advantage to doing this is avoiding interim storage costs if a disposal facility is not immediately available. Another advantage is that using a delay between interim and final end state enables a less stringent clean-up as it can allow radioactive decay of short lived radionuclides over a specific period of time. If the interim clean-up is not sufficient to rely on radioactive decay alone then a second clean-up can be performed later. Interim states therefore provide flexibility, can target specific areas, allow an iterative approach, or can be used to represent different phases in the remediation process. They also provide an opportunity to develop better options in the long term and may improve worker safety by allowing time for some radioactive decay. It is important to be mindful that any interim clean-up activities do not preclude any future reasonable end state options or become the final clean-up activity by default.

National policies prohibit or hinder some alternatives

In some instances, national policy may dictate what the clean-up criteria will be, making at least some of the optioneering goals and objectives not open for discussion or assessment. For example in Germany, mandatory end state criteria are specified and all lands must meet unconditional clearance contamination levels. When that is the case, the evaluation regarding possible options for the end state becomes a formality or is perhaps not even required.

Sustainability

When choosing a remedial option, sustainability should be considered. The remedy should not be worse than the initial problem. Consideration should be given to how many trees will be removed, how much of the wildlife will be disrupted, how many trucks will be needed to transport waste and how far will they have to travel, how much fuel will they need and how much air pollution will they cause? These factors

are being considered now by EDF in France and will form part of the decision-making process when planning remediation activities. Further information can be obtained from the bibliography.

Waste disposal issues

In Spain, Enresa shows that site remediation activities can generate very large volumes of Very Low Level Waste (VLLW) that will need to be monitored and disposed. Consequently, these large volumes of VLLW must be taken into account when planning remediation projects. In particular, one should have:

- a detailed characterisation of the affected area;
- a predetermined site-specific release level;
- a well-established clearance process for materials that allow minimisation of the generation of radioactive waste;
- an efficient methodology for the classification and segregation of materials in situ, in accordance with the radiological characteristics (isotopic and activity);
- sufficient interim storage capacity onsite before dispatching to the disposal facility;
- a disposal facility for VLLW.

There is no point in digging up high volumes of VLLW that pose very small risk and moving it, with the associated transport risks, to a disposal site.

The availability of a disposal site for the level of activity and for the required volumes is an important consideration. Low-Level Waste (LLW) disposal sites should be preserved for more active wastes within the LLW category. The Brennilis (France) case study indicates the importance of the development of a sustainable remedial option, considering the overall impact on the environment (including land clearance and lorry transports).

The waste form may also be an issue e.g. the soil is too wet to meet the waste acceptance criteria for the waste disposal site, or it may need additional treatment. The remediation may also generate wastes that are difficult to dispose of because they contain roots and leaves and require additional sorting, as described in the Brennilis case study.

3.5 Remedial action/implementation

3.5.1 General description

Remedial actions are those actions taken in the event of a release or threatened release of a hazardous substance into the environment. The goal of remedial actions is to prevent or minimise the impact of the release so contaminant migration does not result in an unacceptable risk, now or in the future, to humans or the environment. Removal of all of the contamination is not necessarily the optimum action and may not be practical for many reasons.

Remedial actions may include:

- excavating and removing contaminated soil and other wastes;
- installing groundwater treatment facilities;
- installing caps, walls or other types of containment;
- other types of action, such as monitoring or natural attenuation
- characterisation of waste to determine storage or disposal pathways, if unable to do so in advance.

3.5.2 Issues and experiences

Remediation activities should strive to be safe and cost effective (optimised), but any number of issues may arise along the way. Equipment may not be available or, if it is, it may not perform as expected, workers may be assigned to the project without proper training, other priorities on the site may take resources from the project or it may be that high background levels of radiation thwart attempts to determine how much contaminated soil or groundwater needs to be removed. Contingency plans can be in place to deal with these issues, but not all hiccups can be easily foreseen, particularly when performing first-of-a-kind work.

Technology and techniques

During the course of remediation, excavated material requires characterisation for classification and disposal purposes. Real time scans can fill the data gaps regarding the extent of materials not meeting waste acceptance criteria during excavation. They can also help to identify the need to upgrade personal protective equipment requirements in the excavation area.

Efficient characterisation of soil in the field can be problematic however. In the German case study at Hanau operators were able to efficiently perform waste classification of excavated soil using a conveyor with an attached detector. Soil suspected to be radioactive, as determined by the detector, was separated and placed into drums. Filled drums were then measured again by an approved drum scanner to confirm the conveyor information. Results from the drum scanner were used for final classification of the waste drums for disposal.

This method also worked for characterisation of saturated material. In the same German project, lowering of the water table or using sheet piling to access saturated soil was not feasible in some areas. Other technology options, i.e. large diameter hollow or barrel drilling and backfilling of a drill hole were utilised, along with the conveyor and detector method. Conveyor detector measurements compared successfully with gamma spectrometry analysis of representative samples of the saturated soil.

Contaminated soil can easily become airborne during excavation with large equipment. Field work technologies need to be assessed to ensure contamination is not inadvertently spread around the worksite. In the course of removing soil, an excavator can very easily scatter contaminated soil to a previously clean area, thereby increasing the footprint of the area requiring clean-up and increasing the amount of waste that needs to be managed. This is particularly important when clean-up objectives are very low (see the discussions on the Grenoble remediation project).

Dust is visible to the public so there may be a need to consider dust suppressants/enclosures for public reassurance purposes even if they are not required for worker safety. Dust suppression is a major part of a project involving significant excavation of soil and should be planned for adequately at the front end of a project. At Fernald in the United States, dust control was required during excavation, during the loading of the materials into the trucks used to transfer material to the disposal facility, and during placement into the disposal facility, resulting in significant expense and time.

Contaminated groundwater exists at many sites. Both pump-and-treat systems and permeable barrier technologies have been used successfully by the US DOE (Case studies 8 and 9). The method chosen depends on several factors, including which contaminants are to be removed, the type of soil and the local geology. At Hanford, a pump and treat was installed at the 200 Area to capture carbon tetrachloride from a groundwater contamination plume emanating from a plutonium separations plant. More than 10 900 kg of carbon tetrachloride have been removed with this technology since 1994. At West Valley in New York, the DOE has been remediating groundwater using a pump-and-treat system, but found that it was not mitigating the advancement of a portion of the plume. The possibility of utilising a permeable barrier was assessed and found to be feasible. The permeable barrier was installed using a single pass trenching technique. This technique involves a trencher moving along the alignment and bringing trench spoils to the surface using a chain-saw like cutting boom at the rear of the trencher. The trench is supported and immediately backfilled behind the

cutting boom using a delivery system that resembles a moving trench box. The advantages of using this method include greater installation efficiency, ease of construction and cost effectiveness.

To help evaluate the effectiveness of decontamination technologies, the United States Environmental Protection Agency (US EPA) has issued two technical guidance documents. The *Technology Reference Guide for Radioactively Contaminated Media* [15] evaluates various technologies that can be used to treat radioactive contamination present in liquid media, including ground water, surface water, and waste water, and solid media, including soil, sediment, and solid waste. Information on 21 technologies is presented in technology profiles, which can be used to compare technologies for site-specific application. Five emerging technologies are also profiled in this guide. Technology profiles provide information on both chemical and physical decontamination technologies, including target contaminants, waste management issues, operating characteristics, and associated cost. The information presented in this guide allows technologies to be compared for site-specific use. In the Interstate Technology and Regulatory Council (ITRC) document *Decontamination and Decommissioning of Radiologically Contaminated Facilities* [16], Chapter 6 provides information on additional technologies not discussed in the EPA documents. The ITRC has also developed an online training course for this document [17].

Sometimes you have to adapt a chosen technology to the field conditions. EDF, while treating non-radioactive contaminants in groundwater by a pump-and-treat system, found that a huge amount of bacteria was developing and plugging the filters. The bacteria provided an unplanned naturally occurring opportunity to enhance the decontamination and this was utilised further by promoting bacterial growth. On another site where non-radioactive contamination was treated by in-situ injection of specific bacteria, the soils were found to have a higher pH than usual and to be very dense. It was therefore necessary to first de-compact the soils to one metre depth, and then to inject lactic acid to lower the pH. Following this, the bacteria were selected very precisely.

The choice of equipment to be used for a particular purpose should also be matched, in advance, to the level of effort required. Equipment that is too small may be inefficient or time consuming. Mock-up exercises should determine, in advance whether the most appropriate equipment has been identified to perform a given task.

Workforce

A properly trained, skilled workforce is necessary for a safe, efficient and cost effective remediation project. Workers can be trained on the job, but their efficiency can be quite low until the project is well advanced, as discussed in the Korean case study. It can take a significant period of time to train staff. Therefore, there is a need to maintain specialisms and a specialist supply chain when preparing for remediation and throughout the remediation process. This needs to be managed carefully to ensure that suitable trained staff are available on the timescales required for the remediation project. In many cases, the actual remediation is performed by staff members that are not nuclear specialists, and therefore there is a need to train them in the basics of radiological issues so that they are familiar with working in a nuclear environment.

Contingency planning for unforeseen circumstances

In the CEA's case study, the impact of unforeseen hazards leading to schedule delays and cost overruns was an important lesson. The presence of explosive devices can lead to work modifications, disruptions or stoppage. Planned waste disposal routes may need to be altered or closed off completely. In this case study, work stoppage lasted for over a year, and work practices, when they finally did resume, were changed requiring the presence of explosives experts, thus reducing the pace of work by a factor of three.

Each country that responded to the questionnaires has learnt exactly how long it takes to carry out characterisation of a site prior to remediation work, implement the remediation project and process the waste at the end of the project. Methods to reduce the time spent include maximising use of in-situ technologies for characterisation, for example using DQO or Triad methodologies. Even then, contingencies need to be built into project cost estimates and schedules. If characterisation prior to field remediation activities is not adequate and additional contamination is discovered

during the fieldwork phase, several additional years can be added to the project schedule (as in the Korean case study).

There should also be contingency planning for a variety of foreseen circumstances e.g. extreme weather events, fires, power interruptions.

As part of contingency planning, contracting methods should be flexible and adaptive. This helps one to change quickly to accommodate the new situation without schedule delays or added costs to the project (unchecked project overspend).

Clean-up on an operating site

Clean-up on an operating site requires additional considerations. As the site continues its operational activities, interferences with other activities and workers should be minimised. Good communication with operational groups on the site can help in getting the resources required for a remediation project, but regardless, contingency should be added to project schedules to allow for resources being diverted to other higher priority work on the site. On large and complex sites, it is very important to make senior management aware of remediation requirements and to integrate remediation in the overall site management strategy, as detailed in the Sellafield case study. Remediation areas should be physically separated from the site operational areas to the extent possible.

Remediation on an operating site usually also means limitations in the areas in which to perform the remediation work. Often, smaller sized equipment and machinery must be used, as found in the Spanish Lenteja case study. The restricted access may therefore complicate and delay the completion of remediation tasks. The proximity of nearby buildings and buried underground services must also be taken into account.

Storage space for wastes while waiting for disposal is also problematic if space in general is in short supply. In such cases, lack of storage must be dealt with in any remediation plans.

The site operators should be made aware of future remediation goals and not build new buildings that will compromise the ability of the remediation team to achieve interim clean-up goals.

3.6 Project closeout

3.6.1 General description

Project closeout includes a variety of activities. A key step is the verification that no further project clean-up actions are appropriate or anticipated and, if necessary, the regulatory agencies concur. Characterisation activities are carried out to ensure waste acceptance criteria are met or to verify that a remediated site meets the clean-up criteria. In the closeout phase, some form of institutional control may still be required, but the remedial actions within the scope of the remediation project have been completed. Project details are documented in a project closeout report, which includes a description of work done, summary of site conditions, monitoring results, and the overall technical justification for project completion. Lessons learnt are documented and project records are stored.

Issues and experience

Project closeout activities should document the project remedial actions and leave a record of project completion for future land users. Verification surveys, or final status surveys, have to meet stakeholder expectations, but must also be feasible and cost effective. Verification records and other project details must be maintained in such a way that future users can access them.

Verification surveys

The objectives of the verification/final status survey are to demonstrate that the project objectives have been met. The verification/final status survey includes planning, selecting measurement techniques and assessment of the data collected during the final status survey.

Although verification surveys incorporating 100% coverage of the clean-up footprint would satisfy stakeholders, efforts to achieve 100% coverage of the site were not always worth the use of time, or necessarily cost effective. In many countries, MARSSIM is an appropriate methodology to be used for this purpose. It is a flexible, yet rigorous, cost effective, widely used and recognised tool with worldwide application.

At the Lenteja site in Spain, Enresa has performed the final radiological characterisation by applying MARSSIM methodology with direct measurements. A final soil core sampling campaign was carried out at random points and also at specifically selected locations.

In France, MARSSIM methodology was applied by EDF for the final survey of a former effluent discharge channel. Certain parts of the methodology had to be adapted: for example due to the narrowness of the channel and its topography, the systematic sampling grid had to be slightly changed. Due to the geology of the area, in-depth boreholes had to be used to verify that contaminants were not accumulating. An alternative statistical approach has been used by CEA at the Grenoble site to obtain the average residual activity using the gamma spectrometry data.

A component of the final verification survey is demonstrating that no further wastes exist within the footprint of the clean-up, e.g. demonstrating that no contaminated piping that is above the agreed clean-up levels remains buried in the ground. A thorough characterisation study, along with a resulting conceptual site model has been found to be very useful for demonstrating to stakeholders that the site is, in fact, cleaned to the desired level and that the wastes have been removed or are controlled.

Verification/final status surveys are an area where it is useful to allow contingency time and money for the unexpected event. The Republic of Korea case study illustrates unexpected contamination that was not found until the end of the project when all the buildings had been removed and the final survey was being performed. A further two years was required for the project to deal with the additional contamination.

Small areas are sometimes found above the remediation criteria in the final survey. Averaging areas or statistical techniques can be used to interpret whether this requires further clean-up. In several case studies contamination levels above release criteria were locally detected and further confirmatory work was needed.

The question of whether the final survey is sufficiently comprehensive or not is important, and hence a contingency is required to allow for further work.

Record keeping

Record keeping for decommissioning or environmental remediation purposes is different from those records kept for operational purposes. Operational records are kept for the safety of operations and the facility. Hence, operational records often do not give all the information that is needed for environmental remediation. Environmental remediation needs information to delineate boundaries of clean-up areas, site release criteria. What information will be important in the future can be difficult to predict during the operational phase. However, operational records should aim to include environmental data.

Other record management issues include staff turnover, destruction of records (through fire, for example), and the incompatibility of evolving electronic data storage technologies. Not everyone sees the importance of maintaining records and so many records may be intentionally destroyed.

Having a well-used and maintained records management tool and system will help with remediation planning. Some countries have a central information management system as well as a project level management system. Often, however, the systems may be cumbersome or difficult to search through. If the system discourages people from using it, it will not be used to the extent it should be. Once a site has been released for unrestricted use, the record keeping requirement will be reduced.

A well-designed set of records is essential for institutional control to be effective. Updates need to be scheduled if electronic media are used to ensure that it can still be accessed after some time has passed. The costs need to be calculated and funding set aside for maintenance.

3.7 Institutional control

3.7.1 General description

Once remediation activities have been completed and verified, post remediation activities can begin. These activities may consist of maintenance and monitoring and/or administrative controls, depending on the achieved site end state or the intended end use [18]. The duration of these activities should be commensurate with the degree of hazard and risk remaining after the site clean-up activities have been completed.

Institutional control of a site is often designated by the laws of the particular country in which the site is located. Controls may be passive (e.g. zoning controls, signage, land use records) or active (e.g. monitoring, surveillance, fencing).

Institutional control activities may include:

- monitoring the long-term stability and performance of barriers which isolate and contain contaminated materials;
- monitoring environmental indicators within and down-gradient of the remediated site;
- prevention of intrusion if contamination is not fully removed or if the land is returned for limited use;
- use of controls to ensure adherence to licensing conditions;
- use of administrative controls (e.g. deed restrictions).

3.7.2 Issues and experiences

Full life-cycle planning of institutional controls is recommended to ensure their long-term effectiveness. Planning for institutional controls should begin early and be an ongoing process. It generally should begin prior to selecting substantive use restrictions and continue during the process of converting desired use restrictions into actual institutional control instruments; that planning, in turn, should include establishing approaches for assuring compliance with institutional controls over their duration. Many common problems experienced by practitioners using institutional controls often can be avoided by critically evaluating and thoroughly planning for the entire institutional control lifespan, to the extent possible, early in the response selection and design process.

During all stages of institutional control planning and particularly early on, site managers and site attorneys should seek input (and evaluate the capacity for institutional control involvement) from state, tribal, and local governments, responsible parties, affected communities, natural resource trustees, and other stakeholders in order to help ensure that the most appropriate response, including institutional controls, is selected. Early co-operation and co-ordination among these parties often can be critical to ensuring long-term institutional control provides protection at a site. Stakeholders should be made aware of the institutional controls under consideration and should also be given the opportunity to provide input. The following subsections highlight additional considerations that may be important in evaluating and planning for the institutional control life cycle. EPA has developed guidance for helping site managers plan for institutional controls [19].

Certain US DOE sites, namely Fernald in Ohio and Rocky Flats in Idaho have several decades of experience with institutional control. Making the transition from active remediation to institutional control required unforeseen changes in staffing, information management and regulatory affairs. Some lessons learnt from Rocky Flats are given in [4].

Staffing

The transition from a larger decommissioning project organisation to a smaller institutional control organisation following project closeout may bring unforeseen challenges. In the early years after closure, additional work may be needed that had not been included in the closure plan. Staffing levels in the initial years may need to be higher than anticipated due to the ramping up of work needed to get the site to the eventual steady state post closure workload. Once a stable institutional control phase scenario is achieved, staffing levels may decrease to a lesser, sustained level.

During the institution control phase, not only is the staffing level smaller, but the type of staff needed may be very different. When fewer people are on site to deal with problems as they arise, staff must have a more diverse set of tools with which to deal with the wide range of issues that can arise. Staff must be generalists rather than specialists, ready to respond to any situation that may arise.

The smaller staffing levels mean that staff can make decisions quickly, but it also means that a limited number of staff can be overloaded if site conditions warrant an extra amount of work.

Regulatory issues

Regulatory changes could also occur after the initial post closure plans were made. Physical and administrative control requirements could change, as could monitoring and surveillance requirements. Each of these changes impact staffing levels and budgets. Multiple regulatory agencies may invoke multiple requirements, leading to higher workloads. Changes in security requirements may also need to be accounted for, whether required by regulators or for public perception purposes.

Occasionally, unexpected work may be required to enable regulatory requirements such as inspections and monitoring to be fulfilled. Even physical controls may require upfront preparation work in order to implement.

Security

Although security might not be an obvious concern, at Rocky Flats in the United States for example, unattended areas were found to be attractive to vandals even though nothing at the site seemed likely to be attractive to them. A recommendation was made to consider hiring a security firm to maintain a security presence at the site.

Closeout information and information technology (IT) transfer

Lessons learnt from Rocky Flats indicate that sufficient time should be allowed for information handover from an operating IT group to an institutional control IT group. At Rocky Flats, this process turned out to be a multi-year process. As an example, the handover of the GIS software was delayed several years due to delays in updating the final closure condition co-ordinates.

Information on the closure of the site and the remaining physical conditions needs to be transferred to the information management system of the post closure activity planning and implementation team. If this work is not adequately done during the project closeout phase, extra time and effort will be required post-closeout and this will delay implementation of the institutional controls.

Hydrogeologic conditions that applied to the site during the remediation phase may not apply to the new post closure regime. Consequently, before implementing controls in the post closure phase, new hydro-geologic information may be required, further delaying implementation of the institutional control phase.

3.8 Summary of experiences

The case studies were analysed to identify good practices and difficulties and these are summarised in Table 3.2.

Table 3.2: Summary of experiences

	Good practices	Issues	Other comments
Stakeholder engagement	<p>Involve stakeholders early in the decision-making process (since problem definition) and provide them access to site remediation documents.</p> <p>Providing funding for independent experts to advise stakeholders.</p> <p>Cultivate relationships with media and institutions.</p>	<p>Adapt the information level depending on stakeholders' knowledge and interest.</p> <p>Be very thorough when results are presented.</p> <p>Establish relevant communication tools to facilitate stakeholders' comprehension.</p> <p>Stakeholder concerns may lead to unnecessary clean-up from the point of view of the actual risk to humans and the environment.</p>	<p>The site management team can also be considered to be stakeholders that need to be engaged at an early stage. This enables remediation to be integrated in the overall site management process and assigned the relevant priority. These stakeholders are also decision makers.</p> <p>Regulators are special stakeholders as they may not approve remediation plans. They may also need to communicate with the public.</p>
Problem definition	<p>Site land quality management plans and early characterisation of problem areas and/or new areas for development.</p> <p>Establish the root cause of the problem so it can be addressed.</p> <p>Obtain the stakeholders agreement on a written definition of the problem to be solved.</p> <p>For naturally occurring radionuclides, seek early agreement on clean-up criteria taking into account local background levels.</p>	<p>Assumptions about land and groundwater quality need to be verified by direct measurement – this can be problematic under existing facilities.</p> <p>Obtaining sufficient and adequate information.</p> <p>Potential ambiguities in regulatory requirements.</p> <p>Ambiguous or inflexible final end state requirements (stakeholder view uncertain, not adequately taking into account risk-based approach or future use of land).</p>	<p>A key part of the problem definition is determining whether or not the problem requires a response (i.e. is justified).</p> <p>A poor problem definition can lead to performing nugatory and/or expensive and inefficient projects.</p>
Remedial investigation (Characterisation and Assessment)	<p>Use methodologies as DQO and statistical or geostatistical interpretation of measurements for decision making.</p> <p>Use real time data collection methodologies in the field for minimising repeat field trips.</p> <p>Take into account workers hazards (exposure) in the course of collecting field data.</p> <p>Consider integrated investigative methods such as direct push or directional drilling techniques.</p> <p>Integration of assessment for non-radioactive and radioactive contaminants.</p>	<p>Incomplete historical records.</p> <p>Characterise surfaces under buildings (access problem) or near operational activities (background elevation).</p> <p>Stratification of contaminants with depth below grade (scaling factors evolution with depth, surface characterisation not representative of in-depth contamination).</p> <p>Geophysical surveys' reliability.</p> <p>Define the optimised samples number and depth. Extrapolate the contamination level between point samples, particularly with heterogeneous contaminated materials (waste trenches for example).</p> <p>Obtain a reliable hydrogeological model.</p> <p>Availability of suitably skilled and trained staff and contractors in the investigative techniques as well as those trained in health physics.</p>	<p>Different approaches for characterisation are used in different countries.</p>

Table 3.2: Summary of experiences (cont'd)

	Good practices	Issues	Other comments
Remedial planning	<p>Favour a risk-based approach to defining a site end state.</p> <p>Establish a decision-making process that includes uncertainty and sensitivity analyses.</p> <p>Use a graded approach: adapt the decision-making process complexity to the case complexity (large and high contamination case; small and slight contamination case).</p> <p>Consider sustainability in the decision-making process.</p> <p>Take into account the needs of interim waste storage areas if disposal facility not available.</p> <p>When waste clearance authorised, have a well-established clearance process.</p> <p>For multi-purpose sites with an ongoing operational mission, consider the development of an interim state to permit safe uses of the site.</p> <p>Consider the “implementability” and maturity of the technology to the situation.</p>	<p>When no national clean-up criteria or policy is available, it may be difficult to justify remediation objectives that are acceptable to the regulator and stakeholders (for example taking into account impact, cost, sustainability, feasibility).</p> <p>The difficulties of remediation planning on an operational site (e.g. with competing priorities and objectives).</p> <p>The availability of waste disposal facilities for large volumes of very low level radioactive waste.</p> <p>Financial assurance/funding aspects and uncertainties in allotted budget may need to be addressed.</p>	<p>Failure to include a key stakeholder can lead to a remedial solution that will not be acceptable.</p> <p>From a sustainability point of view, the remedy should not be worse than the initial problem (i.e. it should do more good than harm).</p>
Remedial action/ implementation	<p>Implement mock-up exercises or pilot schemes. When feasible, use real time scans during excavation for waste segregation and to measure progress in meeting clean-up criteria.</p> <p>Use of flexible and adaptive contracts, with contingency plans.</p>	<p>Need to avoid contamination spread and implement dust control measures.</p> <p>Availability of properly trained and skilled workforce.</p> <p>Cost and schedule impacts when unforeseen circumstances occur (e.g. additional contamination discovered).</p> <p>Manage interferences from others and limitations on available work areas on an operating site.</p>	
Project closeout	<p>Land reuse is defined with stakeholders.</p> <p>Use of recognised and proven methods for final surveys (for example MARSSIM).</p> <p>Good use of records management tool and system that is well maintained.</p>		
Institutional control	<p>Update hydro-geologic model.</p>	<p>Correct staffing levels (number and skills).</p> <p>Adaptation to regulatory changes.</p> <p>Transition between closeout stage and institutional control stage (staff, information systems).</p> <p>Uncertainties that controls (institutional) can be maintained for prolonged periods and burden on future generations (inter-generational equity).</p>	

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4. Discussion and observations

This chapter presents a number of observations and recommendations for site remediation, including suggestions for future research.

The previous sections and the case studies illustrate a variety of remediation situations and associated issues. In particular, remediation cost and duration can be very significant in comparison to some decommissioning projects and can be problematic if the scope, cost and schedule are not fully considered in advance. The completion of site remediation is the last step before nuclear site release is achieved, and therefore it is the most sensitive phase regarding stakeholders and public opinion. Hence, it is important to find solutions to remediation challenges as well as to optimise remediation work, i.e. select the option with the greatest net benefit taking into account costs and other factors.

4.1 Factors of major importance for the different remediation phases

Different factors have been identified as key elements during the remediation process. Table 4.1 summarises the importance of each factor for the different remediation phases:

Table 4.1: Importance of key factors in the different remediation phases

Important factors	Health and safety (workers)	Public and environment protection	Waste management	Technical specification	End state development	Cost and schedule	Uncertainty management	Stakeholder confidence
Problem definitions	■	■	■	■	■	■	■	■
Remedial investigation	■	■	■	■	■	■	■	■
Remedial planning	■	■	■	■	■	■	■	■
Remedial action/ implementation	■	■	■	■	■	■	■	■
Project close-out	■	■		■	■	■	■	■
Long-term monitoring	■	■		■	■	■	■	■

Notes:

Health and safety (workers): Moving to long-term acceptable state but may be short-term increase in risk during implementation.

Public and environment protection: Current state should be tolerable increasing importance after closeout when controls are passive and receptors closer.

Waste management: Waste route availability could be a key constraint in project design.

Technical specification: Increases in importance towards implementation.

End state development: End state can drive the problem or be informed by it.

Cost and schedule: Cost and schedule are full life cycle issues but the speed of implementation may be resource/affordability limited.

Uncertainty management: Uncertainty should decrease to closeout. Long-term record keeping is important.

Stakeholder confidence: Important throughout.

4.2 Recommendations

All this gathered experience leads to the identification of some recommendations for the optimisation of current remediation projects and for reducing the remediation cost in future decommissioning projects.

Prevention

A parallel can be established between waste management and remediation management: in both cases the priority is to avoid production of contaminated material, i.e. to prevent pollution in the case of land remediation. So facility design and organisation should integrate approaches and techniques to prevent site pollution i.e. to prevent leaks. The primary aim of remediation is not to detect leaks, though the monitoring may in fact discover some unexpected contamination. Leak detection is an operational activity.

Nuclear site operators should not wait until planning is underway for the decommissioning phase before they consider site remediation. Best practice could be to determine the end state for the site with regulators and stakeholder participation at the facility design stage. This will allow consideration of defence in-depth and contingency arrangements to ensure the planned end state is achieved. This approach would include development of an agreed conceptual model at the design stage that would allow optimisation of groundwater monitoring systems and would in turn provide early warning of potential compromises to the end state. Monitoring would not need to be onerous if design and facility controls provide confidence that leaks will not occur. Safety cases will ensure prompt and early action if leaks were to occur allowing for the implementation of remedial actions if there is potential for the end state to be affected by these events.

Generally, pollution prevention is now required by national regulations. These regulations are often more recent than the first generation of nuclear facilities. This partly explains the current problems encountered on old sites, in which large areas of contaminated land exist with high activity concentrations of some radionuclides. On the other hand, the presence of these regulations indicates that more recent nuclear facilities, although subject to more stringent regulation, will have to deal with fewer and smaller scale site remediation issues during decommissioning.

Minimisation (contamination spread and remedy work)

Generally, it would be good practice to clean-up leaks immediately to minimise spread of contamination (concentrate and contain principle) if this is practical. Despite best intentions the above situation is not reflected at all sites and there is an increasing legacy of issues that need to be managed.

Once the decision has been taken to remedy, the challenge is to find the remedial action that fits with risk/cost/schedule/objective criteria. A key factor in the decision-making at this step is the degree of uncertainty on the extent of the contamination. Use of DQO and statistical interpretation of measurements is a key area for accurate mapping of contamination and supporting early remediation decisions.

It is also important to minimise spread of contamination during excavation work so that the volumes of contaminated waste are reduced.

Characterisation

As seen before, characterisation is an essential step in the remediation process. Before beginning characterisation it is essential to define the objectives and strategies of the characterisation in terms of:

- quality and quantity of data;
- phasing;
- planning;
- health and safety;

- sampling and analysis;
- quality assurance plan;
- data management plan;
- project management.

At the international scale, a very varied approach for characterisation is observed, except for verifying surveys for which MARSSIM is the most used approach (sometimes with local adaptations). The task group recommends further international discussions to develop good practice guidance. Geostatistics is one of several tools that can help to reduce the uncertainties in certain cases and in particular during characterisation. There are already a number of international groups that provide guidance on characterisation (ITRC, SAFEGROUNDS, UK NDA Group, US EPA, ISO). Further international discussions to consolidate this good practice guidance would be beneficial.

Successful characterisation typically occurs where the strategy is consistent with the characterisation objectives and acceptable level of uncertainties. The following aspects should be taken into consideration:

- Identify the problem that the characterisation is to address.
- Determine the decision to be made.
- Identify inputs to the decision.
- Define the study boundaries.
- Develop a decision rule.
- Specify limits on decision errors.
- Optimise data design.

A sampling and analysis plan should be developed to conduct the characterisation in the field and in the laboratory. Planning documentation should also define analytical procedures for the measurements to determine detection limits, precision, and accuracy. Further examples of good practice are given in Section 3.3.

Experience shows that radionuclide levels in background can be very heterogeneous, varying over very small distances, due to geological/hydrogeological characteristics. It is therefore necessary to develop methodologies to define background taking into account this variability.

It is important that the remedial action makes most effective use of available funding. This also means that the scale of the contamination should be kept in perspective. There are many remediation projects that are very small in scale.

In order to optimise characterisation cost and schedule and to avoid inadequate remedial planning and work, it is important to systematically integrate the characterisation and assessment for both non-radioactive and radioactive contaminants, in correlation with the historical assessment.

Decision-making/remedial planning

The US EPA approach to decision-making at long-term Superfund programme sites is worth considering. A national flexible approach to clean-up standards such as EPA's is necessary and a range of doses is useful as a guide but flexibility is usually greater if the operator can demonstrate good culture and has safety and environmental protection as high priority.

Decision-making processes should explicitly incorporate the identification of uncertainty.

In the remedy decision process, it is necessary to develop common methodologies to assess and compare the costs and impacts in order to identify the optimum choice for a sustainable approach to the soil remediation. A range of attributes should be considered in the decision process. The implementability of the option is one attribute that should be considered in the decision analysis.

On operating sites, the focus may be on monitoring and modelling of contamination rather than active clean-up.

For complex sites that may also include shallow engineered radioactive waste disposal facilities there are more options for remediation but responses will need to be targeted and informed by an integrated environmental assessment that considers the long-term implications of authorised disposals. Where there are local disposal facilities it is more likely that land will be remediated (since there is a disposal route) but it is necessary to consider the overall environmental benefits of transferring waste to the disposal facility.

Early on in the decision-making process the issue of capability should be addressed, in terms of skills, funding, laboratory capacity and capability, contractor availability, etc. Depending on the situation, it could have a significant impact on remedial planning. For example, it could be necessary to invest in mobile laboratories if existing laboratory capacities were not sufficient, or to develop specific training or to extend the invitation to tender to international companies.

Monitoring and assessment

For most environmental remediation projects, a maintenance and monitoring period may be required after site closeout. The sites that are released without restrictions will not require any long-term monitoring. However, the sites released with conditions, or released for restricted use will require long-term monitoring and post-remediation activities, at least to check that the land quality evolution is as expected.

Funding and responsibility for the measurements should be assigned to a single organisation. To ensure the quality of the measurements the laboratories should be involved in inter-laboratory calibration programmes. To guarantee impartiality it is reasonable to have a third party take confirmatory samples (usually a small percentage). The post-remediation monitoring programme can take samples on an as needed basis. As post closeout monitoring can be very long (even for perpetuity), it is of major priority to reduce its burden. Use of improved telemetric systems should be favoured.

Regulation

The type, severity and extent of contamination can vary quite widely. Though lessons learnt from the past help appreciably in reducing the severity of such events, they will not eliminate them completely. It is therefore important that a country's national strategy be developed accordingly and that an adequate regulatory framework exists to ensure that environmental remediation actions can be undertaken as appropriate to the problems at hand. National laws and regulations on environmental protection, radiation safety, occupational safety, and human health will need to be considered. The degree of the regulatory framework required will vary from country to country. Where a detailed regulatory framework is lacking, the national government may wish to refer to the guidelines from international agencies such as the IAEA and the International Commission on Radiological Protection (ICRP).

It is recognised that radioactive waste management has a very important role in any environmental remediation operation. As such, the strategy and regulatory framework for environmental remediation should be consistent with that for radioactive waste management.

The remediation criteria in the different countries differ, ranging from complete removal of contamination to a risk-based criterion corresponding to a dose of 10 $\mu\text{Sv}/\text{y}$ or a dose of up to 300 $\mu\text{Sv}/\text{y}$. The task group favours a risk-based approach to define remediation objectives e.g. contamination levels, and for priorities phasing, as for example the approach taken in United Kingdom, United States, Canada and Spain. An internationally agreed range of risk-based values is worth considering.

Relations with stakeholders

A lot of progress has been achieved in the United States regarding stakeholder involvement since the first decommissioning projects. Lessons learnt should be very useful for other countries and quite easy to adapt to national regulatory regimes.

Regarding communication with stakeholders, the task group identified the need to develop some tools to facilitate the understanding of the risk assessment of pollution, in particular when it exists as natural or artificial background (e.g. Chernobyl fallout). The goal is to share the difficulty of delineating slight pollutions where the residual impact is sufficiently low to be acceptable. Maps are useful tools for communication with stakeholders. It is also recommended that arrangements are made to enable stakeholders to access independent experts. Independent peer review of the decision-making process and technical reports is good practice and is highly recommended as it is very important in developing trust.

The site management team can also be considered to be stakeholders that need to be engaged at an early stage. This enables remediation to be integrated into the overall site management process and assigned the relevant priority. These stakeholders are also decision makers.

4.3 Knowledge sharing and working with international partners

4.3.1 Introduction

Remediation is a complex technical subject and therefore to allow adoption of best practice and innovation it is important to have appropriate levels of, and mechanisms for, knowledge sharing and experience sharing between problem holders and solution donors. It is very important for stakeholders to achieve a common understanding of all the main issues involved in remediation. The responsibility for disseminating this information rests with the site operator, however international organisations can play a key role in this regard.

The questionnaires identify different levels of knowledge sharing, at site, project and international level:

- Sharing of information between owners and operators is essentially for project management and technical purposes.
- Sharing of information between owners, operators, regulators and stakeholders is focused on strategy, project objectives, implementation and regulatory issues.

The analysis of the national questionnaires indicates that 90% of the countries have a network for information exchange between site owners, operators, regulators and stakeholders (Annex 4), though 30% of the countries reported limited exchange of information. The general trend is to improve transparency and to facilitate access to information, and this is sometimes required by regulation.

Remediation experience is very heterogeneous among countries, depending on the number of nuclear facilities and which phase of the nuclear facility life-cycle has been reached. Considering factors such as the number of available contractors, capability and capacity of radioanalytical laboratories, skills and capabilities, the importance of international exchange becomes clear.

Knowledge sharing networks are well established in a few countries. There are good examples in North America and in the United Kingdom. However, in other countries these networks are less well-established or non-existent. International institutions such as the IAEA, OECD/NEA and the European Commission (EC) play an important role in facilitating information sharing. The IAEA have established the CONNECT¹ knowledge management hub. This knowledge management information tool is in the early stages of development and its success will depend on administrative and technical support within the IAEA and then on the effective participation of interested professionals. A good

1. <http://nucleus.iaea.org/sites/connect/Pages/default.aspx>

example of a knowledge management tool is called KM-IT.¹ This hub provides a platform for sharing best practice on decommissioning primarily in the United States but also includes some content from the United Kingdom. The reason this has been successful is that the US DOE has invested significantly in technical and administrative support for this tool.

4.3.2 Existing networks

IAEA and OECD/NEA

The IAEA Network of Environmental Management and Remediation (ENVIRONET) is an important international forum for environmental remediation including nuclear site remediation. The IAEA has significant resources to support remediation planning and decision-making, including remediation approach [1], process [2], planning [3], technologies [4] and stakeholder participation [5]. A more complete list of IAEA publications for environmental remediation is provided at www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/WTS/remediation-publications.html.

The IAEA CIDER project [6] developed under the auspices of the ENVIRONET and the International Decommissioning Network *(IDN) [7] – both IAEA networks – is examining the constraints that reduce the pace or even impede the implementation of remediation works worldwide. After the identification of these barriers the project will work towards the provision of solutions that can help overcoming the identified constraints. The IAEA, in co-operation with other organisations and member states, will then work to mobilise necessary forces to facilitate the implementation of the identified solutions. The project involves the participation of representatives from different national organisations from IAEA member states and also counts on the support of international organisations like the United Nations Development Programme (UNDP), the European Bank for Reconstruction and Development (EBRD), the EC and the United Nations Environment Programme (UNEP).

Within the NEA, the Working Party on Decommissioning and Dismantling (WPDD) of the Radioactive Waste Management Committee (RWMC) provides a focus for the analysis of decommissioning policy, strategy and regulation, including the related issues of management of materials, release of buildings and sites from regulatory control and associated cost estimation and funding. Beyond policy and strategy considerations, the WPDD also reviews practical considerations for implementation such as techniques for characterisation of materials, for decontamination and for dismantling [8]. Other relevant reports are available on the WPDD website: www.oecd-nea.org/rwm/wpdd/

European networks

On a regional basis the EU has funded research on site remediation. The *Environmental Radiation Survey and Site Execution Manual* (EURSSEM) provides information and guidance on strategy, planning, stakeholder involvement, conducting, evaluating and documenting radiological environmental and facility (surface) surveys based on best practices for demonstrating compliance with dose or risk-based regulations or standards, remediation, reuse, short-term and long-term stewardship on radioactively contaminated and potentially radioactively contaminated sites and/or groundwater, see www.eurssem.eu/wiki. NICOLE (www.nicole.org) is a leading forum on contaminated land management in Europe, promoting co-operation between industries, academia and service providers on the development and application of sustainable technologies. The overall objective of NICOLE is to pro-actively enable European industry to identify, assess and manage industrially contaminated land efficiently, cost-effectively and within a framework of sustainability. The NICOLE forum has published a sustainable remediation roadmap [9] and the technical basis for this roadmap [10].

National networks

There are many useful national networks. Some of the more useful are highlighted below.

1. www.dndkm.org/

UK SAFEGROUNDS is a forum and learning network focusing on contaminated land on nuclear and defence sites and on non-active/low activity waste from nuclear and defence site decommissioning in the United Kingdom. The network covers technical, regulatory, public opinion and commercial issues, recognising the inter-relationships between these and the solutions adopted for contaminated land and decommissioning waste issues (www.safegrounds.com/index.html).

Contaminated land: applications in real environments ([claire](http://claire.co.uk/), www.claire.co.uk/) is a respected independent not-for-profit organisation established in 1999 to stimulate the regeneration of contaminated land in the United Kingdom by raising awareness of, and confidence in, practical and sustainable remediation technologies.

In France, a dedicated part of the Ministry of Ecology website deals with the national policy on contaminated land. There are many guides dealing with the different steps of the methodology for contaminated land management and links to technical reports, see www.developpement-durable.gouv.fr/-Sites-et-sols-pollues-.html

North American networks

The US EPA website: www.clu-in.org/ and the US DOE Environmental Management website: (www.em.doe.gov/Pages/EMHome.aspx) provides information about both site experiences and innovative treatment and site characterisation technologies. The US EPA [11] and US DOE [12] also provide numerous case studies. The general conclusion of the case studies is that a common understanding among states, stakeholders, sites, and agencies of how various clean-up levels have been or could be derived will make this process more efficient, defensible, and consistent. The use of science-based clean-up criteria reduces the likelihood of clean-up being delayed by litigation and/or other factors. The DOE website also provides links to numerous reports and publications on site remediation. Decision makers at DOE and other facilities need to be aware of the context used to establish clean-up levels at other sites contaminated with radionuclides. Consistency and transparency in decision-making for developing clean-up goals will enhance selection and deployment of appropriate environmental remediation and characterisation technologies.

The Electric Power Research Institute (EPRI) established a “remediation and decommissioning technology development programme,” as part of a groundwater protection initiative at the direction of the Nuclear Energy Institute (NEI) Nuclear Strategic Issues Advisory Committee (NSIAC). The programme purpose is to assess, evaluate, and develop technologies related to remediation and decommissioning, provide lessons learnt, to capture expertise from remediation and decommissioning efforts and to develop guidance. The main goal is to prevent offsite migration of contaminated groundwater, to support transitioning of the NPP and staff from operational mode into decommissioning, and to develop and execute plans for license termination, plant demolition, systems removal, and radioactive waste disposal. This programme comprises multiple areas of remediation and decommissioning technologies such as: 1) information and data to enhance risk reduction to workers; 2) enhanced planning tools and management logistics; 3) experience and lessons learnt; 4) application of investigation results on use of advanced technologies; and 5) provide technical guidance addressing unresolved issues pertaining to groundwater and soil protection and remediation, low-level waste management, site characterisation, radiation dose modelling for site release, and license termination plans. EPRI is a restricted US network that also includes other countries such as Spain and France. It provides a number of reports to the network members for free. There is a limitation with respect to sharing information outside the EPRI network (and the reports have to be purchased if you are outside the network). The EPRI site can be accessed at: www.epri.com/Pages/Default.aspx.

The Interstate Technology and Regulatory Council (ITRC) is a public-private coalition working to reduce barriers to the use of innovative environmental technologies that reduce compliance costs and maximise clean-up efficacy. ITRC is a programme of the Environmental Research Institute of the States (ERIS), incorporated in the District of Columbia and managed by the Environmental Council of the States (ECOS). ITRC produces documents and training that broaden and deepen technical knowledge and expedite quality regulatory decision-making while protecting human health and the environment. ITRC achieves its mission through its technical teams, which are composed of

environmental professionals, including state and federal environmental regulators, federal agency representatives, industry experts, community stakeholders, and academia. Since 1995, ITRC has published hundreds of documents and reached tens of thousands of participants through training courses on hundreds of topics. ITRC co-ordinates and schedules at no-cost Internet-based training courses for those with an interest in learning more about innovative environmental technologies and approaches specific to areas of characterisation, monitoring and remediation as well as other environmental topics. ITRC is a state-led coalition working together with industry and stakeholders to achieve regulatory acceptance of environmental technologies. Examples of guidance documents and training materials for radionuclides [13], [14] can be found on their website.

The US Nuclear Regulatory Commission (NRC) regulates the decontamination and decommissioning of nuclear facilities and has developed waste, decommissioning, and environmental protection management programmes. The decommissioning programme activities include 1) developing regulations and guidance to assist staff and the regulated community; 2) conducting research to develop data, techniques, and models used to assess public exposure from the release of radioactive material resulting from site decommissioning; 3) reviewing and approving Decommissioning Plans (DPs) and License Termination Plans (LTPs); 4) reviewing and approving license amendment requests for decommissioning facilities; 5) inspecting licensed and non-licensed facilities undergoing decommissioning; 6) developing Environmental Assessments (EAs) and Environmental Impact Statements (EISs) to support the NRC's reviews of decommissioning activities; 7) reviewing and approving final site status survey reports; and 8) conducting confirmatory surveys.

For more information go to: www.nrc.gov/about-nrc/regulatory/decommissioning.html; for information on specific sites, see the *Status of Decommissioning Program 2013, Annual Report and Sites Undergoing Decommissioning (by Location or Name)*.

Skills and capability

Remediation is a complex technical area that requires continual professional development of practitioners. It is important to set out at the outset the skill requirements at each phase of remediation. This is a developing area and there is an increasing need for suitably qualified and experienced people. There are concerns that not enough is being done to facilitate the transfer of skills and experience from contractors involved in non-radioactive site remediation. National and international networks may be able to help in this respect.

In France, a procedure for certification of contractors dealing with site remediation was set up by the Ministry of Ecology in 2009. The French standards NF X 31-620 were approved in 2011 and cover requirements for capabilities and skills, in assistance and control services, and engineering services for remediation works. The Ministry is also establishing two training schemes, starting in September 2014 and September 2015, respectively: a high school certificate +3 training (qualified technician) and a high school certificate +5 training (engineer). Students will be trained in a co-operative programme between universities and employers; teachers are expected to have a professional background in the field. At present the scheme is for non-radioactive site remediation.

It is also recognised that regulator knowledge and experience varies throughout the OECD/NEA group of countries. An example of good practice is the guidance produced by NRC for staff and the regulated community.

4.3.3 Dissemination

Knowledge sharing and communication between countries engaged in environmental remediation is an important area for further development. This is a rapidly developing field and there is an increasing need for suitably qualified and experienced people. It is important that suitable training courses and material are available.

4.4 Research and development priorities

The analysis of the questionnaires indicates that barriers to remediation that could be of R&D interest are mainly in the field of characterisation, monitoring and remediation techniques.

There is a parallel task group in the NEA WPDD working on decommissioning research and development and their report was undergoing final drafting at the time of writing this report. The task group has reviewed the section in their draft report that provides an overview of site remediation R&D and future needs.

A study conducted by the United States National Research Council of the National Academies on various aspects of the clean-up of sites being implemented by the US DOE [15] led to the conclusion that some science and technology gaps exist in this field and that R&D is needed to fill the identified gaps. In terms of groundwater and soil remediation the following areas have been identified:

- The behaviour of contaminants in the subsurface should be better understood.
- Better understanding of site and contaminant source characteristics.
- Improvement in the assessment of the long-term performance of trench caps, liners and reactive barriers.
- Demonstration of the long-term ability of cementitious materials to isolate wastes.

4.4.1 Characterisation and monitoring R&D needs

It is obvious that the more accurate, relevant and reliable the remedial investigations are, the more accurate the project planning and cost estimates will be. The experience described in this report demonstrates that the lack of remedial investigation is the main cause of project cost over-runs, delay, and public/regulator unacceptance.

However, it is impossible to obtain an exhaustive characterisation, 100% reliable, at a reasonable cost. Hence it is important that the project team understands the characterisation uncertainties and limits so as to define realistic remediation objectives and more widely the remedy strategy.

Regarding the post closeout phase, site monitoring could continue for many decades with dedicated staff in charge of collecting data as required by the monitoring plan. Some data could require sampling or on site data reading, that is cost consuming.

Therefore, the R&D needs identified for characterisation and monitoring are:

- **Characterisation methodologies that allow 3-D cartographies of pollution with confidence interval maps**, for example by using statistics/geostatistics models. It should both allow the management of uncertainties, including interpretation of scaling vectors, and the optimisation of measurements and sampling plan required to define remedy work. Discrimination of levels of activity from natural background levels caused by weapon testing and the Chernobyl fallout is also required.
- **Measurement technologies that reduce the need for intrusive sampling** since it is costly, time consuming and sometimes can lead to exposure of workers to radioprotection risks. The need is particularly important for hard to detect radionuclides (e.g. non gamma emitters as ^3H , ^{90}Sr , alpha emitters), which are not detectable by the usual mapping devices in a soil matrix. Greater use of data from measurable radionuclides in the radionuclide fingerprints (vectors) will help to identify the presence of these difficult to detect radionuclides.

- **Increase our knowledge of the contaminant transport through soil and groundwater**, so as to limit the post monitoring plan to the minimum needed, and to be able to justify it to regulator and stakeholders. Although this topic has been and is still extensively studied in many countries, some additional research is still needed. For example, EDF (France) has a R&D project in order to get specific parameters such as K_d or infiltration velocities for EDF sites.
- **Characterisation of inaccessible areas**, due to physical issues (e.g. soil underneath operating facilities) or due to risk issues (radiological or chemical hazards). The sooner the contamination extent and level are known, the sooner the remedy scenario will be relevant and risks associated with the project management will decrease. The issue for a reliable characterisation is often the access to inaccessible areas; hence the need is to develop devices able to reach such areas and to carry out the measurements/ samples required.
- **Use of remote sensing and satellite technologies** to monitor, record, and transmit characterisation and environmental monitoring data. The objective is to reduce the cost of post remediation monitoring and the need to have dedicated local staff.
- **Complex issues for migration**: the role of organics, micro-organisms and colloids in radionuclide transport is an immature science; further work is needed to determine the importance of colloids in considering uncertainties in modelling radionuclide transport. Local deposition of radionuclides due to solubility/precipitation events is also not well understood.

4.4.2 Remediation techniques and R&D needs

To help evaluate the effectiveness of decontamination technologies, the US EPA has issued technical guidance documents. The technology reference guide for radioactively contaminated media [15] describes five emerging technologies, and Chapter 6 of the ITRC document decontamination and decommissioning of radiologically contaminated facilities [16] provides information on additional technologies not discussed in the EPA documents.

To date the most common remediation technique used for radiological pollution is to excavate and dispose of the contaminated soils. The sustainability of this technique is not obvious when considering all environmental aspects if the contamination level is comparable to VLLW. Issues such as the transportation of the waste, using the sometimes limited capacity in waste disposal facilities (often large amounts of soil have to be disposed), and ecological aspects (biodiversity) are relevant and need to be considered.

More effective methods of remediation are required, especially for more mobile radionuclides such as tritium and ^{36}Cl . Developments in these methods may also bring benefits in the protection of the environment from shallow land waste disposal facilities.

Another aspect regarding remediation techniques is groundwater treatment, with large amounts of water to be treated, and often with impacts outside the site boundary.

The R&D needs identified in the remediation techniques field are:

- **Technology for removing mobile radionuclides, e.g. ^{129}I , ^{36}Cl and ^3H** : in particular tritium is generated by numerous nuclear facilities (reactors essentially), and options for remediating tritium leaks are limited. This should therefore be an area for co-ordinated international research.
- **Groundwater clean-up**: as shown by the United States sites remediation experience, remediating large volumes of lightly contaminated groundwater is sometimes required. The groundwater clean-up system generally used (pump and treat) is costly and needs to be implemented over a long timeframe. Therefore, developing new clean-up systems or improving the efficiency of the current systems while minimising the generation of secondary wastes is of major importance. Monitored natural attenuation may be an

alternative to clean-up and although guidance is available on its applicability [16] to radiologically contaminated media, further work is required on discussions of the advantages and disadvantages with stakeholders, particularly considering the long timescales that may be involved.

- **Waste-reduction volume:** the excavation and dispose method leads to the generation of a huge amount of contaminated soils, most of them are lightly contaminated (very low level waste). This can quickly be a big issue if adequate disposal routes are not available or if available, with an insufficient capacity. Thus techniques for volume reduction by soil washing or rapid but accurate bulk monitoring (e.g. using conveyor belts) are being developed to reduce the volume of material that is classified as radioactive waste. Alternatively, the development of both in-situ remediation techniques and fixing contamination in soils techniques (for preventing rainwater percolation or groundwater flow through contaminated zones) could lead to the optimum option being to leave contaminated soils in place, hence reducing significantly the waste production. Another intermediate solution could be to develop techniques to treat soils after removal until they meet clearance levels, if authorised by national regulatory. Further work is required on bioremediation and modelling of natural attenuation.
- **Groundwater protection:** the first priority is to prevent or mitigate against contaminant migration in groundwater, further research is required to optimise these techniques in different circumstances. Techniques for significantly reducing the migration velocity of radionuclides that are not readily attenuated should be developed.
- **Remediation techniques for land underneath operating facilities:** when contamination is identified underneath buildings that are still in operation and the contaminants can migrate to groundwater, it would be much better to treat it immediately from the risk and cost points of view, instead of waiting until building demolition (potentially decades afterwards) and having to manage groundwater contamination. That is why developing remediation techniques for land underneath operating facilities is of major interest.

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Annex 1 – Glossary

Accident: Any unintended event, including operating errors, equipment failures and other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

Activities: Include the production, use, import and export of radiation sources for industrial, research and medical purposes; the transport of radioactive material; the decommissioning of facilities; radioactive waste management activities such as the discharge of effluents; and some aspects of the remediation of sites affected by residues from past activities.

Contamination: Radioactive substances on surfaces or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places.

Conceptual model or site conceptual model: A set of qualitative assumptions used to describe a system

Decommissioning: Administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility (except for a repository or for certain nuclear facilities used for the disposal of residues from the mining and processing of radioactive material, which are “closed” and not “decommissioned”).

Facility: Includes nuclear facilities; irradiation installations; some mining and raw material processing facilities such as uranium mines; radioactive waste management facilities; and any other places where radioactive material is produced, processed, used, handled, stored or disposed of – or where radiation generators are installed – on such a scale that consideration of protection and safety is required.

NORM: Material containing no significant amounts of radionuclides other than naturally occurring radionuclides. The exact definition of “significant amounts” would be a regulatory decision. Materials in which the activity concentrations of the naturally occurring radionuclides have been changed by human made processes are included. These are sometimes referred to as technically enhanced NORM or TENORM.

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

***Site:** An area containing radioactive materials and having a designated boundary for the purposes of radiological control. For the purposes of this survey, this will include nuclear sites, sites with radioactive contamination, NORM sites and uranium mining and milling sites. However, small sites such as hospitals and educational laboratories are not included.

***Legacy sites:** Sites on which radioactive materials have been left or where contamination occurred due to activities in the past, and for which there is no longer any operator or the former operator cannot any longer be held responsible for remediation. In general the State has taken over responsibility from previous operators.

These definitions, except those that are marked with an asterisk (*), are taken from the *IAEA Safety Glossary: 2007 Edition* (IAEA, Vienna, 2007) and/or the *Radioactive Waste Management Glossary: 2003 Edition* (IAEA, Vienna, 2003).

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US NRC	2000 Multi-Agency Radiation Survey and Site Investigation Manual, MARSSIM (Revision 1), NUREG-1575 Rev. 1, Environmental Protection Agency EPA 402-R-97-016 Rev. 1, Department of Energy DOE EH-0624 Rev. 1, US Nuclear Regulatory Commission August 2002 www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1575r1/		Decommissioning Surveys and Sampling	USA
US NRC	2000 NUREG/CR-6676 Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-Build Codes U.S. Nuclear Regulatory Commission, Washington, DC: July 2000 http://web.ead.anl.gov/resrad/documents/NUREG_6676.html		Clearance Level Modeling	USA
US NRC	2000 NUREG/CR-6692 Probabilistic Modules for the RESRAD and RESRAD-Build Computer Codes, U.S. Nuclear Regulatory Commission, Washington, DC: November 2000 http://web.ead.anl.gov/resrad/documents/NUREG_6692.pdf	The RESRAD and RESRAD-BUILD codes are part of the RESRAD family of codes developed by the U.S. Department of Energy. For many years, these deterministic codes have been used as dose assessment tools for cleanup of sites contaminated with radioactive materials. The RESRAD code applies to the cleanup of soils, and the RESRAD-BUILD code applies to the cleanup of buildings and structures. This report is the third in a series documenting the procedures used to enhance the deterministic RESRAD and RESRAD-BUILD codes for probabilistic dose analysis. A six-step procedure was used in developing default parameter distributions and the probabilistic analysis modules. These six steps include (1) listing and categorizing parameters, (2) ranking parameters, (3) developing parameter distributions, (4) testing parameter distributions for probabilistic analysis, (5) developing probabilistic modules, and (6) testing probabilistic modules and integrated codes. These six steps are discussed and summarized in this report. Steps 4 and 5 are documented in separate NUREG/CR reports (NUREG/CR-6676 [Kamboj et al., 2000] and NUREG/CR-6692 [LePoire et al., 2000]). The reports for steps 1, 2, 3, and 6 are included in this report as attachments.	Clearance Level Modeling	USA
US EPA	2000 Soil Screening Guidance for Radionuclides: User's Guide, Office of Emergency and Remedial Response and Office of Radiation and Indoor Air, Washington, DC, OSWER No. 9355.4-16A www.epa.gov/superfund/health/contaminants/radiation/pdfs/ssuserguide.pdf		Clearance Level Modeling	USA
US EPA	2000 Soil Screening Guidance for Radionuclides: Technical Background Document, Office of Emergency and Remedial Response and Office of Radiation and Indoor Air, Washington, DC, OSWER No. 9355.4-16 www.epa.gov/superfund/health/contaminants/radiation/pdfs/ssbdb.pdf		Clearance Level Modeling	USA
EPR	2000 1000951 Embedded Pipe Dose Calculation Method Nov. 2000 www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductID=000000000001000951		Decommissioning Surveys and Sampling	USA

ANSI	2001 ANS.I.HPS N13.49-2001. Performance and Documentation of Radiological Surveys http://hps.org/hpsc/N13_49_2001.html	USA	Decommissioning Surveys and Sampling
US NRC	2001 NUREG 5512 V2 Residual Radioactive Contamination From Decommissioning: User's Manual Draft Version 2.1 http://pbadupws.nrc.gov/docs/ML0109/ML010940257.pdf	USA	Clearance Level Modeling
ANL	2001 ANL/EAD-4, User's Manual for RESRAD Version 6. C. Yu et al. Environmental Assessment Division Argonne National Laboratory, July 2001 http://web.ead.anl.gov/resrad/documents/resrad6.pdf	USA	Clearance Level Modeling
IAEA	2001 IAEA Safety Guide Series No. WS-G-2.4 Decommissioning of Nuclear Fuel Cycle Facilities, June 18, 2001. www.pub.iaea.org/MTCD/publications/PDF/Pub1110_web.pdf	International	Decommissioning Surveys and Sampling
EPRI	2001 1003030 Determining Background Radiation Levels in Support of Decommissioning Nuclear Facilities Nov. 2001 www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductID=0000000000001003030	International	Decommissioning Surveys and Sampling
EPRI	2002 User Guide to on Site Characterization, Dose Modeling, and Final Status Survey Documentation June 2002	USA	User Guide
ITRC	2002 Determining Cleanup Goals at Radioactively Contaminated Sites: Case Studies. The Interstate Technology and Regulatory Council Radionuclides Team. Environmental Research Institute of the States (ERIS). http://itrcweb.org/Documents/RAD-2.pdf	USA	Case studies
Environment Agency	2002 Guidance on the Characterisation and Remediation of Radioactively Contaminated Land, May 2002. www.sellfieldsites.com/land/documents/lea%20guidance%20on%20radioactively%20contaminated%20land.pdf	UK	Guidance
US EPA	2002 Simulating Radionuclide Fate and Transport in the Unsaturated Zone: Evaluation and Sensitivity Analyses of Select Computer Models http://nepis.epa.gov/Adobe/PDF/900G0V00.pdf	USA	Clearance Level Modeling
EPRI	2002 1003426 Summary of Utility License Termination Documents and Lessons Learned Oct. 2002 www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductID=0000000000001003426	USA	Decommissioning Surveys and Sampling
EPRI	2002 1003196 Guide to Assessing Radiological Elements for License Termination of Nuclear Power Plants www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductID=0000000000001003196	USA	Decommissioning Surveys and Sampling

12 case studies. A common understanding among states, stakeholders, sites, and agencies of how various cleanup levels have been or could be derived will make this process more efficient, defensible, and consistent. The use of science-based cleanup criteria reduces the likelihood of delayed cleanup due to litigation and other factors. Decision makers at DOE and other facilities need to be aware of the context used to establish cleanup levels at other sites contaminated with radionuclides. Consistency in decision making for developing cleanup goals will enhance selection and deployment of appropriate environmental remediation and characterization technologies.

EPRI	2002 1006949 Use of Probabilistic Methods in Nuclear Power Plant Decommissioning Dose Analysis May, 2002 www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=0000000000001006949	USA	Decommissioning Surveys and Sampling
EPRI	2002 1003423 Trojan License Termination Plan Development Project Apr. 2002 www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=0000000000001003423	International	Decommissioning Surveys and Sampling
US EPA	2002 Common Radionuclides Found at Superfund Sites (OSWER No. 9200.1-34, July, 2002). www.epa.gov/superfund/health/contaminants/radiation/pdfs/nuclides.pdf	USA	Stakeholder Involvement
IAEA	2003 Remediation of Areas Contaminated by Past Activities and Accidents. SAFETY STANDARDS SERIES No. WS-R-3, Vienna. www.pub.iaea.org/MTCD/Publications/PDF/Pub1176_web.pdf	International	Decommissioning
ANL	2003 ANL/EAD/03-1, User's Manual for RESRAD-BUILD Version 3. C. Yu et al, Argonne National Laboratory, June 2003 http://web.ead.anl.gov/resrad/documents/ANL-EAD-03-1.pdf	USA	Clearance Level Modeling
IAEA	2003 Radioactive Waste Management Glossary, 2003 Edition. www.pub.iaea.org/MTCD/publications/PDF/Pub1155_web.pdf	International	Glossary
IAEA	2004 Site restoration and cleanup of contaminated areas. 11th International Congress of the International Radiation Protection Association, Madrid. Linsley G. http://irpa11.irpa.net/pdfs/KL-6b.pdf	International	Decommissioning
Environment Agency	2004 CLR11 – Model procedures for the management of land contamination, 2004 http://publications.environment-agency.gov.uk/pdf/SCHO0804BIBR-e-e.pdf	UK	Land management
US EPA	2004 EPA 402-R-04-002C, Volume III, Understanding Variation In Partition Coefficient, Kd, Values, Review of Geochemistry and Available Kd Values for Americium, Arsenic, Curium, Iodine, Neptunium, Radium, and Technetium www.epa.gov/radiation/docs/kdreport/vol3/402-r-04-002c.pdf	USA	Clearance Level Modeling
Environment Agency	2005 Land Contamination: Technical Guidance on Special Sites: Nuclear Sites, June 2005 https://publications.environment-agency.gov.uk/pdf/sp5-042-tr-5-e-e.pdf	UK	Guidance
EPRI	2005 1011735 A Practical Guide for the Performance of Combined Risk Assessment at Nuclear Power Plant Decommissioning Sites Dec. 2005	USA	Decommissioning Surveys and Sampling
SAFEGROUNDS	2005 Assessments of health and environmental risks of management options for contaminated land. www.safegrounds.com/guidance.htm	UK	Risk assessment

The Model Procedures for the Management of Land Contamination are intended to provide the technical framework for structured decision-making about land contamination. The basic process can be adapted to apply in a range of regulatory and management contexts, subject to any specific constraints arising from these contexts. The Model Procedures are intended to assist all those involved in "managing" the land – in particular landowners, developers, industry, professional advisers, financial service providers, planners and regulators.

Environment Agency	2005 Land Contamination: Technical Guidance on Special Sites: MoD Land, June 2005 http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98f72d550b.r19.cf3.rackcdn.com/sp5-042-tr-1-e-e.pdf	This report is one of a series of technical guidance documents relating to Special Sites that are part of the statutory regime for contaminated land introduced by the implementation of s.57 of the Environment Act 1995 that added Part IIA into the 1990 Environmental Protection Act (EPA 1990). The application of this primary legislation is via the Contaminated Land (England) Regulations 2000 and the accompanying DETR Circular 02/2000. This report provides technical information relevant to Ministry of Defence (MoD) Land.	Guidance	UK
Environment Agency	2005 Secondary Model Procedure for the Development of Appropriate Soil Sampling Strategies, June 2005 http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98f72d550b.r19.cf3.rackcdn.com/sp5-066-tr-e-e.pdf	Model Procedures for the Management of Contaminated Land have been developed for the Department of the Environment Transport and the Regions, and the Environment Agency (1999, in preparation). These incorporate existing good technical practice, including the use of risk assessment and risk management techniques, into a systematic process for making decisions about and taking appropriate action to deal with contamination, in a way that is consistent with UK policy and legislative requirements.	Guidance	UK
EPRI	2005 1011730 Groundwater Monitoring Guidance for Nuclear Power Plants Dec. 2005 www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=0000000000001011730		Decommissioning Surveys and Sampling	USA
US EPA	2005 Uniform Federal Policy for Implementing Environmental Quality Systems: Evaluating, Assessing, and Documenting Environmental Data Collection/Use and Technology Programs. EPA: EPA-505-F-03-001, DoD: DTIC ADA 395303, DOE: DOE/EH-0667, Version 2 Washington, DC. www.epa.gov/fedfac/pdf/ufp_v2_final.pdf		Policy	USA
DEFRA	2006 Environmental Protection Act 1990: Part 2A. Contaminated Land. Defra Circular 01/2006, United Kingdom. www.defra.gov.uk/publications/2011/03/28/contaminated-land-pb12122/	It has two functions: first it promulgates the statutory guidance as now amended, which is an essential part of the regime; secondly, it sets out the way in which the extended regime is expected to work, by providing a summary of Government policy in this field, a description of the regime, and a guide to the other relevant Regulations and Commencement Orders.	Legislation	UK
IAEA	2006 IAEA Series No. WS-G-5.1, Release of Sites from Regulatory Control on Termination of Practices Safety Guide, November 08, 2006. www.pub.iaea.org/MTCD/publications/PDF/Pub1244_web.pdf		Clearance Level Modeling	International
EC	2006 TREN/04/NUCL/S07 40035, Inventory of Best Practices in the Decommissioning of Nuclear Installations Final Report, European Commission, Directorate General Energy and Transport, Brenk Systemplanung GmbH (BS) Heider-Hof-Weg 23 52080 Aachen, Germany and Nuclear Research Institute Rež p.lc Husinec-Rež, Op. 150 25068 Rež, Czech Republic Aachen, 30 June 2006. http://ec.europa.eu/energy/nuclear/decommissioning/doc/05_2006_11_decommissioning_best_practice_report.pdf		Decommissioning Surveys and Sampling	EU
IAEA	2006 IAEA Safety Requirements Series No. WS-R-5 Decommissioning of Facilities Using Radioactive Material, October 18, 2006. www.pub.iaea.org/MTCD/publications/PDF/Pub1274_web.pdf		Decommissioning Surveys and Sampling	International

ITRC	2006 Interstate Technology Regulatory Council (ITRC) 2006. Real-Time Measurement of Radionuclides in Soil: Technology and Case Studies www.itroweb.org/Documents/RAD_4Web.pdf	Real-time measurement systems allow radionuclides in both surface and subsurface soil to be measured more rapidly than they can be with traditional sampling approaches. The basic technologies for these real-time systems are two different types of solid-crystal gamma detectors: sodium iodide and germanium. Understanding the advantages and limitations of each is an important consideration when planning a real-time survey. When these instruments are combined with new location technologies, the ability of real-time measurement systems to present data in an immediately useful format is greatly enhanced.	Monitoring	USA
US EPA	2006 Technology Reference Guide for Radiologically Contaminated Surfaces. www.epa.gov/radiation/docs/cleanup/402-r-06-003.pdf	The U.S. Environmental Protection Agency (EPA), Office of Radiation and Indoor Air (ORIA) developed this Technology Reference Guide For Radiologically Contaminated Surfaces (Guide) to help identify surface decontamination technologies that can effectively remove radiological contaminants from building, structure, and equipment surfaces. These technologies may also be useful in the removal of non-radiological contaminants, such as hazardous metals, from surfaces. This Guide is designed to provide easy access to critical information on technologies that are commercially available. This information is presented in technology profiles that can be used to compare technologies for site-specific application. The technologies selected for presentation in this Guide include those that could be considered for response actions.	Guidance	USA
NEA	2006 NEA WPPD, the release of sites of nuclear installations - a status report. www.oecd-nea.org/nwm/docs/2006/nwm-wpdd2006-4.pdf		Overview	International
US NRC	2007 NUREG/CR-6937 User's Manual for RESRAD-OFFSITE Version 2. C. Yu et al. Argonne National Laboratory, Environmental Science Division, June 2007		Clearance Level Modeling	USA
IAEA	2007 Remediation process for areas affected by past activities and accidents. IAEA SAFETY STANDARDS SERIES No. WS-G-3.1, Vienna. www.pub.iaea.org/MTCD/Publications/PDF/Pub1282_web.pdf		Clearance Level Modelling	International
IAEA	2007 IAEA Safety Glossary. Terminology Used in Nuclear Safety and Radiation Protection, 2007 Edition www.pub.iaea.org/MTCD/publications/PDF/Pub1290_web.pdf		Glossary	International
SAFEGROUNDS	2007 Good practice guidance for land quality records management. www.safegrounds.com/guidance.htm		Records	UK
IAEA	2007 IAEA Modelling the Transfer of Radionuclides from Naturally Occurring Radioactive Material (NORM). Report of the NORM Working Group of EMRAS Theme 2 www.nis.iaea.org/downloads/nw/projects/emras/final-reports/norm-report.pdf		Clearance Level Modelling	International

US EPA	2007 Technology Reference Guide for Radioactively Contaminated Media. www.epa.gov/superfund/health/contaminants/radiation/pdfs/technology_ref_guide_for_contaminated_media.pdf	The U.S. Environmental Protection Agency, Office of Air and Radiation, Radiation Protection Division's Radiation Site Cleanup Center, produced this Technology Reference Guide for Radioactively Contaminated Media (Guide) as a reference for technologies that can effectively treat radioactively contaminated sites. The Guide is designed to give easy access to critical information on applied technologies that address radioactive contamination in solid and liquid media. The solid media include soils, sediment, sludge, and solid waste, but do not include buildings and structures. The liquid media include groundwater, surface water, leachate, and waste water. This information is presented in technology profiles that can be used to compare technologies for site-specific application. This Technology Guide is a revision of "Technology Screening Guide for Radioactively Contaminated Sites," EPA 402-R-96-017, published in 1996.	Guidance	USA
Environment Agency	2008 Contaminated Land Exposure Assessment (CLEA) guidance, August 2008		Guidance	UK
Environment Agency	2008 An Ecological Risk Assessment Framework for contaminants in soil, October 2008 https://publications.environment-agency.gov.uk/PDF/SCHO1008BOTK-E-E.pdf		Guidance	UK
ANSI	2008 ANSI/HPS N13.59-2008. Characterization in Support of decommissioning Using the DQO Process		Decommissioning Surveys and Guidance	USA
Environment Agency	2008 Guidance for the safe development of housing on land affected by contamination. R&D 66: 2008 www.environment-agency.gov.uk/static/documents/Leisure/SR-DPUB66-e-e.pdf	This guidance is intended for Environment Agency (Agency) officers, and organisations involved in the characterisation and remediation of radioactively contaminated land, where the Agency will regulate the disposal of the wastes arising from remediation. Guidance is given on the regulatory context for radioactively contaminated land; the interpretation of the Radioactive Substances Act 1993; and some of the relevant Exemption Orders issued under the Act.	Decommissioning Surveys and Guidance	UK
ITRC	2008 Interstate Technology Regulatory Council (ITRC) Decontamination and Decommissioning of Radiologically-Contaminated Facilities. Rad 5 The Interstate Technology and Regulatory Council Radionuclides Team. Environmental Research Institute of the States (ERIS). www.itroweb.org/Guidance/ListDocuments?TopicID=21&SubTopicID=24#		Clearance Level Modeling	USA
HSE	2008 Health and Safety Executive. Delicensing guidance, Guidance to inspectors on the interpretation and implementation of the HSE policy criterion of no danger for the delicensing of nuclear sites, August 13, 2008 www.hse.gov.uk/nuclear/operational/assessment/hs-per-in-005.pdf		Decommissioning Surveys and Sampling	UK
NEA	2008 NEA No. 6403, Release of Radioactive Materials and Buildings from Regulatory Control, Nuclear Energy Agency Organisation For Economic Co-Operation And Development, 2008 www.oecd-nea.org/nwm/reports/2008/nea6403-regulatory.pdf	While clearance or release of materials and buildings of nuclear installations from radiological control is also relevant for operating nuclear installations, it has emerged as an important option for the management of material from decommissioning of nuclear installations. Extensive experience is available from dozens of decommissioning projects worldwide.	Decommissioning Surveys and Sampling	International

IPSN	2008	Gestion des sites industriels potentiellement contaminés par des substances radioactives. IPSN. www.asn.fr/index.php/content/download/32311/234392/file/Guide-Gestion_sites_potentiellement_pollues.pdf	An update of the "methodological guidelines for the management of industrial areas potentially contaminated by radioactive substances," published in 2001 by IRSN. Revisions intended to bring coherence between management of areas polluted by radioactive substances and the general policy applied to polluted sites described in a document published in February 2007 by the French Ministry in charge of Environment.	Guidance	France
IAEA	2009	Integrated approach to planning the remediation of sites undergoing decommissioning. IAEA NUCLEAR ENERGY SERIES No. NW-T-3.3, Vienna. www.pub.iaea.org/MTCD/Publications/PDF/Pub1385_web.pdf		Planning	International
IAEA	2009	An overview of stakeholder involvement in decommissioning. IAEA NUCLEAR ENERGY SERIES No. NW-T-2.5, Vienna. www.pub.iaea.org/MTCD/publications/PDF/Pub1341_web.pdf		Stakeholder	International
SAFEGROUNDS	2009	Good practice guidance for the management of contaminated land on nuclear-licensed and defence sites - version 2 (LM/Gv2). www.safegrounds.com/guidance.htm		Land Management	UK
SAFEGROUNDS	2009	Guide to the comparison of contaminated land management options. www.safegrounds.com/guidance.htm		Land Management	UK
SAFEGROUNDS	2009	Good practice guidance for site characterisation - version 2. www.safegrounds.com/guidance.htm		Characterisation	UK
Environment Agency	2009	Updated technical background to the CLEA model, January 2009 www.environment-agency.gov.uk/static/documents/Research/CLEA_Report_-_final.pdf		Technical manual	UK
US NRC	2009	NUREG-1575, Supp. 1, EPA 402-R-09-001, DOE/HS-0004, Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME), Final, January 2009. www.nrc.gov/reading-rm/doc-collections/huregs/staff/sr1575/supplement1/index.html		Decommissioning Surveys and Sampling	USA
IAEA	2009	Safety Assessment for the Decommissioning of Facilities Using Radioactive Material, February 24, 2009. IAEA Safety Guide Series No. WS-G-5.2. www.pub.iaea.org/MTCD/publications/PDF/Pub1372_web.pdf		Decommissioning Surveys and Sampling	International
EPRI	2009	1019228 Characterization and Dose Modeling of Soil, Sediment and Bedrock During Nuclear Power Plant Decommissioning Dec. 2009 www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001019228	Restricted to members	Decommissioning Surveys and Sampling	USA
ASN	2009	Policy and legal overview from Autorité de sûreté nucléaire www.french-nuclear-safety.fr/index.php/content/download/15547/100856/JCVFinale.pdf		Policy overview	France
ISO	2010	ISO 11929-2010. Determination of the characteristic limits for measurements of ionizing radiation. Fundamentals and applications. www.iso.org/iso/catalogue/catalogue_tc/catalogue_detail.htm?csnumber=43810		Decommissioning Surveys and Sampling	International

EURSSEM	2010 European Radiation Survey and Site Execution Manual (EURSSEM), Version 01, May 17, 2010 www.eurssem.eu/wiki	Decommissioning Surveys and Sampling	EU
IAEA	2010 IAEA TRS 472, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, International Atomic Energy Agency, 2010 www.pub.iaea.org/MTCD/publications/PDF/trs472_web.pdf	Clearance Level Modeling	International
SAFEGROUNDS	2011 Community Stakeholder Involvement www.safegrounds.com/guidance.htm	Stakeholders	UK
DEFRA	2011 Guidelines for Environmental Risk Assessment and Management. Green Leaves III www.defra.gov.uk/publications/files/pb13670-green-leaves-iii-1111071.pdf	Risk assessment	UK
		This document provides generic guidelines for the assessment and management of environmental risks. The guidelines supersede earlier versions published in 1995 by the Department of the Environment, and in 2000 by the Department of the Environment, Transport and the Regions and the Environment Agency. This revision brings the guidelines in England and Wales in line with current thinking in the field of environmental risk management. Methods are described for estimating the probability of harm to, or from, the environment, the severity of harm, and uncertainty are described. The guidelines focus on generic principles, rather than domain-specific risks, such as from river flooding, animal disease or hazardous wastes.	
US NRC	2011 NUREG/CR-7021, A Subsurface Decision Model for Supporting Environmental Compliance, U.S. Nuclear Regulatory Commission, January 2011, Robert Stewart, University of Tennessee http://pbadupws.nrc.gov/docs/ML1202/ML12026A022.pdf	Decommissioning Surveys and Sampling	USA
US NRC	2011 NUREG/CR-7026, Application of Model Abstraction Techniques to Simulate Transport in Soils, Pachepsky, Y. et al, U.S. Nuclear Regulatory Commission, Washington, DC, March 2011 https://forms.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr7026/	Clearance Level Modeling	USA
US NRC	2011 NUREG/CR-7029, "Lessons Learned in Detecting, Monitoring, Modeling and Remediating Radioactive Ground-Water Contamination, Sullivan, T. et al., U.S. NRC, Washington, DC, (April 2011) www.ntis.gov/search/product.aspx?ABBR=NUREGCR7029	Clearance Level Modeling	USA
ANSI	2011 American Nuclear Society, "American National Standard- Evaluation of Subsurface Radionuclide Transport at Commercial Nuclear Power Plants," ANSI/ANS-2.17-2010, ANS, La Grange Park, IL, 60526, Approved December 23, 2010 by the American National Standards Institute, Inc. (2011) http://global.ihs.com/doc_detail.cfm?currency_code=USD&customer_id=2125452A340A&osid=2125452A370A&shopping_cart_id=2125452A3C0A&rid=Z06&input_doc_number=2.17&mid=5280&input_doc_number=2.17&country_code=US&lang_code=ENGL&item_s_key=00006710&item_key_d ate=891231&input_doc_number=2.17&input_doc_title=	Clearance Level Modeling	USA
SEPA	2011 Remediation of Radioactively Contaminated Sites SEPA (Scottish Environment Protection Agency) (2011). www.sepa.org.uk/about_us/sepa_board/agendas_and_papers/20_sept_2011.aspx	Decommissioning Surveys and Sampling	UK

		Case History	International
IAEA	2011 Redevelopment and Reuse of Nuclear Facilities and Sites: Case History and Lessons Learned. IAEA Nuclear Energy Series, NW-T-2.2, International Atomic Energy Agency, Vienna, 2011 www.pub.iaea.org/MTCD/Publications/PDF/Pub1432_web.pdf		International
IAEA	2011 Policies and Strategies for the Decommissioning of Nuclear and Radiological Facilities. IAEA www.pub.iaea.org/MTCD/Publications/PDF/Pub1525_web.pdf	Policy	International
CEA	2011 Passage Project overview www.iaea.org/OurWork/ST/NE/NEFW/documents/IDN/ANL%20Course/Day_8/Passage_2010_eng.pdf		France
Nuclear Industry Group	2012 Qualitative Risk Assessment for Land Contamination, including Radioactive Contamination. Version 1.1, June 2012. www.safegrounds.com/nig/q.htm	Risk assessment	UK
Environment Agency	2012 Performance standard for laboratories undertaking chemical testing of soil. The Environment Agency has established its Monitoring Certification Scheme: MCERTS to deliver high quality environmental measurements. The scheme provides for the product certification of instruments, the competency certification of personnel and the accreditation of laboratories based on international standards http://a0768b4a8a31e106d8b0500c802554eb38a24458b98f72d550b.r19.cf3.rackcdn.com/geho0312bwuu-e-e.pdf	Standards	UK
US EPA	2012 Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites www.epa.gov/superfund/policy/cic/guide/Final%20PIME%20Guidance%20December%202012.pdf	Institutional controls	
NDA	2013 NDA Research and Development Direct Research Portfolio Annual Report 2012/13 www.nda.gov.uk/documents/upload/Research-and-Development-Direct-Research-Portfolio-Annual-Report-2012-13.pdf	Emerging issues	UK
U.S. EPA.	1994 Guidance for the Data Quality Objectives Process. EPA QA/G4. Office of Research and Development. www.epa.gov/osw/hazard/correctiveaction/resources/guidance/qa/epaqg4.pdf		
U.S. EPA	1993 Data Quality Objectives for Superfund, Interim Final Guidance. EPA 504-R-93/071. Office of Emergency and Remedial Response. Washington, DC. NTIS PB94-963203.		
U.S. EPA	2005 Uniform Federal Policy for Implementing Environmental Quality Systems: Evaluating, Assessing, and Documenting Environmental Data Collection/Use and Technology Programs. EPA: EPA-505-F-03-001, DoD: DTIC ADA 395303, DOE: DOE/EH-0667, Version 2 Washington, DC. www.epa.gov/superfund/health/contaminants/radiation/radvideo.htm		

U.S. EPA.	2000 Soil Screening Guidance for Radionuclides: User's Guide. Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16A www.epa.gov/superfund/health/contaminants/radiation/pdfs/ssuserguide.pdf				
U.S. EPA.	2000 Soil Screening Guidance for Radionuclides: Technical Background Document. Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16 www.epa.gov/superfund/health/contaminants/radiation/pdfs/ssbdb.pdf				
US EPA	2006 Technology Reference Guide for Radiologically Contaminated Surfaces EPA-402-R-06-003 (2006) www.epa.gov/radiation/docs/cleanup/402-r-06-003.pdf				
US EPA	2011 Green Remediation Focus http://clu-in.org/greenremediation/				
Useful links					
ANL	RESRAD models http://web.ead.anl.gov/resrad/documents/	Model	USA	RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials. The only code designated by DOE in Order 5400.5 (Acrobat pdf format) for the evaluation of radioactively contaminated sites. NRC has approved the use of RESRAD for dose evaluation by licensees involved in decommissioning. NRC staff evaluation of waste disposal requests and dose evaluation of sites being reviewed by NRC staff.	
CLAIRE	Demonstration projects www.claire.co.uk/	Projects	UK	CL-AIRE encourages project partners to undertake technology demonstration and research projects ("CL-AIRE projects") to raise the contaminated land industry's awareness of, and confidence in, technologies that have been applied on real sites. CL-AIRE is also heavily involved with a number of other projects and industry-led initiatives (e.g. Waste Code of Practice, Generic Assessment Criteria, SURF-UK) and plays a significant role in the dissemination of useful, relevant and peer-reviewed information on issues affecting the brownfield and contaminated land sector.	
Environet	LinkedIn forum www.linkedin.com/groups?mostPopular=&gid=3256887	Forum	International		
Environment Agency	Contaminated land guidance www.environment-agency.gov.uk/research/planning/33710.aspx	Guidance	UK	Pages list guidance covering many aspects of the management of land affected by contamination. They are split up under headings that match the "Information Map" that is part III of CLR 11, the "Model Procedures for the Management of Land Contamination" All of the documents listed in CLR 11 are included.	
FIU (KM-IT)	Deactivation and decommissioning Knowledge Management site (KM-IT) www.dndkm.org/	Tools	USA	The D&D KM-IT is a web-based knowledge management information tool custom built for the D&D user community. This system was developed by the Applied Research Center (ARC) at Florida International University (FIU) in collaboration with the U.S. Department of Energy Office of Environmental Management (DOE EM), the Energy Facility Contractors Group (EFCOG), and the ALARA Centers at Hanford and Savannah River.	

IAEA	IAEA, International Decommissioning Network (IDN) www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/IDN/overview.html	During the fall of 2007, the IAEA launched a new "Network" to provide a continuing forum for the sharing of practical decommissioning experience in response to the needs expressed at the Athens Conference in Dec. 2006 on "Lessons Learned from the Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities". This network is intended to bring together existing decommissioning initiatives both inside and outside the IAEA to enhance cooperation and coordination.	Network	International
IAEA	Seven IAEA subject networks. http://nucleus.iaea.org/sites/CONNECT/Pages/default.aspx	At the present time there are seven Networks sponsored by the IAEA and managed from within the Department of Nuclear Energy, with the support of the Technical Cooperation program and funding from the European Commission, Underground Research Facilities for Geological Disposal, International Decommissioning Network, Nuclear Knowledge Management, Networking Nuclear Education, Management System Network of Excellence, ENVIRONET - Environmental Remediation and NORM Management Network, Near Surface Disposal of Low Level Radioactive Waste and Coordination Group for Uranium Legacy Sites.	Network	International
IAEA	Publications from the IAEA on remediation. www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/WTS/remediation-publications.html	Environmental remediation publications are organised below according to four major themes: Technology, Management, Databases; and Special Topics.	Resources	International
ITRC	Interstate Technology Regulatory Council (ITRC) Radiation Risk Assessment: Update and Tools. The Interstate Technology and Regulatory Council Radionuclides Team. www.itrcweb.org/Team	ITRC is a public-private coalition working to reduce barriers to the use of innovative environmental technologies that reduce compliance costs and maximize cleanup efficacy. ITRC produces documents and training that broaden and deepen technical knowledge and expedite quality regulatory decision making while protecting human health and the environment. ITRC achieves its mission through its technical teams, which are composed of environmental professionals, including state and federal environmental regulators, federal agency representatives, industry experts, community stakeholders, and academia. Since 1995, ITRC has published hundreds of documents and reached tens of thousands of participants through training courses on hundreds of topics. With private and public sector members from all 50 states and the District of Columbia, ITRC truly provides a national perspective.	Clearance Level Modeling	USA
NEA	Working Party on Decommissioning and Dismantling (WPDD) www.oecd-nea.org/nwm/wpdd/	The Working Party on Decommissioning and Dismantling (WPDD) of the RWMC provides a focus for the analysis of decommissioning policy, strategy and regulation, including the related issues of management of materials, release of buildings and sites from regulatory control and associated cost estimation and funding. Beyond policy and strategy considerations, the WPDD also reviews practical considerations for implementation such as techniques for characterisation of materials, for decontamination and for dismantling.	Network	International
NICOLE	Network for industry contaminated land in Europe. www.nicole.org/pagina/10P/publications.html		Network	EU
SAFEGROUNDS	A Forum and learning network covering contaminated land, waste and stakeholder issues relevant to the nuclear and defence sectors www.safegrounds.com/index.html	A Forum for developing and disseminating good practice guidance on the management of radioactively and chemically contaminated land on nuclear and defence sites in the UK	Forum	UK
SAFEGROUNDS	6 Case studies www.safegrounds.com/case_studies.htm		Case study	UK

SAFESPUR	Event networking www.safegrounds.com/about_safespurplus.htm	SAFESPUR+ is now an event-focused learning network operated by CIRIA with advice from industry and wider stakeholders.	Network	UK
US DOE	Case studies at Federal Remediation Technologies, US DOE Environmental Management. http://cosperformance.org/search.cfm		Case study	USA
US DOE	Department of Energy environmental management site http://energy.gov/em/office-environmental-management	The mission of the Office of Environmental Management (EM) is to complete the safe cleanup of the environmental legacy brought about from five decades of nuclear weapons development and government-sponsored nuclear energy research.	Clearance Level Modeling	USA
US EPA	US EPA contaminated land clean up information web resources. www.clu-in.org/	Probably the best site clean up resource on the planet. Providing information about innovative treatment and site characterisation technologies while acting as a forum for all waste remediation stakeholders	Resources	USA
US EPA	Preliminary Remediation Goals - interactive calculator http://epa-prgs.ornl.gov/radionuclides/	Risk-based PRGs calculated using default input parameters and the latest toxicity values. In addition, ability to modify the input parameters to create site-specific PRGs to meet site specific needs.	Clearance Level Modeling	USA
US EPA	Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) electronic calculator. http://epa-bprg.ornl.gov/	Superfund Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) download and calculation website. The recommended BPRGs on this website are preliminary remediation goals (PRGs) for contaminated buildings, as referenced in the NCP and EPA CERCLA guidance.	Model	USA
US EPA	Surface Preliminary Remediation Goals for Radionuclides (SPRG) http://epa-sprg.ornl.gov/	Superfund Preliminary Remediation Goals for Radionuclides in Outdoor Surfaces (SPRG) download and calculation website. The recommended SPRGs on this website are preliminary remediation goals (PRGs) for contaminated outdoor hard surfaces such as building slabs, outside building walls, sidewalks and roads.	Model	USA
US EPA	Radionuclide ARAR Dose Compliance Concentrations (DCCs) for Superfund electronic calculator. http://epa-dccs.ornl.gov/	Superfund radioactive dose compliance concentrations (DCC) download and calculation website for demonstrating compliance with dose-based Applicable or Relevant and Appropriate Requirements (ARARs). Here you will find DCCs calculated using the dose conversion factors from both International Commission on Radiological Protection (ICRP) 30 and ICRP 60. This website does not address the calculation of DCCs for ARARs based on ICRP 2 dose conversion factors (e.g., 40 CFR 141.66(d), 10 CFR 61.41).	Model	USA
US EPA	ARAR Dose Compliance Concentrations Goals for Radionuclides in Buildings (BDCC) electronic calculator. http://epa-bdccc.ornl.gov/	Dose Compliance Concentrations for Radionuclides in Buildings (BDCC) for Superfund - download and calculation website. The recommended BDCCs on this website are dose levels for contaminated buildings, to help implement the NCP and EPA CERCLA guidance.	Clearance Level Modeling	USA
US EPA	EPA Policies and Tools for enhancing Community Involvement at CERCLA sites. www.epa.gov/superfund/policy/remedy/sfremedy/comminvolve.htm		Stakeholder Involvement	USA
US EPA	Superfund Radiation Risk Assessment and How You Can Help: An Overview. www.epa.gov/superfund/health/contaminants/radiation/radvideo.htm		Stakeholder Involvement	USA
EPRI	Electric Power Research Institute www.epri.com/Pages/Default.aspx		Research Centre	International

Annex 3 – CPD Task Group on Nuclear Site Restoration (TGNSR) questionnaires

CONTENTS

National level questionnaire
Site and project questionnaire
Case study template

Introduction to the national level questionnaire

The Nuclear Energy Agency (NEA) Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking of a limited number of organisations from NEA member countries. The objective of the CPD is the exchange and sharing of information from operational experience in decommissioning nuclear installations that is useful for future projects. The information exchange includes biannual meetings of the Technical Advisory Group (TAG) and supporting projects on topics.

The TAG has decided to form a task group to review nuclear site¹ restoration starting in March 2012 that involves nuclear operators, experts and regulators. The group is supported by the International Atomic Energy Agency (IAEA) that is leading similar work on legacy sites.

Within NEA countries, nuclear sites are being restored for beneficial reuse. Restoration (see definition Page 9) is normally considered the last activity in a sequence of decommissioning steps but increasingly the value of long-term planning and parallel remediation are being recognised as important aspects in the process. It is essential that regulators know that liabilities are well understood (well characterised) and there is adequate financial provision to carry on the remediation work. Operators are also learning that early intervention is needed to ensure prevention and minimisation of leaks and spills of radioactive and non-radioactive contaminants in order to reduce groundwater and soil contamination, thus reducing overall liabilities and ensuring protection of the environment. Early intervention needs to be guided by good practices that include adequate site characterisation, reliable conceptual models and defined goals. Currently, most nuclear site restoration work takes place at legacy nuclear sites. This work has emphasised the need for better clarity in terms of the regulatory expectations for site restoration. At other nuclear sites, the drivers are less evident and there is a risk that land quality issues are overlooked.

The aim of the task Group is to gather information on experiences, approaches and techniques for site restoration and land quality management at nuclear sites and produce a report with conclusions and recommendations of use to current and future practitioners. The project will also highlight the successes and lessons learnt from experience of remediation that will be helpful to operational situations on nuclear sites.

We ask that you support the task group in our evidence gathering to support this project. We have developed a questionnaire to provide a snapshot of the current status of issues associated with site restoration at a national level in NEA countries. We ask that you provide assistance with our evidence by completing and returning this questionnaire.

1. The scope of the work is limited to NEA countries and licensed nuclear sites. The IAEA is covering wider legacy situations across a much larger number of countries.

National level questionnaire

Is there National policy or regulations on nuclear site remediation available in your country?

If yes, please summarise below and provide link to this information or append to the questionnaire

Are there National level **principles** that drive nuclear site restoration?

If yes, could you describe it (e.g. polluter pays, precautionary, sustainability, intergenerational equity, concentrate and contain, as low as reasonable achievable)?

Please state the goal of nuclear site remediation in your country: greenfield/all foreseeable uses (where practicable)/dose or environmental standard target/appropriate restricted end use/groundwater protection objectives and standards/optimised approach, taking account of stakeholder views or other?

What funding arrangements in place within your country for nuclear site remediation? Are there special arrangements for legacy nuclear sites?

Is there in place National regulations, strategy or plan that determines **participation** of government and private organisations and other stakeholders in the formulation of site restoration plans? If yes, please summarise below and provide link to this information or append to the questionnaire

What drives the timing and progress with site restoration in your country?

Driver	Relevance	Please indicate the relevance (H-high, M-medium, L-low)
National strategy or plan		
Regulation		
Stakeholder opinion		
Protection of workforce		
Hazard and risk reduction		
Environmental protection		
Minimising burden on future generations		
Interim state or care and maintenance phase		
Acceleration of site closure		
Financial – sale of land		

In general what has the greatest influence on timing of nuclear site restoration in your country (choose 1)?

- National strategy or plan
- Specification by regulators
- Local site decommissioning strategy and plan
- Re-use of the sites
- Agreement with local stakeholders
- Protection of the environment and worker safety
- Minimisation of remediation costs

What are the barriers or obstacles to remediation or site restoration?

Barriers	Relevancy	Please indicate the relevance (H-high, M-medium, L-low)
Regulation		
Stakeholder opinion		
Dose to the workforce		
Other site priorities e.g. operations		
Finances		
Logistics (e.g. access to the contamination)		
Lack of disposal routes		
Lack of available technology		
Not enough characterisation to make a decision		
Maturity of programmes or plans		
Skills and capability		
Uncertainties with conceptual models		
Fragile facilities		

What are the principal issues (barriers and constraints) and risks (threats and opportunities) with achieving remediation or site restoration?

Please indicate how the following statements apply to the situation in your country. In my country, the network for information exchange between owners, operators, regulators and stakeholders on nuclear site restoration

- is available and information exchange is good;
- is available, but with limited exchange of information;
- is not available because of lack of interest or opportunity;
- is not available, as the number of operators planning for site restoration is small;
- we only use international networks (please state which in comment field below):

Comment:

The approaches for characterisation of nuclear site restoration projects in my country can best be described as follows:

- The approaches of most operators are harmonised.
- A few operators have harmonised their approaches.
- All operators have developed/are developing approaches of their own.
- Don't know.

Comment:

Regulation of contaminated land and groundwater characterisation and management in my country is:

- Prescriptive and based on levels of contaminants
- Semi-prescriptive, based on given risk level and fixed definition of future land use
- Semi-flexible, based on risk range (with need to demonstrate best available techniques) and flexible definition of future land use
- Flexible with responsibility placed on operator to determine how to demonstrate safe management
- Ambiguous and in development

Comment:

Experience with site restoration (management of contaminated land and groundwater) on nuclear sites within your country is:

- extensive
- high
- moderate
- low

Comment:

The number of contractors available in my country that can perform characterisation and remediation of ground and groundwater contaminated with radioactivity is:

- high moderate low low but use resources from other countries

Comment:

The current capability and capacity of (radiochemical) laboratories available in my country to support characterisation and remediation of ground and groundwater contaminated with radioactivity is:

- high moderate low low, but will use resources from other countries

Comment:

The outlook on skills and capabilities generally with respect to remediation of land and groundwater contaminated with radioactivity in my country over the next few decades is:

- good moderate poor poor, but will use resources from other countries

Comment:

Which international/national/organisation guidance and/or websites are most useful in providing guidance on best practice with nuclear site remediation and restoration?

Please insert links and comments:

Is the guidance on best practice for nuclear site remediation and restoration in your country

- good moderate poor use international guidance

Are there identified gaps and plans for further work?

Comment:

What are the national requirements with respect to records management and retention (is there specific guidance?)

What is the estimated volumes/scale of contaminated land issues in your country?

- Low, less than 10 000 m³
- moderate, more than 10 000 less than 100 000 m³
- high, more than 100 000 less than 1 000 000 m³
- very high, more than 1 000 000 m³

Comments:

What is the estimated scale of contaminated groundwater issues in your country?

- Low, less than 10 000 m³
- moderate, more than 10 000 less than 100 000 m³
- high, more than 100 000 less than 1 000 000 m³
- very high, more than 1 000 000 m³

Comments:

Is there a national inventory or registration list that records the land and groundwater contaminated with radioactivity on nuclear sites in your country and does this register include non-nuclear sites?

If yes to the question above please state the level of accuracy required for the national inventory

Is there a national process of prioritisation to remediate these sites?

With respect to the major contaminants of concern in the ground and groundwater are there any R&D needs with respect to remediation or waste treatment?

Please provide any additional information or considerations on site restoration that you find relevant for the work of the CPD task group.

Definition of terms

The IAEA Safety Glossary defines remediation as “any measures that may be carried out to reduce the radiation exposure from existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans.” Radioactive contamination of facilities and the environment can arise, for example, from poor management of facilities and wastes, or nuclear and radiological accidents. Environmental remediation deals with reduction of public exposure to radiation and mitigation of the radiological environmental impact caused by the contamination of environmental media, such as agricultural lands and products, urban environments, forests, and freshwater or marine environments. Removal and immobilisation of radionuclides and modification of pathways of exposure are some of the means to achieve reduction of exposure.

Nuclear site restoration marks the end of decommissioning on a nuclear site (the end state). The end state will have been reached when a contaminated site has been restored by undertaking appropriate and timely remediation to achieve a state suitable for appropriate re-use of the site specified by national bodies, agreed with regulators and/or local stakeholders.

Introduction to the site and project questionnaire

The Nuclear Energy Agency (NEA) Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking of a limited number of organisations from NEA member countries. The objective of the CPD is the exchange and sharing of information from operational experience in decommissioning nuclear installations that is useful for future projects. The information exchange includes biannual meetings of the Technical Advisory Group (TAG) and supporting projects on topics.

The TAG has decided to form a task group to review nuclear site restoration starting in March 2012 that involves nuclear operators, experts and regulators. The group is supported by the International Atomic Energy Agency (IAEA) that is leading similar work on legacy sites.

The aim of the task group is to gather information on experiences, approaches and techniques for site restoration and land quality management at nuclear sites and produce a report with conclusions and recommendations of use to current and future practitioners. The project will also highlight the successes and lessons learnt from experience of remediation that will be helpful to operational situations on nuclear sites.

We ask that you support the task group in our evidence gathering to support this project. We have developed a questionnaire to provide a snapshot of the current status, issues and best practice with site restoration across NEA countries, sites and projects. We ask that you provide assistance with our evidence gathering across sites and projects by completing and returning this questionnaire.

Suitable projects for study include those from sites that have been restored, sites where early remediation has occurred and sites where early remediation is being considered. Projects of interest to the study are:

Strategy and methodology development	Characterisation
Cost estimation/budget	Information management
Socio-economic issues and public consultation	Interim management/restoration action
Safety and licensing	Planning

Questions on the facility/site

Please describe the nuclear facility/site. This section is about the site/facility in general, further sections will ask more detailed questions on projects or parts of the site that has been targeted for remediation.

1.1. Name of site/facility:

1.2. Country:

1. The scope of the work is limited to NEA countries and licensed nuclear sites. The IAEA is covering wider legacy situations across a much larger number of countries.

1.3. *Type of the facility:*

Legacy:

Yes No (If Legacy Site skip to 1.5 if appropriate)

Reactor:

PWR WWER BWR CANDU AGR MAGNOX RR Other

Fuel Cycle:

Enrichment Conversion U fuel fabrication MOX fuel fabrication

Waste treatment Reprocessing

Other type

1.4. *Power (MW_e/MW_{th})/Capacity (e.g. Mg/a):*

1.5. *Description of Site including purpose, approximate size of site/licensed area (m^2 or km^2):*

1.6. *Operation from – to:*

1.7. *Total years of operation (in the case that operation has not been continuous):*

1.8. *Significant events during operation (leakages, spills, fire, etc.):*

1.9. *Shutdown date or time since last operation:*

1.10. *Is there a web link (URL) to the facility?*

No Yes

http://

1.11. *Contact person at the facility for questions or clarifications:*

Name:

Department:

Phone:

E-Mail:

Development of remediation strategies and costs for the facility/site

This section is about the site/facility in general, further sections will ask more detailed questions on projects or parts of the site that has been targeted for remediation (in some cases this may be the entire site).

1.12. How many areas of your site are in the following stages of characterisation/clean-up

Stage of characterisation/restoration	No. of areas	Approximate size	Why are they at the stage? Please insert letter(s) relating to reason (see code below)*
Desk study in progress			
Desk study/fact finding complete			
Preliminary investigation complete			
Preliminary risk assessment complete			
Extensive investigation complete			
Comprehensive risk assessment complete			
Restoration plan in place			
Restoration in progress			
Restoration complete			
Contamination managed in-situ/interim solution in place			
Groundwater monitoring programme in place			

* a) Recent event b) Newly discovered c) Not a site priority d) Lack of funding e) Logistically impossible f) Lack of disposal route/remedial options g) Site priority h) Disposal route available i) Regulator requirement j) Protection of receptors

1.13. If your site has not been remediated, do you have a proposed end state for your site?

No Yes

If yes

What are the timescales for reaching the end state

The next 10 years 10 – 30 years 30 – 60 years more than 60 years

Will the end state have?

Buildings reused for non-nuclear purposes

Buildings demolished to ground level

Buildings and foundations removed

1.14. Please describe the total site restoration strategy chosen/envisaged:

1.15. What drives the need for remediation and having plans in place?

		Please indicate the relevance (H-high, M-medium, L-low)
Regulation		
Stakeholder opinion		
Protection of workforce		
Protection of the environment		
Acceleration of site closure		
Financial – sale of land		
Waste management		
Accurate decommissioning costs and schedules for provision of future funds		

Please comment if any other drivers not listed above:

1.16. What are the obstacles to remediation?

		Please indicate the relevance (H-high, M-medium, L-low)
Regulation		
Stakeholder opinion		
Radiation dose to workforce		
Other site priorities e.g. operations		
Finances		
Logistics (e.g. access to the contamination)		
Lack of disposal routes		
Lack of available technology		
Not enough information to make a decision		

Please comment if any other obstacles not listed above:

2. Information on contaminated land and groundwater at your site

This section is about the site/facility in general, further sections will ask more detailed questions on projects or parts of the site that has been targeted for remediation (in some cases this may be the entire site).

2.1. What is the estimated volumes/scale of contaminated land on your site?

less than 10 000 m³ more than 10 000 less than 100 000 m³ more than 100 000 less than 1 000 000 m³ more than 1 000 000 m³

2.2. What is the estimated scale of contaminated groundwater on your site?

No contaminated groundwater less than 10 000 m³ more than 10 000 less than 100 000 m³
 more than 100 000 less than 1 000 000 m³ more than 1 000 000 m³

2.3. What are the approximate number of areas of potential concern (separate remediation projects) on your site?

1 1 – 5 5-10 more than 10

2.4. What are the major radionuclides of concern in the ground?

2.5. What are the major radionuclides of concern in the groundwater?

2.6. What are the major non-radiological chemicals of potential concern in the ground?

2.7. What are the major non-radiological chemicals of concern in the groundwater?

2.8. Do you have contaminated land and/or groundwater outside your controlled area?

Yes No

2.9. Do you have any receptors (water bodies, groundwater, critical group of people) who are affected by the contamination, if so who or what?

2.10. *If you have any contaminated groundwater, please describe the nature of the plumes – are they spreading, shrinking or staying the same?*

2.11. *Do you analyse your samples for radiological contaminants using analytical laboratories that are:*

- Owned and managed by your site/facility
- Owned by your facility and managed by contractors
- Owned and managed by contractors
- Analysis undertaken by both facility and contractor owned labs

2.12. *Do you analyse your samples for chemical contaminants using analytical laboratories that are:*

- Owned and managed by your site/facility
- Owned by your facility and managed by contractors
- Owned and managed by contractors
- Analysis undertaken by both facility and contractor owned labs

Can you please comment/explain the reasons for your analytical contracting strategy

3. Information management

3.1. *What requirements are placed on you with respect to records management?*

3.2. *What guidance is available to you with respect to records management and is it adequate?*

3.3. *How do you manage data relating to site restoration (such as groundwater monitoring data and characterisation data)?*

- Spreadsheets off the shelf package Site-specific database

3.4. *Is the information (project reports, borehole logs, etc.) held:*

- Centrally within the site records management process
 Locally within the project team
 Both

3.5. *Is the information stored:*

- Electronically
 Paper records
 Both paper and electronic

3.6. *What issues/concerns do you have regarding records management?*

4. Planning for restoration/interim management of contaminated land and groundwater at your site

If no remediation plans are in place on your site, please skip this section. Please complete copies of this section for each area of contaminated ground/groundwater that are being considered as per question 3.3 where appropriate

Name (reference number) of the area of the site if applicable

4.1. *What are/were the management objectives with respect to remediating this area of contamination?*

4.2. *What are/were the remediation targets and how have they been set?*

4.3. *Do the targets relate to:*

- Radiological contamination
- Non-radiological (Chemical) contamination
- Both radiological and non-radiological contamination

4.4. *What decision-making processes have been used to determine the remediation approach to reach the remediation targets?*

4.5. *What was most important in determining the approach to remediation?*

		Please indicate the relevance (H-high, M-medium, L-low)
Regulation		
Stakeholder opinion		
Dose to workforce		
Logistics (e.g. access issues)		
Financial		
Effluent disposal routes		
Solid disposal routes		
Robustness of the technology		
Impact on other site operations/decommissioning projects		

4.6. *How much were stakeholders involved and did they significantly influence the agreed remediation approach?*

4.7. *What is the approximate estimated cost of the remediation?*

4.8. *What are the chief risks associated with the project?*

4.9. *Are there any precursor activities required which will delay restoration (e.g. demolition of buildings, provision of waste disposal facilities)?*

5. Technology implementation

If no remediation has taken place on your site, please skip this section. Please complete copies of this section for each area of contaminated ground/groundwater that is being considered as per question 4.3, if appropriate. Long-term groundwater monitoring is considered, for this purpose, a form of remediation technology.

Name (reference number) of the area of the site if applicable

5.1. *Is the technology been designed for:*

- Radiological contamination
- Non-radiological (Chemical) contamination
- Both radiological and non-radiological contamination

5.2. *For radiologically contaminated groundwater, what technology has been chosen:*

- Pump and treat In ground barrier Pump and re-inject Monitoring
- None Other

5.3. *For radiologically contaminated land, what technology has been chosen?*

- Dig and Dispose In-situ stabilisation Capping None
- Other

5.4. *For non-radiologically contaminated groundwater, what technology has been chosen:*

- Pump and treat In ground barrier Pump and re-inject Monitoring
 None Other

5.5. *For non-radiologically contaminated land, what technology has been chosen:*

- Dig and Dispose In-situ stabilisation Capping None Other

5.6. *What was the contractual mechanism for installation of the technology?*

5.7. *How is the solution being managed long-term?*

- Contractors In-house Both

6. Technology assessment

If no remediation has taken place on your site please skip this section. Please complete copies of this section for each area of contaminated ground/groundwater that are being considered as per question 4.3 if appropriate. Long-term groundwater monitoring is considered, for this purpose, a form of remediation technology.

Name (reference number) of the area of the site if applicable

6.1. *Did the project significantly exceed the estimated cost, if so why?*

6.2. *Did the project achieve its remediation objectives, if not, how did it fail and why?*

6.3. *Did the project achieve its management objectives, if not, how did it fail and why?*

6.4. *If the project failed to meet its management/remediation objective what were the mitigation action and have these allowed the objectives to be met?*

7. Long-term management/monitoring

If no remediation has taken place on your site, please skip this section. Please complete copies of this section for each area of contaminated ground/groundwater that are being considered as per question 4.3 if appropriate. Long-term groundwater monitoring, is considered, for this purpose, a form of remediation technology

Name (reference number) of the area of the site if applicable

7.1. *How long is it planned for groundwater monitoring to be needed post remediation*

- 0-10 years
- 10-30 years
- 30-60 years
- more than 60 years

7.2. *Will there be any restrictions in land-use (please tick all that are applicable)?*

- Remains a nuclear licensed site
- No access to all of the site
- No access to parts of the site
- Access but restrictions on land use, e.g. industrial use only
- Restriction on Groundwater use
- No Restrictions

7.3. *Who will undertake this monitoring?*

- Site owners
- Contractors
- Both

7.4. *What financial provisions are in place to pay for the monitoring and how will these be managed long-term?*

Introduction to the case study template

The case study template will guide presentation and allow easier interpretation of evidence by following a standard format to case studies. The project guidance document explains:

“Task group members will select sites/projects for case study from their own experience or from inside their parent organisation where it may be expected that they can access information at a detailed level. Since it is not practical for each TG member to carry out more than two or three case studies the number will be limited”

The guidance document also explains how we will use case studies:

“The more technical site and project level questionnaires and case studies will be analysed to determine current practice and the status of site restoration by examining information on plans for restoration (interim or end states), drivers for restoration, scale of challenge, infrastructure/resources, stakeholder involvement, technical approaches and information management. Some sites or projects (at various stages of development and delivery) will be considered in more depth (**case study reports**) to reflect current practice, issues, costs, techniques and approaches – selected case studies will be included in the report appendices.”

Case study template

1. Contact information

Name

Address

Phone

Email

2. Site background information

Site name

Site location

Site or project description

- Physical (size, land use, geology, groundwater/soil, contaminants, pathways, receptors: humans and biota, areas of special status: nature, conservation, etc.)
- Operational (site history, former use, types of hazardous substances or wastes that were used, stored or disposed at the site)

Regulatory status of the site or project

3. Clean-up agency/stakeholders

Organisations responsible for clean-up

Regulatory agencies with authority

Site-specific regulatory regime/requirements (as opposed to general national regime)

Local stakeholders

- level of involvement in remediation project
- support or opposition from stakeholders
- frequency of stakeholder meetings

Project drivers (valuable land re-use, programme risk mitigation, restoration planning, regulator or stakeholder concerns)

4. Characterisation

Objectives

Historical assessments

Sources

Risk assessments (degree to which they were used to determine project activities)

Models used (e.g. site conceptual models, dose or risk assessment models, etc.)

Quality assurance: design, standards, guidance, approach, data quality objectives

Results (include plots of contamination)

Statistical methods used to interpret data

5. Remedial objectives

Project success criteria (e.g. sale of land, groundwater protection, improved stakeholder confidence)

Remedial success criteria (e.g. clean-up of X acres of land to Y standards)

Remediation standards (e.g. clean-up criteria, end state criteria, end uses)

6. Options evaluation

Process used to evaluate remedial options

Remedial option selection criteria

Range of options considered

Stakeholder and/or regulator involvement in options evaluation process

Effectiveness of evaluation process

Final selected remedy

Reason the remedy was selected

- advantages
- limitations
- projected benefits of the chosen option

7. Remedy execution

Description of remediation activities/planned activities

- contaminants to be targeted
- technology descriptions
- time to completion
- identified obstacles/barriers

Contract mechanism

Performance metrics

8. Post remedial monitoring

Monitoring approach

Monitoring systems/technologies

Extent of monitoring (temporally and spatially)

9. Major cost elements

Characterisation

Planning

Execution

Post remedial monitoring

10. Lessons learnt

“What went wrong?” and “what went right?” with respect to meeting regulatory requirements, stakeholder participation, agreement on conceptual models, project management, resourcing and organisation, project cost and schedules, project objectives and methodologies, dealing with uncertainties?

How did the technologies used perform against technical success criteria?

How did the project perform as a whole against success criteria and requirements?

What were the barriers to successful characterisation? What were the barriers to a successful project?

What were common issues leading to schedule delays?

How was the project aligned (or not) with any R&D priorities?

What could have been done differently?

Additional comments

11. References

Annex 4 – Evaluation of questionnaires

Evaluation of the NEA Task Group on Nuclear Site Restoration (TGNSR) questionnaire draft

BS Project No. 1210-15

Prepared on behalf of the OECD/NEA

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Remark:

The views expressed in this report are those of the authors and do not necessarily reflect the views and policies of the OECD/NEA.

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It is asserted that this report has been prepared to best knowledge, impartially and without directive with respect to the result.

Inspection and release

scientific technical	clearance
(signature project manager)	(signature company management)

1. Introduction

A questionnaire on the restoration of radioactively contaminated sites has been sent out by the Task Group on Nuclear Site Restoration of the Nuclear Energy Agency (NEA) Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD). It was the aim of this questionnaire to gather and examine experiences in all aspects of site restoration, ranging from legal to technical and administrative aspects, and to gain an idea where additional work is still required.

Table A4.1 provides an overview of the countries from which national questionnaires have been received. Table A4. gives an overview of the sites from which site-specific questionnaires have been received.

Table A4.1: Overview of countries from which national questionnaires have been received with main statements

Country	Remark
United States	<p>Remediation of Nuclear Sites in the US regulated and managed by three primary agencies: The Nuclear Regulatory Commission (NRC), The Department of Energy (DOE) and the Environmental Protection Agency (EPA).</p> <p>The NRC regulates commercial reactors and other non-DOE facilities involved with radioactive materials such as medical isotopes. The DOE is responsible for oversight and remediation uranium mining and milling sites as well as legacy weapons production sites. The EPA oversees remediation of nuclear sites through the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and other national and State and local regulations.</p>
Canada	<p>Specific regulations and policies for environmental remediation on nuclear sites do not exist in Canada. These activities are covered under various overarching documents concerning nuclear activities generally, such as the Nuclear Safety and Control Act which establishes the regulatory framework for nuclear activities in Canada. Regulations made under the Act include Class I Nuclear Facilities Regulations (SOR/2000-204), General Nuclear Safety and Control Regulations (SOR/2000-202), Nuclear Substances and Radiation Devices Regulations (SOR/2000-207) and Radiation Protection Regulations (SOR/2000-203). In support of the regulations, the CNSC has established policies for nuclear activities that are applicable to environmental remediation at nuclear sites, such as P-290, Managing Radioactive Waste and P-223 Protection of the Environment.</p>
France (IRSN and EDF)	<p>The national safety authority, the ministry in charge of environment and the institute for radiological protection and nuclear safety published in 2011 a guideline for the remediation of area polluted by radioactive substances. These general guidelines may be implemented on legacy sites, sites polluted by NORM, as well as on nuclear installation. In addition, the national safety authority will published specific rules for the remediation of nuclear installations.</p> <p>In France, there is no regulation for either nuclear or non-nuclear site remediation. There is a national policy for non-nuclear site remediation with different guides. For nuclear site remediation, there was nothing until very recently (December 2011) with a guideline coming from the Ministry of Ecology, the French Nuclear Authority and its technical support (IRSN).</p>
Germany	<p>This questionnaire does not deal with WISMUT legacy sites or other such sites affected by uranium mining and milling. These are not counted as nuclear installations in Germany. Only nuclear installations like nuclear power plants, fuel cycle facilities and research reactors as well as research sites are included.</p> <p>In Germany, clearance of (larger) sites of nuclear installations has first been practiced in the early 1990s. Therefore, a considerable regulatory framework has been developed. Sites are “cleared” in Germany, i.e. the de-minimise principle is applied upon release. Site clearance is one of the clearance options laid down in the RPO (Radiation Protection Ordinance, Strahlenschutzverordnung) in Sect. 29 Para. 2 No. 1 Letter c. Generic clearance levels are available in App. III Table 1 Col. 7. – It is also possible to perform case-by-case decisions in this matter.</p> <p>On a technical level, clearance measurements of sites are governed by the standard DIN 25457-7 (together with DIN 25457-1) which describes measurements methods and evaluation methods, in particular statistical approaches.</p>
Italy	<p>The national policy is to return the sites to “green field”. No specific regulation or standard currently exist. The decommissioning process to achieve the goal of site restoration is based on a structured licensing process. In compliance with the Euratom directive on ionization radiation, in Italy the Legislative Decree 230/95 – article n.° 55 – defines the authorisation for the decommissioning.. The use of the sites has not been defined yet, since</p>

Country	Remark
	the achievement of this state will need at least ten years from now; stakeholder views will be collected and taken into account.
Netherlands	The policy and legislation on decommissioning require that the licensee shall restore green field conditions, unless there is a special permit from the regulatory body to leave specified and approved restrictions on the site, or to leave e.g. a building that will be reused.
South Korea	In the Atomic Energy Safety Act and its Enforcement Regulations, it is clearly defined that the operator of a nuclear facility, when intending to decommission a nuclear facility, shall submit a decommissioning plan and obtain decommissioning approval from the Nuclear Safety and Security Commission (NSSC). Currently, Korean Research Reactors (KRR-1, 2) and the Uranium Conversion Facility (UCF) are being decommissioned. Korea Institute of Nuclear Safety (KINS) is developing the Technical Standard for the Reuse of Site and Building of Nuclear Facility after the Decommissioning throughout the regulatory experience on the decommissioning of KRR-1, 2 and the UCF.
Spain	The National policy itself (General Radioactive Waste Plan, annex 1) promotes decommissioning when the nuclear facilities complete its lifetime providing a specific framework for its dismantling. In relation to remediation, the situation is not established so clearly. The basic framework for remediation of contaminated sites with lasting exposures is already established in the Regulation on Health Protection against Ionizing Radiations. (please see annex 2) Final remediation objectives are established on a case by case basis, according to the anticipated uses of the sites.
United Kingdom	Site remediation is covered under the Nuclear Installations Act 1965. Application of ALARP principle (as low as reasonably practicable) and risk reduction SFAIRP (so far as is reasonably practicable). Use of the HSE Safety Assessment Principles for Nuclear Facilities (SAPs) and EA Radioactive Substances Regulation Environmental Principles (REPs).

Table A4.2: Overview of facilities from which site-related questionnaires have been received

Country	Facility	Type	Capacity
Slovak Rep.	Bohunice A1	NPP, GCHWR	150 MWe
Slovak Rep.	Bohunice V1	NPP, WWER	2x 440 MWe
United States	West Valley Demonstration Project	legacy site, enrichment	n/a
United States	Fernald	legacy site, multiple	n/a
United States	Hanford	legacy site, multiple	n/a
Germany	AVR	NPP, GCR	15 MWe
France	AREVA	multiple	n/a
France	Monts d'Arrée	NPP	70 MWe
France	CEA Grenoble	3 RR, open pool	35/8/0.1 MW
France	Chinon A	3 NPP	70/200/500 MWe
France	SLA	2 NPP, GGR (nat. U)	480/515 MWe
United Kingdom	Dounreay	legacy site, FBR	248 MWe
United Kingdom	Hunterston A	NPP, MAGNOX	300 MWe
United Kingdom	various MAGNOX	NPP, MAGNOX	300-400 MWe
United Kingdom	various EDF	NPP, PWR and AGR	7 x (2 x ~500 MWe); 1200 MWe PWR
United Kingdom	Sellafield Site	multiple; e.g. mox fuel fabrication, reprocessing, waste treatment	n/a
Spain	CIEMAT	legacy site, multiple	n/a
South Korea	KAERI	Conversion	100 Mg/a UO ₂
Japan	JRTF	legacy site	n/a
Japan	Noritake Sugitsue	Enrichment, conversion	135 Mg U/a 200 Mg SWU/a
Japan	Hamaoka	NPP, 2x BWR	540/840 MWe
Japan	Tokai-1	NPP, MAGNOX	166 MWe
Japan	Fugen	NPP, APR	165 MWe; 557 MW _{th}

Country	Facility	Type	Capacity
Belgium	EUROCHEMIC	Reprocessing	60 Mg HM/a
Canada	Chalk River Lab.	Legacy site, PHW reactor, res. lab.	n/a
Canada	Chalk River Lab.	Research lab.	n/a
Sweden	Barseback NPP	NPP, BWR	2 x 615 MWe/1800 MWt
Italy	Trino NPP	legacy site, PWR	270 MWe

2. Procedure for evaluation of the questionnaires

The two types of questionnaires are evaluated separately. The answers in the filled-out questionnaire files have first been copied to two large tables in an Excel spreadsheet. This allows easier handling of the data.

After this step, the data are interpreted to detect common features, similarities in different answers or to assign a ranking to the answers. In descriptive answers, the main message of the answers is provided. This means that the overview tables in the Annexes have to be consulted for the full answers provided by each facility.

In the final step, conclusions are drawn from the results. This also includes comparison of answers from nuclear installations and of national answers to detect agreement or contradictions.

Multiple choice answers are presented in tables where the first column lists the options, the second column the number of answers for these options, and the third column the percentages. These percentages add up to 100% of the answers that were provided if only one option could be chosen (like yes/no). In cases where one or more options could be chosen, the percentage corresponds to the ratio between the number of marks for this option and the total number of questionnaires.

Answers to question providing a ranking (high/medium/low) were assigned the numbers 3, 2 and 1 and the average was calculated for each option. The final ranking was then derived from these numbers.

3. Evaluation of the national questionnaires

3.1. National policy and principles

Question: Is there a national policy or are there regulations on nuclear site remediation available in your country?

Answer	Number	Percentage
Yes	8	73%
No	3	27%

The majority of countries state that regulations or a national policy on nuclear site remediation are in place. Some countries provided further remarks which are summarised in the following table.

Country	Remark
United States	The most recent summary of national policy and regulations on nuclear site remediation can be found in US Nuclear Regulatory Commission document Nuclear Regulatory Legislation. 112 th Congress; 2 nd Session NUREG-9080 Vol. 1, No. 10. Remediation of nuclear sites in the US is regulated and managed by three primary agencies: The Nuclear Regulatory Commission (NRC), The Department of Energy (DOE) and the Environmental Protection Agency (EPA). The NRC regulates commercial reactors and other non-DOE facilities involved with radioactive materials such as medical isotopes. The DOE is responsible for oversight and remediation uranium mining and milling sites as well as legacy weapons production sites. The EPA oversees remediation of nuclear sites through the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and other national and state and local regulations.
Canada	Specific regulations and policies for environmental remediation on nuclear sites do not exist in Canada. These activities are covered under various overarching documents concerning nuclear activities generally, such as the Nuclear Safety and Control Act which establishes the regulatory framework for nuclear activities in Canada. Regulations made under the Act include Class I Nuclear Facilities Regulations (SOR/2000-204), General Nuclear Safety and Control Regulations (SOR/2000-202), Nuclear Substances and Radiation Devices Regulations (SOR/2000-207) and Radiation Protection Regulations (SOR/2000-203). These can be found at www.laws-lois.justice.gc.ca . In support of the regulations, the CNSC has established policies for nuclear activities that are applicable to environmental remediation at nuclear sites, such as P-290, Managing Radioactive Waste and P-223 Protection of the Environment. These can be found at www.nuclearsafety.gc.ca .
France (IRSN)	The national safety authority, the ministry in charge of environment and the institute for radiological protection and nuclear safety published in 2011 a guideline for the remediation of area polluted by radioactive substances. These general guidelines may be implemented on legacy sites, sites polluted by NORM, as well as on nuclear installation. In addition, the national safety authority will published specific rules for the remediation of nuclear installations.
Germany	<p>This questionnaire does not deal with WISMUT legacy sites or other such sites affected by uranium mining and milling. These are not counted as nuclear installations in Germany. Only nuclear installations like nuclear power plants, fuel cycle facilities and research reactors as well as research sites are included.</p> <p>In Germany, clearance of (larger) sites of nuclear installations has first been practiced in the early 1990s. Therefore, a considerable regulatory framework has been developed. Sites are “cleared” in Germany, i.e. the de-minimise principle is applied upon release. Site clearance is one of the clearance options laid down in the RPO (Radiation Protection Ordinance, Strahlenschutzverordnung) in Sect. 29 Para. 2 No. 1 Letter c. Generic clearance levels are available in App. III Table 1 Col. 7. – It is also possible to perform case-by-case decisions in this matter.</p> <p>On a technical level, clearance measurements of sites are governed by the standard DIN 25457-7 (together with DIN 25457-1) which describes measurements methods and evaluation methods, in particular statistical approaches.</p>
Italy	The national policy is to return the sites to “green field”. No specific regulation or standard currently exist.
Netherlands	The policy and legislation on decommissioning require that the licensee shall restore green field conditions, unless there is a special permit from the regulatory body to leave specified and approved restrictions on the site, or to leave e.g. a building that will be reused. There is no special policy or regulation on site restoration after an accident.
South Korea	In the Atomic Energy Safety Act and its Enforcement Regulations, it is clearly defined that the operator of a nuclear facility, when intending to decommission a nuclear facility, shall submit a decommissioning plan and obtain decommissioning approval from the Nuclear Safety and Security Commission (NSSC). National regulations or policy on Nuclear Site Remediation can also be considered with the regulations relevant to the decommissioning of the Nuclear Facility.
Spain	The National policy itself (General Radioactive Waste Plan, annex 1) promotes decommissioning when the nuclear facilities complete its lifetime providing a specific framework for its dismantling. In relation to remediation, the situation is not established so clearly. The basic framework for remediation of contaminated sites with lasting exposures is already established in the Regulation on Health Protection against Ionizing Radiations. (please see annex 2) Final remediation objectives are established on a case by case basis, according to the anticipated uses of the sites.
United Kingdom	There is no specific regulation but the Nuclear Installations Act 1965 covers site remediation.
France (EDF)	In France, there is no regulation for either nuclear or non-nuclear site remediation. There is a national policy for non-nuclear site remediation with different guides. For nuclear site remediation, there was nothing until very recently (December 2011) with a guideline coming from the Ministry of Ecology, the French Nuclear Authority and its technical support (IRSN).

Question: Are there national level principles that drive nuclear site restoration?

Answer	Number	Percentage
Yes	10	-
No	2	-

The answers to this question indicate that nuclear site restoration is based on national level principles. Only South Korea and Italy have provided a negative answer, with Italy also marking “yes” in brackets. There are some additional remarks provided by some countries which are summarised in the following table.

Country	Remark
United States	Commercial nuclear facilities are responsible for remediation caused by their operations. Remediation of uranium sites is site dependent and usually both the site owners/operators and the government pay the cost. The goal of remediation is risk reduction, restoration of groundwater, containment and long-term monitoring and as low as reasonably achievable.
Canada	Canada has National level Principles. In Canada, the polluter pays principle has been incorporated to varying degrees in environmental legislation since the early 1990s. Many Canadian jurisdictions have legislative provisions requiring persons causing releases into the environment to take steps to control and remediate those releases. A few provinces have specifically enunciated the polluter pays principle as an underlying principle of their environmental legislation. Implementation of the principle in Canadian legislation has been most evident in relation to remediation of land contamination and in the management of radioactive waste. Another principle in Canada is waste minimisation. The generation of radioactive waste is minimised to the extent practicable by the implementation of design measures, operating procedures and decommissioning/remediation practices.
France (IRSN)	There are principles at the national stage: operators are in charge of remediation under supervision by national authorities. The aim is to reduce the level of contamination as low as reasonable achievable. Nowadays, technical and financial constraints of dismantling and remediation are taken into account as soon as the design of a new installation. For legacy sites, a national fund was created in the 90s. Decisions relatives to technical and financial aspect of remediation are taken by a committee in charge of the management of this national fund (CNAR). Operation is conducted by the national agency for the radioactive waste management.
Germany	The overarching principle is triviality of the doses from site release, i.e. 10 µSv/a individual dose. The clearance levels for site clearance have been based on radiological models that are comparable to those from MARSSIM but have been tailored to the German situation. If an operator chooses to apply for a case-specific approach and thus case-specific clearance levels, they must be derived on similar principles, yet may take account of specific features of the site in question. Parts of the site that exceed those clearance levels need to be removed and treated separately (e.g. cleared for conventional landfill disposal). The size of the averaging area is 100 m ² for measurements.
Italy	All the mentioned principles are implicit in the national policy described above. However they are not explicitly included in the national legislation. The decommissioning process to achieve the goal of site restoration is based on a structured licensing process. In compliance with the Euratom directive on ionization radiation, in Italy the Legislative Decree 230/95 – article no. 55 – defines the authorisation for the decommissioning. In particular, the decommissioning of a nuclear installation shall be subject to authorisations (issued as a result of positive opinions from different national authorities) at the request of the licensee. This authorisation is granted for intermediate steps. The decree does not explicitly define the process for site restoration, which will be probably agreed by the interested parties at the time of nuclear license withdrawal.
Netherlands	The principle “the polluter pays” is generally used in the nuclear policy of the Netherlands; however the principle itself has not been formalised in the legislation. Based on this principle, on the basis of the Nuclear energy act the licensee for a nuclear reactor is required to secure appropriate funding for (planned) decommissioning. The way this is done shall be approved by the regulatory body.
South Korea	-
Spain	The polluter-pays principle is being the main driver in the financing of the liabilities associated to decommissioning and dismantling. In relation to remediation, the situation is not established so clearly. The competent authorities must, in these cases and depending on the risks that the exposures entails, perform the opportune actions on the characteristics of the situation.

Country	Remark
United Kingdom	Application of ALARP principle (as low as reasonably practicable) and risk reduction SFAIRP (so far as is reasonably practicable). Use of the HSE Safety Assessment Principles for Nuclear Facilities (SAPs) and EA Radioactive Substances Regulation Environmental Principles (REPs). Assessment of Best Available Technology (BAT) to optimise restoration strategies. Application of risk-based assessment to prioritise restoration i.e. reduction of intolerable risks. For non-radioactive contamination, risk-based approach is used to define clean-up targets. Those principles that are specifically mentioned in the Decommissioning Policy are ALARA, BAT (BPM/BPEO is stated which was the predecessor to BAT) and the progressive reduction of hazard (linked to reduction of intolerable risks). Over recent years national policy has recognised the importance of sustainable development and land use planning. The Governments commitment to sustainable development now permeates and is directly referenced in much national and local policy (e.g. National Planning Policy Framework). Although sustainability is not specifically mentioned in relation to nuclear site restoration, the principles (protection of the environment, social benefits and economic performance) are evident.
Belgium	The polluter-pays principle as generally used in the non-nuclear industry can also be applied in the nuclear industry. As restoration is considered as a final step in the lifetime of nuclear installations, it can be expected that also these fundings (together with fundings for decommissioning) will be issued from the government by means of a decommissioning plan.
France (EDF)	The general principles for non-nuclear site remediation has always been an “as low as reasonably achievable” principle taking into account the use of the site and fixing the remediation objectives with a risk-based approach. And in the late guideline for nuclear site remediation, the same principle is followed. However the French Nuclear Authority so far doesn't apply this principle and when dealing with our dossiers demands the complete removal of all the contamination: no ALARA approach.

Question: Please state the goal of nuclear site remediation in your country

The following answers provided by the countries have been condensed to their essential message. Additional information has already been provided in the answers to two previous questions.

Country	Remark
United States	Cost effective risk reduction and protection of soil and GW.
Canada	Case by case (depends on site use).
France (IRSN)	Removal of contamination. Effort depends on site use.
Germany	Clearance for unrestricted use.
Italy	“Green field”, site use not defined yet. 10 μ sv/y criteria.
Netherlands	Green field, reuse of land (scarce in NL) but special permits for restrictions on site use possible. 10 msv/y criteria.
Spain	Case by case (depends on site use).
United Kingdom	Reducing safety risk (10 μ sv/y criteria), reducing the number of sites and reuse of land.
Belgium	Final remediation objectives: case by case.
France (EDF)	Remove all the contamination; authority prefers the operator to remain the owner.

These answers show that the approach and the goal/objectives are defined on a site-specific basis in many countries and that various uses of sites are possible. Only Germany has provided an answer that indicates that reuse of sites is only possible without restrictions.

3.2. Funding

**Question: What funding arrangements are in place within your country for nuclear site remediation?
Are there special arrangements for legacy nuclear sites?**

The following answers provided by the countries have been condensed to their essential message.

Country	Remark
United States	Legacy sites: funding authorisations from congress. For commercial sites: polluter-pays principle.
Canada	Regulatory requirement defined in CNSC regulatory document G-219. Funding arrangements vary depending on the site. NPP: Decommissioning fee. Laboratories: by Government.
France (IRSN)	Legacy sites: national fund (CNAR). Sites polluted by ²²⁶ Ra: national authority.
Germany	Power utilities: polluter-pays principle, public ownership: state budget.
Italy	Funds provided by ENEL (transferred funds, component of the kWh price).
Netherlands	Polluter-pays principle, approved by regulatory body. After accident: legislation is based on Paris Convention. no specific requirements for legacy sites.
South Korea	No.
Spain	Case by case (National Agency, own budget).
United Kingdom	Private companies: own commercial activities, Commercial (AGR fleet, Sizewell PWR): Nuclear Liability Fund (set up from the sale of British Energy to EdF Energy), MOD sites: Government and commercial activities, decommissioning by NDA: Government and NDA's commercial activities.
Belgium	Funding by government (if Belgian Waste Agency approves the decommissioning plan).
France (EDF)	Decommissioning costs including site remediation have to be included within financial provision. legacy sites: site remediation by ANDRA, funding by government (EUR 4 M/year).

3.3. Site restoration plan

Question: Are there national regulations, strategy or plans in place that determine participation of government and private organisations and other stakeholders in the formulation of site restoration plans?

Country	Remark
United States	Yes (Federal Facility Agreements between DOE or NRC and the EPA and State and local entities, Site Advisory Boards, consultation with Native American Tribes).
Canada	Yes, various. Set by CNSC regulations (for stakeholders and Canadian Council of Ministers of the Environment concerning long-term waste management).
France (IRSN)	Remediation scenario to authority. For nuclear installations: commissions (operator, authority, stakeholders).
Germany	Competent authorities and independent experts review license application for site clearance. Public report on licensing and supervision procedure.
Italy	Stakeholders: participation in final decision for site restoration. Implementing transposition of EURATOM Directive 70/2011.
Netherlands	General administrative act requires and limits public participation.
South Korea	No.
Spain	Yes, by participation of interested parties in the licencing process, involving stakeholder in the D&R project, information and communication programmes for public.
United Kingdom	No legal framework but guidance by regulators; NDA has to undertake stakeholder engagement; licence companies have to refine strategies and plans in consultation with regulators and stakeholders.
Belgium	Licensee develops characterisation process, Belgian Waste Agency verifies and approves characterisation methodologies. Federal Agency for Nuclear Control (FANC) verifies and approves characterisation strategy. Stakeholders' opinion is very important.
France (EDF)	No direct participation of different stakeholders; indirect participation: dossier by operator (land and groundwater state and future site use) on which all stakeholders are consulted on.

**Question: What drives the timing and progress of site restoration in your country?
(first three ranks in bold)**

Answer	Marks (mean)	Rank
National strategy or plan	2.4	3
Regulation	2.5	1
Stakeholder opinion	2.1	5
Protection of Workforce	1.9	6
Hazard and risk reduction	2.4	4
Environmental Protection	2.5	1
Minimising burden on future generations	1.8	7
Interim state or care and maintenance phase	1.4	10
Acceleration of site closure	1.5	8
Financial – sale of land	1.5	8

The timing and progress of site restoration is mainly driven by regulations, the aim to protect the environment and national strategy or plan. Clearly, issues like reaching an interim state or care and maintenance phase or accelerating site closure are not driving issues.

Question: In general, what has had the greatest influence on timing of nuclear site restoration in your country? (multiple answers possible)

Answer	Number	Percentage
National strategy or plan	1	10%
Specification by regulators	2	20%
Local site decommissioning strategy and plan	4	40%
Re-use of the sites	0	0%
Agreement with local stakeholders	0	0%
Protection of the environment and worker safety	2	20%
Minimisation of remediation costs	1	10%

The answers to this question were very diverse. The specifications of the site decommissioning strategy and plan have been named in 40% of the cases as the item with the greatest influence on timing of nuclear site restoration. “Re-use of the sites” or “stakeholder issues” have not been marked.

**Question: What are the barriers or obstacles to remediation or site restoration?
(first three ranks in bold)**

Answer	Marks (mean)	Rank
Regulation	1.9	2
Stakeholder opinion	1.8	4
Dose to the workforce	1.2	12
Other site priorities (e.g. operations)	2.0	1
Finances	1.6	7
Logistics (e.g. access to the contamination)	1.7	5
Lack of disposal routes	1.8	3
Lack of available technology	1.6	7
Not enough characterisation to make a decision	1.7	5
Maturity of programmes or plans	1.4	10
Skills and capability	1.3	11
Uncertainties with conceptual models	1.4	9
Fragile facilities	1.0	13

The three most important barriers and obstacles to remediation or site restoration were site priorities (operation of other plants on the site), regulations and lack of disposal routes for the wastes generated during remediation, followed by stakeholder opinion (rank 4). Logistics and lack of characterisation were considerable issues as well (both rank 5).

Question: What are the principal issues (barriers and constraints) and risks (threats and opportunities) in achieving remediation or site restoration?

Country	Remark
United States	Getting regulatory and stakeholder concurrence on the long-term risk-based end state and what are reasonable expectations for remediation and long-term institutional controls and maintenance of disposal sites.
Canada	The principle barriers to achieving site remediation are the lack of disposal routes for the wastes that would be generated and the means to process/treat the waste to get them fit for the disposal facilities.
France (IRSN)	--
Germany	In general, there are few issues, as site clearance is always done unconditionally, i.e. without restrictions. Some issues arise when certain parts of the facility shall be left in place, e.g. the foundations below a few metres below grade, together with building rubble used for backfilling the cavity inside the foundations. This is usually treated in a case-specific evaluation. Principal issues are in general agreement on how to demonstrate compliance with clearance criteria to the authority and the independent experts.
Italy	Lack of clear legislation and licensing process. However the site release for major decommissioning sites will not occur before ten years from now. Lack of repository.
Netherlands	There is one legacy site in the Netherlands, where available financial resources play the most important role. Also the development of technical solutions (retrieval equipment and transport containers) is for this site an important challenge. For the other site, no challenges are foreseen, except perhaps for the availability of conditioning capacity for special wastes like asbestos-contaminated waste.
South Korea	--
Spain	Establishing site release levels (consistent with the foreseeable uses) which can be accepted by regulator and can be implemented.
United Kingdom	For civil nuclear legacy sites, there are a number of high-risk facilities (e.g. legacy ponds and silos at Sellafield). Resources are focused on decommissioning such facilities, which thereby limits the pace of other restoration activities. At some sites, site remediation is complicated by the existence of facilities (including operating facilities), for example because they restrict access to the subsurface.

Country	Remark
Belgium	Establishing site release levels which can be accepted by regulator and can be implemented.
France (EDF)	No clear regulation goals: no exemption values, no consensual dose limit related to nuclear site release. Furthermore there is a disagreement between the approaches for non-nuclear site remediation and nuclear site remediation. So it is a case by case negotiation and decisions vary from one operator to another. No sustainable approach.

3.4. Information exchange and implementation

Question: In my country, the network for information exchange between owners, operators, regulators and stakeholders on nuclear site restoration...

Answer	Number	Percentage
Is available and information exchange is good	6	60%
Is available, but with limited exchange of information	3	30%
Is not available because of lack of interest or opportunity	0	0%
Is not available, as the number of operators planning for site restoration is small	1	10%
we only use international networks	0	0%

The answers to this question indicate that the overall information exchange is regarded as good or adequate. Only Belgium indicates that information exchange does not take place, as the number of operators planning for site restoration is small.

3.5. Criteria

Question: The approaches for characterisation of nuclear site restoration projects in my country can best be described as follows:

Answer	Number	Percentage
The approaches of most operators are harmonised	4	36%
A few operators have harmonised their approaches	3	27%
All operators have developed/are developing approaches of their own	2	18%
Don't know	2	18%

Canada and Belgium indicate that the operators have developed/are developing approaches of their own. Italy and the Republic of Korea indicate that the status is not known.

Question: Regulation of contaminated land and groundwater characterisation and management in my country is:

Answer	Number	Percentage
Prescriptive and based on levels of contaminants	2	18%
Semi-prescriptive, based on given risk level and fixed definition of future land use	2	18%
Semi-flexible, based on risk range (with need to demonstrate best available techniques) and flexible definition of future land use	2	18%
Flexible with responsibility placed on operator to determine how to demonstrate safe management	4	36%
Ambiguous and in development	4	36%

Some countries added comments to this question as follows:

Country	Remark
United States	Initial evaluation of contamination is based on prescriptive levels and evaluation of risk. Final clean-up decisions incorporate risk and land use into the decisions.
Canada	Canadian regulations are not prescriptive like the US NRC regulations. The onus is on the practitioner to develop a plan and demonstrate that it is safe.
France (IRSN)	The operator has to demonstrate best available techniques but remediation should not be driven by the risk. The objective is to clean-up even when the risk is low.
Germany	Although numerical clearance levels in terms of Bq/g (related to a penetration depth of contamination) are available in the Radiation Protection Ordinance, most operators choose to perform case-by-case evaluations that take account of certain features of the site or the nature of contamination etc. This is usually considered advantageous and allows fixing conditions and limits for the implementation of site clearance better. It has turned out to be crucial to consider always possible contamination pathways to a certain site (How could contamination have occurred? Could spills and leakages be identified?, etc.). Often the operating history has to be consulted thoroughly to understand the contamination mechanisms. Categorisation of sites (no contamination possible/contamination cannot be excluded/contamination likely) without understanding the contamination mechanisms is meaningless.
France (EDF)	A semi-flexible approach applies to non-radioactively contaminated land and groundwater: limits or reference of quality exist for groundwater but not for soils for which it is a risk-based approach depending on the future land use. Ambiguous regulations refer to radioactively contaminated land and groundwater where the risk-based approach is not accepted yet.

3.6. Experience

Question: Experience with site restoration (management of contaminated land and groundwater) on nuclear sites within your country is...

Answer	Number	Percentage
Extensive	2	18%
High	2	18%
Moderate	3	27%
Low	5	45%

These answers show that experience with site restoration is very heterogeneous among countries. Extensive experience is claimed by United States and Germany, while low experience is stated by the Netherlands, Belgium, South Korea and French EDF.

Question: The number of contractors available in my country that can perform characterisation and remediation of ground and groundwater contaminated with radioactivity is...

Answer	Number	Percentage
High	3	30%
Moderate	3	30%
Low	2	20%
Low but use resources from other countries	2	20%

As in the previous question, the answers show a very heterogeneous situation. In general, the number of contractors is correlated with the experience with site restoration (previous question). The Netherlands and Belgium state that resources from neighbouring countries are used. Italy answered with: N/A.

Question: The current capability and capacity of (radiochemical) laboratories available in my country to support characterisation and remediation of ground and groundwater contaminated with radioactivity is...

Answer	Number	Percentage
High	5	50%
Moderate	2	20%
Low	2	20%
Low but use resources from other countries	1	10%

As in the previous question, the situation with laboratories is heterogeneous. There is a correlation with the experience with site restoration (next-to-last question).

Question: The outlook on skills and capabilities generally with respect to remediation of land and groundwater contaminated with radioactivity in my country over the next few decades is...

Answer	Number	Percentage
Good	2	18%
Moderate	7	64%
Poor	2	18%
Poor but will use resources from other countries	0	0%

While the majority of countries considers the evolution of skills and capabilities with respect to remediation as moderate and a few even as good, only Belgium and France (EDF) indicate a poor outlook.

Question: Guidance in best practice guide is... (multiple answers possible)

Answer	Number	Percentage
Good	2	22%
Moderate	3	33%
Poor	1	11%
Use international guidance	4	44%

The majority of countries considers availability of guidance as good or moderate. Only France (IRSN) indicates poor guidance, but at the same time states that international guidance is used.

3.7. Data management and record keeping

Question: What are the national requirements with respect to records management and retention? (Is there specific guidance?)

Country	Remark
United States	NRC, DOE and EPA: specific guidance and requirements for records management.
Canada	NSCA: General requirements for records management. Site license: additional requirements to follow CSA requirements (N294: specifies which records shall be kept and for how long).
Germany	Yes. Clearance decisions records: kept for 30 a in general, long-term waste management: kept during the entire waiting time. (KTA rule 1404)
Netherlands	Licensee is responsible for record management
Spain	RNRF: licensee is responsible for record management. Instruction IS-04: regulates transfer, filing and custody of documents. National Agency responsible for permanently maintaining an archive
United Kingdom	Industry guidance published by Safeground. NDA: developing a Knowledge Management hub
Belgium	Licensee is responsible for record management
France (EDF)	"Arrêté INB: Titre II chapitre V article 2.5.6"

With the exception of a few countries that did not provide answers, the issue of information management and record keeping with respect to site remediation is generally well covered.

3.8. Extent of contaminated land

Question: What are the estimated volumes/what is the scale of contaminated land issues in your country?

Answer	Number	Percentage	Countries
Low	3	38%	Netherlands, Belgium, South Korea
Moderate	2	25%	Germany, Spain
High	0	0%	–
Very high	3	38%	United States, Canada, United Kingdom

Question: What is the estimated scale of contaminated groundwater issues in your country?

Answer	Number	Percentage	Countries
Low	5	63%	Germany, Netherlands, Belgium, Spain, South Korea
Moderate	0	0%	–
High	1	13%	Canada
Very high	2	25%	United Kingdom, United States

Question: Is there a national process of prioritisation to remediate these sites?

Answer	Number	Percentage
Yes	3	70%
No	7	30%

Additional comments were given by the three countries providing positive answers:

- United States: by individual agencies;
- Canada: case-by-case basis;
- Italy: timing is defined by decommissioning programmes.

3.9. Requirements for R&D

Question: With respect to the major contaminants of concern in the ground and groundwater are there any research and development needs with respect to remediation or waste treatment?

Country	Remark
United States	Yes: I-129, Tritium, NA.
Canada	No need for new R&D, adapt existing knowledge and technologies.
Germany	Distinction between Cs-137 from Chernobyl fallout and from site operation; removal and immobilisation of radionuclides from soil.
Italy	R&D defined in the WPDD recent work, no additional specific need.
Spain	Volume reduction of contaminated soils.
United Kingdom	Long-term management of asbestos; characterising material without a reliable gamma fingerprint, remediating large volumes of lightly contaminated groundwater, characterisation of inaccessible areas.
Belgium	Volume reduction by intensive decontamination of contaminated soils.
France (EDF)	Sustainable remediation for RAD contamination.

These answers to possible requirements for R&D show the two issues of

- additional characterisation techniques for specific radionuclides;
- volume reduction of contaminated soils by decontamination.

4. Evaluation of the questionnaires for nuclear installations

4.1. Development of remediation strategies and costs for the facility/site

Question: If your site has not been remediated: Do you have a proposed end state for your site?

Answer	Number	Percentage
Yes	7	27%
No	19	73%

These answers indicate that an end state for the remediation has not been defined for most sites.

Question: What are the timescales for reaching the end state?

Answer	Number	Percentage
Next 10 years	6	29%
10 - 30 years	7	33%
30 - 60 years	0	0%
> 60 years	8	38%

This question was answered only by those who had provided a positive answer to the previous question, plus two additional questionnaires. The answers with the longest timespan originate from Bohunice A1 (Slovakia), Hanford (United States), two Canadian sites and the United Kingdom sites, excluding Dounreay. The long duration is driven by the decommissioning strategy defined for the nuclear installations on these sites.

Question: Will the end state have... (multiple answers possible)

Answer	Number	Percentage
Buildings reused for non-nuclear purposes	2	10%
Buildings demolished to ground level	12	57%
Buildings and foundations removed	9	43%

The answers indicate that in most cases, the end state will not contain any buildings. Hanford (United States) indicated demolishing of buildings to ground level and removal of foundations. Grenoble (F) indicated both possibilities of reuse of buildings as well as removal of other buildings including their foundations.

4.2. Information on contaminated land and groundwater at your site

Question: What is the estimated volume/scale of contaminated land on your site?

Answer	Number	Percentage
Less than 10 000 m ³	17	65%
More than 10 000 less than 100 000 m ³	4	15%
More than 100 000 less than 1 000 000 m ³	2	8%
More than 1 000 000 m ³	3	12%

These answers indicate that the average site for remediation is on the order of one or several hectares. The three very large sites are Sellafield (United Kingdom), Hanford and Fernald (both United States).

Question: What is the estimated scale of contaminated groundwater on your site?

Answer	Number	Percentage
No contaminated groundwater	12	48%
Less than 10 000 m ³	4	16%
More than 10 000 less than 100 000 m ³	2	8%
More than 100 000 less than 1 000 000 m ³	4	16%
More than 1 000 000 m ³	3	12%

The answers provided to the size of contaminated groundwater roughly correspond to the size of the site (previous question). Bohunice A1 (Slovakia) is an exception, as this site provided one of the three answers “more than 1 000 000 m³”.

Question: What is the approximate number of areas of potential concern (separate remediation projects) on your site?

Answer	Number	Percentage
1	9	39%
1 - 5	7	30%
5 - 10	2	9%
more than 10	5	22%

While for most sites, the number of separate remediation projects is small (either 1 or less than 5), the five sites Hanford (United States), Dounreay (United Kingdom), the two Chalk River sites (Canada) and Sellafield (United Kingdom) indicate that there are more than ten separate remediation projects. Clearly, the number of separate remediation projects is related to the size of the nuclear site in total.

Question: What are the major radionuclides of concern in the ground (X)? What are the major radionuclides of concern in the groundwater (x)?

Facility	H-3	C-14	Co-60	Sr-90	Tc-99	I-129	Cs-137	Ra226	U	TRU*
Bohunice A1	x						X			
Bohunice V1	x									
West Valley Dem.				X/x						
Fernald									X/x	
Hanford		X/x		X/x	X/x	X/x			X/x	
AVR				X/x						
AREVA									X/x	
Mont d'Arrée	x						X			
CEA Grenoble							X			
Chinon A1	x						X			
SLA	x						X			
Dounreay				X/x			X		X/x	X
Hunterston A				X/x			X			
United Kingdom sites without Sellafield	(x)			x			X			
Sellafield	x			X/x	x		X			
CIEMAT				X			X	X		
KAERI									X/x	
JRTF	-	-		-	-	-	-	-	-	-
Noritake									X	
Hamaoka	-	-		-	-	-	-	-	-	-
Tokai-1			X				X			
Fugen										
Eurochemic			X				X			X
Chalk River	x			X/x			X		X	
Barseback			X				X			
Trino	X		X	X			X			

*Here, TRU means Pu, Am-241

The most important radionuclides are Cs-137, which is mostly detected in the soil, followed by Sr-90 and U, which are also detected in the groundwater. H-3 plays a role mainly in the groundwater. C-14, Co-60, Tc-99, I-129, Ra-226 and TRU are mentioned only for one or two sites.

It can further be observed that elements which are very mobile, like C, Sr, Tc and I, are observed both in ground and groundwater, as can be expected, while the very mobile H-3 directly moves into the groundwater. Only in Trino (Italy) H-3 is observed exclusively in the ground. U is observed in both media, indicating that it is rather mobile in certain chemical environments.

Question: What are the major non-radiological chemicals of potential concern in the ground and in the groundwater?

Facility	Ground	Groundwater
Bohunice A1	-	P
Bohunice V1	oil, asbestos	none
West Valley Dem.	none	none
Fernald	U	none
Hanford	carbontetrachloride, chromium (Cr+6)	carbontetreachloride, chromium, nitrate, other chlorinated solvents, metals
AVR	none	none
AREVA	metals	chlorinated solvents
Mont d'Arrée	none	none
CEA Grenoble	-	-
Chinon A1	hydrocarbons	hydrocarbons
SLA	hydrocarbons	hydrocarbons, chlorinated solvents
Dounreay	Asbestos, hydrocarbons, Hg, 1,1,1-trichloroethane, Cd?	1,1,1-trichloroethane, Hg, Cd, hydrocarbons
Hunterston A	none	none
United Kingdom sites without Sellafield	asbestos	hydrocarbons
Sellafield	none	nitrates
CIEMAT	none	none
KAERI	none	none
JRTF	-	-
Noritake	fluorine	none
Hamaoka	none	none
Tokai-1	-	-
Fugen	none	none
Eurochemic	none	none
Chalk River	chlorinated solvents, PCBs, Hg, lead, copper, arsenic	chlorinated solvents, PCBs, Hg, lead, copper
Barseback	Petroleum hydrocarbons, zinc	none
Trino	Boron	Boron

This evaluation shows a large variety of non-radiological contaminants. Hydrocarbons, chlorinated solvents and asbestos are mentioned a number of times. The contamination in the ground and in the groundwater is closely related.

Question: Do you have contaminated land and/or groundwater outside your controlled area?

Answer	Number	Percentage
Yes	7	26%
No	20	74%

These answers indicate that in most cases, the contamination is obviously limited to the nuclear site.

Question: Do you have any receptors (water bodies, groundwater, critical group of people) that are affected by the contamination, and if so, who or what?

Answer	Number	Percentage
Yes	7	27%
No	19	73%

Only about a quarter of the answers indicated that environmental media have been affected by the contamination. These environmental media have been named as groundwater and rivers, from where in one case a salmon population (exposure to Cr⁶⁺) and in one case potential off-site groundwater users may be affected.

Question: If you have any contaminated groundwater, please describe the nature of the plumes (spreading, shrinking or staying the same).

Answer	Number	Percentage
Shrinking	5	42%
Staying the same	6	50%
Spreading	1	8%

These answers indicate that at 12 sites where there is groundwater contamination the extent of this contamination is known and traced. The extent of the contamination remains constant or is shrinking in more than 90% of the cases.

4.3. *Information management***Question: What guidance is available to you with respect to records management and is it adequate?**

The answers to this question range from “no guidance” or “not well focused” to detailed and adequate technical guidance flanked by legal requirements. No or insufficient guidance is indicated by France and partly by South Korea and Japan, while the other countries (if answers were provided) state availability of requirements by the national authorities as well as IAEA. These latter countries also state that this guidance is considered as adequate.

Question: How do you manage data relating to site restoration (such as groundwater monitoring data and characterisation data)? (multiple answers possible)

Answer	Number	Percentage
Spreadsheets	14	67%
Off-the-shelf package	2	10%
Site-specific database	15	71%

These answers show that individual software solutions prevail over commercial software. The answer “off-the-shelf package” is given by the Canadian sites, but only in connection with both other answers.

Question: Is the information (project reports, borehole logs, etc.) held...

Answer	Number	Percentage
Centrally within site records management process	5	19%
Locally within the project team	6	23%
Both	15	58%

Question: Is the information stored ...

Answer	Number	Percentage
Electronically	3	12%
Paper records	2	8%
Both paper and electronic	21	81%

The answers to the last two questions indicate that obviously most projects store the data both centrally within site records management process as well as locally to keep it available for the project team, and that various methods for record keeping are used. This indicates a high endeavour for long-term safety of the data.

4.4. Planning for restoration/interim storage management of contaminated land and groundwater

The following three questions are related to specific remediation areas. Therefore, the scope of the remediation project had to be clearly defined so that the following information on the remediation target, the relation to radiological and/or chemical hazards and the costs can be put into the correct perspective. Only those projects that provided answer to at least one question are listed in the following.

The following remediation targets and costs are not directly comparable. The projects range from those with a very limited scope with associated costs of about 1 million EUR to entire large sites with several billion USD.

Facility	Specification of the remediation project	Targets	Rad./chem. haz.	Estim. costs
Bohunice A1		Site clearance	r+c	n/a
Bohunice V1		Site clearance	r+c	23,129,670 EUR (Oct 2012)
West Valley Dem.		Meet drinking water standards off-site	r	n/a
Fernald	Fernald site	Achieve clean-up levels, drinking water standards for groundwater	r+c	4.4 Billion USD
Hanford	Overall Hanford Clean-up Plans		r+c	> 100 Billion USD

Facility	Specification of the remediation project	Targets	Rad./chem. haz.	Estim. costs
AREVA		Impact human and environmental by operator guidance	r	< 5 MEUR
Mont d'Arrée	Discharge Channel	Media-centred sensitivity → remove contamination	r+c	2.5 MEUR
CEA Grenoble	STED (INB 36 and 79) and Siloé (INB 20)	Keeping limiting values based on directives	r	n/a
Chinon A1	Auxiliary PP and Oil tanks	Reduce HC concentration in soils	c	n/a
SLA	2 sub-areas	Collect HC, monitoring solvents in GW and air	c	2 MEUR
Dounreay	general response for >100 facilities	Risk-based targets, specified in contract. Radiological: additional risk of <1e-06 by 2333; chemical: to no significant harm; groundwater: asap	r+c	1.5 billion GSP
Hunterston A	CP7 Compound	Decontaminate soils, passive condition system until Final Site Clearance. Legislation defines critical values for soils	r	5M GSP
EDF sites (United Kingdom)	None required	All sites will be restored as per decommissioning and site clearance plan	c	~ 65 million
CIEMAT	Area 1: "Lentil zone" and Area 2: "Montecillo area"	remove contaminated soil	r	1 MEUR 0.5 MEUR
KAERI	Korea Research Reactor	unrestricted use of site by reducing release criteria to 100 µSv/y	r	2.5 million USD
Eurochemic	Site 1	separate contaminated soil from the non-contaminated soil	r	n/a
Chalk River	Waste Management Areas of the Chalk River Laboratories site	short-term clean-up criteria: risk-based pathways analysis approach on a case by case basis	r+c	Caustic Cells 1and6 ~ 900 000 CAD
Chalk River	Outer Supervised Area of the Chalk River Laboratories site	risk-based pathways analysis approach	r+c	> 100M CAD over 70 a (incl. GW monitoring programme)

4.5. Technology implementation

The following questions on remediation technology are related to the specific remediation projects as specified in section 4.4. Therefore, they do not necessarily refer to the entire nuclear site.

Question: Has the technology been designed for...

Answer	Number	Percentage
Radiological contamination	5	33%
Non-radiological (chemical) contamination	3	20%
Both	7	47%

The answers are related to the question on whether the remediation goals are related to radiological, chemical or both types of hazard in section 4.4. This means that e.g. a mark for technology designed for dealing with both radiological and non-radiological (chemical) contamination corresponds to an answer referring to a site where both types of hazards are present.

Question: For radiologically and for non-radiologically contaminated groundwater, which technologies have been chosen? (multiple answers possible)

Answer	Radiological contamination		Non-radiological contamin.	
	Number	Percentage	Number	Percentage
Pump and treat	4	33%	3	27%
In-ground barrier	4	33%	1	9%
Pump and re-inject	1	8%	3	27%
Monitoring	4	33%	4	36%
Other	2	17%	2	18%

The answers to these two questions show that pumping and treating the groundwater is one of the preferred methods for dealing with both radiological and non-radiological contamination. Groundwater monitoring takes place in at least one third of the projects.

A few other techniques have been mentioned in the answers:

- pump and dispose for radiological contamination;
- bacteria addition;
- in-situ chemical transformation for non-radiological contamination.

In addition, a few remediation projects stated that no remediation technology is applied. This is mainly due to the fact that there is no contamination present in the groundwater.

Question: For radiologically and for non-radiologically contaminated land, which technologies have been chosen? (multiple answers possible)

Answer	Radiological contamination		Non-radiological contamin.	
	Number	Percentage	Number	Percentage
Dig and dispose	12	86%	8	67%
In-situ stabilisation	1	7%	1	8%
Capping	2	14%	1	8%
Other	3	21%	3	25%

The answers to these two questions show that digging up the soil and disposing the contaminated part is the preferred method for dealing with both radiological and non-radiological contamination.

A few other techniques have been mentioned in the answers:

- pumping for radiological contamination;
- in-situ treatment;
- pumping for non-radiological contamination.

In addition, a few remediation projects stated that no remediation technology is applied for non-radiological contamination.

4.6. Long-term management/monitoring

Question: How long is it planned for groundwater monitoring to be needed post remediation?

Answer	Number	Percentage
0-10 years	4	29%
10 - 30 years	5	36%
30 - 60 years	0	0%
> 60 years	5	36%

These answers show a large variety of the expected durations of groundwater monitoring. The sites with the longest expected durations are Hanford (United States), the United Kingdom sites including Sellafield, and the Chalk River Laboratories (Canada). The expected durations of groundwater monitoring indicate different remediation concepts, taking into account the nature and extent of groundwater contamination. The expected durations are, however, not related to any type of radionuclides present or to the size of the site under remediation (see section 4.2).

**Question: Will there be any restrictions in land-use (please tick all that are applicable)?
(multiple answers possible)**

Answer	Number	Percentage
Remains a nuclear licensed site	7	47%
No access to all of the site	1	7%
No access to parts of the site	2	13%
Access but restrictions on land use, e.g. industrial use only	8	53%
Restriction on groundwater use	5	33%
No restrictions	2	13%

These answers indicate several different points:

- The scope for the first option (remains a nuclear licensed site) is not specified. Clearly, it does not imply that the site will remain a nuclear licensed site forever. This option is the generic option for the United Kingdom sites (excluding Sellafield) and has been marked by West Valley Demonstration (United States), Chinon A (France), SLA (France), Dounreay (United Kingdom), and Chalk River Labs. Only the latter indicated that the first option will be pursued until about 2100 while the fourth option (access but restrictions on land use, e.g. industrial use only) will be implemented afterwards. The other sites mostly marked other options in parallel.
- The second option (general prohibition of access to all of the site) has been marked by the UK EDF Nuclear sites.
- The third option (no access to parts of the site) has only been marked for the generic United Kingdom sites in connection with the first option (see above) and by Sellafield.
- The fourth option clearly is the long-term strategy pursued by most sites, i.e. certain restrictions will be applied in the long-term management to avoid certain exposure pathways to happen (e.g. residential farmers or family homes with gardens).
- The fifth option (restriction on groundwater use) has been marked mainly in connection with the fourth option and is thus an extension of the long-term management strategy.
- The sixth option (no restrictions) is pursued only by Monts d'Arrée (France) and KAERI (South Korea). Obviously, the sites can be restored to a status requiring no restrictions with reasonable effort, so that this option is appropriate.

Question: Who will undertake this monitoring?

Answer	Number	Percentage
Site owners	5	36%
Contractors	4	29%
Both	5	36%

5. Annex 1: Overview table for the national questionnaires

	United States	Canada	France (IRSN)	Germany	Italy	Netherlands	South Korea	Spain	United Kingdom	Belgium	France (EDF)
Is there National policy or regulations on nuclear site remediation available in your country?											
No		X		X			X			X	
Yes	X		X		X	X		X	(X)		X
Are there National level principles that drive nuclear site restoration?											
No					X		X				
Yes	X	X	X	X	(X)	(X)		X	X	X	(X)
In my country, the network for information exchange between owners, operators, regulators and stakeholders on nuclear site restoration...											
Is available and information exchange is good;	X	X		X		X	n/a	X	X		
Is available, but with limited exchange of information;			X		X						X
Is not available because of lack of interest or opportunity;											
Is not available, as the number of operators planning for site restoration is small;										X	
We only use international networks											
The approaches for characterisation of nuclear site restoration projects in my country can best be described as follows:											
The approaches of most operators are harmonised.	X					X		X	X		
A few operators have harmonised their approaches.			X	X							X
All operators have developed/are developing approaches of their own.		X								X	
Don't know.					X		X				
Regulation of contaminated land and groundwater characterisation and management in my country is											

	United States	Canada	France (IRSN)	Germany	Italy	Netherlands	South Korea	Spain	United Kingdom	Belgium	France (EDF)
Prescriptive and based on levels of contaminants				X	X						
Semi-prescriptive, based on given risk level and fixed definition of future land use	X							X			
Semi-flexible, based on risk range and flexible definition of future land use			X								X
Flexible with responsibility placed on operator		X				X			X	X	
Ambiguous and in development						X	X			X	X
Experience with site restoration (management of contaminated land and groundwater) on nuclear sites within your country is...											
Extensive	X			X							
High			X						X		
Moderate		X			X			X			
Low					X	X	X			X	X
The number of contractors available in my country that can perform characterisation and remediation of ground and groundwater contaminated with radioactivity is											
High	X			X	n/a				X		
Moderate		X	X					X			
Low							X				X
Low but use resources from other countries						X				X	
The current capability and capacity of (radiochemical) laboratories available in my country to support characterisation and remediation of ground											
High	X	X		X	X		n/a	X			
Moderate			X							X	
Low									X		X
Low but use resources from other countries						X					
The outlook on skills and capabilities generally with respect to remediation of land and groundwater contaminated with radioactivity in my country											
Good			X	X							
Moderate	X	X			X	X	X	X	X		
Poor										X	X
Poor but will use resources from other countries											
Guidance in best practice guide is											
Good	X		n/a	X			n/a				
Moderate		X				X			X		
Poor											X
Use international guidance					X			X		X	X
What are the estimated volumes/scale of contaminated land issues in your Country?											
Low			n/a		n/a	X	X			X	n/a
Moderate				X				X			
High											
Very high	X	X							X		

What is the estimated scale of contaminated groundwater issues in your Country?											
Low			n/a	X	n/a	X	X	X		X	n/a
Moderate											
High		X									
Very high	X								X		
Is there a National process of prioritisation to remediate these sites?											
No			X	X		X	n/a	X	X	X	X
Yes	X	X			X						

Country	Comment
Please state the goal of nuclear site remediation in your country:	
United States	The goal of remediation is risk reduction, restoration of groundwater to highest beneficial use where practicable, containment and long-term monitoring and as low as reasonably achievable. In general Federal and State clean-up goals for soil and groundwater are and objective and if not practicable then institutional controls and other measures are required.
Canada	The goal of nuclear site remediation is determined on a case by case basis. For the Port Hope area, the clean-up goals were developed based on an acceptable risk to residential (unrestricted) users of the land. At Chalk River Laboratories, the clean-up goals were based on potential restricted industrial uses. The degree of stakeholder involvement in developing those goals has also varied from case to case. Stakeholder involvement was extensive for developing Port Hope area clean-up goals while stakeholder involvement has been limited to date in the development of the Chalk River Labs (CRL) clean-up goals as it remains an operational site. The public will be involved as the CRL long-term strategy is developed and clean-up progresses.
France (IRSN)	According to the national guidelines published in 2011, the remediation approach depends if a use is already established on the site or not. In both cases, the removal of contamination is the main objective but the effort will be less important when uses are established because of constraints relative to these uses. A cost benefit approach is applied on sites where use is not established. Criteria considered are: technical possibilities, waste storage available, reduction of contamination transfer, dose for workers and for the population, cost
Germany	The goal is usually clearance for unrestricted use. It is a policy laid down by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in a letter to the ministries of the Federal States to accept only unconditional clearance of sites and to make sure that any radiological models used as a basis for this would take into account all relevant exposure pathways, i.e. not limit them by taking into account current features of the site surrounding, e.g. being a nature reserve etc.
Italy	Stated that the end state is "green field", the use of the sites have not been defined yet, since the achievement of this state will need at least ten years from now; stakeholder views will be collected and taken into account of course. Any decision for the NPP's sites shall be agreed with the Government (Sogin is owner). For the Nuclear research sites, these are still owned by ENEA and the final decision on reuse will be up to this organisation. The dose standard to be complied with is 10 microSv/y.
Netherlands	The policy and legislation on decommissioning require that the licensee shall restore green field conditions, unless there is a special permit from the regulatory body to leave specified and approved restrictions on the site, or to leave e.g. a building that will be reused. The release of the site is based on the 10 mSv per year criterium. Besides environmental and workers protection, and protection of soil and groundwater, the goal of the remediation also is to allow for reuse of land, which is scarce in the Netherlands. There is no special policy or regulation on site restoration after an accident.
South Korea	N.a.
Spain	The basic framework for remediation of contaminated sites lasting exposures is already established in the Regulation on Health Protection against Ionizing Radiations. Final remediation objectives are established on a case by case basis, according with the anticipated uses of the sites.
United Kingdom	The overarching "goal" as defined within the decommissioning policy and NDA strategy is to "remove the hazard the facility poses progressively, giving due regard to security considerations, the safety of workers and the general public and protecting the environment, while in the longer term reducing the number of sites and acreage of land which remain under regulatory control" (The Decommissioning of the UK Nuclear Industry's Facility, paragraph 3). Within the Energy Act the "goal" is to clean-up our nuclear legacy sites so that they are "suitable to be used for other purposes" (s37). HSE (ONR) interpretation of the NIA '65 "no danger" requires that there must be no danger from ionising radiations "regardless of any foreseeable uses of the site". Annex 1 of the Basic Safety Standards Directive (Euratom 96/29) allows exemption of activities where "doses to members of the public are of the order of 10 microSieverts or less per year". HSE considered this dose limit broadly equates to the 1 in a million per year "no danger" criterion. However, the HSE also expects consideration of the Health and Safety at Work Act which requires operators to ensure health and safety risks are, reduced "As Low As Reasonably Practicable" (ALARP). National policy and regulation expects optimisation of decommissioning activities balancing environmental, social and economic factors.

Country	Comment
Belgium	Before a site can be released from regulatory control, the licensee shall (write a specific safety report and) perform a final survey to demonstrate that the end state, as approved by the regulatory body, has been met. The licensee shall not be relieved of responsibility for the site unless the regulatory body has agreed. In case of restricted use the licensee shall provide a long-term impact assessment an appropriate surveillance regime and any proposed land use restrictions. The basic framework for remediation of contaminated sites is established in the Regulation on Health Protection against Ionizing Radiations (called "ARBIS", with release criteria/nuclide and effective individual dose <math>< 10 \mu\text{Sv/y}</math>). Final remediation objectives are expected to be achieved on a case-by-case basis. Since most nuclear facilities in Belgium deal with a very specific type of operation, harmonisation of characterisation strategies is very difficult.
France (EDF)	Ambiguous: to date the goal is to remove all the contamination, but the Authority does not speak about greenfield and prefers that the operator remains the owner.
What funding arrangements in place within your country for nuclear site remediation? Are there special arrangements for legacy nuclear sites?	
United States	For legacy sites the Department of Energy is provided funding authorisations from congress to carry out the site remediation. For commercial sites, the operators set up a fund to address potential site remediation issues. Commercial Reactors also pay into a fund for long-term disposal of spent nuclear fuel.
Canada	The requirement for dedicated decommissioning/remediation funding is a regulatory requirement and is defined in the CNSC regulatory document G-219 <i>Decommissioning Planning for Licensed Activities</i> . Funding arrangements vary depending on the site. Nuclear power stations collect a decommissioning fee as part of the rate charged to customers. An equivalent mechanism exists through the Government of Canada for Chalk River and Whiteshell Laboratories. Those liabilities are recorded as a future expense in the Public Accounts of Canada. The Government of Canada has also accepted responsibility for those wastes that were managed in a manner no longer considered acceptable, but for which the original producer cannot reasonably be held responsible or no longer exists.
France (ISDF)	There is a national fund for remediation of legacy sites (CNAR). In addition a national operation on sites polluted by 226Ra is dealt by the national authority with the technical support of IRSN for few years.
Germany	Funding is generally covered by the provisions that the private power utilities (for nuclear power plants and installations of the nuclear fuel cycle) have accrued during the operational phase and by the state budget for nuclear sites being in public ownership (research reactors, research establishments).
Italy	In Italy the economic resources needed for decommissioning activities are provided by ENEL transferred funds and a component of the kWh price, that will cover all the costs until the completion of site restoration activities and waste disposal by the law.
Netherlands	Based on the principle "the polluter pays", the licensee for a nuclear reactor is required to secure appropriate funding for (planned) decommissioning. The way this is done shall be approved by the regulatory body. For remediation of a site after an accident, the legislation in the Netherlands is based on the obligations posed by the Paris Convention. There are no specific requirements on funding arrangements for (remediation of) legacy sites, other than the general obligation that radioactive waste shall be removed from the site as reasonably possible. Removal of radioactive waste means in practice transferral to the national radioactive waste management organisation COVRA.
South Korea	No.
Spain	Complex plan; see: <i>Sixth General Radioactive Waste Plan</i> – Spanish Ministry for Industry, Tourism and Trade, 2006.
United Kingdom	Private companies (e.g. GE Healthcare) are responsible for funding decommissioning through their own commercial activities. For AGR fleet and Sizewell PWR, funding is held in the Nuclear Liability Fund. This was set up from the sale of British Energy to EdF Energy. Funding for the MOD sites is through the United Kingdom Government and via commercial activities. With regard to legacy nuclear sites, the Energy Act 2004 created the Nuclear Decommissioning Authority (NDA) which is a non-departmental public body. The NDA is responsible for the decommissioning and clean-up of the United Kingdom civil nuclear legacy sites (e.g. Magnox reactor sites, research sites and Sellafield). The NDA work is fund by United Kingdom Government and via the NDA's commercial activities (e.g. energy generation, reprocessing and sale of assets).
Belgium	The licensee asks the government appropriate funding for decommissioning by means of a decommissioning plan. In order to be able to dispose of these fundings, the Belgian Waste Agency has to approve the decommissioning plan.
France (EDF)	For each nuclear operator the decommissioning costs including those regarding site remediation have to be included within their financial provision. For legacy sites which happen to be orphan sites, the site remediation is given to ANDRA (National Agency in charge of Nuclear Waste), which gets an annual budget from the government for this purpose (4 M EUR/year).
What are the National requirements with respect to records management and retention (is there specific guidance?)	
United States	The NRC, DOE and EPA have specific guidance and requirements for records management.

Country	Comment
Canada	General requirements for records management are provided in the Nuclear Safety and Control Act. Any licensed activity in Canada must adhere to the requirements in the Act. Furthermore, additional requirements to follow Canadian Standard Association (CSA) requirements, such as those in N294, can be specified in the site license. N294 specifies which records shall be kept and for how long.
France (ISDF)	N.a.
Germany	Records that relate to clearance decisions (i.e. paper or electronic documentation) have to be kept for 30 a in general, if the license will not require a different approach. Such a case may be long-term keeping of a site prior to its release, where any records on radiological characterisation need of course to be kept during the entire waiting time. The license may require samples to be kept as well, but this is usually limited to shorter periods of a few years.
Italy	Not available.
Netherlands	A licensee for a nuclear facility is required to make provisions to store records and information relevant for decommissioning.
South Korea	N.a.
Spain	The obligation of the licensees of nuclear facilities to adequately compile and conserve information of relevance for future D&R during the operational phase is contained in the RNRF (Regulation on Nuclear and Radioactive Facilities). This Regulation requires all authorised nuclear licensees to possess a document specifically setting out the forecast for its D&R (art. 20 j, RNRF). In addition, on February 5th 2003, the CSN issued Instruction IS-04, regulating the transfer, filing and custody of documents corresponding to the radiological protection of the workers, the public and the environment prior to the transfer of trusteeship of the site to Enresa. In accordance with RD 1349/2003, on the ordering of Enresa's activities, this national agency shall be responsible for permanently maintaining an archive with relevant information for these purposes.
United Kingdom	There is industry guidance published by Safeground (Good practice guidance for land quality records management, August 2007). The NDA is currently development a Knowledge Management hub. The pilot project will run for a year and include several community areas including on for Land Quality Management. If the programme is extended it is intended that it will cover both tacit and explicit forms of information.
Belgium	The licensee shall ensure that relevant records and the final decommissioning report are available and accessible at the end of decommissioning according to the national regulatory system.
France (EDF)	Arrêté INB: Titre II chapitre V article 2.5.6.
With respect to the major contaminants of concern in the ground and groundwater are there any research and development needs with respect to remediation or waste treatment?	
United States	Treatment of Iodine 129 and Tritium and natural attenuation mechanisms are under R&D.
Canada	There is no need for Research and Development work to develop new remediation technologies. Some effort may be required to adapt existing knowledge and technologies to site-specific scenarios, or to ensure applications are efficient for large-scale scenarios.
France (ISDF)	N.a.
Germany	The most obvious R&D need concerns identification of Cs-137 from Chernobyl fallout, as it is possible (and often necessary) to subtract the percentage of Cs-137 that does not originate from plant operation. A general procedure on this subject would be desirable, which should also include sludges in water ducts etc. R&D needs could further be seen in techniques for removal and immobilisation of radionuclides from soil. Techniques in both directions are being pursued, like enhancing removal capabilities of plants growing in contaminated soil or significantly reducing the migration velocity of nuclides so that they decay before reaching the groundwater table.
Italy	R&D needs have been defined in the WPDD recent work. No additional specific need has been determined in Italy.
Netherlands	No.
South Korea	N.a.
Spain	Volume reduction of contaminated soils.

Country	Comment
United Kingdom	Research and development (R&D) is generally defined by the site license companies as majority of problems are site-specific (information should be provided by the SLCs). The NDA sponsors R&D on generic issues that will have estate-wide benefits. R&D needs and opportunities are identified through the Nuclear Waste Research Forum (NWRF) working groups. Potential R&D needs currently identified include: the long-term management of asbestos; characterising material without a reliable gamma fingerprint, remediating large volumes of lightly contaminated groundwater, and the characterisation of inaccessible areas.
Belgium	Intensive decontamination of contaminated soils to minimise the volume of contaminated soil that has to be processed (supercompaction/cementation).
France (EDF)	Great need to work on sustainable remediation for RAD contamination.

6. Annex 2: Overview table for the questionnaires for each nuclear installation

1/2

	Bohunice A1	Bohunice V1	West Valley	Fernald	Hanford	AVR	AREVA	Monts d'Arrée	CEA Grenoble	Chinon A	SLA	Dounreay	Hunterston A	Generic MAGNOX
If your site has not been remediated do you have a proposed end-state for your site?														
No			X											
Yes	X	X		X	X	X		X	X	X	X	X	X	X
If yes, what are the timescales for reaching the end state?														
Next 10 years			X			X		X	X					
10 – 30 years		X		X						X	X	X		
30 – 60 years														
> 60 years	X				X								X	X
Will the end state have...														
Buildings reused for non-nuclear purpose									X					
Buildings demolished to ground level	X				X			X			X	X	X	X
Buildings and foundations removed		X	X	X	X	X			X					
What are the estimated volumes/scale of contaminated land on your site?														
Less than 10 000 m ³						X		X	X	X	X		X	X
More than 10 000 less than 100 000 m ³	X		X				X					X		
More than 100 000 less than 1 000 000 m ³														
More than 1 000 000 m ³				X	X									
What is the estimated scale of contaminated groundwater on your site?														
No contaminated groundwater								X	X					
Less than 10 000 m ³						X				X	X		X	
More than 10 000 less than 100 000 m ³				X			X							
More than 100 000 less than 1 000 000 m ³			X									X		
More than 1 000 000 m ³	X				X									
What are the approximate numbers of area of potential concern (separate remediation projects) on your site?														
1	X		X			X							X	
1-5				X				X						
5-10										X	X			
More than 10					X							X		
Do you have contaminated land and/or groundwater outside your controlled area?														
Yes												X	X	

	Bohunice A1	Bohunice V1	West Valley	Fernald	Hanford	AVR	AREVA	Monts d'Arrée	CEA Grenoble	Chinon A	SLA	Dounreay	Hunterston A	Generic MAGNOX
No	X	X	X	X	X	X	X	X	X	X	X			
Do you have any receptors (water bodies, groundwater, critical group of people) who are affected by the contamination, if so who or what?														
No	X	X				X	X	X	X				X	X
Yes			X ¹⁾	X ²⁾	X ³⁾					X ⁴⁾	X ⁴⁾	X ⁴⁾		
1) Off site groundwater users; 2) river; 3) river →salmon; 4) groundwater														
If you have any contaminated groundwater, please describe the nature of the plumes (spreading (3), shrinking (1), staying the same (2))														
	2	2		1	2	2	2				2	1	1	
How do you manage data relating to site restoration (such as groundwater monitoring data and characterisation data)														
Spreadsheets						X	X	X	X	X	X		X	X
Off the shelf package														
Site-specific data	X	X	X	X	X							X		
Is the information (project reports borehole logs, etc.) held:														
Centrally within site records management process					X								X	X
Locally within the project team							X							
Both	X	X	X	X		X		X	X	X	X	X		
Is the information stored														
Electronically								X					X	X
Paper records														
Both paper and electronically	X	X	X	X	X	X	X		X	X	X	X		
Technology Implementation (area specific, see line below)														
Name (reference number) of the area of the site if applicable														
				Fernald	All area			Discharge channel	STED (INB 36 and 79); Siloé (INB 20)	Auxiliary PP and Oil tanks	2 sub areas	Whole site	CP7 compound	c.f. CP7 compound
Is the technology designed for...														
Radiological contamination			X						X				X	
Non-radiological (chemical) contamination										X	X			
Both	X			X	X			X				X		
For radiologically contaminated groundwater, what technology has been chosen?														
Pump and treat	X			X	X									

	Bohunice A1	Bohunice V1	West Valley	Fernald	Hanford	AVR	AREVA	Monts d'Arrée	CEA Grenoble	Chinon A	SLA	Dounreay	Hunterston A	Generic MAGNOX
In ground barrier			X		X								X	
Pump and re-inject														
Monitoring	X				X									
None							X		X					
Other												X ¹⁾	X	
¹⁾ Pump and dispose														
For radiologically contaminated land, what technology has been chosen?														
Dig and Dispose	X		X	X	X			X	X			X		
In-situ stabilisation					X									
Capping			X		X									
None														
Other							X ¹⁾							
¹⁾ Restriction														
For non-radiologically contaminated groundwater, what technology has been chosen?														
Pump and treat	X				X						X			
In ground barrier					X									
Pump and re-inject				X						X	X			
Monitoring	X				X					X	X			
None							X		X					
Other										X ¹⁾		X ²⁾		
¹⁾ Bacteria addition; ²⁾ in-situ chemical transformation														
For non-radiologically contaminated land, what technology has been chosen?														
Dig and Dispose				X	X			X	X			X		
In-situ stabilisation														
Capping					X									
None					X									
Other										X ¹⁾	X ¹⁾			
¹⁾ In-situ treatment														
Long-term management/monitoring (not area specific)														
How long is it planned for groundwater monitoring to be needed post remediation														
0-10 years			X					X				X		
10-30 years				X			X			X	X			
30-60 years														

	Bohunice A1	Bohunice V1	West Valley	Fernald	Hanford	AVR	AREVA	Monts d'Arrée	CEA Grenoble	Chinon A	SLA	Dounreay	Hunterston A	Generic MAGNOX
> 60 years					X									X
Will there be any restrictions in land-use (please tick all that are applicable)														
Remains nuclear licensed site			X							X	X	X		X
No access to all of the site														
No access to parts of the site														X
Access but restrictions on land use e.g. industrial use only			X		X		X					X		
Restriction on groundwater use				X	X		X					X		
No Restrictions								X						
Who will undertake this monitoring														
Site owners														
Contractors								X		X	X			X
Both			X	X	X		X					X		

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	Various EDF Nuclear	Sellafield	CIEMAT	KAERI	JRIF	Noritake Sugitsue	HAMAOKA	Tokai-1	Fugen	EUROCHEMIC	Chalk River Lab.	Chalk River Lab.	Barseback	Trino
If your site has not been remediated do you have a proposed end state for your site?														
No				X	X	X	X	X		X				
Yes		X	X						X		X	X	X	X
If yes, what are the timescales for reaching the end state?														
Next 10 years			X											X
10 – 30 years									X				X	
30 – 60 years														
> 60 years	X	X									X	X		
Will the end state have...														
Buildings reused for non-nuclear purpose			X											
Buildings demolished to ground level		X								X			X	X
Buildings and foundations removed									X		X	X		
What are the estimated volumes/scale of contaminated land on your site?														
Less than 10 000 m ³	X		X	X		X	X	X	X	X			X	X
More than 10 000 less than 100 000 m ³														
More than 100 000 less than 1 000 000 m ³											X	X		
More than 1 000 000 m ³		X												
What is the estimated scale of contaminated groundwater on your site?														
No contaminated groundwater	X		X	X		X	X	X	X	X			X	X
Less than 10 000 m ³														
More than 10 000 less than 100 000 m ³														
More than 100 000 less than 1 000 000 m ³											X	X		
More than 1 000 000 m ³		X												
What are the approximate numbers of area of potential concern (separate remediation projects) on your site?														
1				X			X	X	X					X
1-5	X		X			X				X			X	

	Various EDF Nuclear	Sellafield	CIEMAT	KAERI	JRIF	Noritake Sugitsue	HAMAOKA	Tokai-1	Fugen	EUROCHEMIC	Chalk River Lab.	Chalk River Lab.	Barseback	Trino
5-10														
More than 10		X									X	X		
Do you have contaminated land and/or groundwater outside your controlled area?														
Yes		X						X			X	X	X	
No	X		X	X	X	X	X		X	X				X
Do you have any receptors (water bodies, groundwater, critical group of people) who are affected by the contamination, if so who or what?														
No	X		X	X		X	X		X	X	X	X	X	X
Yes		X ¹⁾												
1) Groundwater														
If you have any contaminated groundwater, please describe the nature of the plumes (spreading (3), shrinking (1), staying the same (2))														
	1	1									3;(1)			
How do you manage data relating to site restoration (such as groundwater monitoring data and characterisation data)														
Spreadsheets		X		X			X				X	X		X
Off the shelf package											X	X		
Site-specific data	X	X	X					X	X	X	X	X	X	
Is the information (project reports borehole logs, etc.) held:														
Centrally within site records management process							X						X	
Locally within the project team			X					X	X	X				X
Both	X	X		X							X	X		
Is the information stored														
Electronically														
Paper records							X							X
Both paper and electronically	X	X	X	X				X	X	X	X	X	X	
Technology implementation (area specific, see line below)														
Name (reference number) of the area of the site if applicable														

	Various EDF Nuclear	Sellafield	CIEMAT	KAERI	JRIF	Noritake Sugitsue	HAMAOKA	Tokai-1	Fugen	EUROCHEMIC	Chalk River Lab.	Chalk River Lab.	Barseback	Trino
	DNB		Lenti and Montecillo	Uranium Conv. Plant						Site 1	Waste Manag. Areas	Superv. Outer Area		
Is the technology designed for...														
Radiological contamination				X										
Non-radiological (chemical) contamination	X													
Both											X	X		
For radiologically contaminated groundwater, what technology has been chosen?														
Pump and treat												X		
In ground barrier												X		
Pump and re-inject	X													
Monitoring				X								X		
None														
Other														
For radiologically contaminated land, what technology has been chosen?														
Dig and Dispose			X	X						X	X	X		
In-situ stabilisation														
Capping														
None	X													
Other											X ¹⁾	X ²⁾		
¹⁾ Pumping; ²⁾ NA														
For non-radiologically contaminated groundwater, what technology has been chosen?														
Pump and treat														
In ground barrier														
Pump and re-inject														
Monitoring														
None				X								X		
Other														

	Various EDF Nuclear	Sellafield	CIEMAT	KAERI	JRIF	Noritake Sugitsue	HAMAOKA	Tokai-1	Fugen	EUROCHEMIC	Chalk River Lab.	Chalk River Lab.	Barseback	Trino
For non-radiologically contaminated land, what technology has been chosen?														
Dig and Dispose											X	X		
In-situ stabilisation														
Capping														
None	X			X										
Other											X ¹⁾			
¹⁾ In-situ treatment														
Long-term management/monitoring (not area specific)														
How long is it planned for groundwater monitoring to be needed post remediation														
0-10 years				X										
10-30 years	X													
30-60 years														
> 60 years		X									X	X		
Will there be any restrictions in land-use (please tick all that are applicable)														
Remains nuclear licensed site											X	X		
No access to all of the site	X													
No access to parts of the site		X												
Access but restrictions on land use, e.g. industrial use only		X	X								X ¹⁾	X ¹⁾		
Restriction on groundwater use		X												
No restrictions				X										
¹⁾ Following the time of being a nuclear licensed site (~2100)														
Who will undertake this monitoring														
Site owners	X		X	X							X	X		
Contractors														
Both														

Site	Comment
What guidance is available to you with respect to records management and is it adequate?	
Bohunice A1	Executive legal acts, IAEA recommendations. The guidance is adequate.
Bohunice V1	Executive legal acts, IAEA recommendations. The guidance is adequate.
West Valley	DOE and EPA guidance.
Fernald	Department of Energy Orders and EPA guidance.
Hanford	Both national standards for QA/QC, and DOE orders and procedures provide the guidance and it is adequate.
AVR	Standard documents from IAEA (e.g. GS-R-3 and tributary papers), ISO (e.g. 9001 family) or the German Nuclear Safety Standards Commission (KTA) regarding management systems and documentation (KTA-Norms 1402 and 1404). From my point of view these documents are helpful and adequate.
AREVA	No guidance.
Monts d'Arrée	None.
CEA Grenoble	No guidance identified by the project.
Chinon A	None.
SLA	None.
Dounreay	National records guidance is not well focused on site restoration requirements.
Hunterston	Requirements for Land Quality File in Company Standard are informed by Licence Condition relating to generic United Kingdom nuclear site records and by SAFEGROUNDS guidance on land quality record-keeping. Magnox Ltd. is undertaking further work to define records management requirements for 'dormant' sites during multi-decade Care and Maintenance periods (with records to be managed by a 'Hub' organisation rather than by individual sites).
Generic MAGNOX	Requirements for Land Quality File in Company Standard are informed by Licence Condition relating to generic United Kingdom nuclear site records and by SAFEGROUNDS guidance on land quality record-keeping. Magnox Ltd. is undertaking further work to define records management requirements for 'dormant' sites during multi-decade Care and Maintenance periods (with records to be managed by a 'Hub' organisation rather than by individual sites).
Various EDF	Safegrounds and other user group information/guidance.
Sellafield	Good guidance is available.
CIEMAT	--
KAERI	There was no guidance about record management, IAEA TECDOC 411(Record keeping for decommissioning of nuclear facilities) and MARSSIM were used as reference material.
JRTF	--
Noritake Sugitsue	An experienced.
HAMAOKA	--
Tokai-1	No guidance.
Fugen	No guidance.
EUROCHEMIC	--
Chalk River Laboratories	CSA N294 lists the requirements we must follow, as do our internal procedures. Together, this is adequate.
Chalk River Laboratories	CSA N294 lists the requirements we must follow, as do our internal procedures. Together, this is adequate.
Barseback	Guidance is available and adequate.
Trino	Quality procedure.

Annex 5 – The twelve case studies

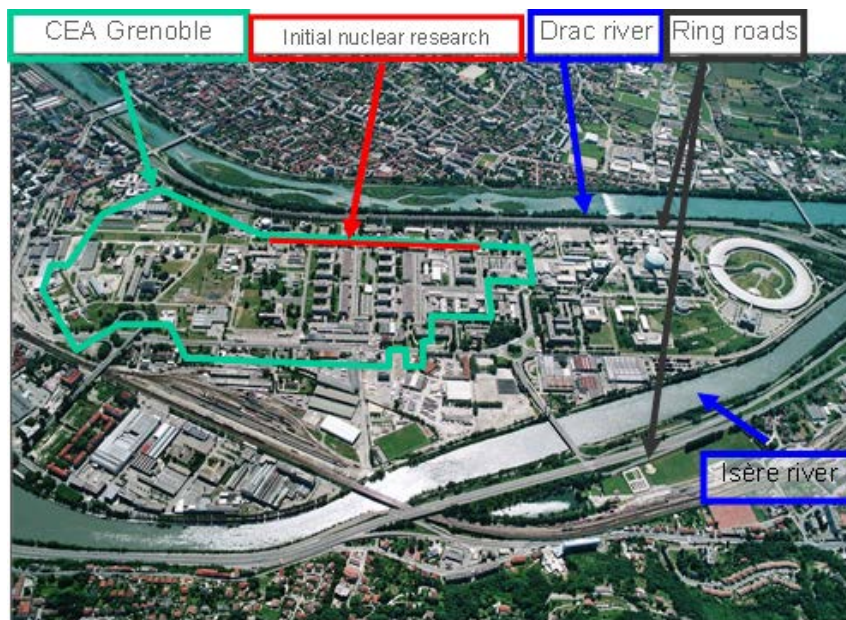
Case study number	Case study title	Country	Brief description
1	CEA's Grenoble STED facility	France	Remediation of contaminated soil around and under redundant solid and liquid waste processing buildings.
2	Monts d'Arree, Brennilis	France	Clean-up of a waste water channel on the Brennilis site.
3	PIMIC rehabilitation project, CIEMAT	Spain	Remediation and waste management activities following decommissioning of a nuclear research facility.
4	Windscale Trenches, Sellafield	United Kingdom	Remediation of historical unlined low-level waste disposal trenches. Enhanced capping selected as the remedial option for interim management.
5	Uranium conversion facility, Daejeon	Korea	Remediation following decommissioning of a uranium conversion facility.
6	Fuel assembly plant, Hanau	Germany	Uranium contaminated soil and sediment under a fuel assembly plant was excavated.
7	618-10 burial ground, Hanford	United States	Removal of contaminated soil and debris from waste trenches is currently underway.
8	Site groundwater, Hanford	United States	A pump-and-treat system and natural attenuation are being used to treat contaminated groundwater at Hanford.
9	In-situ permeable treatment wall, West Valley	United States	A permeable treatment wall system replaced a pump-and-treat system that was not adequately treating ⁹⁰ Sr at a former fuel reprocessing plant at West Valley.
10	Laboratory building decommissioning at Chalk River Laboratories	Canada	Unplanned contamination in soil found under building during decommissioning.
11	"Lenteja" area remediation (PIMIC decommissioning project), CIEMAT	Spain	Site remediation of a contaminated area in CIEMAT.
12	Caustic cells, Chalk River Laboratories	Canada	Retrieval of historical buried radioactive wastes in waste management area.

Case Study – CS1

CEA's Grenoble STED Facility

1. Contact information
2. Site background information

Site name: INB 36/79 – STED (Solid and liquid waste management facility)



Site location: Grenoble (France), inside a CEA research centre

Site description:

Physical (size, habitat areas, surrounding land use, geology, groundwater/soil, contaminants)

STED is a 12 000 m² licensed nuclear facility that includes outside areas (about 7 000 m²) and several buildings. It is located in Grenoble, inside a research centre owned by the CEA (French Atomic and Alternative Energies Research Centre). The total size of the centre is about 600 000 m².

The CEA Grenoble centre was initially located at a distance from the downtown, but with urban development of Grenoble city, it is now in the urban centre. It is located between two rivers (Isère and Drac) and two ring roads.

Due to its location between two rivers, the natural soil is composed of alluviums (sands and gravels) up to 20 m deep, with a high permeability. In the case of the STED facility, the surface layer has been reshaped and new materials have been brought in for construction needs. The thickness of this first layer is quite variable, from 0.5 m to 2 m.

Ground water can be found at the 4-m depth with few level variation and high-speed flow from south to north (from the Drac River to the Isere River).

The Drac and Isere Rivers are mainly used for industry needs: a hydroelectricity and industrial liquid effluents discharge. It is not a source of drinking water.

Groundwater around the site is used for industrial needs, but also for farm irrigation.

- Operational (site history, former use, types of hazardous substances or wastes that were used, stored or disposed at the site)

The CEA Grenoble research centre was created at the end of the 1950s, on a military site formerly used for artillery experiments and exercises.

The first purpose of the CEA Grenoble centre was that of nuclear research, but other non-nuclear research fields have quickly developed, in particular those regarding microtechnology, nanotechnology, biotechnology and new energy technology.

Nuclear research activities were concentrated in the south and east part of the centre, and were implemented in three research reactors and several laboratories (research in the field of safety, fuel manufacturing and irradiated fuel). The STED facility was dedicated to treating and managing solid and liquid waste generated by these activities, and to evacuating packaged containers through available routes.

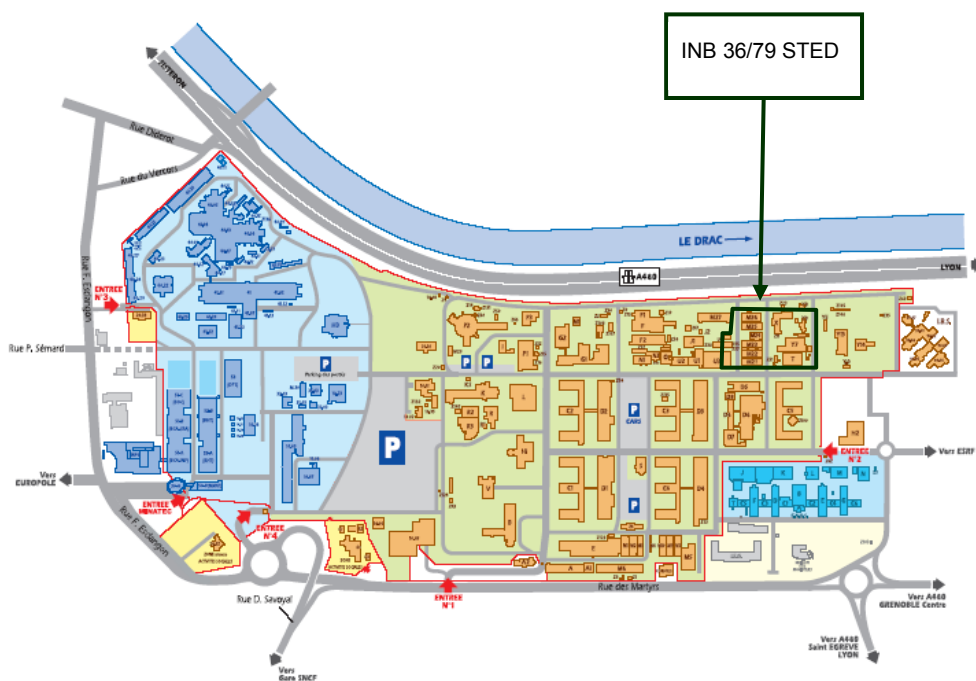
Since the beginning of the year 2000, the CEA has decided to concentrate its nuclear activities mainly in two other CEA centres in France. This decision led to the discontinuation of nuclear activities at the Grenoble centre and to the launching of the nuclear facilities decommissioning project ("PASSAGE" project), while maintaining non-nuclear research activity development. After release, former nuclear areas are expected to be quickly reused for new research activities.

Since the beginning, the STED facility has been dedicated to radiological solid and liquid waste treatment and packaging. Waste emanated mainly from the other nuclear facilities of the centre. First operation licensing was obtained in 1964, with the arrival of Basic Nuclear Installation (BNI) regulatory provisions.

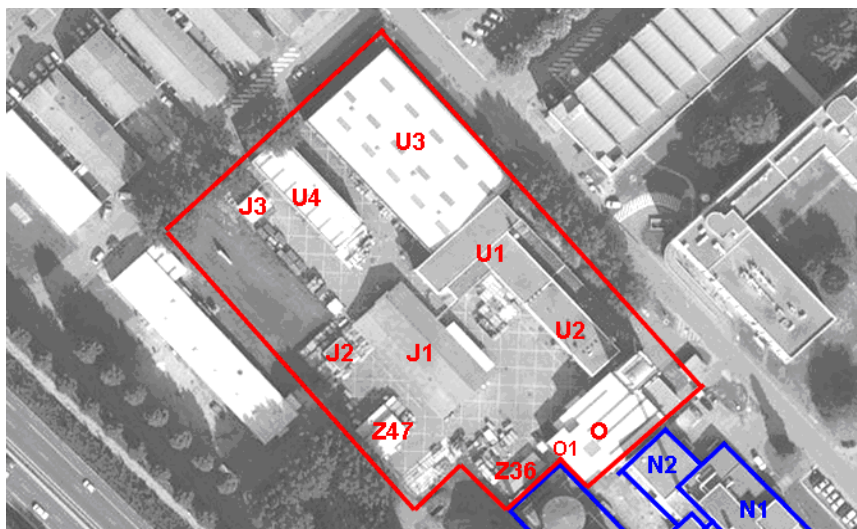
The STED facility was composed of several nuclear buildings, built at different periods for different uses:

- building U1, built in 1964: radioactive solid waste compaction and concreting, sodium and sodium-potassium waste inerting (until 1985);
- building U2, built in 1969: radiological organic liquid waste incineration, and sodium and sodium-potassium waste inerting (from 1985);
- building U3, built in 1988: waste containers interim storage and characterisation before evacuation;
- building U4, built in 1974: dedicated to high-level waste interim storage for radioactivity decreasing, inside a pit with several wells (waste packaged in drums);
- building O , built in 1962: evaporation process and tanks containing radioactive liquid waste to be treated (20 tanks for a 300 m³ total storage volume);
- building J1, built in 1958: radioactive ion exchange resins packaging, evaporation concentrates drying and solid and liquid radioactive waste storage;
- building J2, built in 1966: radioactive solid waste storage;
- building J3, built in 2002: sodium and sodium-potassium waste storage, before inerting;
- building Z47, built in 1977: tanks for radioactive aqueous and organic liquid waste storage, before treatment.

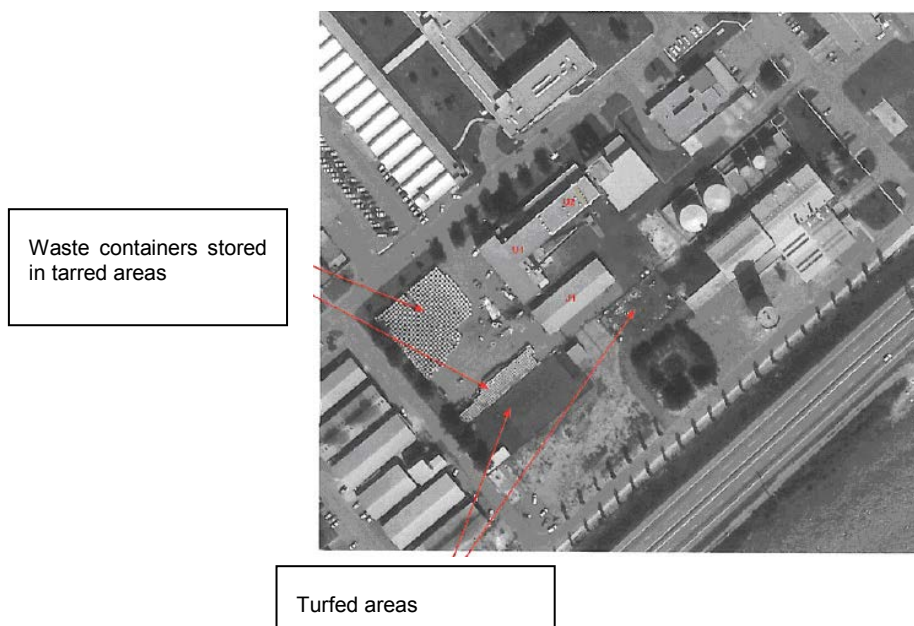
STED location inside CEA centre



STED buildings



Regarding outside areas, some buried pipes linked some buildings to another building for radioactive liquid transfer. A buried radioactive liquid tank was located near buildings U1 and U2. Furthermore, a part of the tarred outside areas was historically used for the storage of waste containers, as illustrated in the picture below (1971).



The nature, quantity and radioactivity level of liquid waste treated are given in the table below

Nature	Location	Radioactivity level	Average annual quantity
Radiological aqueous liquid waste	O, Z47, J1	Max. 10E10 Bq/L	400 M ³
Radiological organic liquid waste	Z47, J1	Max. 4E7 Bq/L	2 M ³
Non-radiological chemical liquid waste	Non-nuclear buildings	-	25 M ³

Since waste was coming from different facilities and laboratories, a wide range of radionuclides were expected. The radiological spectrum could be very different from one building to another, as shown in the table below.

Building	Main radionuclides (contributing to more than 90% of the radioactivity)
O	Cs-137 (44%) C-14 (15%) U-234 (15%) U-238 (13%) Sr-90 (12%)
U1	Cs-137 (64%) Sr-90 (17%) C-14 (16%)
J1	C-14 (52%) Cs-137 (34%) Sr-90 (9%) Co-60 (3%)
U2	U-238 (48%) U-234 (47%)
Z47	Cs-137 (64%) Sr-90 (17%) Co-60 (6%) C-14 (4%) Ag-108m (3%) Ni-63 (2%)

In conclusion, the main radionuclides that can be expected inside buildings are Cs-137, U-234, U-238, C-14, Sr-90 and, at a lower level, Co-60.

Some radiological measurements implemented in 1997 and 1999 in the outside areas identified a few contaminated zones, mainly by Cs-137. In 2002, the area was covered with a new tarred material between the buildings in order to protect contaminated ground from the rain and in this way limit contamination migration while carrying out further characterisation.

Waste treatment processes ceased in 2002-2003, and the dismantling of process devices ended in 2007. Decommissioning of buildings began in 2008. All buildings have been demolished, with appropriate confinements depending on the radiological inventory. The last buildings were demolished in 2011. Ground cleaning began in parallel with the demolition of buildings and is still in progress.

- Regulatory status of the site or project

The CEA centre is globally licensed and controlled by an environment government agency.

Furthermore, each basic nuclear installation (BNI)¹ is individually licensed and controlled by the French nuclear safety authority. The total nuclear licensed area was initially about 50 000 m². As some of the nuclear facilities have already been delicensed, the remaining nuclear licensed area, including the STED facility, is currently (2013) about 30 000 m². The delicensing process has been submitted to the nuclear safety authority for approval.

The STED facility is a BNI. It has been covered by a decommissioning decree since 2008, replacing the operation decree.

3. Clean-up agency/stakeholders

- Organisations responsible for clean-up

The CEA is responsible for its nuclear facilities from construction to delicensing.

Inside the CEA, the Nuclear Energy Department (DEN) is in charge of nuclear facility operation and decommissioning. In the case of the CEA Grenoble centre, a specific decommissioning project organisation has been implemented called "PASSAGE", which is in charge of the decommissioning process (planning and cost management, work implementation, authorisations files), including decommissioning of the STED facility. As the CEA Grenoble centre is under the responsibility of the CEA Technology Research Department (DRT), the PASSAGE Project is co-led by both the DEN and DRT. The DRT is in charge of relationships with the nuclear safety authority, and the DEN is in charge of implementation of the decommissioning project.

- Regulatory agencies

The STED facility is under nuclear safety authority (ASN) control, as is the case with all non-military BNI in France.

The ASN, an independent administrative authority set up by law 2006-686 of 13 June 2006 concerning nuclear transparency and safety (known as the "TSN law") is tasked, on behalf of the state, with regulating nuclear safety and radiation protection in order to protect workers, patients, the public and the environment from the risks involved in nuclear activities. It also contributes to informing citizens.

1. Basic nuclear installations (BNIs) are installations that, due to their nature or to the quantity or activity of the radioactive substances they contain, are subject to particular provisions in order to protect the general public and the environment. Each BNI has its own authorisation decree.

- Regulatory regime/requirements (as opposed to general national regime)

The main requirements coming from the STED facility decommissioning decree and regarding site restoration are:

- Final state: area without buildings, suitable for industrial reuse.
- Three months before ground restoration work, a file has to be delivered to the ASN describing ground radiological state, restoration methodology and radiological objectives; it is submitted for ASN approval.
- Permanent waste disposal inside the BNI area is forbidden.
- Six months after the end of restoration work:
 - a file has to be delivered to the ASN, including feedback, dosimetry and waste review.
 - another file has to be delivered to the Nuclear Safety Ministry and to the ASN, justifying that objectives have been reached. This file is also delivered to the Grenoble Town Council and Isere Prefecture where it must be available to the public.
- The BNI delicensing is submitted to the ASN for approval of these two files and of a third file that must describe the expected reuse of the area and the eventual restrictions proposed by the CEA, based on an impact assessment.

- Local stakeholders

Stakeholders (Grenoble City, Isere Prefecture, urban associations, neighbours, town councils, local media) have been informed since 2001 through annual media conferences. The STED decommissioning risk assessment was transmitted in 2008 to the nearest town councils before publication of the decommissioning decree, where they were available to the public. Furthermore, since 2009, a local information committee has been created and has held meetings twice a year.

In conclusion, stakeholders are regularly informed and to date they have not questioned the restoration approach.

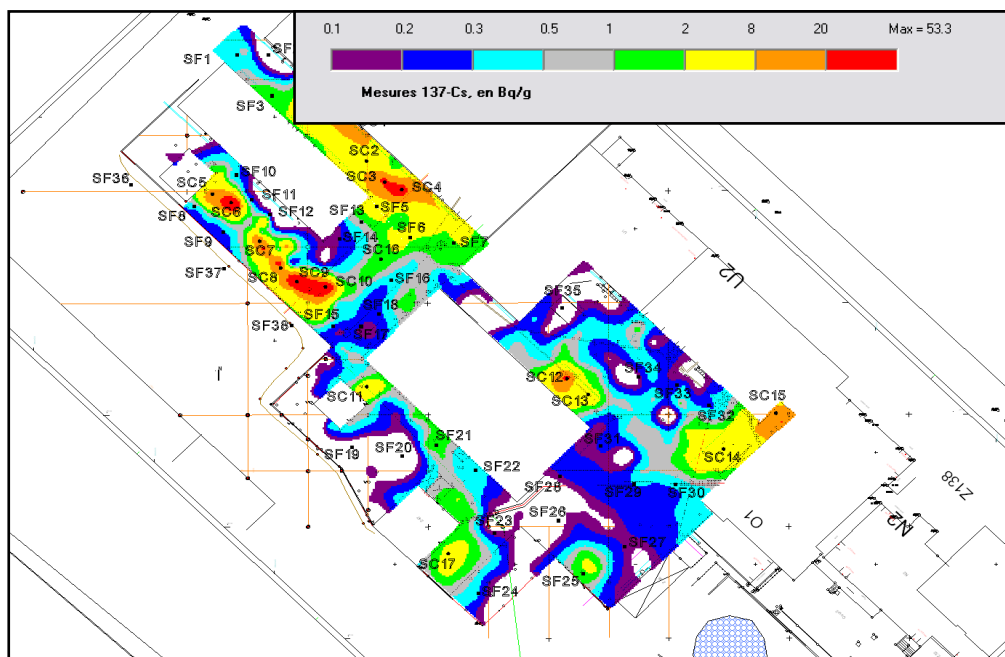
4. Characterisation

- Extent and methods

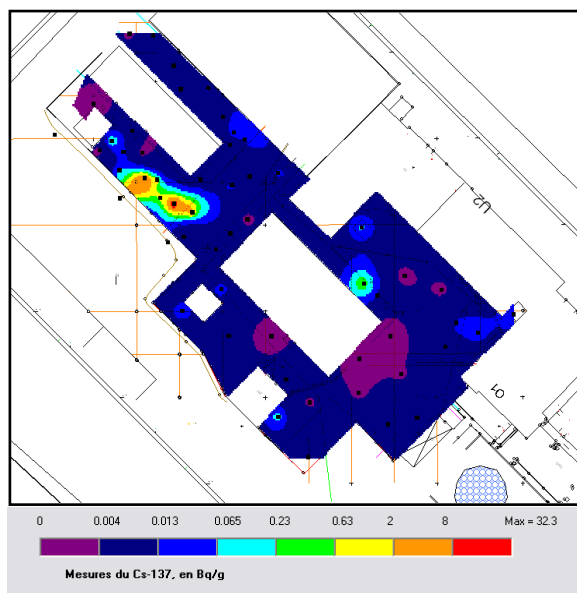
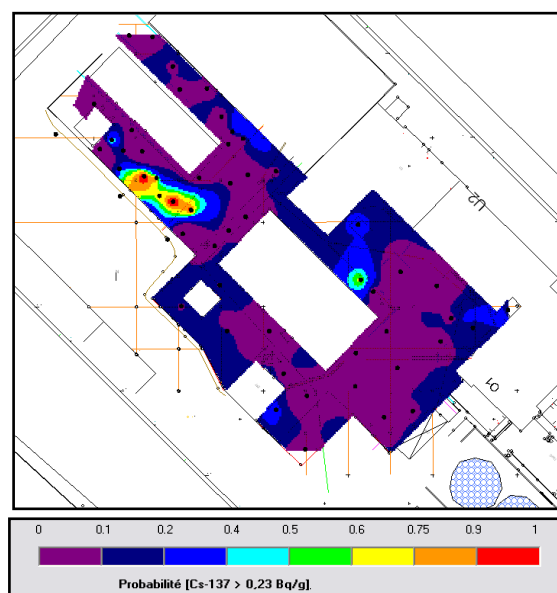
A first campaign of ground characterisation was implemented in 2006. The extent included the tarred area between the STED buildings (“backyard”). It was carried out in two major steps:

- Surface screening with a 5-m mesh by gamma spectrometry devices put on a specific vehicle developed by the CEA. Results were analysed by geostatistic methods that led to a 2D-cartography.

CS-137 2D-cartography of the STED backyard (2006)



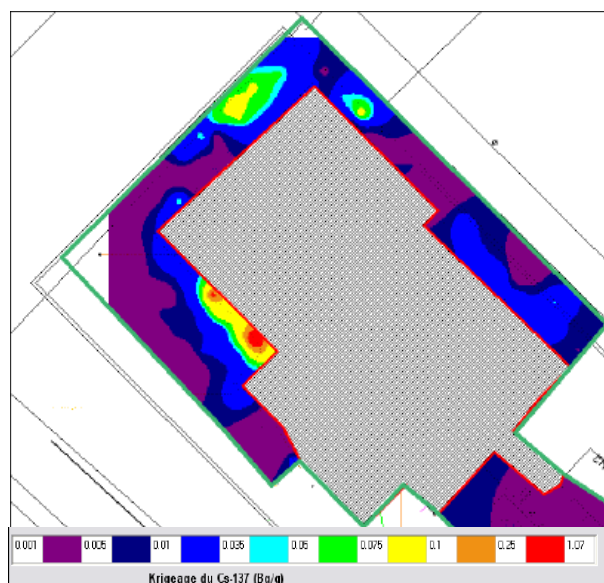
- Drilling campaign: 18 drillings were set inside zones with radioactivity levels above 2 Bq/g (anticipated radiological objective), and 37 drillings were set in other zones. Drillings were two to three metres deep. Each drilling was scanned by a gamma detector so as to have a first idea of the contamination profile in depth. Then 0.1- to 0.5-m-length samples were extracted from drillings and analysed in the laboratory (chemical and radiological analyses). Results were also treated by geostatistical tools, leading to a 2-D and 3-D cartography.

Cs-137 activity cartography at 40 cm deep**Probability to exceed a given Cs-137 activity (40 cm deep)**

In brief:

- there was no chemical pollution;
- radiological contamination of the backyard was located in eight zones;
- Cs-137 was the main radioactive contaminant and its migration was limited to the first metre;
- In some zones, Sr-90 and alpha radionuclides had migrated deeper than Cs-137.

A second campaign was implemented in 2008 for characterisation of outlying areas (mainly turfed areas), with the same methodology as the first campaign. The conclusion indicated the presence of a contaminated turfed zone at the north west of the facility, with a few Bq/g of Cs-137 in the first 50-cm layer.

Cs-137 cartography of the STED outlying areas (2008)

- Historical assessments

Historical assessments have been carried out from 2006 to 2008. Some incidents that could lead or have led to ground contamination have been identified thanks to archives and operators interviews:

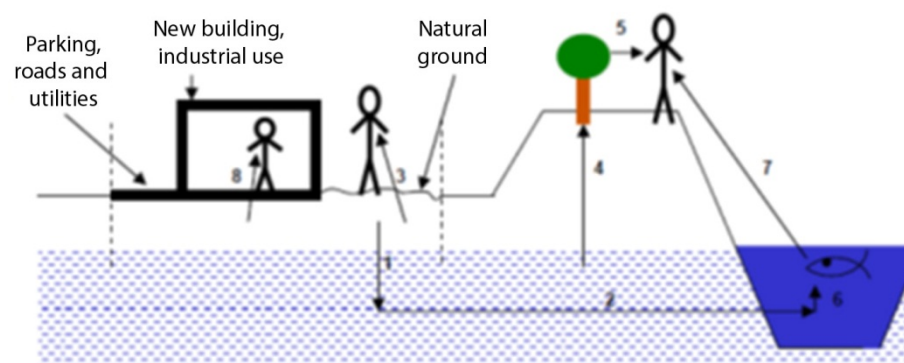
- Evaporator leak (building O) that overflowed out of the building and spread contamination in the backyard in front of buildings O and U2.
- Pipe leak, containing uranyl nitrate, in a gutter between buildings O and U2. Ground around the gutter was contaminated.
- Pipe leak, containing radioactive liquid concentrates, in a gutter between buildings O and J1. There was no data related to the ground contamination below the gutter.

Furthermore, waste containers historically disposed in the backyard were not all watertight and some contamination spread, essentially in the north-west part of the facility.

In conclusion, ten contaminated zones have been identified in backyard and outlying areas as a result of historical assessments and initial characterisation campaigns. Furthermore, since the ratio between radionuclides varies depending on the depth, it is necessary to survey radionuclides that have different migration behaviour. Consequently, three representative contaminants have been chosen: Cs-137, Sr-90 and Pu-238.

- Risk assessments

A conceptual model was established very soon in the characterisation process. It identifies the potential pathways from the contaminated soils to humans and the environment after restoration, in the case of the remaining contamination. This model has been used to validate radiological objectives and to assess residual impact after restoration.



Impact assessments have been calculated in accordance with the French Guide from IPSN (2008 version): *Gestion des sites industriels potentiellement contaminés par des substances radioactives*.

5. Remedial objectives

The remediation targets for this restoration project are:

- residual impact below 0.1 mSv/year for industrial reuse, without technical restriction;
- if reasonably achievable: residual radioactivity below 0.4 Bq/g (or Bq/cm²) for β/γ emitters and below 0.04 Bq/g (or Bq/cm²) for α emitters;
- if previous residual activity targets are not reasonably achievable: the lower residual impact reasonably achievable.

These are based on:

- Euratom directives: impact as low as reasonable and below 0.3 mSv/year;
- environmental directives of the French government: restore compatibility with the uses;
- CEA's political will to enable the development of its new activities without nuclear restriction.

As there is currently no Guide from the ASN regarding nuclear site restoration, restoration methodology applied by CEA is the one described in a common operator practical guide established by AREVA/CEA/EDF (Guide transmitted to ASN):

From the planning point of view, the objective was the restoration work achievement in 2012.

6. Options evaluation

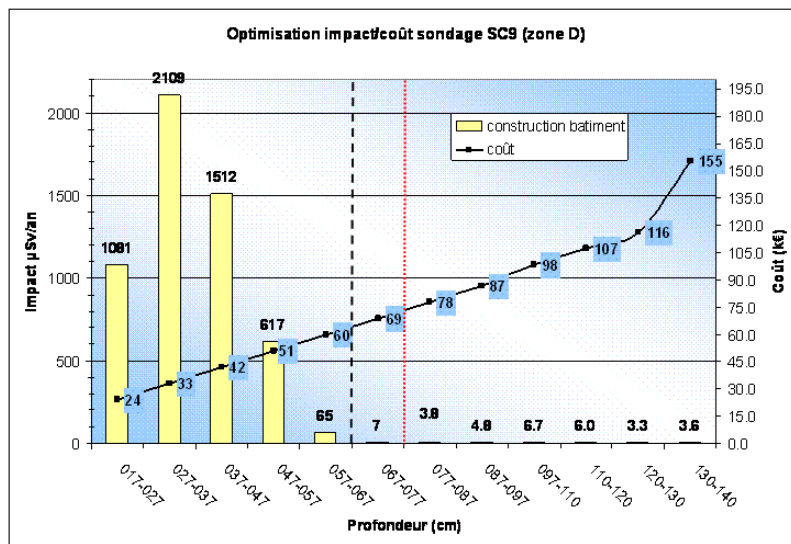
Since the CEA wanted to reuse the land without restriction and gave the priority to contaminated soil removal according to the ASN politics, the choice of excavation techniques was quickly retained.

Regarding remedial criteria, an optimisation assessment has been realised for each contaminated zone, thanks to initial characterisation results and expected residual cost and impact assessments at each depth. The optimisation study is based on the comparison of the residual impact decreasing and cost increasing, using the best available techniques. An optimised depth to be excavated was defined for each zone corresponding to the depth where there is no more significant decrease of the impact or where there is an important increase of the cost (keeping in mind that residual impact has to be below 0.1 mSv/year). The optimised depth is the technical remediation

objective. It takes into account a safety margin regarding uncertainties related to characterisation and excavation techniques (globally around 10 to 30 cm).

In the example optimisation graph below, the cost is increasing regularly while the impact decrease is no more significant after 70-cm depth. The optimised depth retained is 80 cm. Verification is made that the expected residual impact at this depth is below the global remediation objective of 0.1 mSv/year.

Guide Inter-Exploitants/Réhabilitation des sols d'une Installation Nucléaire de Base DPSN-GU-003



7. Remedy execution

The remediation approach described previously was submitted to the ANS for approval in 2007. The ASN has given authorisation to start restoration work but still has questions on radiological criteria, in relation to future reuse and restrictions.

Contaminated soil excavation began at the end of 2009. It was finished in the beginning of 2013 for backyard and outlying contaminated areas.

After the demolition of buildings, soils under the basement have been characterised and some new contaminated zones have been identified. Restoration work for these zones is still in progress and is expected to be achieved by the end of 2013. The main reasons for the delay compared to the project planning objective (2012) are described in the paragraph "Lessons learnt".

All restoration work is performed under a shelter.



8. Post remedial monitoring

The post remedial monitoring method that has been implemented is:

- 100% surface counting to check gamma flux homogeneity (no hot spots);
- in-situ gamma spectrometry, with statistical approach for wide surfaces;
- average samples, for example by alternate hand shovelling. The choice of the sample size and number have been chosen by applying the “PESCAR” method (surface sampling for radiological characterisation and analysis)¹.

The objective of the PESCAR method is the control and validation of the level of residual health impact that was chosen for the rehabilitation of a site, through the determination of the average residual activity. The method is applied in two main sampling phases. The first phase determines the optimum sample weight and number of samples to be collected in the second phase.

The site is divided into ten areas of equal surface. Two sets of ten samples are then collected (two samples in each of these ten areas), the samples of the first set have the same weight m_1 and the samples of the second set have the same weight m_2 ($m_2 \geq 10 m_1$). All samples are homogenised and conditioned in standard containers for analysis in the laboratory. Then all results are statistically analysed (average M_1 and M_2 , standard deviation S_1 and S_2 , variation coefficient $CV = M/S$). Four cases may be observed:

- $S_1 \approx S_2$: the weight of samples is not important regarding the evaluation of the pollution variability. The use of geostatistics is possible if more samples are collected (the minimum amount of data is required).
- $S_1 < S_2$: presence of hot spots. A third set of samples needs to be collected, with a weight m_3 ($m_3 \geq 10 m_2$), and repetition of the first phase for samples of weight m_2 and m_3 .
- If S_1 and S_2 have low values (10% of the averages), m_1 is retained as the optimum weight of the second phase samples.
- $S_1 > S_2$: the optimum weight is obtained by following the following steps:

- Calculating the homogeneity constant A:

$$A = \frac{m_1 \cdot m_2 \cdot (S_1^2 - S_2^2)}{m_1 - m_2}$$

- Calculating the segregation constant B:

$$B = S_1^2 - \frac{A}{m_1} = S_2^2 - \frac{A}{m_2}$$

- The optimum weight is then $m_{\text{optimum}} = A/B$
- The optimum number of samples is

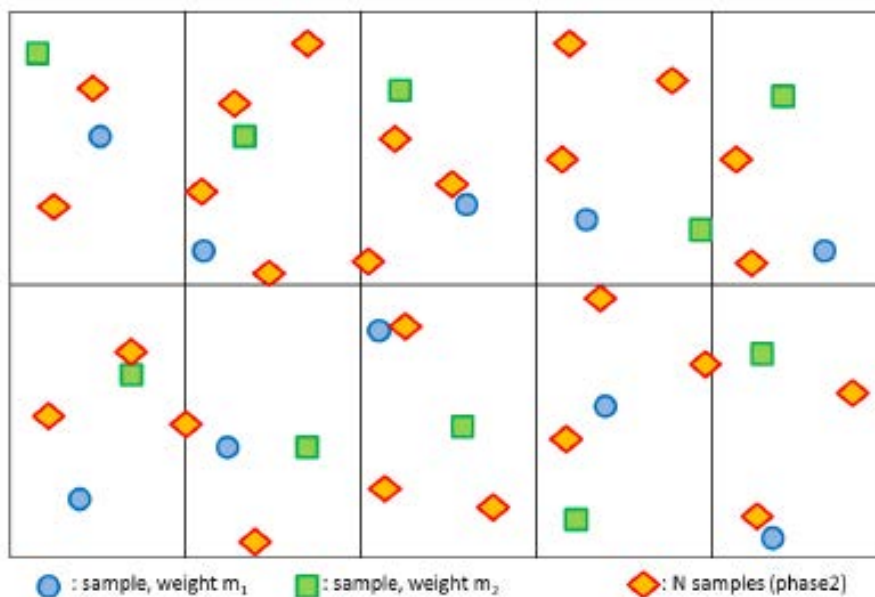
$$N \geq \left\lceil \frac{(Z_\alpha + Z_\beta)^2}{D} \right\rceil + 0.5 \cdot Z_\alpha$$

1. D. Dubot and G. Granier. Site evaluation at the end of clean-up operations – Séminaire CETAMA “Echantillonnage et caractérisation II” - 27-29 avril 2010 - Montpellier

Where Z is the student parameter for a given confidence level and a given test strength (risk of first and second species), and D is the ratio of the desired margin of error by the coefficient CV , previously determined.

All N samples are then randomly chosen within the whole area and primary samples of weight m_{optimum} are collected, homogenised and analysed. The interpretation of the results of analyses of this set of samples will then allow determination of the average residual activity of the site, and this can be used to determine the health impact of the rehabilitation according to the future use scenario.

Post remedial monitoring for backyard and outlying zones began in 2011 and ended in mid-2013, in relation with restoration work progress. For zones under buildings, post remedial monitoring is in progress, as well as the restoration work.



9. Major cost elements

Not available.

10. Lessons learnt

- Characterisation

In some cases, the initial characterisation under-evaluated the extent of ground contamination because of:

- on site radioactive historic waste disposal increasing the radioactive background;
- buildings still in place.

Hence, it has been necessary to implement further characterisation after radioactive waste evacuation and demolition of buildings. These complementary characterisations identified a new low-level contaminated zone outside buildings, and a more significant contaminated zone under a building. As a consequence, project planning and costs have been impacted.

The major risk of an under evaluated initial characterisation is to propose to the safety authority (and stakeholders) a final state that is finally unreachable at initial project cost, planning and with

initial techniques. Consequently, it is recommended to carry out initial characterisation when all areas are free. On the one hand, the advantage is to have a comprehensive overview of the extent of contamination. On the other hand, it delays significantly the start of the land restoration process.

It is also important to highlight that the ratio between radionuclides varies depending on the depth, due to different migration speed in the soil for some radionuclides. And so it is necessary to survey radionuclides that have different migration behaviour, and to take precaution when using scaling factors.

- Restoration techniques

It is important to ensure restoration techniques reliability regarding contamination scattering (for example, to ensure that a part of the contaminated soil removed by excavator is not scattered close by or at the bottom of the excavated pit). It is all the more sensitive when the cleaning objectives are very low. One implemented solution has been to carry out a final accurate cleaning at the end of the cleaning process.

- Project cost and schedule

The restoration project significantly exceeds the estimated cost, mainly because of the presence of explosive devices that led to modifications to restoration work and waste packaging methods, strongly slowing down restoration work. Indeed, digging operations stopped for one year in 2011-2012, and then the digging and waste packaging pace slowed by a factor of three. Digging operations are now systematically assisted by an explosive mine clearance company.

- Release criteria

The French approach without release criteria entails a case-by-case definition of criteria to segregate a nuclear and non-nuclear zone before excavation. After excavation, such criteria are not allowed to segregate nuclear and conventional waste: all soil excavated from a nuclear zone is managed as nuclear waste. Generally, these criteria are very low and nuclear zones are delimited, taking into account a margin. The more the contamination history is various and numerous, the more the margin is significant. And so, a large quantity of soil inside a nuclear zone is potentially under criteria but is nevertheless managed as nuclear waste. Furthermore, in the present case study, embankments necessary for the stability of pits have also been managed as nuclear waste.

Therefore, it seems necessary to find solutions to optimise nuclear waste in order to limit the saturation of nuclear waste routes and to optimise cost: embankments management, margin reduction by reinforcement of measurements, nuclear and conventional soil segregation after excavation by reliable and relevant measurements.

Another drawback of the lack of national release criteria is the difficulty to come to an agreement with the ASN on criteria that would ensure site release without constraints. Consequently, it is difficult to define an optimised restoration scenario with regard to the expected level of constraints after release.

- Data management

- Archives from facility operation

The accuracy of physical state management needed during operation is sometimes not enough for site restoration needs:

- identification changing (buildings/room names, piezometers numbers);
- accurate location of old buildings/tanks/areas already demolished/excavated;
- drawings not always updated.

More generally, documents that have been archived during operations are relevant for operation and safety issues but sometimes not relevant or accurate enough for restoration issues. One reason is the difference of the radiological data used between operation and restoration: in the first case, radiological data is essentially used for safety and radioprotection needs, while for restoration needs,

radiological data is used to delimit parts of the building or ground to be restored. Moreover, radiological restoration targets are in general much lower than radiological criteria for safety or radioprotection needs.

- During decommissioning operations

Difficulty to keep and gather the relevant records for restoration and delicensing steps on a long-term decommissioning project (unaware of what document is important for restoration and delicensing steps, which one has to be archived and for how long, turn-over of people, moving archives from one building to another, etc.)

Defining how to ensure that people in charge of site restoration keep the relevant documents and transfer them to archives. Indeed a lot of data is required by regulation to obtain delicensing, in relation with restoration operations. And operators and managers are not always well informed of the importance of some information. All the more so when it regards very small events without impact on workforce safety and the environment.

The solution implemented by the PASSAGE project is satisfying: documentation management (record and archiving) made by contractor. The contractor assignment is not only to archive documents but also to collect them. The associated cost has to be taken into account in the project cost.

As soon as possible (at the beginning of decommissioning project), the assignment of such a contract should include the search, recording and archiving of all events of interest to the restoration and delicensing process.

11. References

Case Study – CS2

Monts d'Arrée, Brennilis

1. Contact information
2. Site background information

Site name: Site des Monts d'Arrée

Site location: Brennilis, France

Site description:

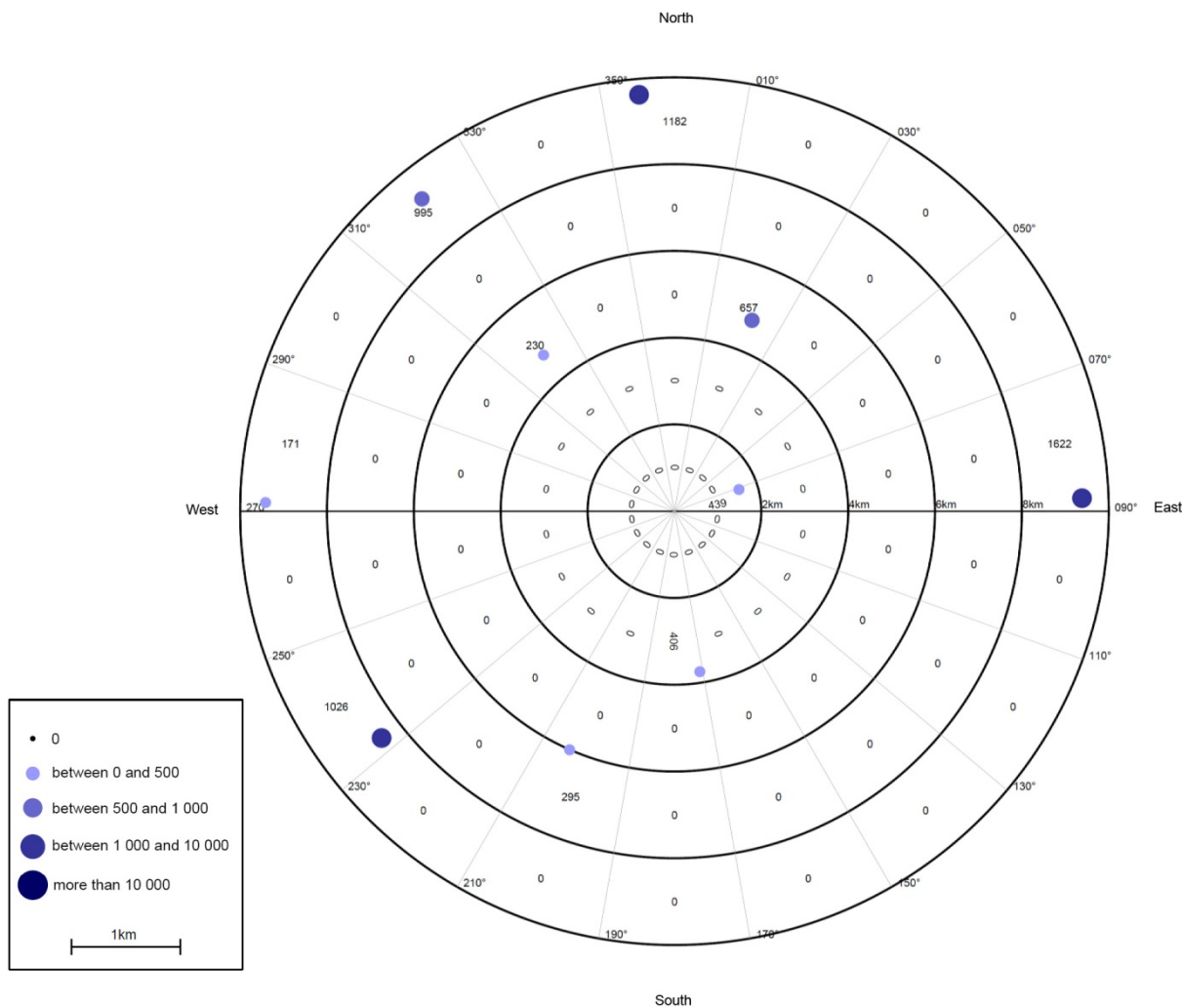
Physical (Size, habitat areas, surrounding land use, geology, groundwater/soil, contaminants)



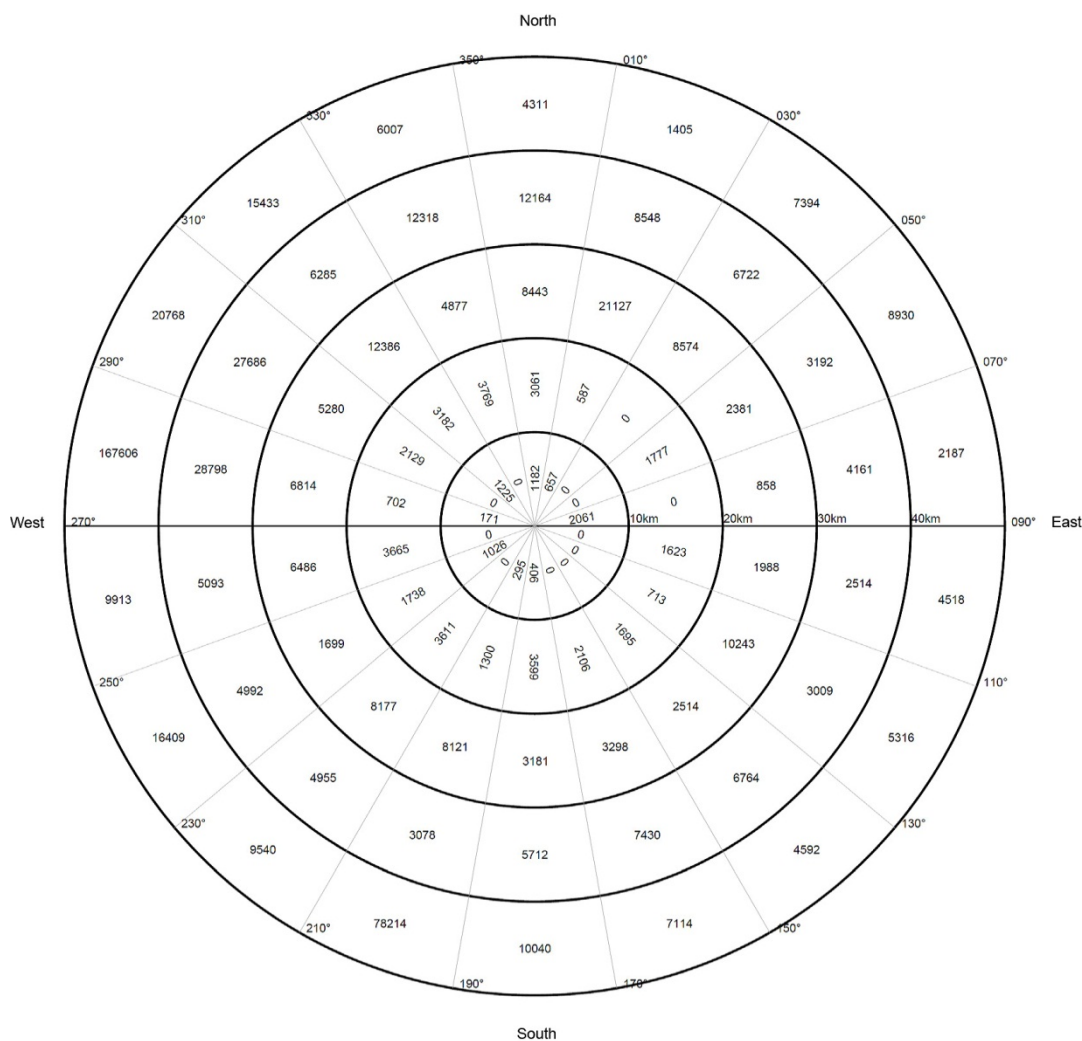
Size: 50 ha in 1967 to 6 ha in 2012.

- Habitat areas:

Number of inhabitants within 10 km around the site



Number of inhabitants within 50 km around the site



Surrounding land use

Tourism during summer time: 14 schools in the 10-km radius; 1 retirement house

Agricultural fields mostly with feed crop in the 10-km radius

Pig farming, cattle breeding and poultry farming well represented in the same area

Drinking water in the 10-km radius: 40 outlets from the groundwater; the nearest well downstream the site is at 1.6 km.

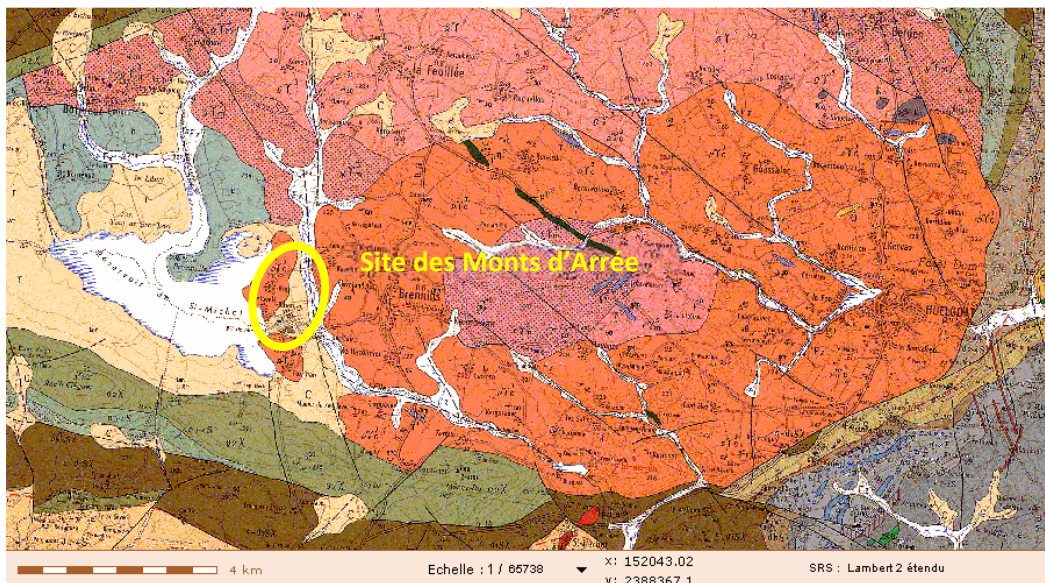
No water outlets in groundwater or surface water identified for industrial use or agricultural use in the 10-km radius.

Leisure activities: in the St-Michel reservoir, fishing, kayaking, sailing; in the Ellez River, fishing; no bathing allowed until the Bay of Brest

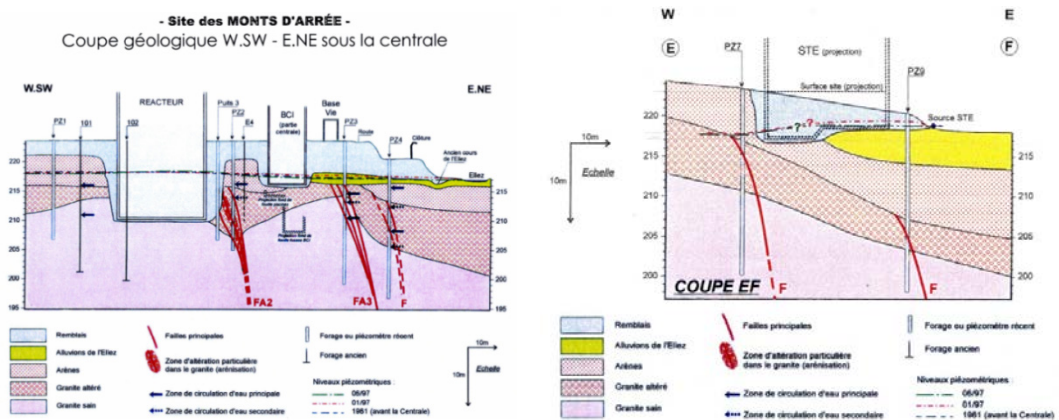
Hunting, with 220 hunting licenses granted in the 10-km radius

■ Geology

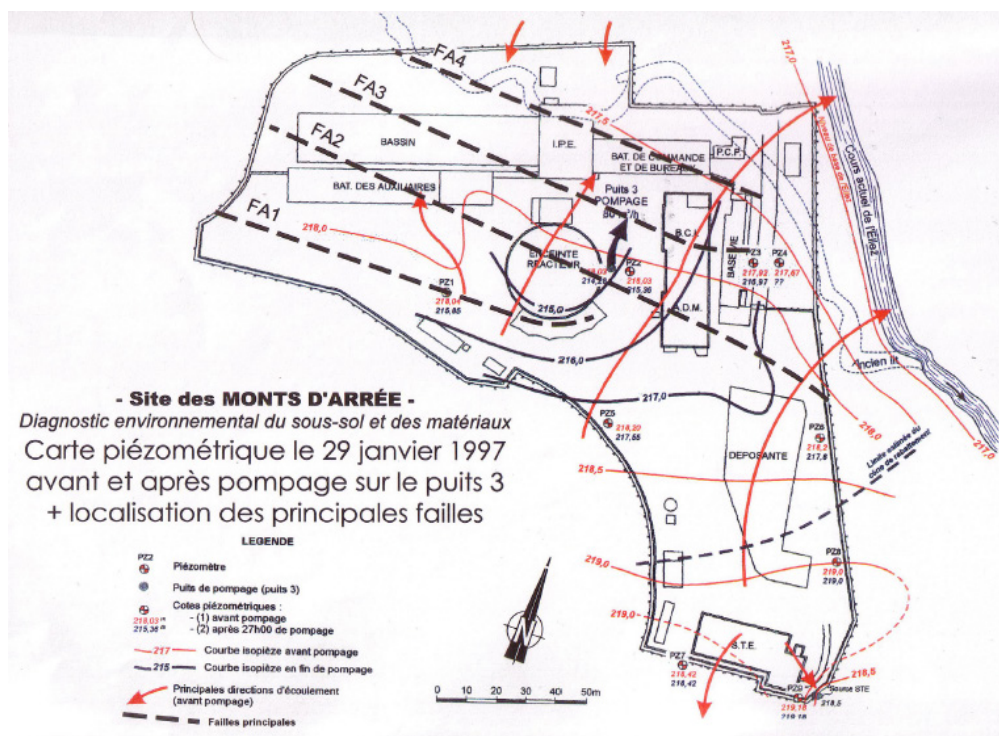
Geology of the area of Brennilis



Geology under the site



- Hydrogeology:



- Operational (site history, former use, types of hazardous substances or wastes that were used, stored or disposed at the site)

Heavy water reactor (HWGCR), Power production 70 MWe, Industrial prototype of the CEA for power production. It operated with poorly enriched uranium, was moderated by heavy water and cooled with carbon dioxide.

Was jointly operated by the CEA and EDF from 1967 to 1985. Decommissioning was done by EDF.

From 1985 until the end of 1992, spent fuel has been evacuated, tritium within the heavy water has been removed, pipes have been emptied and dried, and wastes have been packed.

Since 1997, dismantling has begun, three nuclear buildings have been decontaminated and have been demolished or are under ongoing demolition. The former discharge channel was remediated in 2012. Dismantling of the reactor building will take place in 2015-2020.

- Incidents:

The Sulzer room at the south of the reactor building was dedicated to the reconcentration of the heavy water by fractional distillation. Many small leaks from the room were found in the sump and, between 1987 and 1989 (after the end of operation), a leak was notified coming from a pipe that sampled heavy water within the reactor, just at the crossing of the wall of the room. Contamination of groundwater with tritium was up to 930 Bq/L in October 1988 and GW was pumped.

- Regulatory status of the site

The complete decommissioning of the reactor had been authorised by the decree of the 9 February 2006.

Further to a request made by the anti-nuclear association *Sortir du nucléaire*, the State Council had cancelled the decree on 6 June 2007 because the impact study should have been given to the public before the agreement of the government, in application of the European Directive 85/337/CEE, that was not declined in the French Law at that time but should have been.

Further to that cancellation, the French nuclear authority, in its decision of the 8 October 2007, established a list of operations that EDF could perform while waiting for a new decree that would authorise the dismantling.

In July 2011, a decree for partial dismantling of the site was obtained (the decree for the complete decommissioning was not obtained because of an unfavourable public enquiry): it enables the dismantling of the heat exchangers, the remediation and dismantling of the effluents treatment station including the soils, the dismantling of the waste shed, and all the characterisation and remediation works of soils and groundwater impacted by operation of the site. The dismantling of the reactor building is forbidden.

EDF had to ask for another decree before the 31 December in order to get authorisation for complete dismantling.

3. *Clean-up agency/stakeholders*

Body responsible for clean-up: EDF S.A.

Regulatory agency: ASN (nuclear safety authority)

Local stakeholders: public, ecological associations, national anti-nuclear association, regional nuclear safety authority, regional environmental authority

Support or opposition from stakeholders? Depends on which stakeholder: local associations and national associations, opposition; public, are waiting for an explanation to make their opinion; authorities, light support but will comply with the general mind-set frequency of stakeholder meetings? Local information commission meets with a frequency of a minimum of three times a year, but sometimes every month, depending on the news.

4. *Focus on the channel*

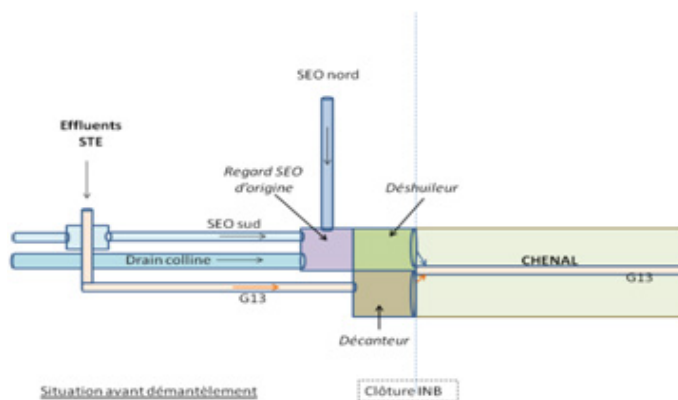
4.1. *Characterisation*

- Historical assessments

Bibliographical studies related to the history of the whole site, and in particular the effluents treatment station (STE), have been conducted with a focus on the incidents during operation, the effluents' spectra and used or produced chemicals.

The channel was a ditch created in 1967 to lead the effluents coming from the treatment station to the nearby Ellez River.

A pipe was laid on the bottom of the channel (dismantled in 2004). An oil/water separator was installed upstream from the channel (dismantled in 2005). During the dismantling of these two elements, damage to the pipe was identified in its upstream part (Picture 1); a partial dredging was necessary to remove the pipe, with placement of the sediments on the southern bank (Picture 2).



- Extent and methods

Three monitoring wells are located downstream the channel in which gamma spectrometry, gross beta and potassium, and tritium are monitored each month. Groundwater never showed the presence of any artificial radionuclides.

Related to the historical assessment, the following substances were sought:

Radionuclides:

^{60}Co , $^{108\text{m}}\text{Ag}$, ^{125}Sb , ^{137}Cs , ^{152}Eu , ^{154}Eu , ^{155}Eu , ^{238}Pu , $^{239+240}\text{Pu}$, ^{241}Am , ^3H , ^{14}C , ^{55}Fe , ^{63}Ni , ^{90}Sr (+ ^{90}Y), ^{241}Pu

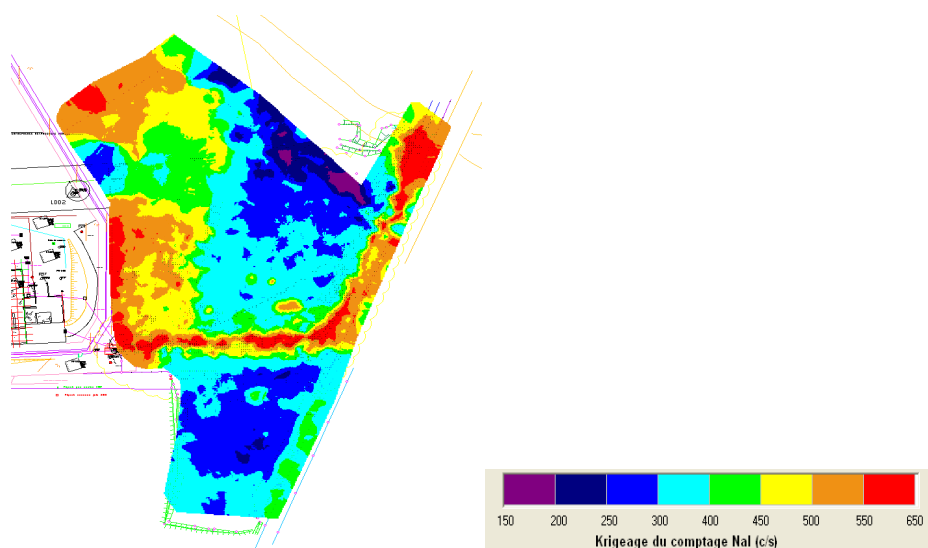
4.1.1. Surface screening (^{137}Cs and ^{60}Co)

The goal is first to identify areas of interest and then to distinguish between natural and artificial radioactivity.

Tools used: 4-wheel vehicle VEGAS (equipped with DSPs, collimated GeHP and NaI gamma spectrometers for in-situ measurements, submetric GPS device) in all areas suitable for vehicles, pedestrian device in a rucksack (submetric GPS device, NaI gamma spectrometer) for all other areas.



A geostatistical approach with an interpolation by a kriging method is completed in order to obtain this kind of map of results.



The red colour is the highest level of the gamma flow detected without being elevated (estimated dose rate by CEA is about 50 nSv/h on average with a maximum of 100 nSv/h).

Second step: distinction between natural and artificial radioactivity using in-situ gamma spectrometries (3" NaI Figure 1, and GeHP Figure 2).

Figure 1

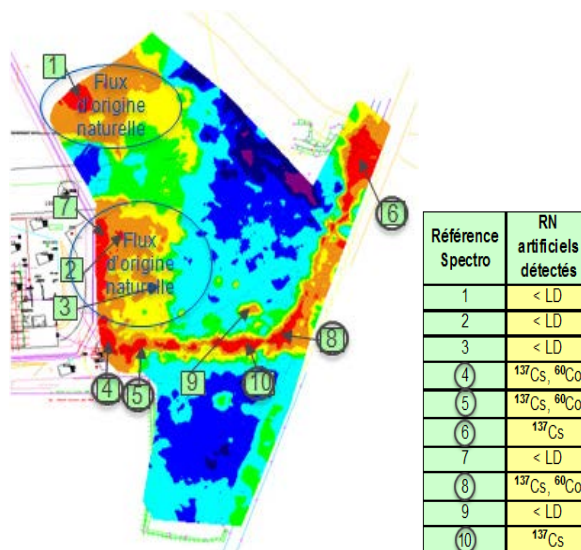
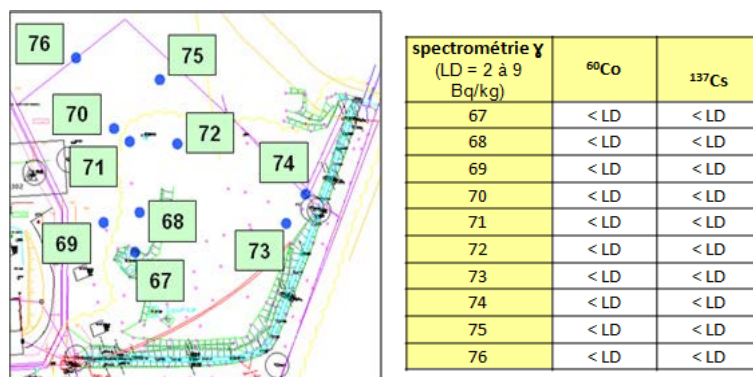


Figure 2



4.1.2. Drilling campaign taking into account the preceding identified areas of interest and history of the site: more than 140 boreholes with a depth varying from 0.30 to 1.60 m, more than 280 radiological analysis and 100 chemical analysis in accredited laboratories

Chemical substances: heavy metals, TPH, PAH, BTEX, chlorinated solvents, PCBs

The preceding drilling campaign enabled to send samples to labs to analyse these substances.

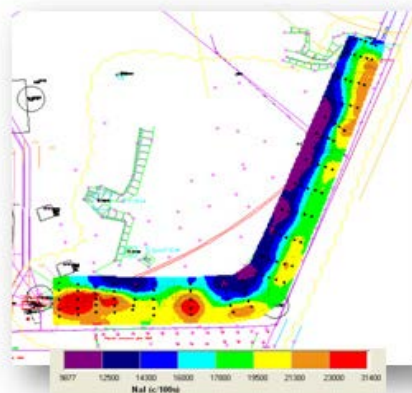
The goal was to find both radioactively and chemically contaminated areas, if any, and to delineate in 3-D of this contamination.

- Risk assessments

A risk assessment study was conducted with different exposure scenarios: it showed the very low impact of the channel after remediation.

- Models used

During the surface screening, software was used to optimise the sampling plan and to handle the data with a geostatistical approach, which enabled an evaluation of the uncertainties. This approach enabled a 2D-model of the signal in a real time approach.



During the final control of the channel remediation, the methodology and tools related to MARSSIM were used.

5. Remedial objectives

Remedial success criteria: operational criteria = $137\text{Cs} + 60\text{Co} < 0.1 \text{ Bq/g}$; overall criteria = $\text{Sum}(\text{every artificial RN measured weighted by the exemption level of the EC Directive 96-29}) < 0.01$; PCBs at one location removed.

Remediation Standards: None

6. Options evaluation

Request to the safety authority for stakeholder involvement: authorisation before remediation works; presentation of future works in a public meeting.

Reason the remedy was selected: compromise between the media-centred sensitivity of the subject (we had to remove “all” the contamination) and the technical aspects (what does “all” the contamination mean as regards the radiological aspects?).

Also, not to create a precedent with a remediation goal that would be too restrictive.

Advantages: exposition lessened.

Limitations: more drawbacks than advantages for the environment (clearing, trucks on the roads with noise and CO₂ emissions).

Projected benefits: complete remediation, no more monitoring needed for the channel.

7. Remedy execution

Description of remediation activities/plan:

- target contaminants: Cs-137, Co-60, PCBs;
- technology descriptions: Dig and dump;
- time to completion: three months, due to very bad weather conditions;
- identified obstacles: bad weather that implied too much water in the channel.

Contract mechanism: call for tender (with one separated for the final survey).

Performance metrics: the final survey conducted with the MARSSIM approach showed that the channel complied with the release criteria.

27/06/12



20/07/12



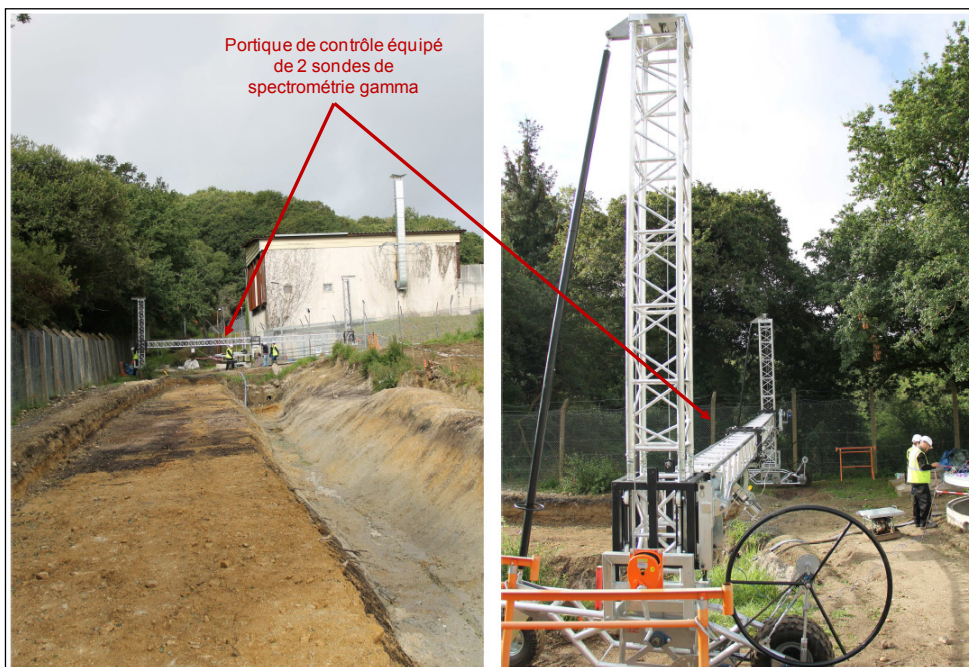
22/08/12



17/09/12



First part of the final survey



Final modelling of the channel (November 2012)



Vegetation recovering (June 2013)



8. Post remedial monitoring

No specific monitoring induced because the channel was completely remediated to the background level as shown by the final survey.

However, the rest of the site is monitored with a complete net of monitoring wells, so until the end of the decommissioning, there will be continued monitoring of the groundwater.

9. Major cost elements

Characterisation, planning, execution:

About EUR 2.5 M of contracts.

10. Lessons learnt

What went wrong? Delays due to the bad weather (nearly three months instead of a month and a half) that implied asking the authority for an extension of the authorisation; too much rain implied a sectioning of the channel in different areas and pumping the water; more waste than estimated (uncertainty in characterisation); we also had to find a solution to lessen the water content of waste, which implied no immediate evacuation of waste but a temporary storage onsite and addition of a desiccant material; we also had to manually sort the roots out of the excavated soils; and finally, because of radon, we had to change the type of storage containers for waste at the last minute.

What went right? Overall work occurred without incidents; Final survey was ok.

What could have been done differently? Less remediation regarding the very low initial impact of the channel that would have led to less waste sent to the nuclear waste facility and less impact to the environment (land clearing, many trucks on the road), so we would like to work on a methodology that could evaluate the sustainability of different remediation options; as regards waste, we should have involved ANDRA more at the beginning of the dossier.

Other lesson learnt:

- Despite the anticipation concerning species protection with different actions planned, 21 months before the beginning of remediation work, some difficulties were met with some stakeholders. Some supplemental meetings were needed to reach agreement.

11. References

SFEN – *Decommissioning Challenges > Industrial Reality and Prospects*, 7-11 April 2013, Avignon (France) – paper no. 13078 – *Brennilis decommissioning – The case of the treatment station and the discharge channel*.

Case Study – CS3

PIMIC rehabilitation project, CIEMAT

1. Contact information

2. Site background information

Site name: CIEMAT

Site location: Madrid, Spain

Site Description:

CIEMAT, formerly *Junta de Energía Nuclear* (JEN), was created in 1951 with the aim of promoting nuclear energy and its peaceful uses in Spain. The research Centre has 19.41 ha, with a total of 76 buildings. It is located in the north area of Madrid, close to a residential neighbourhood and the Complutense University of Madrid in the west part of a City Council protected park. Progressively, the construction of pilot plants linked to the nuclear fuel cycle was promoted, an exception to those related to the enrichment of natural uranium. Between 1951-1984, 59 nuclear and radioactive facilities were built related to benefit of uranium ore, radiochemical laboratories, fabrication of fuel for research reactors, two research reactors (JEN-1 and CORAL), hot cells, reprocessing plant for the spent nuclear fuel used in the JEN-1 experimental reactor, a laboratory for manufacturing and dispensing of isotopes for use in medicine, etc.

In the 1980s, the decade energy research policy changed and centre objectives opened to other energy resources. This fact, together with the obsolescence of facilities and laboratories, promoted a progressive dismantling (D&D) programme. At that time, from the regulatory point of view, CIEMAT became licensed as a nuclear facility formed by several nuclear and radioactive facilities each one with its own license approved by the Spanish Minister with the technical recommendations of the Spanish regulatory commission (CSN).

In January 2000, PIMIC project was created with the following objectives:

- D&D of discontinued nuclear facilities;
- D&D of obsolete radioactive laboratories in order to adapt them radiologically to the current legislation;
- Site restoration.

Dismantling issues are carried out in the PIMIC project by considering two administrative and reporting ways, which has led to a PIMIC project structured in two projects: called PIMIC-dismantling (PIMIC-D) and PIMIC-rehabilitation (PIMIC-R) projects.

PIMIC-D is performed under contract with Enresa (national radiological waste enterprise). It includes the JEN-1 reactor, reprocessing pilot plant, some located areas for remediation issues called Lenteja (main contaminants Cs-137 and Sr-90) and Montecillo (uranium mineral benefited dump) areas, and the liquid radioactive waste treatment pilot plant, all of which are physically close to each other and inside of an isolated area inside the security fence of centre with a specific fence and entrance check point.

The PIMIC-R project is managed directly by CIEMAT. Facilities included in this project were the fuel fabrication pilot plant, checking tanks for liquid waste control, laboratories related to uranium recovery from raw materials, radiochemical laboratories associated to pilot plants such as plutonium laboratories, and the Hot Cell facility, which are located all along the centre, even in buildings where conventional research laboratories work.

With the exception of hot cells, the main contaminants in this project are those coming from the first part of the fuel cycle (uranium radioactive chain), and non-natural alpha emitters (plutonium, americium) coming from research on extraction methods to be used in reprocessing, located in

obsolete laboratories and liquid control tanks. The PIMIC-R project included an extensive hydro-geological study of the centre.

- Regulatory status of the site:

CIEMAT is licensed as a “Unique Nuclear Facility” (UNF) formed by several nuclear and radioactive laboratories/plants each one with its own documents and license approved by the Spanish Minister with the technical recommendations of the CSN. The CSN is informed through monthly and yearly reports on activities of the labs/plant of the UNF.

The present objective of decommissioning is to move licence requirements from the UNF to a research centre with 30 radioactive laboratories commissioned one to one.

An industrial/educational use of site with building construction/maintains works (involving soils removal) has been proposed to CSN in order to define and get the approval of proper clearance limits to be used on remediation. Conservative approaches for clearance values have been considered.

3. *Clean-up agency/stakeholders*

Organisations: CIEMAT and Enresa (as the main contractor of CIEMAT)

Regulatory agencies: CSN

Regulatory regime/requirements (as opposed to general national regime): it is not clear what is meant here: Objective for clearance, type of facility from regulatory commission (i.e. nuclear, radioactive)

Local stakeholders: neighbourhood’s associations, university association, worker unions at the centre

- Support or opposition from stakeholders. Stakeholders are mainly in front of any activity related to radioactive material. Some of the worker unions support activities.
- Frequency of stakeholder meetings? Stakeholder meetings were established once a year. In addition, CIEMAT created a webpage to inform the public in real time on measurements performed from environmental monitors placed at the centre (close to D&D activities and in the external fence). Some errors were detected about “montecillo” contaminants on writing information in the new-format webpage that has not yet been modified. Stakeholders have been informed about this. A defined representative of stakeholders has direct connection with the CIEMAT General Director in order to get information on any questions associations will required between formal meetings.

4. *Characterisation*

Extent and methods: area covered by the centre. A hydrological study has also considered surrounding areas. Radiological characterisation was carried out considering grid of 5x5 m with portable monitors. Soil sampling by defined wells at several depths (0.50 m to 85 m)

Historical assessments: a specific report was written and updated to a close date by considering: descriptive reports from the laboratories/pilot plants and buildings, scientific reports explained research activities performed in the centre, questionnaires to retired workers.

Risk assessments: a hazards analysis was performed and provided to CSN for D&D licence.

Models used: MARSSIM approach

5. *Remedial objectives (are already indicated in other chapters?)*

Management success criteria

Remedial success criteria

Remediation standards

6. *Options evaluation*

Process used

Remedial selection criteria: soil removal until clearance level values in case of artificial nuclides.

Range of options considered: ?

Stakeholder involvement: they are informed as indicated above.

Effectiveness of evaluation process

Final selected remedy

Reason the remedy was selected:

- advantages;
- limitations;
- projected benefits.

7. *Remedy execution*

Description of remediation activities/plan:

- target contaminants;
- technology descriptions;
- time to completion;
- identified obstacles.

Contract mechanism

Performance metrics

8. *Post remedial monitoring*

Monitoring approach

Monitoring systems

Extent of monitoring (temporally and spatially)

9. *Major cost elements*

Characterisation

Planning

Execution

Post remedial monitoring

The main costs are related to characterisation, execution and waste management. Initial characterisation was more extensive than needed as the result of the stakeholder opposition and

specific location of the centre. Also, a lack of real/actualised information from old drainage systems and research activities performed in facilities made necessary a strong effort on site characterisation. In addition, centre evolution includes dismantling work in past with radiological criteria that have been reconsidered taking into account new regulation requirements (after 1999). Finally, it is a live research centre where the public and workers coexist at the same time that D&D activities are performed.

10. Lessons learnt

“What went wrong?” and “what went right?”

The release criteria and final status survey procedures were discussed with the regulatory body, which was very useful and positive to solve differences of criteria approaches. A comparative study of three potential future uses of the site: residential with private agriculture work, industrial, educational, including construction work (with huge soils removals) allowed for the definition of more realistic release values.

Site remediation and a final status survey are not yet finished. Decommissioning of a few facilities in the centre have been reached but soils are at present under regulatory control. Release methodology defined considers the application of the MARSSIM procedures. The MARSSIM procedures are complex to apply, although they provided a flexible and very useful approach. A few of released facilities as the pilot plant for fuel fabrication were 100% survey (buildings) due to pressure from workers and stakeholders. Later application of the MARSSIM approach was sufficient.

Difficulties found to carry out final radiological survey is the continuity of conventional research activities at the centre and the necessity of combining dismantling-restoration activities with research activities and new-facility construction.

The project cost and schedule are far from the initial estimation. Schedule delays mainly caused project cost, location (strong opposition from stakeholders), and definition of release values acceptable by regulatory body able to be technically achieved. Administrative regulation for contracts was also a reason for schedule delays.

One of main items to process optimisation is related to management of potential contaminated solids, which makes accurate cost and schedules. A combination of associated GPS/radiometric techniques with detailed characterisation (including vertical and horizontal testing wells) helps to define more accurate 3-D contamination maps. Therefore, it provides better definition of contaminated areas to be treated. Vertical probes are not sufficient to ensure a good approach, mainly in slopes. Definition of key nuclides from the initial characterisation step and the review of that inventory with samples analyses (Bq/g) is a key factor to process optimisation.

Other factors that should be taken into account are the very long time consumed and the expense of removing huge volumes of soil, as well as the management of low-level waste, very-low-level waste and at clearance level. Characterisation, management and temporary and final storage, if required, were the main reasons for the delay (cost and schedule). A better optimisation of the process could be achieved by testing in-situ methodology, constructions equipment proposed and real volume of solids produced (humidity and swelling factors) with a small real soil area. From results on the testing in situ, decisions were taken related to type/size of equipment, treatment of soils to reduce volume of waste (decontamination, segregation or removal to storage) and reduction of characterisation time. It also contributes positively to ALARA in terms of environment impact of restoration.

It remains to be properly solved how to demonstrate the absence of old and unknown contaminated non-metallic pipes in old facilities where historical reports do not exist or do not include many modifications performed during facility operation/maintenance and where workers are already retired.

Related to hydrogeological study performed, it has been discovered to be a useful tool to demonstrate the absence of contamination from the facility under study and the evolution/quality of work. A detailed study of the area concerning the surrounding geological area where the site is located, together with a detailed study of surface and underground water and groundwater characteristics allowed to define a grid of checking walls to test groundwater evolution. It is very useful to demonstrate to stakeholders the quality of performed work and the required absence of hazards.

11. References

Case Study – CS4

Windscale trenches, Sellafield

1. Contact information
2. Site background information

Site name Sellafield

Site location Cumbria, England

Site or project Description Windscale Trenches

Physical (size, land use, geology, groundwater/soil, contaminants, pathways, receptors: humans and biota, areas of special status: nature, conservation, etc.) The Sellafield site occupies six square kilometres and is located on the north-west coast of England on the margins of the Lake District National Park. The surrounding land use is predominantly agricultural with a number of farms and villages. There are two major surface water features present within and adjacent to the site, the Rivers Calder and Ehen, which join to the south-west of the site where they discharge into the Irish Sea.

- Operational (site history, former use, types of hazardous substances or wastes that were used, stored or disposed at the site)

The industrial history of the Sellafield site began in 1941 when it was developed as a Royal Ordnance Factory for the production of trinitrotoluene (TNT). TNT production ceased at the end of the Second World War and the site was cleared in 1946. In 1947, the site was acquired by the government as the location for Britain's plutonium production plant. The area developed for this purpose is now called the Separation Area and incorporates an area of approximately 31 hectares. In the early 1950s, the world's first civil nuclear power generation reactors (Calder Hall) were constructed on the opposite side of the River Calder from Separation Area and site development and expansion has continued since that time. With the exception of a prototype reactor built in the 1960s, this later expansion has largely been for the purpose of reprocessing spent nuclear fuel and the temporary storage of solid and liquid reprocessing wastes prior to vitrification, encapsulation and storage.

The Windscale Trenches within Separation Area were the main onsite disposal facility for solid radioactive wastes in the 1950s. They are unlined trenches that are thought to contain wastes that would be considered LLW today. There are no disposal records and so estimates of inventory have been made based upon factors such as the analysis of site processes and related contemporary documents, anecdotal evidence, and logical reasoning. Much of the original radioactive inventory is thought to be tritium associated with furnace liners and filters disposed following the Windscale fire; however, other fission products and actinides are also thought to be present and asbestos and solvents are amongst the probable non-radiological components of the inventory. There is also a reasonable possibility that small amounts of short-lived ILW may have been disposed.

There is uncertainty regarding the exact dimensions of the Trenches, but the plan area is approximately 7 000 square metres and the depth is approximately 5 metres. The Trenches are above the water table in the surrounding superficial deposits, which is at approximately 8 metres below ground level, and the sandstone bedrock underlying the site is approximately 25 metres below ground level and classified as a major aquifer.

Around 40-50% of the area thought to be associated with the Trenches has been partially reprofiled (to enhance surface drainage) and capped with tarmac. The tarmac composition was optimised to provide a loading surface for vehicle access and materials storage but is also thought to offer a substantial barrier against infiltration.

The remaining “uncapped” areas of the Trenches are either vegetated or simply covered with hardcore/tarmac, put in place for operational reasons without specific regard for protection of the Trench wastes.

The Trench cover was laid in a number of phases and varies in profile and makeup; the specifically capped area was designed and implemented in the early 1990s. There is an ongoing programme to maintain the surface of the capped area to ensure it provides a suitable base for operations (loading/lay-down, skip monitoring, construction yards, etc.). In places, in particular for the tarmac in the “uncapped” area, there are holes, cracks and ridges. The area is designated as a site “facility”, with associated restrictions on how the land is used (e.g. to avoid excavation or inadvertent intrusion into the Trenches).

The use of land above the Trenches to support site operations is an important issue. Space is at a premium in Separation Area of the site and the availability of working areas is essential for support to decommissioning programmes for higher-hazard facilities.

To the east, the area associated with the Trenches is bounded by a road that is a few metres below the capped tarmac surface, which might be indicative of the original ground level. To the west run the sea-line pipes and associated trenches. Potential interactions with these important site features present key constraints for restoration activities.

- Regulatory status of the site or project

In addition to the wider drivers for action from the perspective of Sellafield Ltd (i.e. to identify, reduce and manage liabilities and develop robust management plans), important drivers for the demonstration of optimisation in the management of the Trenches arise from the regulatory context.

Key considerations are Nuclear Site Licence Conditions 32 and 34, as well as environmental regulatory requirements, including those relating to the Groundwater Directive. Such considerations mean that, even though offsite risks are considered to be low, the potential for uncontrolled release of contaminants from the wastes to the unsaturated zone and groundwater beneath the Trenches requires the identification of an appropriate, proportionate management strategy to control their migration.

3. Clean-up agency/stakeholders

Organisations responsible for clean-up.

Nuclear Decommissioning Authority and Sellafield Ltd

Regulatory agencies with authority.

Environment Agency and Office for Nuclear Regulation.

Site-specific regulatory regime/requirements (as opposed to general national regime).

Local stakeholders:

- level of involvement in remediation project;
- support or opposition from stakeholders;
- frequency of stakeholder meetings.
 - Project drivers (valuable land re-use, programme risk mitigation, restoration planning, regulator or stakeholder concerns)

A stakeholder workshop was held concerning management options for the Windscale Trenches at the Sellafield site.

Workshop participants included representatives of the Sellafield Ltd project team, senior Sellafield Ltd management representatives, and other internal stakeholders. Representatives from Cumbria County Council, Copeland Borough Council, the West Cumbria Sites Stakeholder Group,

Sellafield Ltd’s independent land quality Peer Review Panel, the Environment Agency (EA) and the Office of Nuclear Regulation (ONR) were also in attendance. EA and ONR representatives attended as observers; they provided comment and challenge on matters such as process and interpretation of regulation, but did not actively contribute to the assessment or the resulting recommendations.

The main aim of the workshop was to reach a consensus on the preferred interim management options for the Trenches. The term “interim” is relevant as the focus of the study is on the management of the Trenches over the short- to medium-term, i.e. the next few decades.

There is uncertainty regarding the characteristics of the final end state for the Sellafield site, and the current assumption for when the end state will be achieved is 2120. Therefore, there is not a strong driver to achieve a final end state for the Trenches in the short- to medium-term, although it was recognised as important that the interim management approach should not unreasonably foreclose longer-term options. The primary requirement was to identify an interim management approach and demonstrate that it meets present-day Sellafield Ltd and regulatory requirements.

Participants recognised that the focus of the workshop should be on identifying and comparing management strategy options representative of an overall “direction of travel”, and that detailed optimisation of the preferred option and associated implementation plans would be undertaken subsequently. It was agreed that, while the workshop outcomes should help direct subsequent optimisation activities as far as possible, the focus was on achieving consensus on the overall strategy.

4. Characterisation

Objectives

Historical assessments

Sources

Risk assessments (degree to which they were used to determine project activities)

Models used (e.g. site conceptual models, dose or risk assessment models, etc.)

Quality assurance: Design, standards, guidance, approach, data quality objectives

Results (include plots of contamination)

Statistical methods used to interpret data

In the past, the Trenches were covered by a large mound of spoil material from other site operations. The weight of this mound has compressed the material in the Trenches sufficiently that it is very difficult to distinguish Trench wastes from consolidated soils by remote sensing. Two phases of geophysical surveys were undertaken with very limited success. Moreover, it has proved difficult to insert investigation probes into the material due to its dense nature.

There are upstream and downstream groundwater monitoring boreholes. Some shallow monitoring probes have also been inserted into the soil zones between the Trenches. However, no direct intrusive characterisation of the Trenches themselves has been undertaken to date. This is because there are thought to be components of the inventory that could present a significant hazard to remediation workers should they be encountered by, for example, drilling activities. Site safety authorities consider that the benefits of further characterisation would not outweigh these potentially significant health and safety risks (in other words, the ALARP case has not been made).

There are limited data on the performance of the existing tarmac cover and drains in preventing infiltration; however, one of the downstream boreholes showed a substantial reduction in tritium concentrations following emplacement of the tarmac. Other downstream boreholes did not show this reduction but for those boreholes the concentrations were already low.

Tritium contamination is observed in springs on the beach (i.e. adjacent to the Sellafield site) in a direction that is broadly consistent with the direction of groundwater flow to the south-west of the

facility. It is considered that the tritium is likely to be associated with a number of sources in Separation Area and it is thought that releases from the Trenches probably contribute to the observed concentrations. Even if the contamination were attributable solely to tritium from the Trenches, however, estimates of the radiological impacts that might be associated with the hypothetical ingestion of such waters are in any case very low. Modelling studies suggest that the offsite impacts of any future releases from the Trenches will continue to be negligible. However, the conceptual understanding that underpins the impact models suggests it is likely that, without intervention, there will be a continual release to groundwater, as a result of meteoric water flows through the Trenches and the associated release of radionuclides (including less mobile fission products and actinides) and other contaminants.

Calculations considering the potential risks to workers that might arise if intrusive remediation actions were to be undertaken suggest that the actinides and fission products other than tritium that are thought to be associated with the Trench wastes may present a notable hazard. There are also conventional safety hazards associated with the Trench contents (e.g. asbestos, solvents).

An important consideration in deciding whether to carry out further characterisation is the potential level of benefit that could be realised were intrusive characterisation to be undertaken. As the contents of the Trenches are believed to be very heterogeneous and their boundaries are not clearly known, any single investigation will only build confidence in understanding of the Trench contents in immediate vicinity of where an intrusion is undertaken. Little benefit from such investigation can therefore be anticipated in terms of improved confidence in performance, unless significant excavation was involved. Moreover, because the wastes are highly compacted and it is difficult to differentiate the trench contents from the adjoining ground, there is a risk that intrusions might actually create migration pathways.

5. Remedial objectives

Project success criteria (e.g. sale of land, groundwater protection, improved stakeholder confidence)

Remedial success criteria (e.g. clean-up of X acres of land to Y standards)

Remediation Standards (e.g. clean-up criteria, end state criteria, end uses)

6. Options evaluation

Process used to evaluate remedial options

Remedial option selection criteria

Range of options considered

Stakeholder and/or regulator involvement in options evaluation process

Effectiveness of evaluation process

Final selected remedy

Reason the remedy was selected:

- Advantages;
- Limitations;
- projected benefits of the chosen option.

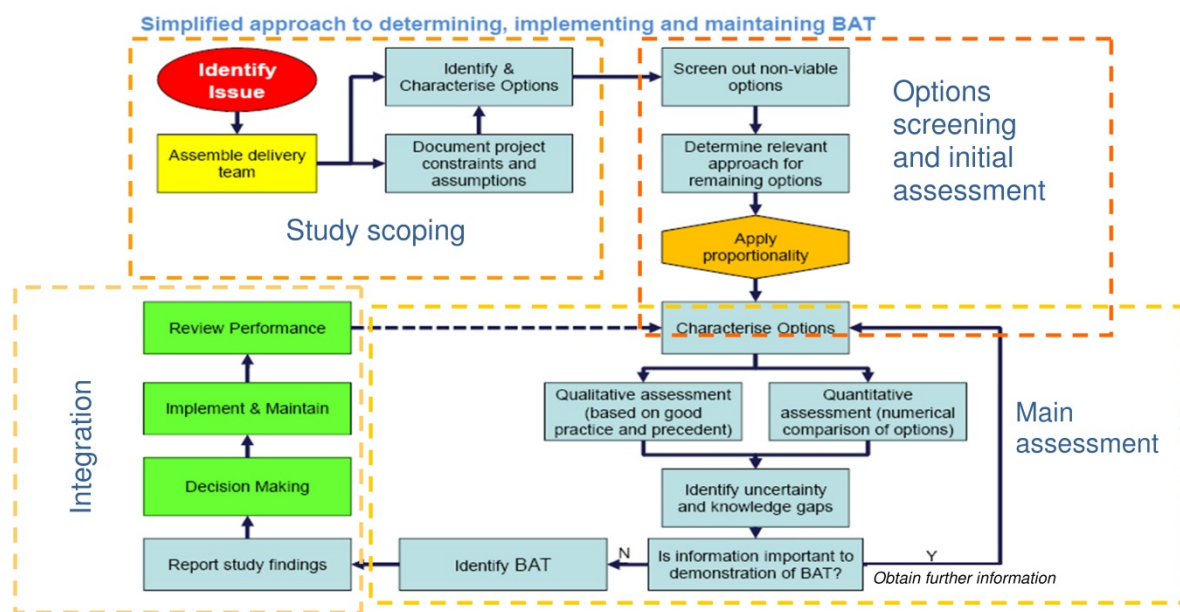
An annotated version of the BAT diagram developed for the Nuclear Industry Safety Directors Forum (NISDF, 2010) BAT “code of practice” was used to illustrate the relationship of key phases of the workshop process (see Figure 3). It was noted the workshop would cover scoping, options

screening and assessment phases (drawing on preparatory work undertaken by Sellafield Limited before the workshop). Formal integration of recommendations into site decision-making would occur after the workshop. In addition, the outcomes are expected to provide a substantial input to the business case to be developed for implementation of the preferred option.

It was agreed that the assessment process would follow a systematic approach, mapping key differentiators between options to identified criteria of interest. A largely qualitative assessment approach was agreed, to avoid being hindered by a fully quantitative “scoring” process that would be difficult to implement given the strategic nature of the analysis and the uncertainties involved. It was noted the qualitative approach is also flexible in so far as it could assist, if required, the assessment of hybrids or combinations of options that may together represent BAT.

A key requirement of the process concerns the appropriate management of uncertainty. It was agreed that it would be important to demonstrate the robustness of outcomes given key uncertainties. Understanding the ability of different options to deal robustly with uncertainties in knowledge and understanding is thus an important aspect of the assessment process.

Figure 3: Annotated version of the BAT “Code of Practice” diagram (after NISDF, 2010)



A set of credible management options was presented, drawing on information gained from a range of Sellafield-specific studies and the wider literature. In addition, a review of national and international experience of managing historical waste burials was presented. Examples were drawn from experience from countries including the United States, France and Australia.

A range of credible options were agreed, noting the outcomes of technology reviews and international experience. Options were characterised based upon answers to the following questions:

- What does this option comprise? (“What might I do?”).
- What are the primary benefits of this option? (“Why would I do it?”).
- Would it achieve its design aims? (“How confident can I be?”).
- How would its performance be demonstrated? (“How would I demonstrate it?”).

The resulting agreed options descriptions are summarised below.

- No change to current arrangements

This option reflects the current situation (i.e. a partial cap, supported by operational functions including monitoring and maintenance of the cap status, as well as onsite and offsite groundwater monitoring). The partial cap will continue to be used to support operations in Separation Area, noting appropriate standards and controls. The main benefits of this option are related to protection of a substantial proportion of the wastes from infiltration, whilst avoiding the operational disruption and other costs that might be associated with other options. However, it is recognised that the partial cap probably allows a greater degree of meteoric water infiltration through the non-capped area, which could present a potential risk of continuing releases of contaminants to the unsaturated zone and groundwater.

- Improved near surface management (enhanced or complete cap)

This strategic option covers a range of sub-options, from extension of the existing cap to cover the other areas over the Trenches that are not currently capped, through to complete re-grading and capping of the entire area associated with the Trenches, with the potential to include a waterproof membrane in its construction.

This option would enhance confidence that water flow through all the Trench wastes will be substantially reduced, which is important as meteoric water flow is the main vector for contaminant movement into the unsaturated zone and groundwater. In addition, a new tarmac area, if capped in an appropriate manner, would provide an extended quality surface that could be of value in supporting operations in Separation Area. Also, implementation of an extended (and/or enhanced) cap together with ongoing downstream monitoring might help to inform on whether the Trenches area remains a substantial source of tritium. More broadly, the response of the local groundwater to the cap will inform on the subsurface conceptual model.

There is substantial confidence that the required performance would be obtained if a complete cap is emplaced with a membrane layer. There is less certainty associated with extension of the existing cap, not least because its performance is not currently monitored. In discussion, it was noted that inspection of the existing tarmac area and the associated perimeter drains, coupled with analysis of its likely performance (via monitoring, test area analysis, and/or desk studies, for example) may be sufficient to provide the required confidence. A maintenance and monitoring plan would be required to provide continuing confidence in performance.

- In-situ stabilisation

This option considers the use of injection grouting to embed the wastes within a cementitious matrix, thereby “fixing” contaminants through chemical conditioning as well as presenting a barrier to water ingress, in order to minimise future release.

Another in-situ alternative, in-situ vitrification, was “screened out” at an early stage because:

- The wastes are too compacted to be easily vitrified.
- Heterogeneity of the wastes indicates that performance would be very uncertain.
- There may not be a sufficient silica content in the Trenches to produce the required glass melt.
- The energy demands would be very high.

Ex-situ vitrification is covered under the excavation options discussed below.

It was considered that a potential advantage of injection grouting was that it could contribute to providing a “final” solution, as well as an interim management approach. Alternatively, given the uncertainty regarding the final site End State, it is not clear whether in-situ grouting (i.e. with the implicit intent of leaving the wastes in place permanently) would be desirable. Nevertheless, grouted material would be easy to break up and remove if the final End State required it.

From a practical perspective, given that the Trench contents are already significantly compacted, it is likely it would be very difficult to inject the grout and achieve sufficient mixing for it to provide a functional chemical and physical barrier. Indeed, during recent investigation works, it proved

difficult even to insert investigation probes into the waste. Confidence in the successful outcome of the process is therefore quite low, which implies that a cap might also be required in order to have sufficient confidence in protection of the unsaturated zone and groundwater.

Undertaking grouting of a test area and digging out and examining the results might help to develop confidence in the technique, but would not provide overall confidence in the outcome for the Trenches in general because of the heterogeneity of the system. On-site experience suggests that remote sensing techniques such as geophysics would not be effective in confirming performance.

The lack of confidence in the ability of injection grouting to achieve or to demonstrate the desired performance led to this option also being “screened out” from further consideration.

- Groundwater pumping or treatment, or groundwater barriers

Vertical barriers intended to prevent or divert lateral water transport into or away from the Trenches were “screened out” on the basis that: a) lateral flows entering or leaving the wastes are low as the Trenches are thought to be located in the unsaturated zone; b) limitations to access, coupled with uncertainty in the lateral extent of the Trenches, mean that it is unlikely a barrier could be successfully emplaced in practical terms; and c) vertical barriers would do little to control the main vector for contaminant migration, which is the infiltration of precipitation into the wastes and subsequent vertical transport.

The focus of this class of groundwater control options is therefore on groundwater pumping, with subsequent treatment and/or discharge.

It was noted that it would not be easy to create a local groundwater depression sufficient to minimise future contaminant entrance to it. Indeed, it is conceivable that pumping could in fact lead to contaminants being drawn out of the wastes and into groundwater. A further concern is that the zone of depression could lead to de-watering and consequent de-stabilisation of land beneath vulnerable high-hazard facilities within Separation Area.

It was therefore agreed that this management option should be “screened out” from the current process, noting that it is likely to be addressed in connection with the planned subsequent study on site groundwater contamination management.

- Partial or complete excavation followed by waste treatment and storage and/or disposal

Comprehensive excavation of the Trench wastes, followed by sorting and segregation, waste treatment and subsequent storage and/or re-disposal elsewhere would offer the highest possible confidence in control of the source term. Not only would it provide an opportunity for immobilisation of contamination prior to long-term management using a facility built to modern standards, it would also enable full characterisation of the wastes, as well as facilitating the early achievement of a final solution for the Trench wastes that would be consistent with any potential site End State.

Partial recovery, targeting specific high-hazard disposals, would be a plausible sub-option if a sufficient understanding of the nature and location of disposals could be developed through characterisation work.

Excavation would not be a simple operation. Although the content of the Trenches is subject to uncertainty, it is nevertheless considered likely that the disposal inventory includes actinides, fission products and non-radiological contaminants that would present a potentially significant hazard to remediation workers. As the nature and location of these wastes is not known, a precautionary approach to excavation would be required that would involve workers wearing full protective clothing, the use of laboratory-style tented enclosures with air-changing operations, shielding etc. Such measures would reduce, although not eliminate, the possibility of workers being exposed to hazards. In addition, given uncertainty regarding the lateral extent of the Trenches, it is possible that excavations would need to extend up to the Sea Line trench; it would be important to ensure that there was no threat to discharge pipelines as excavations progressed.

Overall, even partial excavation would be a significant engineering operation, which would add to the major high-hazard decommissioning works ongoing within the confines of Separation Area.

The activities inherent in waste removal, characterisation, treatment and storage or re-disposal would involve a range of impacts, in addition to potential worker dose and conventional safety implications. These include energy use and transport requirements, including the need to transport the wastes offsite if storage/disposal capacity could not be found at the Sellafield site. If an offsite route were required, participants suggested that disposal of these wastes to the National Low Level Waste Repository would present a challenge to its capacity. Moreover, while treatment would reduce the environmental impact associated with the wastes, they would remain still present a hazard wherever they are re-disposed.

- Identification of preferred management strategy

A systematic qualitative assessment of the strengths and weaknesses of each of the remaining management strategy options against high-level criteria was undertaken. The aim of this analysis was to identify which of the options offered a net benefit in terms of protection of human health and the environment, and to then facilitate achieving a consensus view on which of these approaches represents the proportionate response to achieving these protection requirements.

Based upon the analysis presented above, the following options were taken forward for assessment:

- no change to current arrangements;
- improved near surface management (enhanced or complete cap);
- partial or complete excavation followed by waste treatment and storage and/or disposal.

The high-level criteria for assessment were agreed as follows:

- environmental Impact;
 - including aspects related to protecting against expansion of the waste store and impacts to groundwater; potential impacts to members of the public; generation of secondary wastes; resource use; management of the site working environment, etc.;
- health and safety;
 - conventional and radiological hazards to site workers and the public;
- technical performance and practicability;
 - confidence in ability to implement and to achieve the required technical performance; interactions with other site strategies and operations, and related constraints; timeframes for implementation; potential for benefit to other site operations; etc.;
- socio-economic impacts and security;
- cost.

A detailed set of sub-criteria was discussed. This was used to guide discussions, and provided an audit tool to ensure completeness of the analysis.

A consensus emerged among the workshop participants that it would not be disproportionate to adopt a management strategy based upon improving the current capping arrangements, given the associated benefits in terms of control of the source term and the potential practical benefits for wider operations in Separation Area. However, it was considered that complete removal of the existing cover above the northern end of the Trenches, to enable implementation of a full new cap, was likely to give rise to costs and a degree of disruption that would be disproportionate to the additional benefits achieved in terms of confidence in control, compared with extension of the existing arrangements. Moreover, it was considered important in the context of constraints on land

use within Separation Area that any cap should be able to provide a working surface in addition to a barrier to water ingress.

The basis of the preferred management option identified therefore involves the installation of a reprofiled and drained tarmac cap above those areas of the Trenches not currently capped, thereby providing an integrated single cap over the whole Trench area. Considerations to be addressed in ongoing optimisation concern the detailed design of the cap over the extended area (including, for example, whether it should incorporate a geomembrane barrier beneath the tarmac cover) as well as the possible potential for enhancement of the existing capped area.

It was considered that the necessary optimisation work would not represent a major strategic undertaking and that there would not therefore be a need for a further extended options workshop involving stakeholders. Once evidence has been collated that is sufficient to establish an optimised design and business case for the integrated cap, that evidence should be made available to relevant stakeholders, and a final decision made.

7. *Remedy execution*

Description of remediation activities/planned activities:

- contaminants to be targeted;
- technology descriptions;
- time to completion;
- identified obstacles/barriers.

Contract mechanism

Performance metrics

8. *Post remedial monitoring*

Monitoring approach

Monitoring systems/technologies

Extent of monitoring (temporally and spatially)

9. *Major cost elements*

Characterisation

Planning

Execution

Post remedial monitoring

10. *Lessons learnt*

“What went wrong?” and “what went right?” with respect to meeting regulatory requirements, stakeholder participation, agreement on conceptual models, project management, resourcing and organisation, project cost and schedules, project objectives and methodologies, dealing with uncertainties?

How did the technologies used perform against technical success criteria?

How did the project perform as a whole against success criteria and requirements?

What were the barriers to successful characterisation? What were the barriers to a successful project?

What were common issues leading to schedule delays?

How was the project aligned (or not) with any R&D priorities?

What could have been done differently?

Additional comments.

11. References

Nuclear Industry Safety Directors Forum, 2010. *Best Available Techniques (BAT) for the Management of the Generation and Disposal of Radioactive Wastes: A Nuclear Industry Code of Practice. Issue 1.*

Case Study – CS5

Uranium conversion facility, Daejeon

1. Contact information

2. Site background information

Site name: Uranium conversion facility

Site location: Daejeon, Republic of Korea

Site Description:

The uranium conversion facility, also known as the UCP (uranium conversion plant), was constructed in 1982. The UCP was used to manufacture 100 tonnes of UO_2 powder a year for the Wolsong-1 CANDU reactor. The conversion plant has a building area of 2 950 m² and two main conversion processes. ADU (ammonium di-uranate) and AUC (ammonium uranyl carbonate) processes are installed respectively in the rear and front of the building. In addition to the main plant, there is a lagoon that was used for the storage of waste process water. The lagoon is a rubber-lined concrete enclosure with an area of 760 m². The lagoon contained 300 tonnes (183 m³) of sludge waste, which consists of mainly nitrate salt and 1 wt% of natural uranium. The conversion plant was shut down in 1992 and minimally maintained for the prevention of a contamination by a deterioration of the equipment and the lagoon. The decommissioning programme was launched in 2001 and approved by the regulatory body in 2004. The project was completed in the first half of 2011 with a total budget of 12 billion Korean won (USD 12 million). The work scopes of the decommissioning project were the dismantling of all equipment, decontamination of the dismantled metal waste and concrete of the inside building, treatment of the lagoon sludge waste and decontamination of the lagoon structure, removal of the contaminated soil under the building. The final status survey of the building and the site of UCP were performed after confirming the removal of all radioactive materials; the site and its buildings will be reused for unrestricted use.

The policy and strategy of the decommissioning project:

- immediate decommissioning;
- unrestricted release of the site and building from regulatory control upon completion of decommissioning;
- minimisation of decommissioning wastes;
- preparation for the upcoming decommissioning of large nuclear facilities through the development of related technologies;
- transference of decommissioning techniques and experiences to industries.

Regulatory status of the site:

In the Nuclear Safety Act and its Enforcement Decree and Regulations, it is clearly defined that the operator of a nuclear facility, when intending to decommission a nuclear facility, shall submit a decommissioning plan and obtain decommissioning approval from the Nuclear Safety and Security Commission (NSSC). A decommissioning plan shall include the following:

- a method of decommissioning and work schedule of the nuclear fuel cycle facility;
- a method of removal of radioactive materials and contamination caused by radioactive material;
- a method of treatment and disposal of the radioactive waste;
- measures necessary for preventing any hazards caused by radiation;

- evaluation of the impact of radioactive material, etc. on the environment, and the countermeasure;
- the quality assurance programme with respect to the decommissioning of the nuclear fuel cycle facility;
- other matters as determined by the commission.

National regulations or policy on nuclear site remediation can also be considered with the regulations relevant to the decommissioning of the nuclear facility. The Korea Institute of Nuclear Safety (KINS) is developing the technical standard for the reuse of site and building of nuclear facility after decommissioning throughout the regulatory experience on the decommissioning of KRR-1, 2 and the UCF.

3. Clean-up agency/stakeholders

Organisations: KAERI (Korea Atomic Energy Research Institute)

Regulatory agencies: Nuclear Safety and Security Commission (NSSC) and Korea Institute of Nuclear Safety (KINS)

Regulatory regime/requirements (as opposed to general national regime):

Local stakeholders: Regulatory body, Ministry of Education, Science and Technology

Support or opposition from stakeholders? Support the decommissioning activity with safety manner

Frequency of stakeholder meetings? The decommissioning status was reviewed by the regulatory body once a year. The scope of inspection of the decommissioning status was waste management, radiation protection and measurement, environmental monitoring, fire protection and QC, etc. based on the Atomic Energy Safety Act.

4. Characterisation

Extent and methods: The UCP located in the KAREI site, hydrological status was surveyed by core boring around 20 m from the surface, radiological characterisation survey also carried out based on the MARSSIM method for the site and building. The main contaminant at the site and buildings was natural uranium. The dose rates were measured with survey metres (2 inch NaI) connected with a GPS (Global Positioning System) during the scoping and characterisation survey, and the measured data were used for detecting the existence of hot spots and predicting the soil and building contamination levels. Several soil samples around site and reference area (background area) were collected and analysed at each survey unit of the site and building, to identify the subsurface contamination 10m depth from the surface was sampled. Historical assessments: review radioactive material licenses, site operational records and interviews of retired workers. Identify additional potential radiation site related to the site being investigated from the collected information.

Risk assessments: the release dose criteria recommended by the IAEA were between the dose constraint (300 $\mu\text{Sv/y}$; a portion of dose limit) and a trivial dose range (~ 10 $\mu\text{Sv/y}$). The release criteria had not been established in Korea, but KAERI proposed a dose based release criteria of 100 $\mu\text{Sv/y}$ by considering the future unrestricted use of the site and the urbanisation of the surrounding area. The regulatory body also recommended the same value of criteria. The site-specific DCGL (derived concentration guideline level) was calculated for the UCP site and building by using RESRAD and RESRAD-Build codes separately.

Models used: MARSSIM methods

5. Remedial objectives (are already indicated in other chapters?)

Management success criteria: dose based release criteria of 100 $\mu\text{Sv/y}$ by considering the future unrestricted use of the site and the urbanisation of the surrounding area. The site-specific DCGLs (Derived Concentration Guideline Level) was 10.01 Bq/g for site and 440.5 dpm/100 cm^2 for building respectively.

Remedial success criteria: the same value was adopted.

Remediation Standards: the recommended value of the regulatory body is 100 $\mu\text{Sv/y}$.

6. Options evaluation

Process used.

Remedial selection criteria: 10.01 Bq/g for site and 440.5 dpm/100 cm^2 for building respectively for natural uranium.

Range of options considered: only consider unrestricted use scenario.

Stakeholder involvement: the suggested release criteria was reviewed before final status survey effectiveness of evaluation process.

Final selected remedy.

Reason the remedy was selected:

- advantages;
- limitations;
- projected benefits.

7. Remedy execution

Description of remediation activities/plan

- target contaminants: 10.01 Bq/g for site and 440.5 dpm/100 cm^2
- Technology descriptions: distribution of the contamination soil under the building was surveyed and was contaminated down to 6m from the ground. The contamination was diffused in a flow direction of the underground water. Underground water around the uranium conversion plant was not contaminated based on the surveyed result which is below 10ppb. All contaminated soil wastes were removed down to 5.8 m from the ground. Soil under the base of a column was also contaminated and the column base was reinforced to the support building. A total of 1 600 m^3 of soil waste was generated and stored in a large scale soil waste container.
- Time to completion: sufficient time and budget are required after decommissioning work to carry out a final survey in preparing for an unexpected contamination.
- Site remediation and final status survey: USD 2.5 million.
- Duration: about two years (2009.3 – 2011.2).
- Identified obstacles: our company decided to reuse the building. Reinforcement of the column based to support the building was required.

Contract mechanism:

- Direct contract to the engineering company specialised tasks such as core boring, remediation, ground water monitoring etc., but the final status survey was carried out by KAERI.

Performance metrics

- The results of final status survey could comply with the release criteria successfully. The FSSR (report) was authorised from the regulatory body. The first challenge is the release of the site and building after decommissioning.

8. Post remedial monitoring

Monitoring approach: The site located in the KAERI site where the research reactor and hot-cell laboratories etc., are located. The environmental radiation monitoring was carried out continuously with other nuclear facilities.

Monitoring systems: Measurements of environmental radiation: radiation dose measured by ERM and TLD in the range of the radius of 30 km from the site. The environmental radioactivity on gross α and β uranium, H-3, Sr-90 and gamma radionuclides were analysed in the various samples (soil, air, water, etc.).

Extent of monitoring (temporally and spatially).

9. Major cost elements

Characterisation

Planning

Execution

Post remedial monitoring

Main costs are related to reinforcement work of column in building, removal of contaminated soil and waste management.

Cost: Total decommissioning project: USD 12 million, site remediation and final status survey: USD 2.5 million.

Duration: site remediation and FSS (final status survey) about 2 years (2009.3 – 2011.2).

10. Lessons learnt

“What went wrong?” and “what went right?” with respect to meeting regulatory requirements, stakeholder participation, agreement on conceptual models, project management, resourcing and organisation, project cost and schedules, project objectives and methodologies, dealing with uncertainties?

After all dismantling and decontamination works are completed, the final radiological status of the building and site should be surveyed and evaluated for release site. The project period was extended two years from the initial planning due to unexpected soil contamination under the building. The importance of the characterisation survey cannot be overestimated for a decommissioning project. Sufficient time and budget are required after decommissioning work to carry out a final survey in preparing for an unexpected contamination.

KAERI contracted with an engineering company organised a consortium with three subcontractors for the decommissioning of the UCP. The consortium consisted of engineering,

radiation safety and radiation detection, waste management and quality assurance, and dismantling and decontamination. However, proper special worker were not used and work efficiency was low at the initial stage. Workers could be trained onsite. Although training of experts is needed, there are only a few nuclear facilities to be decommissioned now.

How did the technologies used perform against technical success criteria?

The release criteria and final status survey procedures were not established in Korea. Site remediation and a final status survey for a release site and building were carried out by applying the MARSSIM procedures. The MARSSIM procedures were complex to apply, but it provided to be flexible, scientifically rigorous, and cost effective for final status survey after decommissioning the site and building.

How did the project perform as a whole against success criteria and requirements?

What were the barriers to successful characterisation? What were the barriers to a successful project?

What were common issues leading to schedule delays?

How was the project aligned (or not) with R&D priorities?

What could have been done differently?

Additional comments.

11. References

Case Study – CS6

Fuel assembly plant, Hanau

1. Contact information

2. Site background information

Site name: fuel assembly plant

Site location: Hanau, Germany

Site Description:

At the former NUKEM fuel assembly plant in Hanau, development and production of fuel assemblies for research reactors and HTR were done. The activity that was handled at the site included U-235 with different grades of enrichment (depleted uranium as well as highly enriched uranium) as well as Th-232. The facility was operated with a license according to the German Atomic Energy Act.

The site is situated near the city of Hanau (in the city region of Frankfurt, Germany) in an urban area and forms part of an industrial estate. Industrial activities at the site, including explosive production, started within the 1870th. The industrial estate includes another nuclear facility (500 m north-west of NUKEM) which is now also under decommissioning.

The fuel fabrication facility at NUKEM was operated between 1956 and 1988. Activities started in 1956 with test and development activities for handling uranium metal, uranium oxide, uranium carbide and thorium oxide powders, tablets and spheres as well as UF₆ conversion. Development and production of fuel assemblies for research reactors and HTR started in 1960.

In 1988, all physical development and production activities were stopped. The final closure and decommissioning was applied for at the competent authority, the Environmental Ministry of Hesse (*Hessisches Ministerium für Umwelt, ländlichen Raum und Verbraucherschutz*). TÜV Süd Industrie Service (now TÜV-Süd-AG) was authorised as expert for evaluation within the process in 1989.

Permission for decommissioning according to the German Atomic Energy Act was granted in 2000. The first step within the decommissioning process was the decommissioning of the components and the demolition of the buildings. Soil remediation started in 2001, groundwater remediation in 2002.

One of the major activities at the site has been the development and production of fuel assemblies for research reactors. For that purpose, uranium was handled in metallic, oxide, and carbide chemical form. The grade of uranium-235 enrichment was highly variable. For tests and development, depleted uranium (uranium-235 content less than 0.7%) was used. Fuel assemblies were made with higher grades of enrichment including HEU (uranium-235 content higher than 20%, for special research applications higher than 80%). No uranium from reprocessing has been used. This means, artificial uranium isotopes like uranium-232 and uranium-236 were not found at the site. Transuranic isotopes, like plutonium-239 and americium-241, were only found with very low activities. These contaminations are possibly caused by the use of impure material within the 1960th or channel leakage from the enclosing sites (where also MOX material was used). Transuranic isotopes have no relevance as chemical or radiological contamination at the site.

The fuel assembly production at the site included UF₆ conversion using organic chemicals. Scrap and process water treatment at the site was combined with the occurrence of uranium nitrate.

Fuel assembly production for high temperature reactors (HTR) was also done at the site. Therefore, thorium (isotope thorium-232) oxide was handled.

Regulatory status of the site: 1988 all physical development and production activities were stopped. Permission for decommissioning according to the German Atomic Energy Act was granted in 2000. After successful remediation in 2008, clearance was declared by the supervising authority for the whole area except for 1 000 m², which are still in use for groundwater pump-and-treat facilities.

3. Clean-up agency/stakeholders

Organisations: RD-Hanau GmbH (former NUKEM-GmbH)

Regulatory agencies: *Hessisches Ministerium für Umwelt, ländlichen Raum und Verbraucherschutz* (state ministry, HMULV), TÜV-Süd-AG (former TÜV Süd Industrie Service) as expert for evaluation authorised from the regulatory agency.

Regulatory regime/requirements (as opposed to general national regime).

Local stakeholders: *Industriepark Wolfgang GmbH* (operator of the industrial estate), regional water authorities, City of Hanau, public hearing during the licence process.

Support or opposition from stakeholders?

Frequency of stakeholder meetings? Very frequent meetings between the owner and experts for evaluation at project start and during demanding project phases (temporary office at the site), meetings with regulatory agency were held when required (frequently), a few general meetings (including *Industriepark Wolfgang GmbH* and regional water authorities) on special topics.

4. Characterisation

Extent and methods: Geological and hydrogeological site characterisation was done by core drilling, geo-electrical survey and groundwater level monitoring.

The soil at the site is influenced by urban activities. A major part of the topsoil is backfilling material (sand and gravel up to depths of 1 m). The natural underground is formed by sand and gravel sediments with inclusions of silt structures.

The saturated zone starts at 2.5 m below surface with seasonal variations of about 0.5 m. The top aquifer thickness is approximately 10 m. The hydraulic conductivity is high (approximately 10-3 m/s). Groundwater at the top aquifer is flowing from east to west with an average flow velocity of 1 m/day. Silt-structures with lower hydraulic conductivity cause local variations of groundwater flow direction.

At the beginning of the concept development phase, an extensive land contamination screening (more than 100 drillings at depths between 2.5 and 10 m) was performed. Activity measurements were done by gamma-spectrometry (uranium-235). For a huge number of samples; also, nuclide composition of uranium was measured by mass-spectrometry. Major uranium contamination was found in the topsoil. Minor uranium contaminations were also found in deeper sediments. The remediation area was expected to have a size of 11 000 m².

Natural uranium background in the soil material is about 3 ppm (isotope activity: 0.041 Bq/g for uranium-234 and uranium-238 and 0.0019 Bq/g for uranium-235). Uranium background in the groundwater is less than 1 µg/l (detection limit), corresponding to an activity of less than 0.012 Bq/l for uranium-234 and uranium-238 and less than 0.00062 Bq/l for uranium-235. Thorium background in the soil material is about 3 ppm corresponding to an activity of thorium-232 of 0.012 Bq/g.

The isotopes of interest during the decommissioning process have been:

- uranium-234 (radiological impact, most important);
- uranium-235 (chemical impact);
- uranium-238 (chemical and radiological impact);
- thorium-232 (radiological impact, minor importance).

Uranium found at measurements within the decommissioning process had a uranium-235 content between 0.5% and 20%. An activity ratio of 20 between uranium-234 and uranium-235 was measured for sediment and water samples as well (more than 2 000 measurements with no evidence of different ratio).

Two major pathways for soil and groundwater contamination have been identified:

- Contamination of topsoil was caused by deposition of variable soluble material on surface. The uranium found within the topsoil is slightly soluble (soluble part approximately 5% of total

uranium). Soluble part of uranium undergoes moderate sorption on sediment material (measured K_d -value in the range of 5 to 10 cm^3/g). The thorium found in topsoil is not soluble; therefore, thorium is nearly immobile there.

- Contamination of deep soil and aquifer material was caused by waste water channel leakage. Uranium contaminations from that pathway were highly soluble causing also a significant groundwater contamination. Minor thorium contaminations were found outside of waste water channels but located in the immediate surroundings of the channels. No thorium groundwater contamination was measured.

Additional chemical contaminations (non-aquatic liquid phases, NAPL) with impact on soil and groundwater remediation are relicts from historical industrial use.

Based on the results of contamination screening, areas of different soil excavation depths were planned.

Historical assessments:

Risk assessments: If the found soil contamination in an area was higher than expected, additional contamination screening in the surrounding area was performed. During this screening, the area of suspected contamination was extended from 11 000 m^2 to 32 000 m^2 . The larger extension of the contamination, which is a key parameter for activity criteria calculation, made it necessary to adapt the activity criteria. A few more key parameters were adjusted as well (especially the activity ratio between uranium-234 and uranium-235 was lowered to 20 and areas of zero contamination were considered). Finally, the site average activity remediation criterion for uranium-235 was lowered to 0.0040 Bq/g (including natural background of 0.0019 Bq/g).

Remediation activity criteria (for soil and groundwater) were reviewed considering uncertainty (the largest uncertainty came from area averaging method). Uncertainty estimation was independently done by the operator and by the expert for evaluation.

Models used: no standard models have been used, dose calculation was done on the basis of general administrative provisions to § 47 German Radiation Protection Ordinance, use of groundwater flow and transport models for development of groundwater remediation criteria, use of different spatial averaging methods (including Kriging) for average calculation and uncertainty estimation

5. Remedial objectives (are already indicated in other chapters?)

Management success criteria: conformance with remedial success criteria, approvable by the authorised expert for evaluation.

Remedial success criteria: Buildings: decontamination of building surfaces according to German Radiation Protection Ordinance Appendix III, Table 1, column 10 (buildings for demolition)

Soil: according to the found contamination spectrum, the most restrictive radiation exposure pathway was postulated to be the use of contaminated drinking water and the irrigation of crops by contaminated water. A minor exposure pathway was postulated to be the reuse of contaminated soil for backfilling during construction.

Considering the geological and physical site characteristics dose criteria were compiled into activity criteria: 0.0052 Bq/g uranium-235 on average over the remediation area average (to meet the criteria on drinking water and irrigation exposure pathway) and 0.0160 Bq/g uranium-235 on average over each 25 m^2 area (to meet the reuse of material exposure pathway).

These uranium-235 activity criteria include a natural background of 0.0019 Bq/g. A constant activity ratio of 30 between uranium-235 and uranium-234 (a conservative overestimation value found during decommissioning) and an average uranium-235 content of 5% within the contamination is assumed. Remediation activity criteria could be used for sediment concentration within the unsaturated zone only.

The development of remediation activity criteria for saturated zone turned out with average values, very close to natural background. Such remediation activity criteria were not usable. For the remediation of saturated zone, the following concept was used:

- removal of sediment material with higher contamination;
- compliance of dose criteria by pump-and-treat groundwater remediation;
- development of a remediation activity criteria for groundwater.

Groundwater: total uranium activity of 2.4 Bq/l averaged over 30 measurement points distributed over an area of 10 000 m² and a period of (a minimum) one year of natural groundwater flow (no pumping activities).

Waste: Excavated soil and building rubble could be classified for disposal (underground mine) when activity did not exceed 0.186 Bq/g for uranium-235 or 0.300 Bq/g for thorium-232. Values were developed to ensure 10 µSv/a criteria for transport and mine workers as well as for the public in the area surrounding the mine.

Material with higher activity (considering summation formula) had to be classified as radioactive waste.

Remediation standards: in accordance with § 29 of German Radiation Protection Ordinance, any decommissioning of facilities licensed under the Atomic Energy Act must fulfil the 10 µSv concept. This means that remaining activities must not lead to a dose of more than 10 µSv per year to any concerned member of the public. Unrestricted use (except direct agricultural use of the area) was considered. There have been controversial discussions about the exclusion of direct agricultural use pathway between HMULV and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). As a result of such discussions (also done for other sites), § 29 of German Radiation Protection Ordinance was adapted 2011 (more focus on unrestricted use) by succession of BMU. HMULV clearance declaration, based on 2006 version of § 29 of German Radiation Protection Ordinance persists.

6. Options evaluation

Clearance according to § 29 of German Radiation Protection Ordinance (Requirements for Clearance) is currently the only possible way to handle remediation of sites under the Atomic Energy Act licence. That means no options for restricted use and no options for dose criteria can be considered. An ordinance for legacies from sites under Atomic Energy Act licence does not exist in Germany (for political reasons).

Process used

Remedial selection criteria.

Range of options considered: Option evaluation was limited to technical aspects of the remedy execution.

Stakeholder involvement: major technical aspects of remedy execution were defined within an official instruction and operation manual. This manual and any changes to it had to be approved by the regulatory agency. Deconstruction and excavation activities had to be co-ordinated with *Industriepark Wolfgang GmbH* and approved by public construction authority. Excavation activities had to be approved by Explosive Ordnance Disposal Service (survey for unexploded ordnance from World War II, especially for aerial bombs, was necessary before excavation could start). Groundwater pump-and-treat activities have to be licenced from regional water authorities.

Effectiveness of evaluation process

Final selected remedy.

Reason the remedy was selected:

- advantages;
- limitations;
- projected benefits.

7. Remedy execution

- Description of remediation activities/plan

Target contaminants: uranium (major), thorium (minor)

Technology descriptions: **Soil remediation** started with excavation of the areas planned within the remediation concept. Classification of excavated material was done by a conveyer detector. Charges suspected as radioactive waste by the conveyer detector were separated and filled into drums. Filled drums were measured again by an approved drum scanner. Results from the drum scanner were used for final classification. Filled drums, not classified as radioactive waste were disposed in the underground mine. During removal of aquifer material (see subchapter, Adaption of Remediation Concept), conveyer detector measurements could be compared with gamma-spectrometry analysis of representative samples.

Sediment removal within the saturated zone was a technical challenge. Lowering of water table or the use of sheet piles was not possible in order to avoid damages to existing buildings. At least barrel drilling and backfilling of each single drill hole was successfully used.

During remediation, 7 600 Mg of building rubber, 87 000 Mg of soil and 9 600 Mg of aquifer sediment material was removed and stored in an underground mine. It is estimated that the removed material had a total uranium content of 480 kg including 19 kg of uranium-235 (average uranium-235 content of 4%). The average remaining uranium-235 activity within the soil was estimated to be 0.0035 Bq/g.

A remaining volume of 700 m³ (approximately 1300 Mg) was classified as radioactive waste, including 300 kg of uranium in total (12 kg of uranium-235).

Groundwater remediation (pump and treat) was started in 2002 at two wells with a permitted rate of 5 m³/h. At this time, a chemical remediation criteria (20 µg/l) was defined by water authorities to meet at every monitoring point. Additionally, criteria for NAPL concentration were defined. A periodic groundwater monitoring was started with about 15 monitoring points. Contaminated water treatment was done using ion-exchange technology. In 2006, the permitted pumping rate was raised to 10 m³/h with four remediation wells in use.

In 2008, a radiological remediation criteria (total uranium activity of 2.4 Bq/l averaged on an area of 10 000 m²) was suggested by the site owner and approved by the controlling and regulatory authority.

In 2009, the permitted pumping rate was raised to 15 m³/h in combination with the implementation of a second water treatment facility. At the end of 2012, ten pumping wells were available. Pumping is done alternating at four or five of these wells.

At the end of 2012, about 750 000 m³ of groundwater had been pumped and treated at two facilities. 31 kg of uranium in total, including 2 kg of uranium-235 (average uranium-235 content of 6.4%) were removed from the pumped groundwater. In 2012, an average uranium concentration of 22 µg/l was found with a uranium-235 content of 2.6%.

Time to completion: soil remediation between 2001 and 2004 (2006 for minor areas), remediation of saturated zone between February and May 2004, groundwater remediation between 2002 and 2015 (expected), the classified radioactive waste is stored in an interim storage facility at the site for later shipment (not before 2019, but probably later) to the German low- and intermediate-level waste repository (Konrad).

Identified obstacles:

Contract mechanism: employment of NUKEM-staff (decreasing number with project progress), contracting to the different engineering and consulting companies (excavation, drilling, groundwater monitoring, measurements, concept developing, reporting).

Performance metrics

8. *Post remedial monitoring*

Monitoring approach: groundwater remediation and monitoring is still ongoing at the site, monitoring is done by a consulting company, monthly reporting of measurement results, 3-monthly detailed reporting to the regulatory agencies (HMULV and water authority).

Monitoring systems: 2012: monthly monitoring of uranium concentration and 3-monthly monitoring of isotope activities is done at 30 points, at additional 20 points a supplementary monitoring is done (3-monthly, 6-monthly, or yearly).

Extent of monitoring (temporally and spatially) monitoring started in 2002 with 15 monitoring points (3-monthly) and was extended in several steps to the 2012 scale.

9. *Major cost elements*

Characterisation

Planning

Execution

Post remedial monitoring

Main costs are related to removal and storage of contaminated soil and building rubble and the storage of radioactive waste. Total costs > EUR 100 million

10. *Lessons learnt*

“What went wrong?” and “what went right?”

The first estimations of amount of soil to be excavated were too low. Plans for refilling of excavated material at the site were not realisable. Waste water channels had been shown as major contamination sources.

The use of conveyor belt for classification was very helpful.

The very low remediation activity criteria in combination with the natural occurring nuclides (activities close to the averaged activity criteria) made remediation a very challenging task. A significant part of underground stored activity is therefore natural activity. The complex site situation and the challenging remediation criteria made it impossible to use a generic remediation strategy and generic remediation criteria. An ordinance for legacies from sites under the Atomic Energy Act licence would be very helpful.

Disposal of excavated soil and building rubble at underground mine worked well. However, it would no longer be possible for that special mine (for political reasons, the mine no longer accepts material from restricted clearance). Disposal of material from restricted clearance is becoming more difficult in Germany (dwindling acceptance from disposal facilities). The increased focus on unrestricted clearance for sites make such projects even more challenging. The project has shown that decommissioning on that scale is not only a technical challenge but also a political issue.

How did the technologies used perform against technical success criteria?

How did the project perform as a whole against success criteria and requirements?

What could have been done differently?

Additional Comments:

See lessons learnt.

11. References

Lothar Hummel, Olaf Nitzsche, Sonja Margraf: *Sanierung und Freigabe des Geländes der ehemaligen Brennelementefabrik NUKEM- A Veröffentlichungen der SSK Band 65: Interventionen und Nachhaltigkeit im Strahlenschutz*, ISBN 978-3-87344-159-0.

Olaf Nitzsche, Stefan Thierfeldt, Lothar Hummel. *Remediation of Subsurface and Groundwater Contamination with Uranium from Fuel Fabrication Facilities at Hanau (Germany)*, Proceedings of the 15th International Conference on Environmental Remediation and Radioactive Waste Management, ICEM2013, September 8-13, 2013, Brussels, Belgium (in preparation, accepted for publication).

Case Study – CS7

618-10 Burial Ground – Hanford Site – Washington, United States

1. Background

The remediation of the 618-10 Burial Ground at the US Department of Energy Hanford Site presents unique and unparalleled challenges with respect to waste characterisation, retrieval and packaging for disposal. The 618-10 Burial Ground is located approximately 10 kilometres north of the city of Richland and approximately 400 metres upwind of the primary Hanford Site highway. It was activated in March 1954 and closed in September 1963. The 618-10 Burial Ground contains waste generated primarily from Hanford's 300 Area, where fuel metallurgical analysis was performed and new methods were developed to separate plutonium from nuclear fuel. These wastes consisted of metallurgical sample residues, samples from experiments and other very high dose rate, high alpha contamination wastes. The 618-10 Burial Ground encompasses an area of approximately 30 000 m². It contains burial trenches of various sizes approximately 94 vertical pipe units. The burial ground received a broad spectrum of low- to high-activity, dry, radioactive waste. The waste is primarily contaminated with fission products and plutonium. The trenches received low level waste in cardboard boxes; concreted drums and large miscellaneous items. Higher activity waste held in cans was remotely dropped into the vertical pipe units.

2. Geophysical surveys

Extensive geophysical survey data in 618-10 trenches have been collected during previous mapping activities at the site. The geophysical work included detailed ground-penetrating radar and magnetometer surveys. The results of these activities were documented on site maps using global positioning system-generated co-ordinates.

3. Nonintrusive characterisation

Nonintrusive characterisation activities were designed to provide data and information needed for planning future intrusive characterisation activities and remediation strategies for the 618-10 Burial Ground. Geophysical surveys were performed to locate each of the vertical pipe units and centrelines of the trenches. In 2009, the vertical pipe units and trenches were evaluated using an in-situ radiological multi-detector probe through sealed, metal-cased penetrometer points located just outside each of the vertical pipe units and within the boundaries of each trench structure. Also, approximately 10% of the vertical pipe units were selected as locations for soil sampling, from below each of the selected VPUs. The detectors were specified to measure a broad range of possible waste radiation types and activity levels through the wall of the steel penetrometer casing. The results indicated that a large percentage of vertical pipe units could be classified as transuranic, depending on waste source assumptions. The results of the trench sampling were valuable to note "hot spots". Ten soil samples from below vertical pipe units were analysed for chemicals and radionuclide activity. No radiation levels above background and no chemical constituents of interest were found in any of the soil samples.

4. Intrusive characterisation

After nonintrusive characterisation, the total number of buried drums and the nature/variability of their contents remained unknown. Therefore, an intrusive characterisation of the 618-10 burial ground trenches was performed in 2010. The intrusive characterisation involved digging across select trenches based on previous geophysical studies, analysing soil from each cross-trench and collecting samples of waste material to catalogue waste types, distribution and quantity from within the

trenches selected. Excavation locations were focused in the 618-10 Burial Ground areas that were most likely to have buried drums present based on historical records and geophysical survey results. Another goal of intrusive characterisation was to determine if waste form knowledge was sufficient to support design solutions and methods for remediation of 618-10 burial ground trenches.

Intrusive characterisation provided needed data and information on the various waste types, quantity, level of contamination, condition and retrievability of the waste materials in the 618-10 burial ground trenches. The activity was also valuable to validate the geophysical investigations performed at an earlier time as far as approximate waste locations. However, geophysical data proved to be a poor indicator of drum locations. In some cases, the presumed waste contents and actual contents of individual trenches varied widely. In other cases, the actual trench contents were similar to what was presumed.

5. *Burial ground remediation*

Remediation of the 618-10 Burial ground trenches began in April of 2011. As of August 2013, approximately 108 000 tonnes of contaminated soil and 514 drums of waste have been removed from 618-10 and disposed. This represents approximately 42% of the trench area. Lessons learnt during remediation have led to modifications in approach to problematic waste streams. For example, the volume of bottled waste necessitated the development of a method for “in-trench” treatment. Also, methods for processing potentially pyrophoric uranium oxide drums are under development.

Removal of contaminated soil and debris from the 618-10 trenches is scheduled for completion at the end of 2014. Vertical pipe unit remediation will follow the trench remediation and is scheduled to be complete by the end of September of 2018. The planned remediation methods for the VPUs involve mixing the waste with soil using an auger below ground for personnel and environmental safety. After mixing, low-level waste will be stabilised with cement and excavated for disposal. Potential transuranic waste will be containerised and stored at the Hanford Central Waste Complex for future disposition.

618-10 Burial ground – August 2013



Case Study – CS8

Site groundwater, Hanford

1. Contact information

2. Site background information

The US Department of Energy's (DOE's) Hanford Site is a 1 517-km² (586-mi²) Federal facility located in south-eastern Washington State along the Columbia River (see Figure 1).

The Hanford Site is situated north and west of the cities of Richland, Kennewick and Pasco, an area commonly known as the Tri-Cities. This region includes the incorporated cities of Richland, Pasco and Kennewick, as well as surrounding communities in Benton, Franklin and Grant Counties. For administrative purposes, the Hanford Site was divided into four national priority list (NPL) (40 CFR 300, Appendix B) sites under the Comprehensive Emergency Response and Clean-up Liability Act (CERCLA), one of which is the 200 Area.

The 200 Area NPL site contains numerous waste sites, contaminated facilities and groundwater contamination plumes. To facilitate clean-up, these wastes sites, contaminated facilities and groundwater plumes were grouped by geographic areas, process types and/or clean-up components into several Operable Units (OUs). The 200-ZP- 1 OU includes several groundwater contamination plumes that cover an area of approximately 13 km² (5+ mi²) beneath part of the 200 West Area (Figure 2). The 200 West Area contains waste management facilities and former irradiated fuel-reprocessing facilities. The 200 West Area is located on an elevated, flat area, often referred to as the Central Plateau, and there are no wetlands, perennial streams or floodplains. The major waste streams that contributed to groundwater contamination in the 200-ZP- 1 OU were associated with plutonium-separation operations at the T Plant facilities and plutonium concentration and recovery operations at the Z Plant facilities in the 200 West Area. The liquid waste disposal in the cribs and trenches near these facilities resulted in several groundwater contamination plumes in the 200-ZP- 1 OU. The major COC for the 200-ZP-1 OU is carbon tetrachloride. The other COCs are total chromium (trivalent [III] and hexavalent [VI]), nitrate, TCE, iodine- 129, technetium-99 and tritium.

The DOE has operated an interim remedial measure (IRM) pump-and-treat system to prevent carbon tetrachloride from spreading in the 200-ZP-1I OU since 1994. Carbon tetrachloride concentrations have decreased in the original target area. Since 1994, more than 3.7 billion L (975 million gal) of groundwater have been extracted. More than 10 900 kg (24 000 lb) of carbon tetrachloride have been removed from groundwater and treated since 1994.

A final Record of Decision (ROD) was signed in September 2008. The selected remedy for the 200-ZP- 1 OU involves: Pump-and-Treat, Monitored Natural Attenuation, Flow-Path Control and Institutional Controls, *Record Of Decision Hanford 200 Area 200-Zp-1 Superfund Site Benton County, Washington, September 29, 2008*

3. Pump-and-treat system

A groundwater pump-and-treat system was designed, installed and is operating. The system is designed to capture and treat contaminated groundwater to reduce the mass of carbon tetrachloride, total chromium (chromium III and chromium VI), nitrate, trichloroethylene, iodine-129 and technetium-99, throughout the 200-ZP-I OU by a minimum of 95% in 25 years. The pump-and-treat component is designed and implemented in combination with monitored natural attenuation to achieve clean-up levels contaminants in 125 years. Carbon tetrachloride concentrations in the groundwater above 100 mg/L correspond to approximately 95% of the mass of carbon tetrachloride currently residing in the aquifer. The estimated pumping rate required to reduce the mass of carbon tetrachloride by 95% in the expected timeframe is 2 500 gallons per minute for this action. The fate and transport modelling evaluation estimated that a system comprised of 27 extraction and

27 injection wells is needed to achieve the design requirements. Following extraction, the COCs in groundwater is treated to achieve the clean-up levels. The treated groundwater is then returned to the aquifer through injection wells.

In addition to the pump-and-treat system, natural attenuation processes are used to reduce concentrations to below the clean-up levels. Natural attenuation processes being relied on as part of this component include abiotic degradation, dispersion, sorption and, for tritium, natural radioactive decay. The timeframe necessary to reduce the remaining COC concentrations to acceptable levels through NINA will be approximately 100 years.

Flow-path control is achieved by injecting the treated groundwater into the aquifer to the northeast and east of the groundwater contamination such that the treated injected water in these locations will slow the natural eastward flow of most of the groundwater and, as a result, keep COCs within the capture zone, as well as increase the time available for natural attenuation processes to reduce the contaminant concentrations not captured by the extraction wells.

The treatment system for the groundwater consists of a radioactive ion exchange system and a biological system with air stripping to remove the non-radioactive contamination from the groundwater. The treatment system is unique in having a separate radioactive treatment system followed by fluidised bed bio reactors to denitrify, reduce metals and de-chlorinate carbon tetrachloride and other chlorinated solvent contaminants. An air stripper system is at the lag end of the process as a backup. The well field and the treatment plant were completed in June 2012. The system is currently operating at a nominal flow rate of 1900 gallons per minute using 15 extraction and 11 injection wells with additional wells planned. A site diagram showing the contaminant plume, extraction and injection well system and treatment plant is shown in Figure 2, 200 West Area Groundwater Pump-and-Treat Remedial Design Report, November 2011, DOE/RL-2010-13, Revision 1.

Figure 1: Hanford background – Context for soil and groundwater remediation

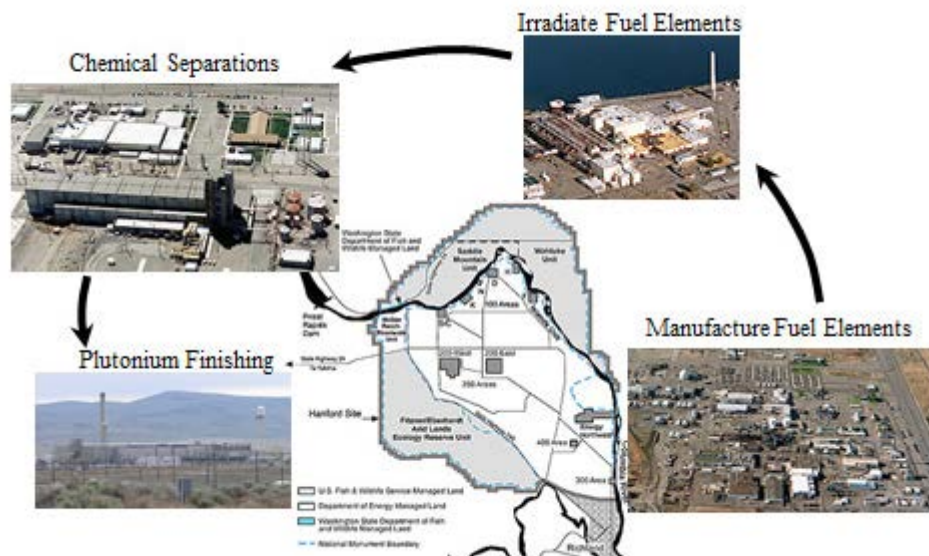


Figure 2: 200 west pump-and-treat system

4. Summary

- The plant has been designed to treat 2 500 GPM, is expandable to 3 750 GPM.
- The facility will utilise over 75 500 feet of transfer piping with 76 Road Crossings.
- The project has installed 26 tanks, the largest ones hold 33 000 gallons each.
- The project has poured more than 12 000 cubic yards of concrete.
- The plan has two primary treatment components: The RAD building and the BIO Building.
- The RAD building removes radionuclide contamination from groundwater.
- The BIO building uses bio-reactors to remove Nitrate, Metals and reduce VOCs.
- Micro filtration and Air Strippers complete the groundwater treatment.
- The RAD Building, BIO Building and BIO Pad contain 52 000 ft² of floor space.
- The Air Stripper Towers are over 75 feet tall (taller than the Federal Buildings).
- 23 Extraction Wells, 16 Injection Wells, and 5 Transfer Buildings will be used to extract water from the aquifer and the return treated water.
- The plume that the facility will treat is in a 250-foot thick aquifer covering about 5 square miles.
- The facility is one of the largest integrated groundwater treatment systems in DOE Complex.
- Treats a wider variety of radionuclide and chemical contaminants than any other facility we know of in the United States.
- Only Leadership in Energy and Environmental Design (LEED) Gold facility in DOE's complex of clean-up sites.

Case Study – CS9

In-situ PTW, West Valley

1. West Valley permeable treatment wall system

The “first in the world” continuous in-situ permeable treatment wall (PTW) intended to remove and contain radioactive Sr-90 from groundwater was installed at a former commercial nuclear fuel reprocessing and vitrification test site in western New York. West Valley, its consultants and researchers at the State University of New York (SUNY) at Buffalo collaborated to design an approximately 850-foot (260 metre) long by 3-foot (1 metre) thick zone of granular zeolite (composed of approximately 85% of the mineral clinoptilolite) that will remove Sr-90 in situ from an advancing plume in groundwater through ion-exchange reactions. The innovative design uses a one-pass trencher to simultaneously remove unconsolidated aquifer material and replace the excavated zone with zeolite along the entire alignment to depths up to 30 feet (9 metres). Remedy selection and design of the full-scale PTW involved multiple years of engineering, site characterisation, numerical modelling and evaluation of laboratory treatability studies.

According to officials at the West Valley Demonstration Project, the installation of the treatment wall is an important first step toward eventually closing the facility. Additionally, the success of the PTW project is seen as key to advancing both the US Department of Energy’s remediation programme, as well as the State of New York’s approach to environmental remediation. The project has support from the American Resource Recovery Act of 2009 (US Federal Stimulus Funding programme). Additionally the passive remediation of Sr-90 results in significant cost savings over traditional active remediation methodologies.

- Project background

The western New York nuclear service centre (WNYNSC) property comprises approximately 3 300 acres of northern Cattaraugus county, New York. A portion of the property known as the “North Plateau” was used to process commercial nuclear fuel from 1966 to 1972. Commercial nuclear fuel reprocessing activities were terminated in 1972 and decontamination activities started for planned upgrades. In 1982 the US Department of Energy (DOE) assumed operational control of the WVDP premises (~ 200 acres) to solidify high-level liquid radioactive waste using vitrification technology at the then newly designed/constructed vitrification facility also located on the North Plateau. The facility is no longer operational and is currently in the process of being decommissioned.

The WVDP is located within a fluvial drainage basin that contains a shallow groundwater zone underlain by a thick/impermeable glacial till which forms an aquitard beneath the shallow groundwater. The surface of the Lavery till undulates and varies in-depth across the site from 10 to 30 feet below ground level. Groundwater flow is in sediments above the till, which include surficial sand and gravel deposits. Groundwater at the site generally flows to the north and east and occurs at depths ranging from approximately 3 metres (10 feet) below ground level to near the ground surface.

Sampling and analysis of groundwater at the site identified a plume of Sr-90 impacted groundwater (with activity levels ranging from less than 1 000 pCi/L to more than 100 000 pCi/L extending approximately 1 000 feet from the plant in a north-easterly direction following the general groundwater flow direction. The leading edge of the plume was identified to have three primary lobes (western, central and eastern) migrating in a north-north-easterly direction toward topographically low groundwater discharge areas. As a result of this groundwater discharge at the surface, Sr-90 activity has been detected in surface water flowing from the site beyond the WVDP premises.

A groundwater extraction and treatment system (i.e. pump-and-treat system) was installed in 1995 and operated to collect and remove Sr-90 from impacted groundwater near the leading edge of the plume. While operating, the recovery system reduced discharge to surface water, but it did not mitigate the advance of the Sr-90 plume toward the north and northeast. A pilotscale PTW filled with zeolite treatment media was constructed in 1999 to intersect a small portion of the plume to assess the feasibility of plume mitigation using passive in-situ ion exchange technology. Monitoring results for the pilot-scale PTW indicated that the technology was feasible for full scale application.

Remedial Action Objectives (RAOs) were developed and formed the design basis to address Sr-90 migration in groundwater at the North Plateau. The RAOs are as follows:

- Reduce or eliminate Sr-90 presence in groundwater seepage leaving or potentially leaving the North Plateau to as low as practically achievable, with a goal to be less than the DOE.
- Derived Concentration Guide (DCG) of 1 000 picocuries per litre (pCi/L).
- Minimise the future expansion of the Sr-90 plume beyond its current mapped limits.
- Ensure that a technology selected for current containment of the Sr-90 plume does not preclude any strategies for addressing the plume during site decommissioning.
 - Design challenges for full-scale PTW

Several design challenges were overcome to successfully implement the remedy. The design team completed several technology demonstrations and applied lessons learnt from the 1999 pilot PTW in order to overcome them. Pre-design studies included: evaluation of pilot scale PTW hydraulic performance and Sr-90 removal; laboratory column studies to evaluate treatment capacity and longevity for two different zeolite treatment media sources; evaluation of zeolite source material geotechnical properties; detailed site characterisation along the proposed PTW alignment; and, groundwater flow modelling to assess flow velocity variations across the plume.

Critical components of the PTW geometry included alignment (location, length, orientation), depth and wall thickness. The primary criterion used to select the alignment of the PTW was ensuring the capture of the currently mapped Sr-90 isopleths. Modelling results indicated that groundwater flow direction varies across the PTW alignment but the variations generally result in longer flow paths through the wall and are therefore conservative

The PTW thickness design parameter was evaluated using both a one-dimensional transport model and a numerical flow model. The transport simulations were conducted using a range of input parameters (e.g. velocity) considered to be representative of field conditions. A select number of representative velocities were used in the transport simulations to estimate a threshold velocity value that could potentially lead to early breakthrough of Sr-90 at 10 000 pCi/L. The velocity profile across the installed PTW was then estimated with the numerical flow model (pumping wells turned off, higher-permeability PTW in place) and compared to the one dimensional transport threshold velocity to identify sections of the PTW that would potentially be vulnerable to early breakthrough. The results of the modelling exercise in conjunction with the treatment media evaluation (discussed below) indicated that a 3-foot zeolite thickness could meet the desired design-life of 20 years.

2. Treatment media selection

Ion exchange is an industry standard process to remove exchangeable ions, such as strontium and Sr-90 from aqueous solutions and was selected by WVES engineers as the process for use in an above ground pump-and-treat remedy. WVES staff also identified this process as a likely method for successfully removing Sr-90 passively from groundwater in an in-situ application and identified natural zeolite as a material that could provide the necessary removal process. The treatment matrix for the pilot PTW was composed of the mineral clinoptilolite, a zeolite whose general solid solution formula is $[(Ca, Mg, Na_2, K_2)(Al_2Si_{10}O_{24}.8H_2O)]$. This material was intended to effectively reduce the activity level of Sr-90 in affected groundwater by promoting ion exchange between the dissolved divalent Sr-90 cation and less affinitive cations (such as potassium and sodium) within the mineral

structure of the zeolite, although other, naturally occurring divalent cations in site groundwater (such as calcium and magnesium) also will compete for these sites.

Zeolites, such as clinoptilolite, are minerals well known for their ability to exchange cations readily. The potential for a material to promote such exchange is referred to as the cation exchange capacity (CEC), which typically is reported as either moles or as milliequivalents (meq) of exchangeable cation per gramme (or 100 grammes) of zeolite. The CEC for pure clinoptilolite generally is shown as between about 1.6 and 2.2 meq/g. Other zeolite minerals have higher CEC values, but may not be appropriate for use in a PTW because of a number of factors including material strength, other mineral content, commercially available material quantities and cost. Because zeolitic minerals generally are abundant and can be provided in granular form, they make excellent candidates to be used within a PTW system – the zeolite has a greater density than water, is structurally competent and can be handled by most construction equipment without unusual or special needs or health and safety concerns.

- Installation methods

Single-pass trenching was selected as the preferred installation method for the 3-foot thick PTW. A single-pass trencher moves along the alignment and brings trench spoils to the surface using a chain-saw-like cutting boom at the rear of the trencher. The trench is supported and immediately backfilled behind the cutting boom using a delivery system that resembles a moving trench box. Backfill material (zeolite in this case) is loaded into a conveyor system at the front of the trencher that continuously delivers backfill material to a hopper located on top of the moving trench box system. The single pass trencher was selected because of certain advantages that it offered in this application, compared to other trenching methods. Some of the advantages include:

- **Greater installation efficiency:** the excavation and backfilling activities can be performed simultaneously in a single pass because the backfill material is supplied to the trench as the soil cuttings are removed by the cutting boom. This greatly increases the installation efficiencies of the single pass trencher compared to more conventional methods.
- **Ease of construction:** Dewatering and bracing, or slurry-supported trenching, which are generally required while excavating deep trenches were not required while using the single pass trencher.
- **Cost effectiveness:** The single pass trencher was more cost effective compared to conventional methods because of higher efficiency and ease of constructability. Two substantial installation challenges were identified during the design process: maintaining the design thickness for zeolite over the entire length and depth of the PTW; and, managing the trencher cuttings as they are brought to the surface. Several trencher demonstrations were performed offsite with zeolite to evaluate methods to mitigate these challenges

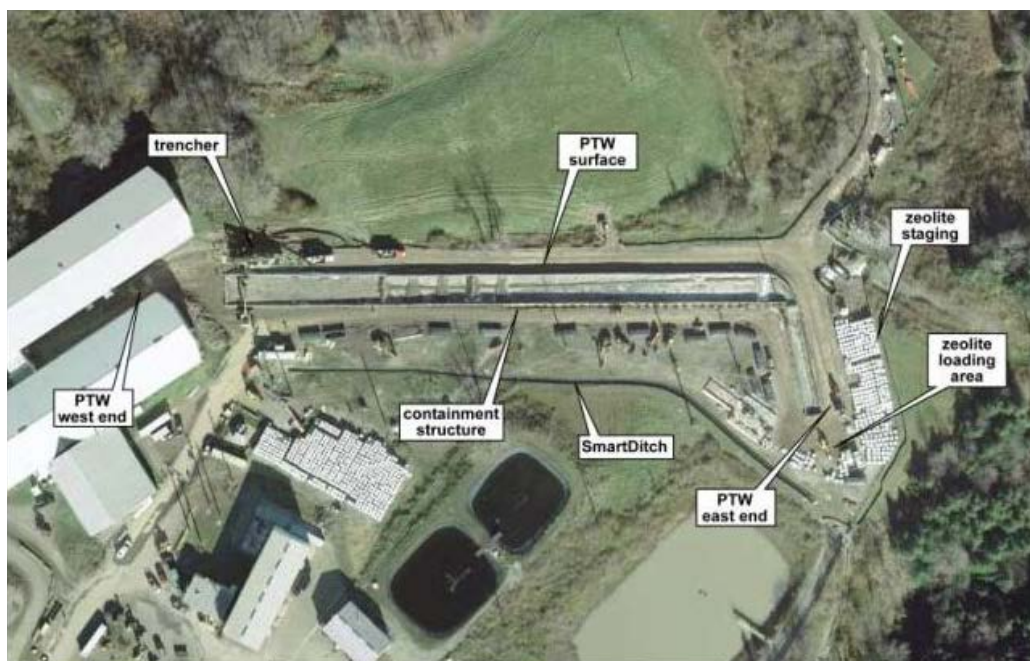
Early trencher testing demonstrations showed that the in-place zeolite thickness could be less than the operational width of the trencher. Although zeolite is heavier than water, the bulk density of the milled aggregate is approximately 960 kilogrammes per cubic metre (60 pounds per cubic foot), nearly half that of typical sandy soil. In the trencher demonstrations, the as-built trench width was less than the width of the trench box delivery system, indicating that the test trench walls were moving inwards as earth and/or hydraulic pressure was greater than the pressure exerted by the zeolite backfill. Modifications to the trencher and zeolite deliver methods were made to pre-soak the treatment media before delivery to the trencher and to provide the ability to add water to the excavated trench. These modifications had the following beneficial results: Pre-soaking the zeolite significantly increased the bulk density, aiding in material placement and increasing the pressure exerted by the zeolite backfill. It also had the added benefit of reduced dust during material handling. Water added to the excavated trench increased the hydraulic pressure within the trench, counteracting lateral earth pressures resulting from trench excavation.

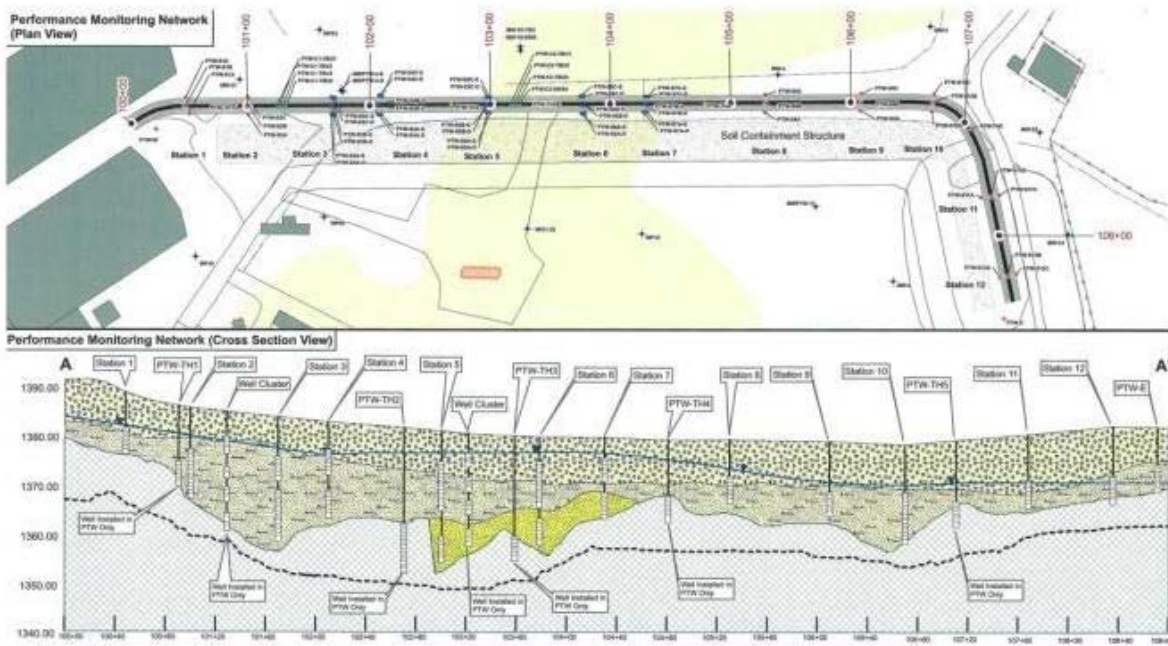
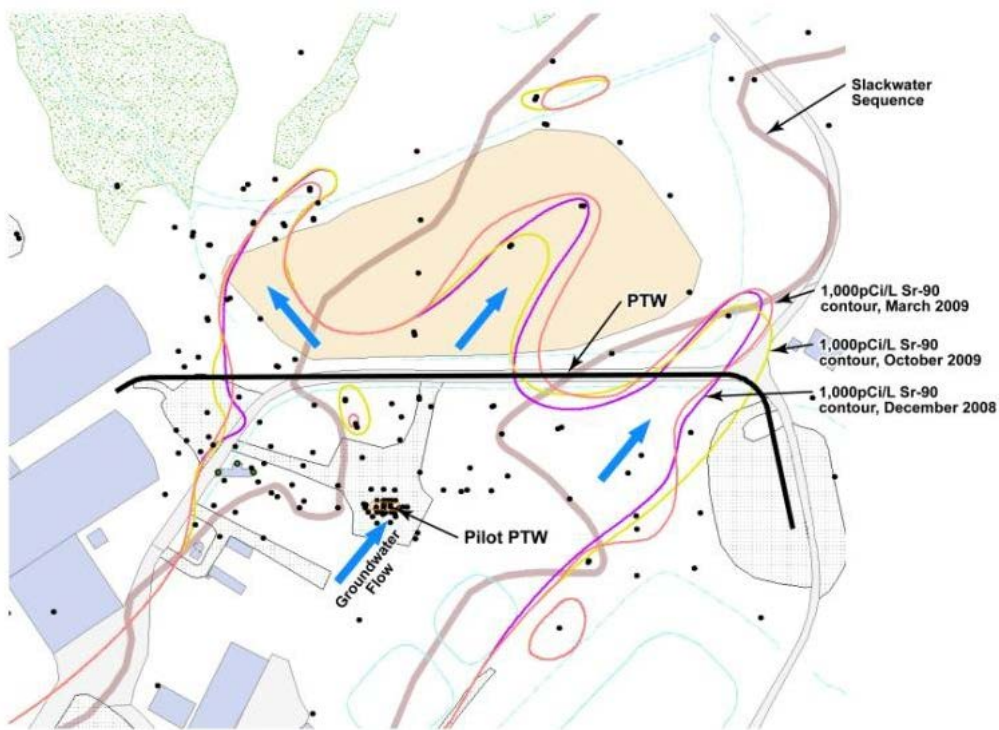
- Performance monitoring programme

The intent of the performance monitoring programme is to evaluate, in three dimensions (and in each key hydrogeologic unit) the treatment of both target constituents (i.e. Sr-90) and other parameters important to assessing performance including key inorganic constituents that can affect the ion exchange treatment process (i.e. potassium, sodium and calcium) and hydraulic parameters, including flow velocity via tracer testing. The monitoring frequency should be a combination of short-interval (e.g. quarterly to annual) events for monitoring standard parameters to longer-interval, more comprehensive monitoring events. A detailed performance monitoring plan was developed to evaluate the effectiveness of the PTW by assessing if the functional requirements of the PTW were being met.

- PTW performance

Following PTW construction, the PTW performance monitoring system was installed on the PTW platform. The monitoring system consists of 66 monitoring wells comprised primarily of twelve monitoring stations. Each station consists of three monitoring locations installed on a transect oriented approximately perpendicular to the PTW alignment. Monitoring stations are located within segments of the wall that are expected to experience comparatively larger Sr-90 loading with additional stations located in between. Other monitoring points include cluster wells installed to monitoring vertical hydraulic gradients within the PTW within the SWS and TBU zone depths. Early monitoring data (i.e. First Quarter 2011) indicated that expected hydraulic performance and Sr-90 removal from groundwater was consistent with experimental bench-scale column testing. Measured Sr-90 activity inside the PTW was typically below 100 pCi/L and frequently not detectable. By contrast, Sr-90 levels immediately upgradient of the PTW were greater than 10 000 pCi/L. Geochemical testing of groundwater for major cations and anions indicate calcium concentrations are higher immediately downgradient from the PTW as effective cation exchange processes occur to remove Sr-90 from groundwater. The increase in calcium is consistent with column study results during the early stages of loading. Longer-term performance monitoring is necessary to fully assess the effectiveness of the PTW.





Case Study – CS10

Laboratory building decommissioning at Chalk River Laboratories

1. Contact information

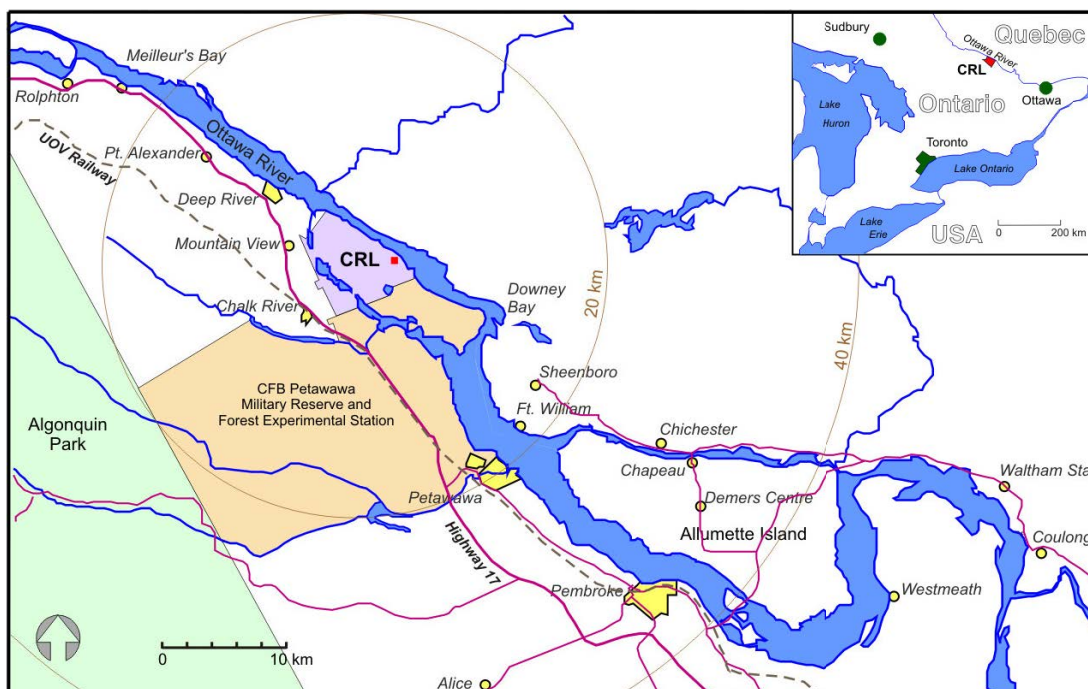
2. Site background information

Site name: AECL, Chalk River Laboratories

Site location: Chalk River, Ontario, Canada

Atomic energy of Canada Limited's (AECL) Chalk River Laboratories (CRL) site is located in Renfrew County, Province of Ontario on the south shore of the Ottawa River (Figure 1). Nearby communities include the Village of Chalk river, seven km west of the site, and the Town of Deep River, 10 km northwest, on the river. The town of Petawawa and the Canadian forces base (CFB) Petawawa are located 20 km southeast of CRL.

Figure 1: Location of CRL Site



■ Site description

The CRL site consists of gently rolling hills made of a mixture of exposed bedrock, glacial till, fluvial sand interspersed with small lakes and marshes. The CRL site itself is 4 000 hectares (40 km²), divided into a “Built-Up Area” adjacent to the Ottawa River and a “Supervised Area” which is comprised of the remaining, mainly wooded property in the background (Figure 2).

Figure 2: CRL Site looking northwest (Ottawa River and built-up area are in the foreground and the supervised area is in the distance)

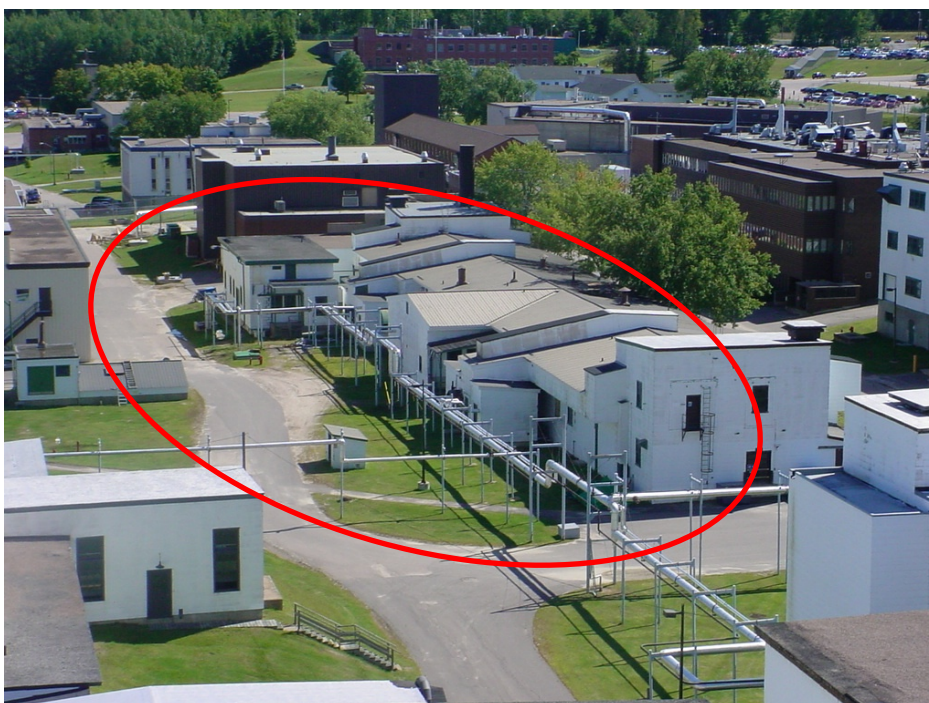


The built up area contains the reactors, laboratory buildings and other site support facilities. waste management areas are located in the supervised areas.

Construction at CRL began in August of 1944. Nuclear research at the Chalk River site began shortly afterwards in the ZEEP and NRX reactors and other research facilities. The research focus shifted in 1954 from plutonium production to the application of nuclear technology for isotope production and electrical power generation based on the natural uranium fuelled, heavy water moderated concept, or CANDU® (CANada Deuterium Uranium). Support facilities and services such as machine and instrument shops, analytical laboratories, engineering, computation, stores, radiation protection, environmental and biological research, nuclear materials and waste management, administration, cafeteria, etc. were installed, as required.

- Building 107 description

Building 107 (shown in Figure 3) was a 112.8 m long and 31.7 m wide, wooden frame structure, except for the north end, which had a reinforced concrete floor and walls. A crawl space spanned the length of the building except for the southernmost part of the building, which had a basement. The original portion of the building was constructed in 1945 with a number of additions made over the years resulting in a mixture of roof levels and types (flat, sloped, metal, asphalt shingles, etc.). External walls were mostly clad with asbestos shingles.

Figure 3: Building 107, looking south

- Building use

Building 107 was used throughout its existence as a laboratory building containing radioactive material. Radioactive laboratories occupied the North and South ends of the building, while offices, storage areas and machine shops were in the middle. Activities carried out over the years in Building 107 laboratories were wide ranging and included:

- experiments involving pure alpha emitters;
- x-ray radiography;
- heavy ion range studies;
- production of Pu-Be neutron sources;
- mass spectrometry;
- preparation of ^{14}C foils;
- development of Plant for Active Waste Liquids (PAWL) process equipment;
- experiments to support the heavy water programme;
- chemical processing of radioactive materials;
- experiments with a Van De Graff accelerator;
- work for the Atomic Vapour Laser Isotope Separation (AVLIS) and Resonance Ionization Mass Spectrometry (RIMS) programmes;
- preparation of experimental NRX Pu-Al fuel rods;
- hydrogen-water isotopic exchange experiments;
- research on fission products for routine production of radioisotopes from fission products;
- research on plutonium and actinides.

In 2002, Building 107 began safe shutdown activities in preparation for its eventual dismantling and site restoration.

Decommissioning activities for Building 107 commenced in 2006. Remediation of the south end of Building 107 site was completed by the end of 2007. This portion of the site was returned to site operations for immediate re-use. Decommissioning of the north end of the building did not progress as smoothly as planned. This case study focuses on the remediation of the Building 107 North-End Concrete Floor-Slab (shown in Figure 4) and the subsequent lessons learnt.

Figure 4: Building 107 north-end concrete floor slab



3. Clean-up agency/stakeholders

- Organisations responsible for clean-up

Natural Resources Canada (NRCan) provides funding and oversight. AECL plans and performs the work. AECL performs the “contractor” role and engages subcontractors on an “as required” basis.

- Regulatory Agencies

Chalk River Laboratories is a nuclear R&D/Industrial site operated by AECL in accordance with a Nuclear Research Test Establishment Operating Licence and the Non-Power Reactor Operating Licence issued by the Canadian Nuclear Safety Commission (CNSC).

Regulatory agencies with authority include:

- Canadian Nuclear Safety Commission (CNSC) because CRL is a licensed nuclear site
- Department of Fisheries and Oceans because the Ottawa River forms a portion of the site boundary.
- Environment Canada oversees the safety of the environment generally, on the CRL site.
- Health Canada regulates human safety on the CRL site.
 - Site-specific regulatory regime/requirements (as opposed to general national regime)

AECL is a federal crown corporation and as such is subject to federal regulations. In areas where no federal regulations exist, provincial regulations may apply. Applicable provincial regulators may include Ontario Ministry of the Environment, Ministry of Natural Resources, Ministry of Labor and in the case of offsite transport of waste, the Department of Transport federal regulations are followed. Additionally, AECL has internal compliance programmes, such as Environmental Protection, Radiation Protection, Operating Experience and Operational Health and Safety, which set additional requirements that any decommissioning project must meet.

- Local stakeholders

Local stakeholders include the Algonquins of Pikwakanagan First Nations Community, recreational users of the area (cottagers), local communities and employees of CRL.

- Level of involvement in remediation project

The CRL Site Environmental Stewardship Council, consisting of local councils and groups, is kept apprised of planned projects and results through meetings three times per year. Public information sessions about decommissioning and remediation projects are held, booths are set up at community events and information is distributed following completion of individual projects in community newsletters.

- Support or opposition from stakeholders

Minimal stakeholder feedback was solicited or received.

- Frequency of stakeholder meetings

There is no requirement for external stakeholder meetings for these types of projects. Frequent updates were provided through the Environmental Stewardship Council. Internal employees directly involved in the projects typically hold planning meetings prior to project implementation.

- Project drivers

Project drivers included the need to have the site available for a new building, the need to reduce health and safety risks associated with an aging building structure, address health, safety and environmental issues and the need to reduce care and maintenance costs.

4. Characterisation

- Objectives

Objectives for characterisation of both the initial building/soil survey and the follow-up characterisation of the soil under the north concrete slab included obtaining sufficient information to:

- ensure worker safety during implementation of the project;
- plan project technical details, such as remote or contact handling waste retrieval methods;
- place geographical boundaries on the project scope;
- identify suitable (interim) remediation criteria;
- identify waste categories and volumes for post-project waste disposition pathways.

- Historical assessments

Sources of historical information included historical memoranda, operational technical reports, engineering drawings, historical and current radiological survey reports, historical photographs and interviews with current and past employees who had occupied Building 107 or who had previously entered the crawl space under the slab.

- Risk assessments (degree to which they were used to determine project activities).

Risk assessments and dose assessments were done as part of radiological work assessments to ensure worker and environmental safety during the project.

- Quality assurance: Design, standards, guidance, approach, data quality objectives

The quality requirements were defined in AECL quality assurance manuals, which are compliant with ISO 9001 and the CSA N296 series of nuclear standards.

US NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* was used for guidance in survey design, establishing survey implementation requirements and the assessment and conclusion of survey results.

Samples were taken as the project proceeded and included both the concrete and associated soils.

The end state survey design consisted of:

- Direct scanning measurements for beta-gamma contamination over 100% of the soil surface prior to final grading.
- Direct static measurements for beta-gamma activity in random locations prior to final grading.
- Composite soil samples taken from 0.6 m and 1.2 m depths after final grading.

- Results

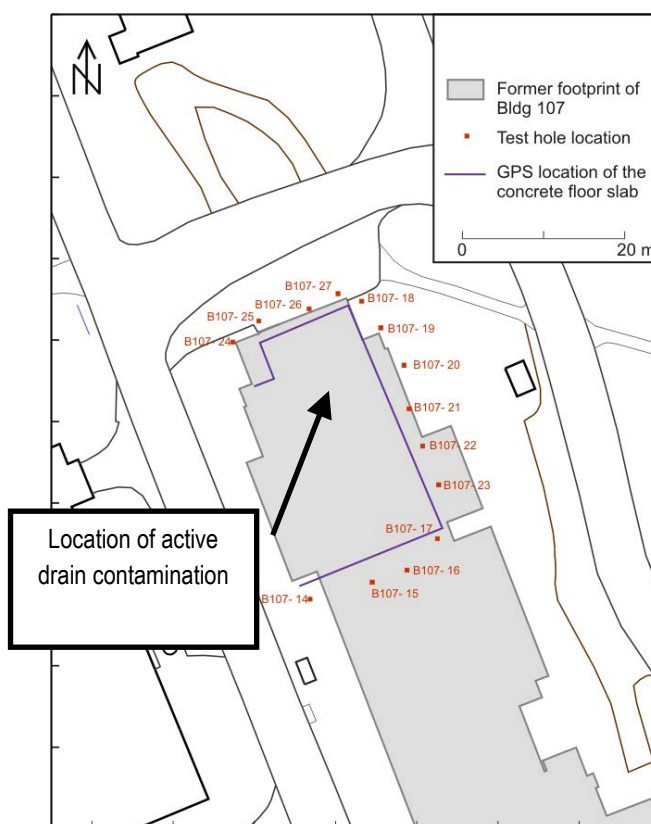
Prior to beginning decommissioning of Building 107, a full survey and sampling of the building and the soil in the crawl space under the building was performed. In particular, a 100% survey was completed for the entire area under the north concrete slab, including the ground and the concrete. No contamination was found. During Building 107 dismantling work, a localised area of soil contaminated with radioactive material was discovered beneath the concrete floor slab (in the crawl space, adjacent to an old and abandoned, radioactive drain line) at the North end of the building (shown in Figure 4). Consequently, a decision was made to retain the concrete floor slab and the adjacent portion of the site, so that further characterisation of the area around and below the floor slab could be performed to identify the nature and the extent of contamination. Retaining the concrete floor slab prevented exposing the contaminated area to the elements, thereby precluding the spread of contaminants. After additional sampling was performed and the full extent of contamination was determined, the radioactive drain line (portion under the building slab) and contaminated soil were removed. The slab was then removed. Upon completion of the project, the fully restored site was turned over to Operations for future use.

Figure 5 shows the location of the test holes for soil sampling in the area surrounding the concrete slab. Also shown is the footprint of Building 107 before its removal. To access the soils below the slab, several holes were also drilled through the slab.

Most of the samples retrieved consisted of sand and gravel, sometimes with a moderate content of silt-sized particles.

From past analyses of uncontaminated local soils, sandy soils at CRL generally contain between 0.4 and 0.8 Bq.g⁻¹ of total beta activity (primarily from ⁴⁰K) and between 0.03 and 0.13 Bq.g⁻¹ of gross alpha activity from natural uranium and thorium series radionuclides. Only three of the samples contained total beta concentrations above 0.8 Bq.g⁻¹, and in one of these samples the total beta concentration (0.82±0.08 Bq.g⁻¹ where the uncertainty is 1 standard deviation from the counting statistics) was not significantly above local soil background. In another sample (0.94±0.09 Bq.g⁻¹) is within two standard deviations of background. This leaves the third sample, (1.15±0.09 Bq.g⁻¹) to have clear evidence of total beta contamination, albeit at a trace level.

Twenty-three of the 36 samples taken contained gross alpha concentrations below the average Minimum Detectable Activity (MDA) for the analyses, which lay at the upper end of the range of background soil alpha concentrations. Most of the remaining 13 samples yielded gross alpha concentrations within 1 standard deviation of the MDA, with the highest recorded gross alpha concentration being 0.29±0.13 Bq.g⁻¹, less than 2 standard deviations away from the gross alpha MDA.

Figure 5: Soil sampling locations

- Statistical methods used to interpret data

None required.

5. Remedial objectives

The objective of the Building 107 (including the footprint of the North End concrete slab) decommissioning project was the complete removal of the building and associated systems within one metre from the perimeter of the building. Building 107 was located in a current operating area, therefore interim project clean-up criteria were used rather than final site end state criteria. The property was to be returned to Site Operations in a condition suitable for reuse consistent with the requirements for its location in the Built Up area. The final CRL site end state will be established when CRL ceases operation, currently planned to occur in 2100.

6. Options evaluation

Three options were considered before the decision to decommission was made. These alternatives were: continued use of the building; long-term storage with surveillance; and prompt removal. The building was approximately 60 years old and past its design life, with outdated systems (fire, water, ventilation, electrical, etc.). It would not have been cost effective to upgrade those systems. To avoid care and maintenance costs, the option selected was to promptly demolish the building.

7. Remedy execution

- Description of remediation activities/planned activities

Building 107 removal involved:

- dismantlement of the Lab 26 Area and building fan houses;
- dismantlement of the south end of the building;
- dismantlement of the middle area of the building;
- dismantlement of the North Tower;
- removal of active drain lines and concrete (floor slab, beams, piers, footings, foundation) from the north end and site remediation;
- service terminations to Building 107 and update drawings;
- soil sampling around north end;
- site Survey;
- project completion report;
- site restoration.

Work on the northern portion of the building included shaving/grinding of the concrete walls and floors to remove any contamination, then cutting of the walls into manageable slab sections. This was followed by the removal of a historical active drain line underneath the concrete slab. Both the drain line and soil immediately adjacent to the drain line were contaminated. During the operational life of the building, the floor slab was supported approximately 1.2 m off the ground by concrete piers, so the bottom of the concrete floor slab was not contaminated. After removal of floor slab further soil monitoring and soil removal was possible.

Work on the northern concrete portion of the building was delayed 20 months, due to AECL self-imposed restrictions for working in an actinide environment. Actinide work restrictions lasted from 2007 January until 2008 August.

When the slab was finally removed and the soil beneath it was remediated, the site was levelled with clean fill and graded. In November 2009 the entire former Building 107 perimeter up to the temporary office trailers located at the south end of the Building 107 site was fenced with a winter snow fence (to block pedestrian traffic from the site) and a contractor was brought in to Hydro-seed the site (Figure 6).

Figure 6: Interim site conditions: Building 107 and concrete slab removed



- Contaminants to be targeted

Any contamination found to be above background was to be removed. Soil analysis showed that the nuclides of interest in the soil due to leakage of the active drain line included Cs-137, Am-241, Co-60, thorium, uranium, plutonium and curium isotopes.

- Technology descriptions

Conventional decommissioning and demolition equipment was used on this project.

- Time to completion

Most of the southern and middle portion of the building was demolished in the first season. When unexpected actinide contamination was found under the northern concrete floor slab, the project was placed on hold until further characterisation could be completed and radiological work plans revised. This additional work caused a delay until the next decommissioning field season. This project took approximately two years, since one field season was lost to the extensive characterisation required to delineate the unexpected identification of a high hazard (actinide) hot spot under the northern floor slab.

- Identified obstacles/barriers

Alpha contamination was found under the north end of the building after the initial screening survey. Even though the contamination was localised around a historical active drain pipe, due to insufficient data at the time of the first positive sample, the site was treated as though the alpha contamination was widespread under the floor slab. Procedures and adequate facilities were not in place to handle the estimated amount of actinide analyses that were required to resolve the issue.

- Contract mechanism

A contract was let for the removal of the concrete slab.

- Performance metrics

The performance metrics included schedule, cost and achievement of the project objectives (return of the land to the Site Landlord).

8. *Post remedial monitoring*

- Monitoring approach

After the removal of the drain line and the adjacent soil the concrete slab was supported using a zoom boom, then cut and laid at the southern end of the site where the concrete blocks were monitored 100% for beta gamma activity prior to being shipped to the concrete lay-down area at the Waste Analysis Facility.

- Monitoring systems/technologies

An array of four Ludlum 44-9/44-89 gamma probes was used for the soil survey.

- Extent of monitoring (temporally and spatially)

The surface of the soil was scanned 100% for beta-gamma activity during the concrete slab removal and any soil above background was removed. After the site was cleared, but prior to final grading, this survey was repeated. No contamination above background was detected using the four probe array.

The end state surveys were done with a partially cleared site, (i.e. complete removal of the building structure and piers with a few containers of equipment remaining and a single block of concrete); the remaining areas were monitored once the site had been entirely cleared of containers/materials.

9. Major cost elements

- Pre-project

Pre-Project planning and characterisation = CAD 1 196 K.

- Execution

Project execution = CAD 7 715 K. Of that, CAD 704 K were waste management costs (ongoing onsite waste storage and off site waste processing). Waste disposal costs are covered under a separate project.

- Post remedial monitoring

No post remedial monitoring is required for this project.

10. Lessons learnt

- “What went wrong?” and “what went right?”

A full sampling plan was in place and it was executed prior to beginning removal of the concrete slab. Work plans were then produced based on the sampling results. As work progressed, further sampling indicated previously unidentified contamination under the north end concrete floor slab. The contamination was only found in one particular area. The question was raised as to how the contamination was missed during the initial surveys. Speculation centred on soil disturbance or abrasion of the (rusty) drain pipe subsequent to the initial sampling either by humans or animals. Storm water runoff from adjacent areas may also have contributed.

Had the contamination not been found, the usual process would have allowed removal of the concrete slab and a final survey would have been performed, allowing an additional opportunity to find any previously un-identified contamination.

The impact of the contamination discovery forced a delay to the project. Procedures and work plans for retrieving actinides from under the slab were not in place. It took one year to revise the working level procedures and provide worker training that met Health Physics requirements. In addition, this schedule delay was compounded by the onset of winter conditions (loss of an outdoor field season).

- How did the technologies used perform against technical success criteria?

The technologies performed well and achieved the intended results.

- How did the project perform as a whole against success criteria and requirements?

Schedule slippage was a problem due to the self-imposed work stoppage while additional procedures and training were developed. The seasonal nature of outdoor work in Canada also contributed to schedule delays.

- What were the barriers to successful characterisation? What were the barriers to a successful project?

Barriers included the lack of specific knowledge and experience on performing ground surveys and characterisation along with the lack of contingency planning for unforeseen contamination events (work plans and procedures for working in an actinide environment).

- How was the project aligned (or not) with any R&D priorities?

This project was not aligned with any R&D priorities.

- What could have been done differently?

Decommissioning staff and support staff were not initially trained and procedures and work plans were not in place for the unplanned discovery of actinide contamination under the building floor slab. Contingency planning and training might have prevented the one year schedule delay.

Case Study – CS11

PIMIC “Lenteja” at CIEMAT

1. Contact information

2. Site background information

CIEMAT (Centre for Energy-Related, Environmental and Technological Research)

MADRID- University campus.

CIEMAT is one of the most important research centres in Spain, it has an extension of 20 Ha, and its history began in the 1950s, when it was known as the Nuclear Energy Board (JEN), and it had more than 60 facilities in operation that allowed a wide range of activities in the nuclear field and in the application of ionising radiations.

In 2000, CIEMAT started the Integrated plan for the improvement of CIEMAT facilities (PIMIC), with the aim of becoming a more modern facility, having installations adapted to new research requirements.

At present, the centre is authorised as a single nuclear installation. The objective of the PIMIC project is to transform CIEMAT into a non-nuclear research centre with radioactive facilities, each regulated with its specific authorisation.

This plan was divided in two different projects:

- PIMIC Decommissioning project executed by Enresa;
- PIMIC Restoration project executed by CIEMAT.

PIMIC Decommissioning has included activities for the decontamination and dismantling of obsolete installations. Currently, all dismantling activities have finished and site remediation of contaminated areas is in progress.

As an example of soil remediation, it is worth pointing out the case of the Lenteja zone, where in the 1970's an incidental leakage of radioactive liquid occurred during a transference operation from the reprocessing plant to the liquid treatment facility, contaminating about 1 000 m³ of soil. The contaminated area is called Lenteja, which means lentil in Spanish, because of the initial shape of the contamination.

At that time, part of the ground was removed, the hole filled with clean soil and covered with a concrete slab. The final affected area was 450 m² and up to 8 metres deep.

3. Clean-up agency/stakeholders

On 14 November 2005, a Ministerial Order authorising the decommissioning of several nuclear facilities and the restoration of contaminated areas was issued.

Although CIEMAT is the owner of the site, Enresa is responsible for the execution of site remediation activities. Currently, all facilities have been dismantled, and so all activities have to do with restoration of contaminated land.

Relevant stakeholders are CIEMAT workers (more than 1 000 researchers), the neighbourhood association, the university and, of course, the authorities as Nuclear Safety Council, the City Council and the Ministry of Industry

- Regulatory agencies with authority.

The regulatory body is the Nuclear Safety Council.

- Site-specific regulatory regime/requirements.

As the site has a restoration plan approved, the general criteria for the release of land and spaces is 0.1 mSv/year.

Values greater than 0.1 mSv/year must be justified by an optimisation study and must have a favourable report from the Nuclear Safety Council.

4. Characterisation

- Objectives and historical assessments

Old borehole campaigns and historical data were analysed and three new borehole campaigns were performed (2004-2006), including surface samples (277) and up to 16-metre boreholes, in order to ascertain the contamination plume distribution of the affected area.

After analysing the results, the spatial distribution of activity in the area of action was determined and two isotopic vectors were found.

It was concluded that Sr-90 and Cs-137 were predominant, distributed in two areas that had a clearly differentiated Sr-90/Cs-137 relationship.

- Sources

The affected area covered about 450 m², up to 8 m deep and with an estimated volume of contaminated soil of 3 000 m³. The activity concentrations of Sr-90 and Cs-137 varied according to the vicinity to the point where the release occurred and the depth of the field.

To estimate the radiological inventory, the drilling samples more active in Sr-90 or Cs-137 (≥ 1 Bq/g) were considered. The surface was divided into square areas and each of these areas was assigned to the nearest drill made.

The estimated radiological inventory was 7.80 E+10 Bq for beta emitters and 2.94 E+09 Bq for alpha emitters.

The relationship for the two defined isotopic Sr-90/Cs-137 is as follows:

Isotopic vector	Sr-90/Cs-137
PAL	3,10E+02
FCL	8,81E-01

In the PAL area, (that represented a small area compared to FCL area), the low Cs-137 activity implied that Sr-90 values are above the clearance levels. However, in the FCL area, the material could be classified initially as very low-level waste or material to be released.

With regard to the depth, from 5 m, the soil activity significantly decreased and in general, at 9 m, the values for Cs-137 and Sr-90 were less than 1 Bq/g.

5. Remedial objectives

After the remediation works, the residual activity levels should be:

- Release levels of land defined for CIEMAT for the measurements on the ground.

Nuclide	Release level (Bq/g)
Ac-227	6.75E-01
Am-241	9.23E+00
C-14	3.86E+01
Co-60	1.45E-01
Cs-134	2.61E-01
Cs-137	6.21E-01
Eu-152	3.15E-01
Eu-154	2.92E-01
Eu-155	1.14E+01
Fe-55	2.44E+04
Gd-152	5.79E+01
H-3	4.15E+02
Ni-63	1.14E+03
Np-237	1.69E+00
Pa-231	6.04E-01
Pb-210	1.08E+00

Nuclide	Release level (Bq/g)
Pu-238	1.16E+01
Pu-239	9.26E+00
Pu-240	9.26E+00
Pu-241	3.03E+02
Ra-226	1.95E-01
Ra-228	2.30E-01
Sr-90	8.62E-01
Th-228	2.66E-01
Th-229	9.86E-01
Th-230	2.60E-01
Th-232	1.37E-01
U-233	1.03E+01
U-234	2.57E+01
U-235	2.55E+00
U-236	7.76E+01
U-238	1.23E+01

- Clearance levels for reuse (RP113) for measurements made in the walls (Sr-90 = 100 Bq/cm² and Cs-137 = 1 Bq/cm²).

To summarise, restoration of the area called Lenteja has comprised three radiological characterisation processes:

- Initial radiological characterisation that provided information about the radiological characteristics of the soil in order to plan the scope of the work and management of the resulting materials.
- In-situ radiological characterisation that enabled segregation of the radioactive waste and the material to be released. Approximately 66% of the soil was released.
- Final radiological survey, which enabled verification that the radiological conditions of the resulting excavation and the subsurface met the regulatory requirements.

6. Options evaluation

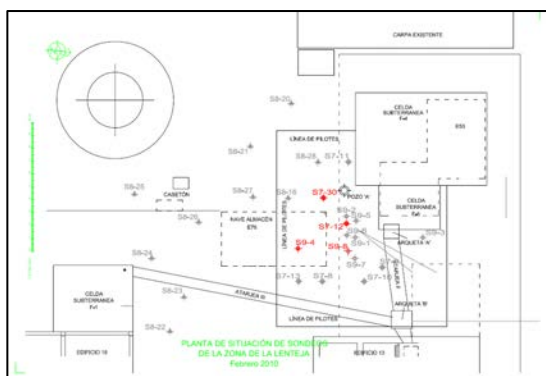
For the decontamination of the area, the option of excavation and removal of soil was chosen. However, to minimise the volume of radioactive waste to manage, a clearance process was established and approved by the Nuclear Safety Council.

The application of this methodology has resulted in about 50% of the material coming from the Lenteja area (soil) being released, after authorisation by the Nuclear Safety Council.

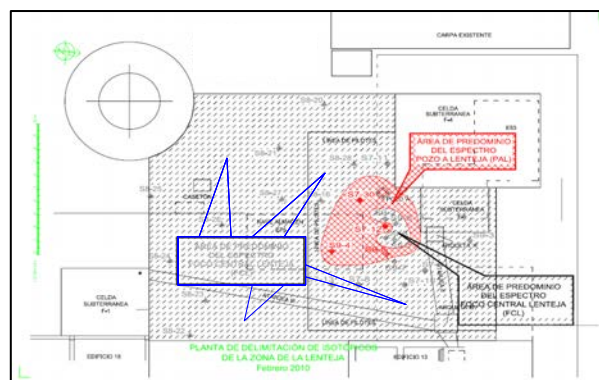
7. Remedy execution

Restoration activities began in 2010 after an exhaustive radiological characterisation of the soil.

Borehole campaigns



Isotopic vectors distribution



Taking into account the physical characteristics of the zone and the limited space within the area for handling equipment, the above ground and underground structures were demolished (Figure 1).

Before the soil extraction activities, it was necessary to construct a containment boundary wall with piles and a tie beam that allowed the removal of contaminated soils (Figure 2).

Figure 1



Figure 2



The affected area and a temporary storage were then confined by a tent (Figure 3), as a measure of protection against water infiltration and to control airborne emissions.

Figure 3**Figure 4**

Excavation was carried out slowly with a small digger, in order to assure the radiological control of materials and zones. The containers at the bottom of the excavation were loaded and lifted by crane anchored to the ground.

When the excavation reached a depth of 4.5 m, a radiological characterisation of soil and walls was performed (measurements of contamination). The soil removal continued until the end of 2010, when it was stopped at a depth of 7.1 m and 8.5 m (Figure 5).

Figure 5**Figure 6**

After new radiological monitoring, some contamination in the area at 8.5m depth was detected. Then, manual digging had to continue one more metre in that zone. To do that, it was necessary to construct two new concrete beams and a support pillar (Figure 6).

When it was determined by surface measurements that it was not necessary to dig deeper, the final drill hole campaign began. It included:

- 15 boreholes at 2-m depth from ground level in the static measuring points, to rule out contamination in the subsurface;
- 6 intentional boreholes at 15-m depth from the initial ground level (between 6 and 8 metres from ground level).

In the month of September 2011 as a step prior to insulation, the hole with gunite, a final radiological control of the vertical surfaces was made. This was followed by final radiological control soil before filling with clean soil.

Once the excavation was completed in August 2011:

- 66% released material (1 878 tonnes);
- 34% radioactive waste (968 tonnes);
- very-low-level waste (961 tonnes);
- low- and intermediate-level waste (7 tonnes).

8. *Post remedial monitoring*

The final radiological characterisation was performed with the following scope:

- Soil: applying MARSSIM methodology, with direct measurements, and a new borehole campaign at random points and at intentional points was carried out.
- Walls: direct measurements were made with portable not spectrometric equipment on the walls to ensure that the levels of residual activity remaining were below clearance levels for reuse.

After verifying the absence of residual activity, the gap was filled with clean soil (April 2012).

9. *Major cost elements*

Characterisation of soil in-depth is a complex process with significant uncertainties, which means a significant probability of increasing costs. As the contaminated land has to be measured to determine whether to continue with the removal or not, it may result in a delay of the planning.

The limitation of space is another key aspect to take into account, due to the need to work with small machinery that could not be available in the required timeframes, such as small diggers, telescopic cranes, drilling machines and electrical vehicles.

Working conditions of the personnel that use protective gear also can increase cost and time.

The large amount of waste materials generated in a short time may slow down its management, with a consequent increase in costs

10. *Lessons learnt*

Since site remediation generates large volumes of material to be monitored and large amounts of very-low-level waste to be disposed, it is very important to have, at the beginning of activities:

- a detailed characterisation of the affected area;
- site-specific release levels developed for industrial scenarios (0.1mSv/year);
- a well-established clearance process of materials that allows us to minimise the generations of radioactive waste;
- an efficient methodology for the classification and segregation of materials in-situ, in accordance with their radiological characteristics (isotopic and activity);
- enough capacity of interim storage areas “in site” that give us time to complete the requirements of taking material out of site, because commissioning of waste stores facilities requires approval and it takes time;
- a disposal facility for very-low-level waste.

11. References

- EU RP 122: Practical use of the concepts of clearance and exemption.
- EU RP 89: Recommended radiological protection criteria for the recycling of metals from the dismantling of nuclear installations.
- EU RP 113: Recommended radiological protection criteria for the clearance of buildings and building rubble from the dismantling of nuclear installations.
- 057-IF-PI-0619 *Informe físico, descriptivo de las estructuras y sistemas relacionados con las instalaciones del área de la lenteja.*
- 057-RE-EN-0001 *Plan de Restauración del Emplazamiento CIEMAT.*
- T-00-NUC-037 *Distribución de la radiactividad en el terreno de la lenteja.*
- 057-IF-PI-0629 *Informe metodológico de caracterización final de terrenos del hueco de la zona denominada lenteja.*

Case Study – CS12

Caustic cells, Chalk River

1. Contact information

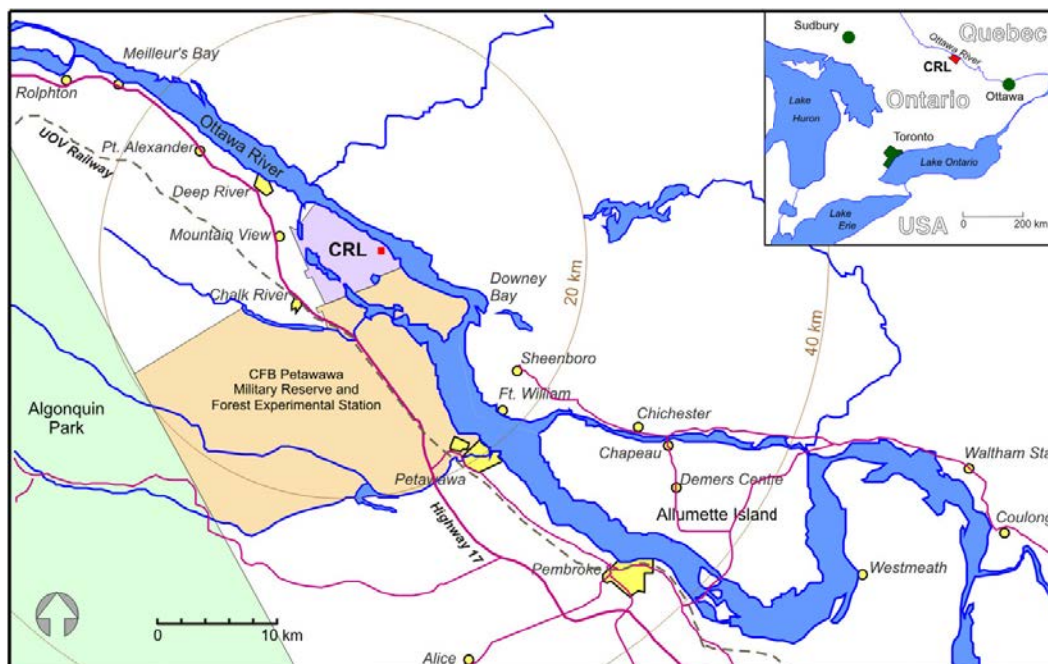
2. Site background information

Site name: AECL, Chalk River Laboratories

Site location: Chalk River, Ontario, Canada K0J 1J0

Atomic Energy of Canada Limited's (AECL) Chalk River Laboratories (CRL) site is located in Renfrew County, Province of Ontario on the south shore of the Ottawa River (Figure 1). Nearby communities include the Village of Chalk River, 7 km west of the site and the Town of Deep River, 10 km northwest, on the river. The Town of Petawawa and the Canadian Forces Base (CFB) Petawawa are located 20 km southeast of CRL.

Figure 1: Location of CRL site



▪ CRL site description

Land use in the region consists primarily of forestry, recreation and tourism, with limited agriculture, trapping and mining. The area supports a wide range of wildlife species, including moose, deer, black bear, ruffed grouse, hare, beaver, mink, fisher, martin, otter, muskrat, turtles, fox and raccoon. The CRL site consists of gently rolling hills made of a mixture of exposed bedrock, glacial till, fluvial sand interspersed with small lakes and marshes [1].

The CRL site itself is 4 000 hectares (40 km²), divided into a “built-up area” adjacent to the Ottawa River and a “supervised area”, which is comprised of the remaining, mainly wooded property to the west (Figure 2).

Figure 2: CRL site looking northwest (Ottawa River and the built-up area are in the foreground, and the supervised area is in the distance)



The built-up area contains the reactors, laboratory buildings and other site support facilities. Waste management areas are located in the supervised areas (Figure 3).

Figure 3: Supervised area looking southeast, showing waste management areas



Construction at CRL began in August of 1944. Nuclear research at the Chalk River site began shortly afterwards in the ZEEP and NRX reactors and other research facilities.

The research focus shifted in 1954 from plutonium production to the application of nuclear technology for isotope production and electrical power generation based on the natural uranium fuelled, heavy water moderated concept, or CANDU® (CANada Deuterium Uranium). Support facilities and services such as machine and instrument shops, analytical laboratories, engineering, computation, stores, radiation protection, environmental and biological research, nuclear materials and waste management, administration and cafeteria were installed, as required.

- Waste management areas

Beginning in 1946, wastes generated at the CRL site, as well as some offsite wastes, were placed in unlined sand trenches and covered with additional sand and vegetation. When the first waste management area was fully utilised in 1952, a second waste management area was constructed. Over the years, additional facilities were added with varying methods of emplacement being developed for different waste types.

One particular waste management area, WMA B, is a radioactive waste management facility located approximately 1.8 km west of the CRL main built-up area. WMA B is approximately 14 hectares and houses a variety of waste facilities such as unlined sand trenches, concrete trenches, tile holes, cylindrical bunkers and other miscellaneous engineered structures. Although several facilities in WMA B are currently receiving waste, one area, known as the special burials area, is in a storage-with-surveillance state (shown circled in red in Figure 4). As such, it undergoes periodic monitoring and surveillance, but no additional waste emplacements. Burials were “special” if they contained liquids, had extremely high radiation fields or contained fissile materials.

Figure 4: Waste management area B (the special burials area is shown in the red circle)



- Caustic cells description

One of the types of structures containing “special burials” is the caustic cells (CS), six concrete waste blocks containing drums of radioactive liquid wastes. At CRL, in the early 1960s, ^{60}Co was produced for cancer therapy units and other commercial gamma irradiators. An Aluminum (Al) encased ^{60}Co pellet was irradiated in the NRX reactor and then placed in a sodium hydroxide (NaOH) caustic solution to dissolve the outer aluminum (Al) casing. The used caustic solution was then placed into 45 gallon carbon steel drums in the hot cells and transferred to the special burials area of WMA B where the drums were collected on concrete pads. When a sufficient number of drums had accumulated, the pad and the drums on it were reported in historical records of the day to have been entombed in a concrete block. The process was stopped after six concrete blocks had been constructed.

A field project was undertaken in the summer of 2006 to investigate the six caustic cells (CS). Caustic cells 2 through 5 (CS 2 through CS 5) were found to be intact concrete blocks with little or no deterioration. No evidence of exposed drums or leakage from the drums inside the concrete was observed. CS 1 and CS 6 were excavated and found to consist of 55 gallon carbon steel drums that were exposed to the surrounding environment (Figure 5). Contaminated sand was found in the bottom of the CS 6 concrete box, indicating that the drums could potentially be leaking. Similarly the drums in CS 1 were observed to be potentially leaking as there were holes in the drums themselves. As the remainder of the CSs (i.e. CS 2 through CS 5) were enclosed as concrete monoliths, the assessment of CS 1 and CS 6 was advanced separately due to their observed configuration and poor condition (i.e. CS 1 and CS 6 are not completed concrete monoliths).

Figure 5: CS 1 (on left), CS 6 (on right)

Disposals were made to CS 1 in 1959. The “cell”, consisted of a concrete slab 5.5 m long by 1.8 m wide with five drums (45 gallon) placed on top (four of which were bituminised together in one solid monolith). The monolith was measured in the field to be approximately 1.1 m high.

Disposals were made to CS 6 in 1968. CS 6 was a concrete box with four walls, a pad, but no lid. The dimensions were 3.7 m long by 2.4 m wide and an interior height of 1.6 m. The cell contained five (45 gallon) drums with the remainder of the cell backfilled with sand.

3. Clean-up agency/stakeholders

- Organisations responsible for clean-up

Natural Resources Canada (NRCan) provides funding and oversight. AECL plans and performs the work. AECL performs the contractor role and engages subcontractors on an “as required” basis.

- Regulatory agencies with authority include
 - Canadian Nuclear Safety Commission (CNSC) because CRL is a licensed nuclear site
 - Department of Fisheries and Oceans because the Ottawa River forms a portion of the site boundary
 - Environment Canada generally oversees the safety of the environment on the CRL site
 - Health Canada regulates human safety on the CRL site
- Site-specific regulatory regime/requirements (as opposed to general national regime)

AECL is a federal crown corporation and as such is subject to federal regulations. In areas where no federal regulations exist, provincial regulations may apply. Applicable provincial regulators may include Ontario Ministry of the Environment, Ministry of Natural Resources, Ministry of Labor, and in the case of the offsite transport of waste, the Department of Transport federal regulations are followed. Additionally, AECL has internal compliance programmes, such as environmental protection, radiation protection, operating experience and operational health & safety, which set additional requirements that remediation projects must meet.

- Local stakeholders

Local stakeholders include the Algonquins of Pikwakanagan First Nations Community, recreational users of the area (cottagers), local communities and employees of CRL.

- Level of involvement in remediation project

Stakeholder involvement in the retrieval of selected legacy buried wastes has been limited. Information about remediation projects has been distributed following completion of individual projects in community newsletters. The CRL Site Environmental Stewardship Council, consisting of local councils and groups, is kept apprised of planned projects and results through meetings three times per year.

- Support or opposition from stakeholders

Minimal internal stakeholder feedback on the caustic cell project was solicited or received.

- Frequency of stakeholder meetings

No external stakeholder meetings for these types of remediation projects have taken place. Internal employees directly involved in the planning or monitoring of environmental remediation projects typically hold planning meetings prior to project implementation.

- Project drivers (valuable land re-use, risk mitigation, restoration planning, regulator or stakeholder concerns)

Project drivers included the prevention of the spread of contamination further into the environment and retrieval of inappropriately stored waste for more suitable packaging and storage in more beneficial storage locations.

4. Characterisation

- Objectives

Characterisation objectives include obtaining sufficient information to:

- justify the immediate removal of two of the caustic cells (uncontrolled releases to the environment);
- ensure worker safety during implementation of the remediation project;
- plan project technical details, such as remote or contact handling waste retrieval methods;
- place geographical boundaries on the remediation project scope;
- plan waste categories and volumes for post-project disposition pathways.

- Historical assessments

Sources of historical information include:

Waste management area logbooks (kept by waste management area personnel), disposal slips (filled out by the waste generator), monthly reports to Health Canada, internal quarterly division progress reports (engineering division, biology division, maintenance and construction division), historical photographs, criticality records.

- Risk assessments (degree to which they were used to determine project activities)

Risk assessments have been used to assess risk to humans and non-human biota. The risks to date have been low for the hazards assessed.

- Models used (e.g. site conceptual models, dose or risk assessment models)

A qualitative risk assessment was performed using analogies with known risks from other pertinent sources of contamination on the CRL site. No conceptual models were used to inform the risk assessment. No modelling software was used to make the assessment.

- Quality assurance: Design, standards, guidance, approach, data quality objectives

Data quality objectives were not established. quality assurance/quality control of laboratory sample analyses was determined by laboratories performing the analyses.

- Results (include plots of contamination)

Soil sampling was performed around the two caustic cells, first in 2006 and again in 2009. Although contamination was found immediately adjacent to the drums comprising the caustic cells, in neither case was radiological or chemical contamination outside the cells found to be above background levels. No conceptual models were developed using the data obtained from the sampling. The data obtained was used to develop waste management plans for the retrieval project.

- Statistical methods used to interpret data

None required.

5. Remedial objectives

The project remedial objectives were twofold:

- To achieve interim clean-up criteria (local background);
- to meet HSE objectives – ensure the release of radionuclides into the environment is controlled by proactive prevention, i.e. removal of the source.

Project success criteria included:

- the removal of the liquid waste inventories of CS 1 and CS 6; the recovered liquid wastes placed into appropriate waste packaging and suitably dispositioned;
- solid wastes (e.g. concrete, emptied drums, soil and used personal protective equipment and clothing) dispositioned;
- removal of any soil not meeting operational site-wide contamination criteria;
- the worksite backfilled and restored to pre-project physical conditions (ground levelled and seeded).

Because the caustic cells are located in a currently operating waste management area, project clean-up criteria were used rather than final end state criteria. The final end state will be established when the site ceases operations, currently planned for 2100.

6. Options evaluation

- Process used to evaluate remedial options

A formal decision-making process was used to evaluate the remedial options. It is a seven step process:

- Problem definition;
- Strategic requirements;
- Initial proposal;
- Feasibility study;
- Options evaluation;
- Business case;
- Project/activity concept.

- Remedial option selection criteria

Selection criteria for the caustic cells included:

- Licensability (alignment with internal compliance programmes as outlined in the site license, likelihood of receiving regulatory approval);
- Health and Safety
 - Public health and safety;

- Worker health and safety (compliance with Canada Labor Code, minimisation of exposure or direct contact).
- Environmental impact
 - Physical environment (air and water quality, primary and secondary waste discharges to land, visual impact, noise, traffic, energy usage).
 - Preservation of flora and fauna.
- Technical
 - Feasibility (availability of resources, site-specific applicability).
 - Reliability.
 - Proven Effectiveness (at CRL and elsewhere in the industry).
- Overall costs
 - Short term costs.
 - Life cycle costs.
 - Cost certainty.
 - Range of options considered
- **Option 1: Full retrieval.** This option requires excavation and complete removal of CS 1 and CS 6. The option involves conditioning and dispositioning the wastes.
- **Option 2: Partial retrieval.** Similar to Option 1, however, only the liquid waste and the drums are removed from CS 1 and CS 6. The concrete structure of the burials and soil remain in the ground.
- **Option 3: In-situ decay with monitoring.** Analogous to the status quo, CS 1 and CS 6 and the waste inventory of the cells are left in place for natural decay processes to occur.
- **Option 4: In-situ solidification.** This option requires solidifying the liquid waste within the drums to prevent migration of the waste into the environment in the event that the drums were to fail.
- **Option 5: In-situ containerisation.** This option requires completing the original construction intent to encapsulate the drums of waste in a concrete monolith.
- **Option 6: In-situ decay with engineered cover.** This option is similar to Option 3 but requires the addition of a barrier mechanism (e.g. aggregate cap or synthetic membrane) as a control measure to minimise infiltration of run-off and precipitation.
 - Stakeholder and/or regulator involvement in options evaluation process

Internal stakeholders (no external stakeholders were included) involved in the options evaluation process represented:

- Waste Management, who is both the line management responsible for the remediation site as well as potentially the waste receiver;
- WMA Facility Safety, to ensure all safety and licensing aspects pertaining to WMAs are considered;
- Radiation Protection Programme, to ensure all RP policies and requirements are considered;
- Environmental Protection Programme, to ensure all environmental protection policies and requirements are considered;
- Waste Management Programme, to ensure all waste management policies and requirements are considered, including waste minimisation principles;

- Nuclear Legacy Liabilities Programme, Strategic Planning representative, who is responsible for ensuring the proper management of CRL liabilities in a fiscally responsible manner.
 - Effectiveness of evaluation process

The process was effective. It allowed for a systematic, transparent evaluation. Having stakeholder involvement in the evaluation process provided a thorough and robust evaluation, although the choice of stakeholders could affect the outcome of the evaluation process. The thoroughness of the feasibility study also affects the results.

- Final selected remedy

The final selected remedy was Option 1: Full Retrieval.

This remedial option included the retrieval of the CS 1 and CS 6 burials (i.e. inventory and structure). Work activities to complete this remedial option included: excavation, removal of the waste inventory, retrieval of the cells' structures and the contaminated soil inside of and surrounding the cells. Subsequent characterisation and processing of waste to satisfy waste dispositioning pathways was also included in the scope. The design of this remedial option included:

- Site preparation: excavation of cell to expose the structures and drums in CS 1 and CS 6.
- Waste inventory retrieval: once field tests confirmed the drum inventories, the liquid contents were transferred with a peristaltic pump into awaiting double contained new drums. The majority of the activity had settled into a sludge at the bottom of the drums. Absorbent media was added to the drums to solidify the sludge before placing them into new over pack drums to ensure containment.
- Cell structure retrieval: demolition of the cells' structure and removal of any contaminated soil that may be attributed to CS 1 and CS 6 was included in this option. Due to the open configuration of CS 6, the soil inside the cell was to be dewatered and the water would likely require processing.
- Waste characterisation and processing: as the wastes were retrieved, it was necessary to verify that the waste characteristics met the dispositioning requirements. As liquid is no longer an acceptable waste form within the CRL WMAs, the inventory from CS 1 and CS 6 would require processing.
- Waste dispositioning: the assumed pathway for the recovered liquid waste was to an offsite waste processor for incineration. In the past, similar types of waste have been processed in this manner. The remaining retrieved solid waste, following appropriate characterisation, would be segregated and packaged for onsite waste storage.
- Site restoration: this option would also require site restoration activities (e.g. area backfilled, levelled and seeded).
- Operation and maintenance: as this option includes the complete removal of the burial, no further operation or maintenance of the burial will be required. A long-term monitoring programme for this option is not required.
 - Reason the remedy was selected
- Advantages:
 - This option scored the highest among the remedial options evaluated. Specifically, it was more cost effective over the life time of the Chalk River site (until 2100). Partial retrievals (liquids only) or in situ management/disposal may not meet regulatory approval for final end state (industrial reuse), while full retrieval was more certain to meet the final end state. The remediation methodology was demonstrated to be feasible and safe to the environment, workers and the public, having been previously performed on several other remediation projects.

- Limitations:
 - A limitation in evaluating remedial options is the lack of site end state knowledge. Lifecycle costs are difficult to determine without knowing how much contamination needs to be removed and how “clean is clean”.
 - The option chosen required the most significant upfront costs and resources.
- Projected benefits of the chosen option:
 - Liquid wastes are removed from the environment and will not migrate and contaminate further soils or groundwater. Complete removal of the waste packages means no further monitoring over the next 100 years will be required and no risk of future contamination being dispersed into the environment.

7. Remedy execution

- Description of remediation activities

Figure 6 shows CS 1 and CS 6 being remediated. The general description of the retrieval activities for each caustic cell are:

- excavate around the caustic cell using heavy equipment and manual digging;
- expose the tops of the drums within the caustic cell, using hand tools;
- for each drum:
 - perform a visual inspection to confirm number of drums and physical state;
 - verify inventory is consistent with historical records by:
 - monitoring drums in situ with gamma spectrometry;
 - accessing the drum contents to perform additional field verification tests (e.g. pH paper).
 - pump any liquid and sludge contents of the drums into awaiting containers on grade;
 - obtain samples of newly drummed recovered inventory for waste characterisation;
 - add solidification media to the emptied drums, as required;
 - for CS 1, hoist the four drums that were bituminised together into a container for storage in the onsite interim storage facility.
 - in CS 6, dewater (drumming water collected for characterisation) as well as remove and characterise interstitial soil;
 - using a crane, empty drums will be hoisted into awaiting double-plastic flask bags on surface (to be sent to compactor);
 - survey concrete and mark areas of contamination;
 - break up concrete and segregate as appropriate;
 - remove any soil not meeting the requirements established for the site;
 - perform verification survey and sampling of the excavation site;
 - replace any excavated soil that is reusable and/or backfill the site with new fill as required;
 - level, tamp and seed the worksite;
 - perform a close out radiation survey of the ground surface at the worksite;
 - confirm completion of work activities with a post-job brief or email to the facility manager;
 - complete the requirements to disposition all inventory recovered and generated waste as per the waste management plan;
 - issue a project closeout report.

Remediation activities were performed on the cells consecutively, completing one cell before moving to the next. The concrete structures were brought on grade and then demolished after the inventory from both cells had been removed and both excavation sites had been restored. The retrieval of CS 1 occurred first as the anticipated hazards were less significant and the complexity of the retrieval was simpler in comparison to CS 6. Following the retrieval of CS 1, a post job review was held to identify any lessons learnt which should be carried forward for the retrieval of CS 6.

Figure 6: CS 1 (left), CS 6 (right)



- Contaminants to be targeted

The CSs are individual structures that contain drums of radioactive, caustic solution from the Cobalt-60 (^{60}Co) processing that were emplaced in the late 1950s and into the 1960s. It was estimated that 187 MBq of ^{60}Co would migrate via groundwater to the nearest receptors in the Perch Lake watershed as a result of CS 1 and CS 6 containment failure.

- Technology descriptions

The following equipment was used on this project:

- RP monitoring equipment (beta/gamma contamination meter, alpha contamination meter and gamma radiation detector);
- explosive gas detection equipment;
- thermoluminescence dosimeters (TLDs);
- whole body personal alarming dosimeters (PADs);
- drums in which to put recovered liquids/sludge;
- over-pack drums and secondary containment for primary drums;
- container (i.e. B25 bin) for storage of bulk materials;
- drum sampling equipment (e.g. sample rods, bottles and wipes);
- field test equipment (e.g. pH paper, gamma spectrometry equipment);
- remote video scope camera;
- protective clothing (tyveks, chemical resistant/splash clothing, C4 respirators, cotton and rubber gloves, Controlled Area footwear, hearing protectors);
- emergency shower and eyewash station;
- drums/bags or other suitable containers in which to put contaminated soil and other generated waste;
- chemical spill kits including HazMat absorbent fabric and neutralising agents;

- loose absorbent materials;
- air sampling monitoring equipment;
- transfer pump assembly including peristaltic pump and hoses;
- pneumatic shears;
- generator and air compressor;
- heavy equipment including crane and backhoe or excavator;
- spades and spoon shovels;
- barricades and caution tape to prevent access when site is unattended;
- tarps;
- aluminium discs and silicone for resealing drums;
- water to moisten any contaminated soil and concrete to mitigate the risk of dust inhalation;
- brass wrenches, spray lubricant to open bungs and brass tools (awls) to puncture small holes in drums;
- collapsible containment pallets.
 - Time to completion

The overall field project took approximately two months to complete. The actual waste retrieval began in 8 August 2011 and was completed in 14 September 2011.

- Identified obstacles/barriers

None identified.

- Contract mechanism

No contracts were placed for pre-project preparation (work planning, risk assessments) or for the field retrieval portion of the project. A contractor was used for the transfer of certain radioactive liquid wastes to a thermal treatment facility in the United States. This service was arranged through an internal purchase order.

- Performance metrics

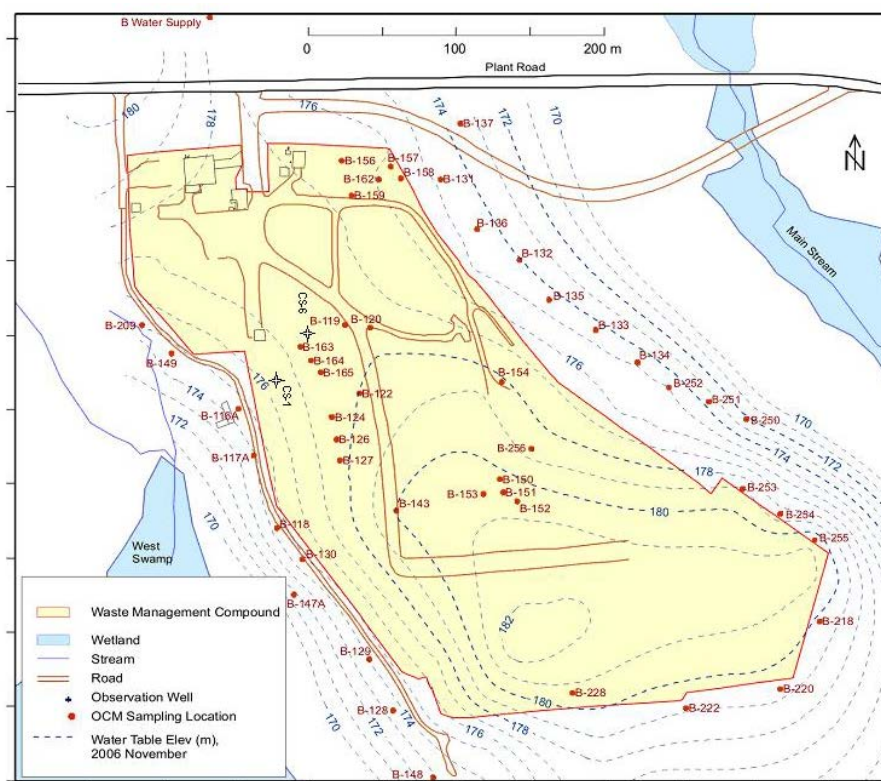
The performance metrics included schedule (Schedule Performance Index – SPI), cost (Cost Performance Index – CPI) and achievement of the project end state.

8. *Post remedial monitoring*

- Monitoring approach

Environmental and groundwater monitoring at CRL is performed at a waste management area facility level. Specific monitoring following smaller waste package retrievals is not performed because contaminant migration due to the smaller waste packages would be eliminated when the packages were removed. Also, the effects of contaminant migration would be overshadowed by the affects of contamination migrating from larger nearby waste trenches. The larger waste management area, as a whole, has environmental and groundwater monitoring, as shown in Figure 7.

Figure 7: Map showing the approximate locations of monitoring wells in waste management area B.



- Monitoring systems/technologies

Sampling wells are used to retrieve groundwater samples, which are then analysed in a combination of in-house and external laboratories.

- Extent of monitoring (temporally and spatially)

The waste management area as a whole is monitored twice per year (spring and fall) as part of an operation control monitoring (OCM) programme. Sampling wells line the perimeter of the waste management area and are strategically located within the waste management area, positioned such that potential major sources of groundwater contamination are monitored (Figure 7). The caustic cells themselves have no specific associated monitoring wells.

9. Major cost elements

- Characterisation

Characterisation costs amounted to just under CAD 310 000.

This was ~34% of the total project cost of CAD 901 000.

- Planning

Planning and execution costs were CAD 355 000, or 39% of the total project cost.

- Execution

Execution costs are included in the planning costs of CAD 355 000. Also included are project closeout costs, final site verification, closeout documentation and waste disposition charges. Ongoing onsite waste storage and offsite processing bring the project total up to CAD 901 000.

- Post remedial monitoring

No post remedial monitoring have been required for this project.

10. Lessons learnt

- “What went wrong?” and “what went right?” with respect to meeting regulatory requirements, stakeholder participation, agreement on conceptual models, project management, resourcing and organisation, project cost and schedules, project objectives and methodologies, dealing with uncertainties?

This project encountered the difficulties of performing environmental remediation on an operating site. Attention to other higher priority projects in the area diverted resources away from characterisation activities for this project resulting in the delay of the project by over one year and causing commitments to the customer to be deferred [2].

- How did the technologies used perform against technical success criteria?

A BROKK™ 90 with a pneumatic concrete chisel tool was used to break larger pieces of concrete. The BROKK™ did not always have adequate traction on soft sandy terrain if the slope was too great. Additionally, the concrete would have more readily been broken into pieces if it was elevated slightly off the ground. The use of the BROKK™ to break concrete was more time consuming than if a simple back hoe bucket would have been used. In part, this may have been a result of using undersized equipment for the job. A larger BROKK and attachment might have performed the job more efficiently, but the project made use of the existing smaller equipment because it was readily available.

- How did the project perform as a whole against success criteria and requirements?

The performance measures were schedule, cost and achievement of the project remedial objectives mentioned in Section 5.

Project completion was delayed by one year.

The original long-term planning budget of CAD 284 000 allowed for the remediation of the two caustic cells. An independent external cost estimate for the remediation of six caustic cells was CAD 867 000 and was aligned with the original long-term planning estimate of CAD 284 000 for two cells. The projected budgeted cost, as estimated by the project, was 320% above the long-term planning budget of CAD 284 000. The actual project cost was 15% below the project budgeted cost.

The project met the remedial objectives as well as the project success criteria, as presented in Section 5.

- What were the barriers to successful characterisation? What were the barriers to a successful project?

Challenges to characterisation and implementation of the remediation project included the competition for resources on an operating site. In addition, access to the waste management area itself had to be carefully managed due to conflicts with other, sometimes higher priority operational activities onsite.

These barriers were eventually overcome and the project was successfully completed, but not without significant schedule delays.

- What were common issues leading to schedule delays?

Other activities and projects occurring elsewhere on site in general, and in the waste management areas in particular, competed for attention and resources.

- How was the project aligned (or not) with any R&D priorities?

This project was not aligned with any R&D priorities.

- What could have been done differently?

Mock-ups could have been built to test the functionality of remediation equipment (BROKK™) early in the project planning phase.

Other lessons learnt revolved around planning work on an operating site. Planning should include:

- Keeping other functional groups informed with respect to project plans is very important to avoid conflicting schedules;
- Co-ordination of resources with other functional groups is very important;
- Allowing ample time (schedule contingency) for projects that do not have a high priority and that may get delayed if more urgent, unforeseen work arises and diverts resources.
 - Additional Comments

None.

11. References

- [1] “Chalk River Laboratories: A Description of the Environmental Baseline for Environmental Assessments”, CRL-509200-ENA-001, R2, August 2008.
- [2] “Remediation of caustic cells 1 and 6 in WMA B”, 3611-508350-PCR-003, R0, August 2012.

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Nuclear Site Remediation and Restoration during Decommissioning of Nuclear Installations

Decommissioning of nuclear facilities and related remedial actions are currently being undertaken around the world to enable sites or parts of sites to be reused for other purposes. Remediation has generally been considered as the last step in a sequence of decommissioning steps, but the values of prevention, long-term planning and parallel remediation are increasingly being recognised as important steps in the process. This report, prepared by the Task Group on Nuclear Site Restoration of the NEA Co-operative Programme on Decommissioning, highlights lessons learnt from remediation experiences of NEA member countries that may be particularly helpful to practitioners of nuclear site remediation, regulators and site operators. It provides observations and recommendations to consider in the development of strategies and plans for efficient nuclear site remediation that ensures protection of workers and the environment.