REVIEW OF THE ONR INTERNAL REPORT 'ASSESSMENT OF RADIOACTIVELY CONTAMINATED LAND REMEDIATION TECHNIQUES'

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Prepared for:	Office for Nuclear Regulation Redgrave Court, Merton Road, Bootle, Merseyside L20 7HS
Prepared by:	Nuclear Technologies plc Chadwick House, Birchwood, Warrington, Cheshire WA3 6AE
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Verification Statement

This document has been internally verified and approved by Nuclear Technologies[redacted]plc prior to issue to the client. The scope of the verification was to confirm that:

- The document has been verified and approved by SQEP personnel
- The modelling/calculations performed are accurate and correct
- The references are approved
- The document is internally self consistent

DOCUMENT ISSUE/AMENDMENT SHEET

Issue No.	Date	Description of changes
Draft A	14.1.18	Issue for client comment
Draft B	15.2.19	Amended to address client comments
Rev 0	6.3.19	Final version

SUMMARY

TUV SUD Nuclear Technologies (NT) has been engaged by Office for Nuclear Regulation (ONR) to undertake a review of an internal report on the options for land quality management as it applies to the ONR vires under the Nuclear Installations Act 1965. The review was undertaken on the basis that it would identify actions to be taken to refine and develop the existing internal report to create a guidance document that can be used by ONR inspectors to assess remediation schemes put forward by site operators.

An initial rapid review of the internal report determined that this document comprised a comprehensive list of land quality management techniques, but that there were opportunities to consider the format and completeness of the information.

Suggestion have been made on the structure and format of the information already collated in order to form a useable guidance document. This includes the need to establish UK context for land quality across the range of site for which ONR has regulatory responsibility. The internal report provides information on the theoretical application of land quality management (LQM) techniques along with limited case study examples. It is apparent that there is relatively limited track record of implementation of many of the techniques in the UK when specifically applied to radioactively contaminated land. The applicability of each identified technique should be reviewed against the UK context and any guidance prepared having prioritised those techniques that are likely to be the most applicable.

Suggestions for further research are made in respect of the identified LQM techniques, largely to assist with clarity and the understanding of applicability. The Internal Report has presented a comprehensive list of LQM techniques and included information on not just the science and engineering involved in each but also the constraints that apply to implementation. It is intended that the recommendation for additional work does not expand what has already been collated but actually allows a reduction by focussing on those LQM techniques that are most applicable to the UK context.

The work proposed in this report is intended to move the current Internal Report towards becoming the Guidance Document that fulfils ONR requirements should there be a desire to proceed with the next phase of the project.

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1 INTRODUCTION

The Office for Nuclear Regulation (ONR) has identified a requirement to develop internal guidance on the remediation (clean-up) of land affected by radioactive contamination on UK nuclear licensed sites. The ONR has vires for the regulation of such contaminated land under the Nuclear Installations Act 1965 which requires ONR inspectors to make regulatory judgements based on an adequate understanding of technical and scientific information.

ONR has recognised that Land Quality Management (LQM) requires the remediation of contamination in both soil and groundwater and that there are multiple techniques that may be applicable to a particular site/situation. Further, it is also recognised that remediation technologies are evolving and that emergent technologies may be available to use as part of LQM. ONR expects to be able to make effective 'as low as reasonably practicable' (ALARP) assessments of remediation strategies put forward by site operators based on knowledge of the benefits and limitations of the full range of potential LQM techniques.

An initial internal report (hereafter referred to as the 'Internal Report') has been prepared by ONR and TUV SUD Nuclear Technologies (NT) has been engaged to undertake a review of this Internal Report to identify information gaps and to propose further action to develop this Internal Report into a guidance document for ONR reference. Work to address the recommendations in this report will form Phase 2 of the project should ONR wish to proceed.

1.1 PURPOSE OF THE GUIDANCE

NT understands that the purpose of the project is to collate information on remediation techniques with a view to producing a LQM guidance document (hereafter referred to as the 'proposed guidance') that provides ONR with an appropriate level of information in relation to applicable remediation techniques to fulfil the needs set out above. The level of information required needs to be defined in the context of the ONR vires and the fact that the intended audience will be highly technically skilled in nuclear health and safety, but not necessarily in the field of land remediation.

ONR has defined LQM in the relevant Nuclear Safety Technical Assessment Guide on Land Quality Management NS-TAST-GD-083 (Ref 1) as including '*the prevention of new contamination and management of existing contamination of both land and groundwater and extends to remediation (including control and monitoring) of radioactive and non-radioactive contamination on the surface of the ground, in the ground and in groundwater*'. LQM can be considered a 'catch all' term that applies to the whole process of site characterisation; risk assessment; remediation optioneering, design and optimisation; implementation and verification. This guidance document is concerned with the remediation implementation stage of LQM only, but it is recognised that the ability to select and optimise a remediation strategy should only be undertaken having already carried out a suitably robust characterisation and risk assessment exercise.

Ref 1 sets out principles of risk assessment and characterisation but doesn't address techniques for undertaking this work. Characterisation itself presents several potential techniques and challenges that could be the subject of additional guidance to assist ONR in understanding the validity of the information that is underpinning a remediation strategy.

The proposed guidance is required to provide sufficient information to assist ONR inspectors in determining whether the LQM approach being taken (or proposed) by a license holder or site tenant is technically appropriate and ALARP. In this context, the following information will be needed:

- An overview of the technology behind the remediation technique, demonstrating how its application can manage/mitigate risk to public safety and the environment;
- Maturity/availability of technology in the UK and international market;
- Information on the reliability of the technique, case studies to illustrate implementation and demonstrate success;
- Information on the timescale required to implement and longevity of the risk mitigation provided;
- Infrastructure requirements including space, resources, energy demands;
- Unit costs for implementation;
- Consideration of waste arisings – primary and secondary wastes along with availability of disposal routes in UK and internationally;
- Other environmental / public nuisance impacts;
- Verification and aftercare requirements (including consideration of whether the LQM approach is temporary or permanent solution);
- Regulatory compliance and stakeholder acceptance.

In the context of the ONR vires the consideration of remediation technologies can be limited to addressing radiological contamination issues. However, given that many of the UK's nuclear sites will have both radiological and conventional contamination issues on the same site, it is appropriate to consider whether the presence of conventional contamination (under the vires of the environmental regulators) could have an impact on the applicability or effectiveness of a remediation technique. It is also appropriate to consider the waste disposal issues that might apply to mixed contaminants where it might be necessary to apply a secondary treatment process to a waste or where disposal routes could be constrained.

1.2 REVIEW STRATEGY

The Internal Report has been reviewed using the information requirements set out in Section 1.1 above, drawing on knowledge of the remediation sector and specific experience of the Nuclear Decommissioning Authority (NDA) Group Sites and other UK nuclear operators. Following our initial review of the Internal Report it was apparent that the work undertaken provided a comprehensive overview of the remediation techniques that were likely to be relevant to the ONR vires. What was also apparent was that there was opportunity to consider the format and presentation of the document and how this might be amended to produce the proposed guidance document. There was also the need to look at the extent of the technical information provided, identifying information gaps and areas requiring clarification.

The structure of this report is as follows:

1. Recommendations for the format and presentation of the proposed guidance document;
2. Comments and recommendations on the initial sections of the Internal Report;

3. A review of each technique and recommendation in relation to information gaps;
4. A summary of recommendations for further work to be undertaken as Phase 2 of this project;
5. Conclusions.

In undertaking this review, we have referred to existing guidance documents, sought further information from the public domain and had discussions regarding the availability of more focussed information with other suitable parties. We have not specifically sought to address any of the identified information gaps as this will form Phase 2 of the project should ONR wish to proceed.

Our findings are presented in the form of a series of recommended actions with accompanying text to justify the actions.

2 FORMAT OF THE PROPOSED GUIDANCE

From discussions with ONR, it is understood that the intention is to produce an internal guidance document and that will be in the public domain. The content of the proposed guidance therefore needs to be free of any protective security marking that would prohibit public dissemination.

There is a wealth of existing guidance available on remediation, some that is specific to the nuclear sector, but the majority of which is not. The particular issues relating to radioactive contamination and the practicalities of implementing works on nuclear licensed sites mean that it is important that any general information is carefully considered to assess relevance and applicability to the nuclear sector. As a general point, any non-nuclear sector guidance and case studies need to be careful reviewed/considered and put into context before applying to a nuclear sector scenario. The same applies to non-UK examples, whether in terms of environmental setting or contamination scenario.

The following section sets out recommendations in relation to the format of the proposed guidance, giving due consideration to existing guidance with similar objectives.

2.1 STRUCTURE

Recommendation – the structure of the technical information should be presented in a format that clearly identifies applicable media and whether the technique is in situ or ex situ.

The high-level division of remediation techniques provided in the Internal Report into physical, chemical, biological etc is clear and logical. However, it is recommended that there is also a clear recognition of the media to which a technique applies (soil or groundwater) and a differentiation between in situ and ex situ remediation.

The adoption of an ex-situ remediation will require either the excavation of soil or the pumping of groundwater via boreholes (‘pump and treat’). These are effectively the two baseline remediation options with other technologies being components of a remediation scheme. It may be beneficial to structure the proposed guidance around a description of each of these with other processes identified as a component of each.

Some remediation techniques such as solidification/stabilisation can be applied both in situ and ex situ, but the logistical challenges and constraints will be different in each scenario. It would also be beneficial to distinguish between remediation techniques and what can be considered waste treatments. Taking ion exchange as an example, this process can be applied in situ, for example by using a permeable reactive barrier, or ex situ by pumping groundwater and treating at surface. The structure of the proposed guidance therefore needs to show how individual treatment techniques fit into a full LQM scheme.

Consideration of the logistics involved in excavation of soil or extracting groundwater (the ‘pump’ in pump and treat) need to be set out in the guidance as this could be the more challenging aspect from a logistical viewpoint than the treatment of the extracted soil/water.

Existing guidance already exists that presents a logical structure, see the example matrix from Safegrounds W28 (Ref 2) in Appendix A.

2.2 PRESENTATION

Recommendation - the format of the proposed guidance warrants further consideration to make it useable and concise.

There is already a multitude of technical information sources, good codes and good practice guidance and regulatory instruments that apply to LQM. These can be used to give some direction on how the proposed LQM guidance might be presented, but at a high level it is suggested that the use of the following should be considered:

- Templates to provide consistency of data presentation;
- Flow/process diagrams to illustrate LQM;
- Diagrams to illustrate remediation principles;
- Photographs to show the practicalities of implementation;
- Matrices to enable rapid comparison of techniques;
- Case studies to show implementation.

Use of a template approach for each remediation technique will help to ensure consistency of information presented. There will be variable levels of information to present depending on the complexity and maturity of the technique, use of a set format would allow easy comparison of the key attributes of each technique. A suggested format, suitable for further refinement and development, is provided in Appendix B. Given the purpose of the proposed guidance it is suggested that each technique could be kept to a single sheet (double sided if required) to include a case study.

Diagrams and photographs are useful ways to illustrate the concept of remediation techniques and give an idea of the practical issues around implementation.

LQM follows a process that includes iteration loops and can be concisely presented on a flow diagram. An example of this can be found in the Safegrounds guidance W28 (Ref 3), included as Appendix C, which shows the relationship between remediation and the preceding characterisation and optioneering stages. It would be beneficial to include a suitable process flow diagram in the proposed guidance. It may also be possible to produce a tailored flow chart which identifies the key questions that should be asked by ONR in assessing whether an LQM strategy represents ALARP.

The use of tables/matrices can assist with the speedy screening and comparison of techniques and can be used to illustrate their applicability to different media and contamination types. The example matrix in Appendix A requires some updating but would form the basis of a useful addition to the proposed guidance document.

The use of case studies to illustrate the application of remediation techniques is a powerful way of demonstrating track record and highlighting lessons learned. There are a number of case studies presented in the Internal Report that use nuclear site examples. In order of preference, the use of UK based nuclear site examples should be regarded as the best source of relevant information with non-UK studies present where required. The use of non-nuclear applications of techniques may also be helpful but should be treated with caution and carefully considered to ensure that they are relevant.

2.3 CASE STUDIES AND SOURCES OF INFORMATION

Recommendation – the proposed guidance should include case studies for all key remediation techniques.

The Internal Report includes some case study information to illustrate the applicability of remediation techniques. Potential sources of additional information have been considered as part of this review exercise. The information gathering undertaken to date, both in the drafting of the Internal Report and in undertaking this review has been based on public domain searches. There is a list of Codes of Practice and Good Practice Guides included in Ref 1 and this is not reproduced in full as part of this review.

The recommendation to include case study information where possible raises the need for sources that are as directly applicable to the UK situation as possible. The ideal case studies will show the implementation of a remediation technique on a UK nuclear site. Where no such studies can be identified the use of non-UK or non-nuclear site case studies may be helpful, but these should be regarded with caution. Variations in a wide range of factors, from the regulatory and legislative framework through to geology and climate, means that the direct consideration of such case studies could give a misleading picture of remediation technology suitability in the UK.

Initial enquiries made by NT confirm that there are likely to be relatively few UK nuclear site case studies that can be drawn upon. We are aware of several remediation schemes that have been or are being implemented across the UK nuclear estate, but that these will not cover the broad range of potentially viable remediation techniques identified in the Internal Report. We have engaged with the Nuclear Industry Group on Land Quality (NIGLQ) and sought agreement to engage further in the development of case studies. Particular discussions with Site License Companies (SLC) have been restricted to Magnox Ltd, but from this it is clear that there are limited examples of remediation works having been implemented. Nevertheless, we would propose carrying out a consultation exercise with SLCs, via groups such as NIGLQ, to identify case studies that can be used. In engaging with NIGLQ it would also be possible to capture MOD case studies.

It is also possible that suitable case study information can be obtained from remediation contractors (although it is unlikely that they will be able to supply detailed information relating to works on licensed sites).

3 CONTEXT AND GENERAL INFORMATION

The following recommendations and observations relate to the introductory text in the Internal Report or to text that is considered should be included. It is assumed that introductory sections will provide the necessary background to allow the information on the specific remediation technologies that follows to be correctly interpreted and understood without excessive reference to multiple other documents. However, in making the following recommendations it is acknowledged that existing ONR guidance, particularly Ref 1, could provide the additional information by cross referencing rather than repeating it in the proposed guidance. It should also be recognised that the proposed guidance needs to be consistent with other documents.

3.1 RISK ASSESSMENT

Recommendation – the proposed guidance should include additional information in relation to the process of risk assessment and how this relates to remediation optioneering.

The Introduction in the Internal Report contains some brief text on the Source-Pathway-Receptor (S-P-R) model that is the basis of the risk assessment process set out in the Defra UK guidance CLR11 (Ref 4) and repeated in many other guidance documents relating to LQM including the Safegrounds (Ref 2) guidance. As this model is fundamental to the selection and optimising of remediation works, it is important to ensure that the concept is clearly set out before presenting information on individual remediation techniques.

Whilst, as stated in the Internal Report, it would seem preferable to remediate by removing the source of contamination, this option would not necessarily be the optimal solution in all cases. A remediation strategy needs to be determined with reference to not just the technological feasibility, but also in full consideration of the specific site situation and ongoing and future plans for the land area in question.

Recommendation - the proposed guidance should include an appropriate level of information to explain the how the development of a Conceptual Site Model underpins the selection of a remediation strategy.

The development of a Conceptual Site Model (CSM) is used in LQM to provide a written or diagrammatic representation of the S-P-R relationships and therefore to highlight linkages between source and pathway. Reference to a CSM is often a simple way of articulating the fundamental basis for a particular remediation strategy. An example CSM which illustrates how LQM can control risk and would be a useful addition to the proposed guidance.

Recommendation - the proposed guidance should explain the influence that the overall site decommissioning/development strategy has on the scope of remediation.

Differing environmental, socio-economic and political drivers will apply to UK decommissioning sites that will directly influence the LQM approach. For example, many of the Magnox Ltd sites are now preparing to enter a Care and Maintenance phase where the site is put into a quiescent state for a period of c. 80 years post end of generation.

Publication of the finalised ‘Guidance on Requirements for Release’ (Ref 5) provides a strong driver to use risk-based remediation strategy to achieve a sustainable end state. This will allow materials that might otherwise have been subject to remediation and disposal to be used as backfill to voids and for land contamination to be managed in situ, where this can be demonstrated as fit for purpose and justified by a suitably robust risk assessment.

Equally, the recent consultation on the ‘Regulation of Nuclear Sites in the Final Stages of Decommissioning and Clean Up’ and proposed changes to primary and secondary legislative in relation to delicensing of nuclear sites needs to be considered and could lead to changes in the way that remediation strategies are developed and provide for on-going regulatory control outside of nuclear licensing before a site end state is reached.

Brief information on relevant guidance and the overlap between LQM and other legislative regimes should be considered for inclusion in the proposed guidance document. This should include a brief explanation of the application of the planning regime to remediation and the potential requirement for environmental impact assessment (EIA) to be undertaken to fulfil the requirements of the Nuclear Reactors (Environmental Impact Assessment for Decommissioning Regulations) (EIADR) or as part of an application for permission under the Town and Country Planning Act.

3.2 UK REMEDIATION CONTEXT

Recommendation - explanatory text is included in the proposed guidance that provides a UK context on the nature of the contamination risk that exists across the nuclear sector.

The legacy of contamination on UK sites is unlikely to be any more significant than ‘environmental’ levels of dispersed contamination in the majority of cases. Contamination of the magnitude found following a major incident such as Chernobyl or Fukushima is not present in the UK. As a result, some of the remediation methods that have been applied internationally (such as cryogenic containment), whilst technically possible, are unlikely to be feasible in the context of remediation for UK site given the complexity and cost of implementing. Post-accident land remediation can be very situation-specific, and it is recommended that is excluded from the scope of the guidance.

The provision of international case studies needs to be in the context of the circumstances in which they were deployed, with a recognition that they may not be applicable to the current UK circumstances. In general terms, it can be said that certain remediation techniques are better suited to higher levels of contamination, but do not work efficiently for lower activity dispersed contamination.

An up-front section describing the nature of the potential contamination across the UK nuclear sector and a broad assessment of the risks that are likely to require remedial action would be beneficial to the proposed guidance. The likelihood is that containment, excavation and separation and monitored natural attenuation (via radioactive decay) will be the predominant techniques in the near term on UK nuclear sites.

It would also be beneficial to understand the typical fingerprint for radionuclide contamination of the ground. Whilst this will not provide a definitive list of radionuclides present, it could be useful in conducting a course screen of the remediation technologies set out in the guidance and be used to filter them for relevance in the UK and by site type. It is likely that some sites will, because of their operational history, have a more varied and complex fingerprint than others.

Consideration of the typical fingerprints associated with different types of nuclear sites would be a more appropriate level of information than detailed and site-specific fingerprints. It would be useful to consider whether typical fingerprints for nuclear power generating sites, research sites, reprocessing and defence related sites etc could be included in the proposed guidance as an indication of the dominant radioactive species that might be expected to have caused contamination of land.

It would also be beneficial to provide information on the implications of radioactivity concentration on the selection of LQM techniques. For example, the ability to remediated high levels of activity using techniques such as permeable reactive barriers or other ion exchange techniques should be explored to aid understand of whether remediation strategies can be successfully implemented, reaching the desired end point within a permissible programme.

Finally, consideration should be given to the presence of conventional contamination and the impact that this could have on the application of radioactive contamination remediation techniques. Extensive characterisation information already exists on sites that confirm the presence of multiple contaminants as a result of previous uses (which might not be restricted to nuclear site use). Power generation sites can generally be expected to have been impacted by hydrocarbons and solvents from turbine halls as well as other contaminants typical of an industrial site. A number of nuclear sites were previously in MOD control and therefore may also be impacted by contaminants resulting from defence related use.

3.3 REMEDIATION COSTS

Recommendation – the inclusion of information on the cost of implementing a remediation solution would be beneficial to the proposed guidance.

The consideration of cost benefit should be a factor in the remediation optioneering process, with cost being weighed against factors such as timescale, certainty of success as well as cashflow and the economic benefit of land remediation. It would be beneficial for the proposed guidance to include some measure of cost against each remediation technique and to explain the relevance of cost to the assessment of ALARP.

It can be assumed that the consideration of the cost benefit relationship is of relevance, as it is with the environmental regulators whose vires includes conventional land contamination. The extent of remediation required by a regulator has to be proportional to the potential harm posed by contamination. As the level of contamination becomes lower, the costs for achieving further reduction for what can be marginal decreases on risk can become exponentially higher and disproportionate to the benefits gained.

The estimating of costs for remediation work has always been a difficult area. In contrast to a traditional construction scheme, there is a far greater level of uncertainty in remediation works because of the inherent difficulties in scoping below ground works on the basis of ground investigation data. If suitable unit costs can be estimated there is usually significant variation in quantity that leads to a wide range of cost outcomes. The calculation of actual scheme costs will also need to include all associated costs such as mobilisation, set up, disposal of wastes, post completion verification (or ongoing monitoring).

For the purposes of the guidance document the provision of relative costs would perhaps be the best option. Various sources of cost data are likely to be available as follows (in order of reliability):

- Actual implementation costs – nuclear site,
- Actual implementation costs – non-nuclear site
- Contractors estimated unit costs
- Published cost information

Various published sources of cost information are available, but these are relatively few and far between. Contractors may be happy to provide estimated unit costs for the application of a particular technology, for example soil washing per cubic meter, but if the volume of soil to be treated is in a wide range, then the cost uncertainty will reflect this. The cost of remediation is also dependent on site specific conditions such as space availability, ground conditions etc. In the context of work on a nuclear site there is the added complication of adherence to security protocols and radiation protection measure to be adopted.

Sources of published information have been briefly reviewed as part of this exercise and no directly relevant cost information has been found. A guide to redevelopment costs has been produced by The Homes and Communities Agency (now Homes England) (Ref 6), but this includes only generic costs for remediation of land against redevelopment scenarios.

3.4 WASTES ARISING FROM REMEDIATION

Recommendation – consideration is given to the waste disposal requirements arising from the implementation of each remediation technique.

As radioactivity will only decrease through decay or specific activity decrease by migration the use of remediation techniques to address radioactive contaminated ground will effectively either:

- contain the material in one place or allow managed migration;
- alter the chemical state to reduce mobility where it can be safely allowed to decay over time; or
- allow the material to be removed to an engineered disposal facility.

The Internal Report currently refers to the disposal of generated wastes against a number of the identified remediation techniques but given the constraints on disposing of radioactive waste streams, it is suggested that further consideration of this is warranted. In particular, consideration of the waste form and volume arising from a remediation technique should be set out along with the availability of suitably permitted disposal facilities and the practicalities of handling such wastes.

It is also relevant to consider the disposal of secondary wastes arising from the implementation of remediation. Wastes streams such as filter media and ion exchange resins have the potential to concentrate activity and thereby pose disposal challenges.

3.5 SUSTAINABILITY CONSIDERATIONS

Recommendation – guidance is provided on the key sustainability issues in relation to implementing LQM techniques.

The assessment of ALARP in relation to LQM should consider the proportionality of the direct costs involved but should also have cognisance of the wider sustainability of a proposed scheme. In its broadest sense, the sustainability of a remediation scheme is a wide-reaching subject that includes environmental factors alongside socio-economics. An assessment of the sustainability of an LQM scheme would need to identify the impacts of implementing the scheme and allow these to be weighed against the benefits. Direct impacts such as waste generation and energy and material usage (including associated transportation can be balanced against the removal of actual or potential pollution, the benefit of bringing land back into economic use and the creation of employment etc.

The avoidance of unintended environmental (including ‘nuisance’) impacts should also have been assessed. These could include impacts to air quality, noise generation, visual impact and traffic load during remediation works. The carrying out of an EIA (as described in Section 3.1), either as a compulsory requirement of fulfilling obligations under associated legislation, or as a voluntary action, would be expected to assess these elements for a proposed remediation scheme. Overall, the remediation scheme should demonstrate that the proposed solution is optimised considering radiation protection within a holistic assessment of all other impacts and implications.

3.6 VERIFICATION AND AFTERCARE

Recommendation – for each identified remediation scheme there should be an indication of the need for and extent of verification along with any specific on-going maintenance and aftercare requirements (including monitoring).

Almost every remediation technique will require some form of verification to demonstrate completion in line with defined objectives. For some remediation techniques this will be a relatively simple case of sampling and testing, but in other cases there will be significant periods of monitoring to demonstrate on-going function of a system or process.

The likely timescale for this should be identified and any restrictions that this might place on land management should be explored. As an example, the installation of a reactive barrier is likely to require a lengthy period of groundwater monitoring via a network of boreholes to confirm the correct functioning of the system until such time as the contaminant source is depleted. It is also likely to require access to replace the reactive element, possibly on several occasions.

4 REVIEW OF REMEDIATION TECHNIQUES

In reviewing the Internal Report we have considered the information contained in the context of the requirements that are set out in Section 1.1 of this report. The Internal Report currently provides details on specific remediation techniques, including information on the process, timescale and constraints on implementation. The following makes specific recommendations in relation to information gaps, opportunities for clarification and context/presentation (in line with the general recommendations made in Sections 2 and 3 of this report).

As a general comment on the content of the Internal Report, we would suggest that it provides a comprehensive overview of the available remediation techniques relevant to the ONR vires. The primary opportunity is to clarify and refine this information and tailor it to the UK context. Our review concentrates on the presentation and context of the information and any opportunities to augment and clarify information that has already been collected.

4.1 CONTAINMENT

Capping and encapsulation with in-ground barriers are all LQM techniques that have an extensive track record, including on nuclear sites. The Internal Report provides comprehensive details on the application and constraints associated with the use of containment but recommendations to enhance this are provided below.

To assess the applicability of containment to manage risks from contaminated land it is essential that there is a full understanding of the CSM and a robust underpinning risk assessment. To use the S-P-R terminology, containment is used to break a pathway and it is therefore important to fully understand all the pathways that are active to inform the design of an LQM scheme.

The use of diagrams as recommended in Section 2.2 of this report will be helpful in articulating the factors involved in assessing the suitability of containment as a remediation solution. Issues such as the need to manage lateral migration, requiring the use of vertical barriers, or the need for a basal liner to prevent leaching of contamination to groundwater can be more clearly explained by reference to the CSM for a site. It should also be identified that the installation of containment will necessitate measures to control surface water run-off and potentially manage groundwater levels.

NT understands that there are examples of the use of containment remediation techniques on UK nuclear sites. This presents the opportunity to use directly relevant case studies to illustrate implementation, including the consideration of constraints.

The Internal Report includes an example of the use of cryogenic containment at Fukushima as a case study. Whilst cryogenic containment is a feasible method of containing radioactively contaminated groundwater where ground conditions permit, the cost of maintaining such containment (as alluded to in the Internal Report) are likely to mean that there will be limited application to LQM in the UK context.

Recommendation - the durability of materials used to make up composite capping systems and in-ground barriers should be explored.

The use of mineral caps, using a layer of low permeability clay over contaminated material is still used to provide capping. It is also common to use composite capping 'systems' using membranes and geo-composites such as High-Density Polyethylene (HDPE) or Geosynthetic clay liners (GCLs) along with low permeability soils to achieve the required permeability.

The use of capping on nuclear sites could be as a temporary measure, to manage in situ contamination pending a permanent disposal, or as the permanent solution. Given the potential timescale involved in either option it is important to understand the durability/longevity of the specific materials used to form the cap. The maturity and track record of this remediation technique means that there is existing research into the lifespan of commonly used composite capping materials considering the impacts of multiple factors such as exposure to light, temperature and ground chemistry (Ref 7). The Internal Report refers to capping being suitable for timescales of tens to hundreds of years, but the durability of a particular cap will need to be established against an understanding of the longevity of the material making up the cap.

The Internal Report does allude to the potential vulnerability of in-ground containment to degradation as a result of ground and groundwater chemistry. There are further sources of research in this area (examples in Refs 8 and 9) that should be reviewed and relevant findings considered in the proposed guidance.

Recommendation – consider the inclusion of hydraulic containment as a specific technique for contaminated groundwater.

The concept of hydraulic containment should be set out in the proposed guidance. The limiting of contamination mobility by controlling the groundwater gradient can form an LQM strategy (Ref 10). Pumping from boreholes to lower groundwater levels and thereby influence flow direction can be an effective means to prevent a plume reaching a particular receptor. This may also include an element of treatment of the abstracted groundwater.

As with the use of cryogenic barriers, the deployment of hydraulic containment as an LQM strategy may be of limited application in the UK nuclear context as the operational costs would preclude long term application. Further research would be beneficial to determine whether this is the case.

4.2 BIOLOGICAL PROCESSES

Like containment-based remediation techniques, the use of biological process is tried and tested within the remediation sector in the UK. The internal report provides a full assessment of biological processes, but care needs to be taken to understand the particular relevance of these techniques to the remediation of radionuclides. The vast majority of the track record for biological remediation is related to hydrocarbon contamination that can be broken down to non-hazardous compounds.

The use of phytoremediation is viable to address diffuse near surface contamination on sites where sufficient time can allocated to the technique. The Internal Report sets out the key information requirements and constraints that could apply and it is considered that this technique is adequately covered.

Specific recommendations in relation to biological remediation of radionuclides are given below.

Recommendation - Further information should be provided on the applicability of MNA to particular radionuclides.

The Internal Report provides a comprehensive review of Monitored Natural Attenuation (MNA). This is recognised and mature LQM technique that is likely to have wide application on nuclear sites in the UK (particularly where the radionuclides have a relatively short half-life, i.e. of a few years to a few decades). As stated in the Internal Report there is existing UK guidance on the application of MNA (Ref 11), but this does not include the specific consideration of radionuclides.

As with containment, the use of MNA requires a detailed and robust CSM to be developed and a full understanding of the risks to be established. The acceptability of an MNA solution will be particularly linked to the provision of a fully justified CSM to prevent it being seen by stakeholders as a ‘do nothing’ option.

The Internal Report currently refers to MNA under ‘biological processes’ and care is needed to distinguish between the application of MNA to conventional and radioactive contamination. As stated in the Internal Report the application of MNA to address hydrocarbons and solvents in the UK is proven and the biological degradation of the contamination load will be a factor in the attenuation process. In the case of radionuclides, radioactive decay is the primary attenuating factor, although dilution and sorption will also lead to attenuation. Factors such as changes to groundwater chemistry may need to be considered if an MNA strategy is to be justified.

Due to the likelihood of MNA being a feasible LQM technique in many situations and the need to ensure that this is fully underpinned, further research into applicability for different radionuclides would be beneficial for the proposed guidance.

Recommendation - further consideration of the work required to establish a monitoring network should be undertaken along with exploration of advances in monitoring techniques.

The Internal Report identifies that fundamental to the viability of MNA is the ability to carry out reliable and efficient monitoring throughout the remediation programme. Further information is recommended to illustrate the technologies available to undertake this monitoring. The requirement for an extensive network of monitoring locations, most usually boreholes, should be set out (albeit that each scheme will be bespoke). It is also possible that access will be required to third party land to establish a full monitoring network.

Current practice relies on regular in situ analysis along with sampling and laboratory testing to demonstrate that adequate attenuation is continuing. This entails visits by technicians to undertake these works and obviously requires that monitoring locations can be easily accessed. The advent of wireless connectivity and remote sensing technologies means that in future it may be possible to reliably collect data remotely, but in situ / 'on-line' measurement of environmental levels of radioactivity is not a mature science, particularly where activity concentrations are relatively low. This is worthy of further investigation, particularly given the timescales over which MNA remediation might be undertaken on nuclear sites.

Recommendation – further information should be sought regarding the applicability of bioaugmentation and biostimulation and the potential to accelerate MNA.

The Internal Report identifies that bioremediation of radioactive contamination effectively falls into the category of sequestration (via phytoremediation or microorganisms) or alteration of radionuclides to reduce contaminant mobility. Both bioaugmentation and biostimulation are identified as potential techniques in respect to the latter but these need to be examined in the context of enhanced MNA. Information on the potential to enhance attenuation exists (Ref 12 and 13) and it would be beneficial to explore the applicability of this in relation to the UK context, including an assessment of the prevailing ground conditions.

The practicalities involved in implementing these techniques warrants further exploration. The introduction of fertilizers or aeration of groundwater via boreholes should be examined and incorporated in a description of enhanced MNA as a distinct LQM technique. Note, as mentioned above these relate to sequestration or contaminant mobility and will have no effect on the overall inventory of radioactivity.

4.3 CHEMICAL PROCESSES

As outlined in Section 2.1 of this report, chemical processes should be considered in the context of them being an element of a remediation system rather than a LQM technique on a stand-alone basis. Techniques such as solvent extraction and ion exchange should be included in the proposed guidance, but more clearly shown in the context of being a component of scheme involving a reactive barrier or ex situ treatment of soil and groundwater. Specific recommendations in relation to chemical processes are given below.

Recommendation - the potential for the creation of difficult waste streams resulting from chemical processes needs to be examined and considered in the context of available disposal routes.

Ex situ solvent extraction is a proven technique for the treatment of excavated soils in both conventional and radioactive contamination scenarios.

There appears to be relatively limited information on the effectiveness of solvent extraction in a UK nuclear context. Care is required in the use of mining related applications of solvent extraction of uranium from experience in the extractive industries as these may not be directly analogous to remediation work. Indeed, what experience there is of the application of solvent extraction to radionuclide remediation suggests limited effectiveness. Pilot trial work undertaken at Harwell (Ref 14) showed that solvent extraction could be used to remediate to risk-based clearance levels, but that the use of strong acids was required, particularly in the case of caesium contamination.

Consideration needs to be given to the waste arising from solvent extraction. The disposal of liquid radioactive waste needs to be considered as part of any solvent extraction scheme, particularly if this generates an acid/solvent based active effluent.

Similarly, the use of ion exchange is a mature technology, deployed in both nuclear and conventional land remediation to address contaminated groundwater. The process can be used both in-situ, as a component in the form of a Permeable reactive barrier (PRB), or ex-situ, as a pump and treat system. Once captured on the exchange media a new waste form is created. It may be necessary to consider if this waste form passes a disposability assessment or meets the criteria for disposal.

Recommendation – review the application of ion exchange in situ in comparison with ex situ application.

The internal report provides information on the process of ion exchange but does not consider the potential issues with deployment as part of an in situ LQM strategy (such as a PRB) in comparison to ex situ. The effectiveness of ion exchange may well be limited by ground conditions when applied in situ.

The primary constraints are the abundance of competing ions taking exchange sites, saturation limits of the exchange materials and potential large organic & inorganic molecules clogging up the pores or the exchange sites and reducing effectiveness. This latter issue is of relevance to many UK nuclear sites where the presence of hydrocarbon contamination can be expected.

Recommendation - the logistics and constraints for implementing Pump and Treat based remediation need to be explored.

An overview of the type of work required to install a groundwater abstraction network would be a useful addition to the proposed guidance. Whilst this will have to be addressed at a generic level that recognises the many factors that will influence specific design, it is possible to set out the type of work required to install boreholes and the necessary infrastructure to pump groundwater for ex situ treatment. This will also need to address the discharge/disposal of treated water.

Recommendation – augment the existing information on Permeable Reactive Barriers to illustrate their use with in-ground barriers to direct groundwater through the reactive element.

The use of PRB is a mature remediation technology within the remediation sector. In the UK their application has been for non-radioactive contamination.

A PRB effectively combines the in situ application of a chemical process (such as ion exchange) with the use of in-ground barriers to ‘funnel’ contaminated groundwater through the permeable reactive element. This will probably be best illustrated using diagrams and a case study of possible but is necessary to fully appreciate the application of a PRB.

4.4 PHYSICAL PROCESSES

As with chemical processes, the use of physical processes should probably be considered as a component of a remediation scheme rather than a stand-alone LQM technique. The Internal Report provides a full overview of the physical processes that can be applied to remediation but further consideration of applicability to the UK nuclear context would be beneficial.

Recommendation – review the differences between in situ and ex situ deployment for adsorption and soil washing.

Adsorption should be considered as a component of a groundwater remediation solution rather than an LQM technique in its own right. It shares with ion exchange, the potential to be impacted by the presence of oils and heavy metals that clog the pores in the adsorption media and the need to consider the waste generated by the process.

Soil washing undertaken in situ (soil flushing) needs to be expanded on and carefully considered in the context of radionuclide remediation. The potential to mobilise contamination as a result of the flushing process needs to be carefully considered in the UK nuclear context.

Recommendation – address excavation and dry separation in greater detail as a stand-alone remediation technique.

The Internal Report does not currently include a specific section on excavate and segregate as an LQM technique. As stated in Section 2.1 above, the baseline remediation process for all ex situ soil remediation techniques is excavation of contaminated soil. Once excavated material can then be subjected to further processing (stabilisation, soil washing, physical removal of fraction etc) or could be simply segregated on the basis of activity levels and sentenced for disposal or reuse where appropriate.

Outside of the nuclear sector the use of ‘dig and dump’ techniques to manage contaminated land was dominant but has been in decline for a number of years as costs have risen, due to factors such as the application of landfill tax, and other techniques have advanced.

In the context of nuclear site land management there is likely to continue to be many viable applications for excavate and segregate solutions to deliver remediation within a short timescale. The removal and disposal of contaminated material provides a degree of certainty of risk reduction that means that this may well be the preferred solution even if other viable options exist.

As with several of the remediation technologies addressed in the Internal Report, excavate and segregate solutions rely on the effective segregation and sentencing of radioactive waste. Whilst this is a mature and proven technique, the method of on-site waste segregation needs to be carefully considered in the overall scheme design. If contamination can be demonstrated to be concentrated in a particular fraction of the soil mass then simple physical separation techniques like sieving could be effective in removing the radioactive component for disposal. An understanding of the radionuclide fingerprint of the contamination is required and consideration of the activity concentration limits to which the material needs to comply will dictate the segregation technique.

Current systems for the on-site assay of excavated waste include both low and high resolution gamma spectroscopy to monitor excavated waste on conveyors, in excavator buckets or in other bulk containers. The ability to assay waste at a speed that doesn't unduly slow the excavation process is central to the viability of these techniques. This technology requires separate consideration in the proposed guidance document as it is likely to continue to be part of remediation schemes within the UK nuclear sector.

Recommendation – consider whether flotation should be included as a feasible technique

As with several techniques identified in the Internal Report, flotation is limited to ex situ application of excavated material and therefore falls into the waste treatment category. It is suggested (Ref 12) that flotation is essentially an enhancement to soil washing rather than a standalone LQM technique. Further consideration of flotation in the context of the UK would be beneficial. There appears to be limited examples of the application in terms of LQM. The Fukushima case study presented does demonstrate successful implementation but as suggested in Section 2.3 of this report, non-UK case studies need to be carefully considered to see how they align with the UK context.

4.5 SOLIDIFICATION/STABILISATION

As with chemical and physical processes, care is required to be explicit in distinguishing proven waste treatment processes and how these relate to LQM. The solidification of radioactive waste is proven in the ex situ treatment of waste but the application in situ as an LQM technique is less well understood.

Recommendation – consider the durability of stabilising agents, particularly in respect of in situ application and the presence of conventional contaminants.

The Internal Report addresses the potential use of solidification/stabilisation techniques for the in situ and ex situ treatment of radioactive waste. The potential use of cement-based grouts and chemical agents such as thermosetting polymers is set out and the potential issues of durability are highlighted.

There is a significant volume of literature on the durability of cementitious grouts, along with methods for improving durability by addition of materials to the mix. The presence of hydrocarbons alongside radioactive contamination would need to be established as this has the potential to degrade stabilising media (Ref 15). The in situ application of stabilisation for radioactive contamination will also need to take account of the potential for long term changes in ground chemistry including variations in pH and microbial conditions.

The Internal Report suggests that the use of chemical agents to stabilise contamination could offer more durable solutions.

4.6 THERMAL PROCESSES

The Internal Report already includes a comprehensive overview of the available thermal techniques for both in situ and ex situ remediation. These are relatively well developed techniques, including international application to radioactive contamination.

Recommendation – review thermal processes in UK context and confirm relevance to diffuse contamination.

The use of thermal processes to immobilise radionuclides in soil have been applied to remediation works but there does not appear to be any track record of use in the UK. Consideration of these processes in the UK context would be beneficial to determine whether application to generally low levels of diffuse contamination renders them of limited use. The potential costs of implementing thermal processes, particularly in situ, may mean that there will be limited application to UK remediation.

4.7 OTHER/EMERGING REMEDIATION TECHNIQUES

Appendix 1 and 2 of the Internal Report contains brief details on other remediation techniques and emerging technologies. ONR's desire to understand emerging techniques is understood and any remediation guidance will require regular updates to make sure that advances in technologies are captured. In our view, the list of other and emerging techniques is comprehensive and that these techniques do not generally warrant further consideration at this stage. The exception to this is the use of electrokinetic remediation.

Recommendation – undertake further research into the use of electrokinetic remediation.

A review of available literature suggests that electrokinetic remediation (Ref 16) might be applicable to LQM on nuclear sites. The application of electrokinetic remediation to radionuclides in low permeability soils where techniques based on pump and treat are ineffective, could have applicability to the ground conditions prevailing on many UK site.

5 SUMMARY OF RECOMMENDATIONS FOR PHASE 2

The review of the Internal Report has identified a number of recommended actions to develop the work already undertaken into a guidance document that fulfils ONR requirements and objectives. Where additional research and information gathering is recommended the purpose is not necessarily to expand the volume of information that is contained in the proposed guidance. Rather it is to allow the guidance to be tailored and focussed on those LQM techniques that have a proven or high potential relevance to the remediation of radioactive contaminated land in the UK.

The recommendations from this review, along with a brief consideration of the scope of work required to address them and the expected output are shown on the following table. Actions have been prioritised using a simple red-amber-green structure, where green should be regarded as essential and red as optional for the purposes of the proposed guidance:

Action No.	Recommended Action	Scope	Expected Outcome
1	Structure the technical information to clearly distinguish between applicable media and whether the technique is in situ or ex situ.	Review current Internal Report structure. Refer to existing guidance and agree structure for proposed guidance that best suits ONR requirements.	Revised structure to provide greater clarity on remediation implementation requirements, differentiating between in situ and ex situ, groundwater and soil.
2	Consider format of proposed guidance to make it useable and concise.	Review other available guidance documents for good practice examples. Assemble library of usable diagrams and photographs. Refine proposed template. Develop matrix of remediation techniques.	Diagrams and photographs to aid quick appreciation of science and practicalities involved in remediation techniques, template approach to aid consistency and matrices to allow quick comparison of viable LQM techniques.
3	Include appropriate case studies for all key remediation techniques (or as many as possible).	Engage with suitable industry groups to establish availability of case study information (recognising that UK case studies will be limited). Consider applicability of each case study and provide explanatory narrative as required.	Aim for a representative case study for each key technique using diagrams/photographs where available to show practicalities of implementation for each technique.
4	Expand text on process of risk assessment and how this relates to remediation optioneering.	Draft text to provide additional background to risk assessment process using existing available guidance information.	Provide clear illustration of how risk assessment underpins the selection of a remediation technique to assist in understanding

			applicability of each technique.
5	Explain the how the development of a CSM underpins the selection of a remediation strategy.	Linked to above action – introduce the use of CSM to illustrate pollutant linkages. Create a suitable generic CSM.	Reinforce the importance of understanding the Source-Pathway-Receptor model to assist in understanding applicability of each technique.
6	Explain the influence that the overall site decommissioning and development strategy has on the scope of remediation.	Draft additional text using examples where possible to show how differing end state requirements and timescales impact LQM approach. Use examples from UK where possible.	Demonstrate how differing end state requirements, environmental, socio-economic and political drivers influence remediation strategies.
7	Provide a UK context on the nature of the contamination risk that exists across the UK nuclear estate.	Engage with site operators to establish what information can be gained on baseline conditions – geology, contaminant finger print etc.	Prioritise LQM techniques for UK situation. Focus further research effort on techniques most likely to be regularly deployed.
8	Provide information on the cost of implementing each remediation solution.	Explore sources of cost information for each identified technique. Use any existing published data and consider alternative sources of information (e.g. specialist contractors).	If no reliable sources of cost information can be obtained, use relative cost information for each remediation technique to assist in understanding cost-benefit position.
9	Discuss waste disposal requirements arising from the implementation of each remediation technique.	Establish waste arisings where relevant to a remediation technique and availability/capacity of disposal routes. Discuss with contractors and waste disposal operators as required.	Provide an indication of waste generation against each technique and implications on disposal routes to aid understanding of feasibility.
10	Provide information on the key sustainability issues in relation to implementing LQM techniques.	Identify the key sustainability metrics that should be considered in the demonstration of ALARP for an LQM scheme	Provide an understanding of the overall impacts and benefits of an LQM scheme to allow a robust assessment of ALARP.
11	Consider remediation verification and specific on-going maintenance and aftercare requirements.	Establish typical verification and maintenance requirements using case study reviews, discussions with other environmental regulators.	Include an indication of generic verification and aftercare requirements against each technique.

12	Consider the durability of materials used to make up composite capping systems and in-ground barriers should be investigated.	Review existing information on material durability for typical material types by reference to published research and manufacturer product data.	Provide an understanding of the likely durability and longevity of containment.
13	Consider the inclusion of hydraulic containment as a specific technique for contaminated groundwater.	Review existing guidance and seek out any examples of implementation to control radioactive contamination.	Possible inclusion as an additional LQM technique.
14	Consider the applicability of MNA to particular radionuclides.	Establish understanding of MNA practicality for different radionuclides. Further research as required.	Refine list of applicable contaminants that MNA could be applied to (and those that it cannot).
15	Consider the work required to establish a monitoring network and research advances in monitoring techniques.	Use examples of MNA implementation to assess typical monitoring network requirements. Research monitoring advances with specialist contractors.	Allow the full scope of an MNA LQM scheme to be understood.
16	Gather information on the applicability of bioaugmentation and biostimulation and the potential to accelerate MNA by reducing contaminant mobility.	Research enhanced MNA and consider application to radioactively contaminated land and UK context. Use case studies and engage with specialist contractors if beneficial.	Add enhanced MNA to existing technique description if applicable to UK.
17	Examine the potential for difficult waste streams resulting from chemical processes and considered in the context of available disposal routes.	Review solvent use in chemical extraction and determine waste form generated, assess this against disposal routes.	Details on wastes generated by application of chemical extraction and availability of waste disposal facilities.
18	Review the application of ion exchange in situ in comparison with ex situ application.	Consider implications of conventional contamination and possible impact on effectiveness of ion exchange in situ.	Establish potential limitations of in situ application of ion exchange.
19	Establish the logistics and constraints for implementing Pump and Treat based remediation need to be explored.	Set out typical Pump and Treat requirements by reference to case studies and consider in context of nuclear site implementation.	Include section in guidance on logistics of implementing Pump and Treat LQM techniques.
20	Augment the existing information on PRBs to illustrate their use with in-ground low permeability barriers to funnel groundwater through the reactive element.	Use existing guidance to source additional information, case studies where available.	Present PRB use in the context of a groundwater management scheme, showing how a PRB can be deployed in conjunction with other in-ground barriers.

21	Review the differences between in situ and ex situ deployment for adsorption and soil washing.	Reference to case studies and specialist contractors to determine in situ methods for deployment.	Understand the relevance to UK nuclear context, particularly in situ deployment.
22	Address excavation and dry separation in greater detail as a stand-alone remediation technique.	Reference to case studies from UK and review of segregation technologies, engaging with specialist contractors as required.	Set out as a standalone LQM technique. Excavate and dispose is likely to continue to be a viable solution for UK nuclear sites.
23	Consider whether flotation should be included as a feasible technique.	Further review of case studies and research to determine the extent of track record. Flotation could be better seen as an emerging technology.	Consider whether flotation should be categorised as an emerging LQM technique.
24	Consider the durability of stabilising agents, particularly in respect of the presence of conventional contaminants.	Refer to specialist contractors and manufacturers to gain better understanding of durability of stabilising agents.	Determine whether non-cementitious agents increase potential application of in situ stabilisation due to improved durability.
25	Review thermal processes in UK context and confirm relevance to diffuse contamination.	Use UK context to assess applicability of in situ thermal processes. Case studies and cost information to be reviewed.	Determine whether in situ thermal processes are applicable LQM techniques in the UK nuclear context.
26	Undertake further research into the use of electrokinetic remediation.	Assemble further information to determine whether electrokinetic remediation should be addressed as a LQM technique.	More detailed section on electrokinetic remediation may be warranted.

6 CONCLUSIONS

NT has completed a review of the ONR Internal Report. Based on the initial rapid review of the Internal Report it was agreed with ONR that the review would focus on:

- Considering the format and presentation of a proposed guidance document; and
- Suggesting opportunities to augment and clarify the information already collated.

It is suggested that there is a need to restructure the information in the Internal Report if ONR wished to proceed with the development of a guidance document and recommendations are provided on how this should be carried out.

There is opportunity to restructure the information to provide greater clarity on the work that is entailed in the implementation of the remediation techniques. The structure should reflect the fact that the base remediation techniques are:

- Contain or treat contamination in situ
- Excavate and treat/dispose of soil ex situ
- Pump and treat groundwater ex situ

The increased use of diagrams, photographs, matrices and a common template approach will add to the usability of the proposed guidance. It is also suggested that the up-front section of the report should provide additional information with respect to the process of risk assessment that underpins the LQM strategy.

Establishing context in terms of radiological remediation in the UK would be highly beneficial. The nature of the contamination that can be expected, ground conditions and site-specific constraints should be established, as far as possible, to allow comment to be made on the relative applicability of the remediation techniques to LQM in the UK. It is suggested that this is fundamental to developing understanding of the theoretical application of a technique verses the reality of deployment on a UK nuclear site.

A suggested Contents List for the proposed guidance is included as Appendix D.

Initial contact with industry groups has confirmed a willingness to engage and assist with the provision of information on context and case studies. The current UK position is that excavation and separation and containment-based remediation schemes have been predominant in the UK and the adoption of what might be regarded as more innovative techniques appears to be limited. Engagement with suitable groups within the sector should provide access to case study information and wider views on LQM on nuclear sites. This will assist in developing guidance that is focussed on the UK situation and therefore directly relevant to the ONR vires.

Should ONR wish to proceed with the development of the proposed guidance the Internal Report provides the basis for further research work. The key challenge relates to the placing of each identified LQM technique in the context of the UK nuclear sector, clearly highlighting the constraints (and opportunities) to implementation. The aim of the proposed additional work will be to focus the proposed guidance rather than expand on the information already presented.

7 REFERENCES

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8 APPENDICES

Appendix A: LQM Applicability Matrix

Summary of remedial techniques and their applicability

Category	*In situ* techniques	Heavy metals	Organics	Radiological	*Ex situ* techniques	Heavy metals	Organics	Radiological
Physical	Electroremediation	M	M	E/M	Excavation and disposal	C	C	C
	Capping	C	C	M	Soil washing	C	C	E
	Barrier	C	C	M	Electroremediation	E	E	E/M
	Hydraulic containment	M	M	M	Soil vapour extraction	NA	C	NA
	Detector based segregation	NA	NA	C				
	Soil vapour/dual phase extraction	NA	C	NA				
Chemical	Soil flushing by chemical leaching	C	C	M	Soil washing by chemical treatment	C	C	E
	Solidification/ stabilisation	C	C	C	Chemical Treatment	C	C	E.M
	Surface amendment	M	M	M	Solidification/stabilisation	C	C	E/M
					Surface amendment	M	M	M
Biological	Phytoremediation	E	E	E/M	Bioremediation	NA	C	NA
	Monitored natural attenuation	C	C	M				
	Bioremediation	NA	C	NA				
Thermal	Vitrification	M	M	NA	Incineration/thermal desorption	C	C	NA
					Vitrification	M	M	E

Key

C Commonly used, well developed technology, effective

M Maybe suitable either in conjunction with the techniques, and/or following detailed consideration of site-specific characteristics

E Experimental/pilot scale

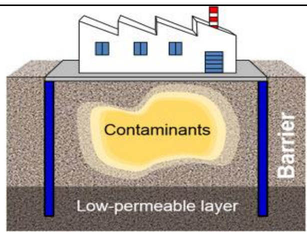
NA Not Applicable

Appendix B: Suggested template format

Technique	Vertical In-Ground Barriers		
Type, media	**Applicable contaminants**	**Technology maturity (M-MMMM)**	**Costs (£ to ££££)**
Containment, groundwater	All mobile contaminants	MMM	££

Technology

Vertical in-ground barriers are constructed using low permeability material, usually bentonite clay slurry, grout or piles, to contain the lateral migration of mobile contaminants in groundwater. Their use is well established in the UK remediation sector to contain a variety of mobile contaminants. Additional containment can be provided by the inclusion of a membrane installed within slurry walls.



Implementation

Bentonite walls can be installed to depth of up to 25m using conventional excavation plant to dig a trench which is backfilled with bentonite slurry as it is dug. Wall thickness is typically around 1m. The technique has the benefit of the trench being self-supporting and therefore not requiring any temporary support. Clam shell buckets can also be used to excavate individual panels to greater depths than long reach excavators. Bentonite is delivered to site in dry form, hydrated and mixed with cement to form a pumpable slurry.
The mix of bentonite and cement can be varied according to site conditions. Using just bentonite or small quantities of cement will create a flexible barrier able to accommodate some ground movement. Higher cement content will increase the material strength, but at the expense of increased brittleness and a reduction in the ability of the barrier to tolerate ground movement.
Grout barriers are formed by the injection of grout into the ground using boreholes spaced to ensure a continuous wall of grout.
Piled barriers are usually formed using sheet piles that installed using percussion to drive the piles to the required depth.

Constraints

Access. Construction requires full access to the length of the wall and room for plant to dig a trench, inject grout or install piles.
Site conditions. The ground conditions must be suitable for the chosen technique. Bentonite slurry walls require ground that can be excavated, grout injection requires soil permeability to be sufficient to ensure that a continuous barrier is formed, and piles require ground suitable to allow installation to depth. All of these require the presence of a low permeability layer into which the barrier can be keyed to prevent contamination passing under the barrier. Slurry walls require level topography and consideration needs to be given to the management of groundwater levels as installation can alter the groundwater regime.
Timescales. In ideal ground conditions the installation of slurry walls can be a
Durability. The vulnerability of in-ground barriers to degradation due to ground chemistry needs to be considered in the design. Certain chemicals are known to
Barriers need to be protected from damage throughout their operational life, but limited breaches of slurry walls will 'heal' due to the flexibility of the clay.

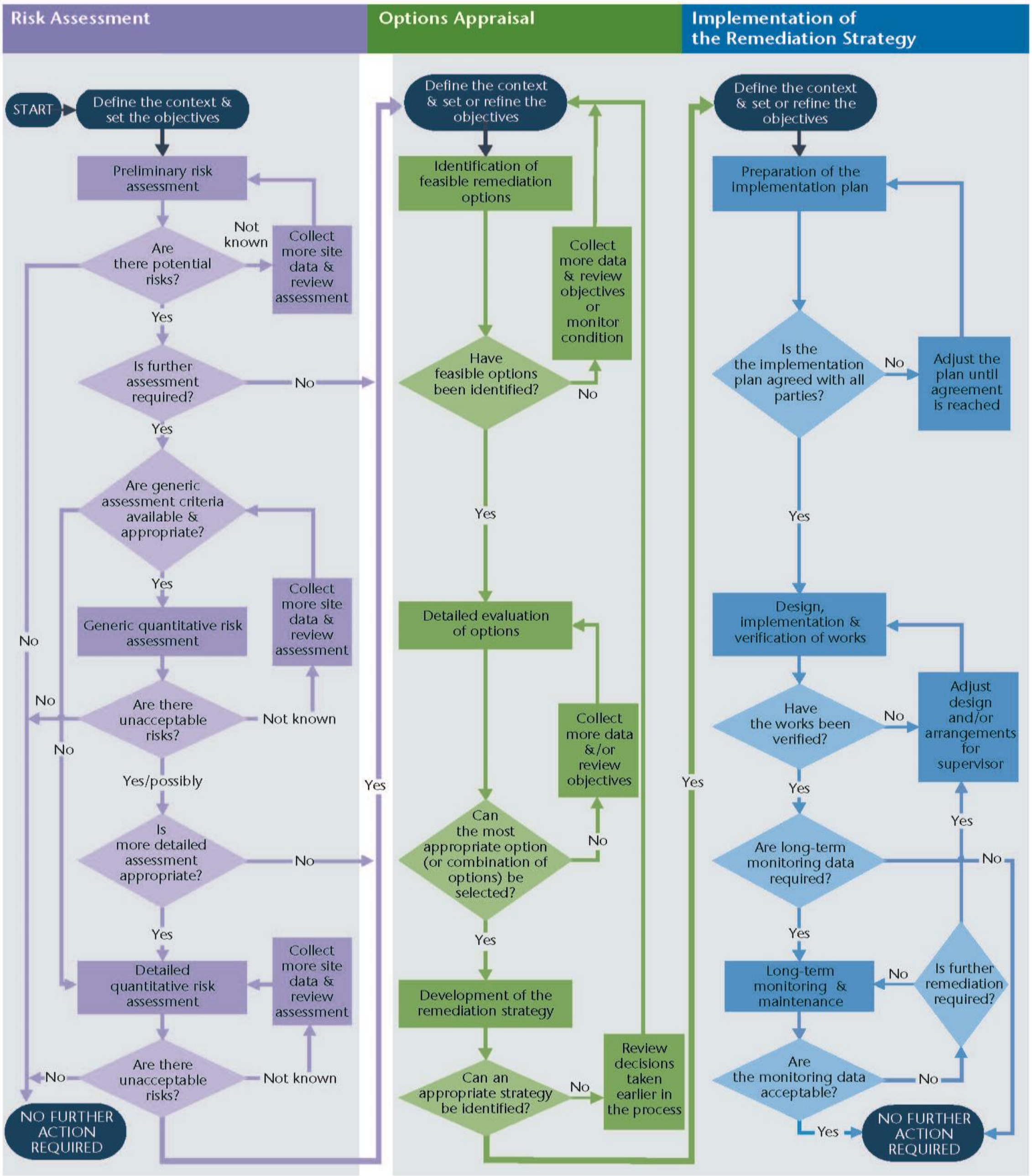
Aftercare

Monitoring of groundwater quality down gradient for a period after installation is usually required to demonstrate correct functioning. There are no specific aftercare requirements, but barriers need to be protected from break by future excavation works and bentonite slurry walls need to be kept hydrated.

Guidance

ICE, CIRIA, BRE and DETR. 1999. Specification for the construction of slurry trench cut-off walls as barriers to pollution migration. Thomas Telford.

Appendix C: Example LQM Process Flow Diagram



Appendix D: Suggested Contents List for Guidance Document

1. Introduction
2. Purpose and Scope of Guidance
3. Risk Assessment
    - 3.1. UK Regulation and Land Quality Management Guidance
    - 3.2. Characterisation and Conceptual Site Model
4. Land Quality Management Technique Selection Considerations
    - 4.1. Process [incorporating decision flow diagram]
    - 4.2. Logistics, space and time
    - 4.3. Sustainability
    - 4.4. Waste Disposal
    - 4.5. Costs
    - 4.6. Aftercare
5. Land Quality Management Techniques [using matrix then template format]
    - 5.1. In situ Containment
        - 5.1.1. Capping
        - 5.1.2. Vertical in ground barriers
        - 5.1.3. Permeable reactive barriers
    - 5.2. In situ Biological
        - 5.2.1. Bioremediation
        - 5.2.2. Phytoremediation
        - 5.2.3. Monitored natural attenuation
    - 5.3. In situ and ex situ Physical/Chemical
        - 5.3.1. Solidification/stabilisation
        - 5.3.2. Thermal vitrification
        - 5.3.3. Soil washing/flushing
    - 5.4. Ex situ Physical/Chemical
        - 5.4.1. Excavate and separate
        - 5.4.2. Soil Washing
        - 5.4.3. Solvent Extraction
        - 5.4.4. Flotation
        - 5.4.5. Ion exchange
        - 5.4.6. Electrokinetic
6. Summary
7. References