Geological Disposal
Science and Technology Plan

May 2016
Conditions of Publication
This report is made available under the Radioactive Waste Management Transparency Policy. In line with this policy, Radioactive Waste Management is seeking to make information on its activities readily available, and to enable interested parties to have access to and influence on its future programmes. The report may be freely used for non-commercial purposes. However, all commercial uses, including copying and re-publication, require permission from the Nuclear Decommissioning Authority (NDA). All copyright, database rights and other intellectual property rights reside with the NDA. Applications for permission to use the report commercially should be made to the NDA Information Manager.

Although great care has been taken to ensure the accuracy and completeness of the information contained in this publication, the NDA cannot assume any responsibility for consequences that may arise from its use by other parties.

© Nuclear Decommissioning Authority 2016. All rights reserved.
ISBN 978-1-84029-529-0

Other Publications
If you would like to see other reports available from RWM and the NDA, a complete listing can be viewed at our website www.nda.gov.uk, or please write to us at the address below.

Feedback
Readers are invited to provide feedback on this report and on the means of improving the range of reports published. Feedback should be addressed to:

RWM Feedback
Radioactive Waste Management Limited
Building 587
Curie Avenue
Harwell Oxford
Didcot
OX11 0RH

e-mail rwmfeedback@nda.gov.uk
Abstract

This Science and Technology Plan presents an analysis of the nature and timing of RWM’s future generic research and development activities. By ‘generic’, we mean those activities that can be undertaken without specific knowledge of the eventual host site for the geological disposal facility. The document is primarily an internal document, however publication of this document will provide opportunities for dialogue and involvement of interested parties in the development of our knowledge base for the safe geological disposal of radioactive waste. This document provides significantly more detail of our research needs, objectives and indicative scope than previously published. Feedback is welcomed, particularly in relation to innovative approaches which may address the identified research needs and objectives.

This is a second issue of the Science and Technology Plan, containing a number of enhancements.
Executive Summary

Radioactive Waste Management Limited (RWM) is the UK Government’s nominated implementer for delivering a geological disposal facility (GDF) for the UK’s higher activity radioactive wastes. The purpose of this document, the ‘Science and Technology Plan’, is to provide details of the nature and timing of our planned generic research and development activities. By ‘generic’, we mean those activities that can be undertaken without specific knowledge of the eventual host site for the geological disposal facility. It is intended that publication of this document will provide opportunities for dialogue and involvement of interested parties in the development of our knowledge base for the safe geological disposal of radioactive waste. While we have consulted widely with industry, academia and other Waste Management Organisations in developing our Science and Technology Plan we welcome feedback, particularly in relation to innovative solutions to our identified research needs and objectives.

This is the second version to be published and it contains the following enhancements:

- Full alignment with RWM’s Science and Technology Programme (which replaces our Technical Programme Document); this plan supersedes part C of the previously published programme document and identifies a clear “golden thread” from the major products identified in the programme to individual task sheets presented in the plan.
- A ‘change control’ appendix, identifying and justifying changes to the previously published plan, including completion, deferral, deletion, etc of individual tasks.
- A number of new tasks, recognising the iterative development of the GDF project, whereby arising needs are included in the plan.

This document comprises a short discussion of the context within which this plan has been developed and the methodology which we have used to develop the detailed analysis, together with the detailed plan contained in the appendices to this document:

- Appendix A is a breakdown of all the topics within RWM’s technical programme which require research and development in this generic phase of our programme.
- Appendix B comprises a set of task sheets describing the specific research requirements in a structured manner which provides stakeholders with clarity of the specific research needs, objectives and suggested scope of every task we currently foresee to be required to appropriately address RWM’s generic knowledge gaps.
- Appendix C is a simple long-range graphic showing the phasing of the generic research and development activities detailed in Appendix B.
- Appendix D documents changes to the plan between version 1 and version 2.

Throughout our analysis of knowledge gaps and their proposed closure we have utilised Scientific Readiness Levels (SRLs†), developed by the National Nuclear Laboratory, as a tool to consider the maturity of the knowledge base as it evolves, and to consider what level of scientific maturity is required as an end-point to our generic activities.

We have prioritised the schedule in line with the available budget underpinning RWM’s business plan, utilising a series of prioritisation questions and recognised drivers for research and development.

Having undertaken three decades of research into the geological disposal of UK wastes, significant progress has been made. Challenges to the viability of geological disposal concepts have been overcome (although implementation may be subject to site-specific challenges) and the remaining key uncertainties are currently subject to large focused research projects. Such tasks are identified in the Science and Technology Plan, together with the remaining generic body of research and development required to address
knowledge gaps associated with the Disposal System Safety Case, disposal concept development and disposal system design.

Once a potential candidate site has been identified a programme of site investigation will be undertaken in order to reflect the real environment in the safety case, together with research, development and demonstration studies associated with the optimisation of the disposal system to the local geological environment. These site specific research and development activities are not included in this plan and will be subject to future analysis once a suitable site becomes available.
List of Contents

Abstract iii

Executive Summary v

1 Introduction 1
1.1 Background 1

2 Purpose of this Document 2
2.1 How to Use this Document 4

3 Development of Our Knowledge Base 4
3.1 RWM’s Science and Technology Hierarchy of Documentation 4
3.2 Current Position 9

4 Assessment and Comparison of Scientific Maturity 11

5 Description of Science and Technology Plan Contents 13
5.1 Planning and Prioritisation of Research Projects 13
5.2 Task Descriptions and the Long-range Graphic 14

6 Interfacing of Generic with Site Specific Research 16

7 Review and Scrutiny 17

8 Feedback 18

9 References 19

Appendix A – Work Breakdown Structure
Appendix B – Task Sheets
Appendix C – Long-range Graphic
Appendix D – Change Control record
1 Introduction

1.1 Background

The UK Government has adopted geological disposal, coupled with safe and secure interim storage and a programme of ongoing research and development, as the way forward for the long-term management of higher activity radioactive waste. This approach is described in the UK Government policy document, *Implementing Geological Disposal* (hereafter referred to as the ‘White Paper’) [1].

The White Paper allocated to the NDA the role of implementing body for geological disposal, including carrying out appropriate research to support implementation. Radioactive Waste Management Limited (RWM) is the UK government’s nominated implementer for delivering a geological disposal facility (GDF) for the UK’s higher activity radioactive wastes.

In September 2014 we published our first Science and Technology (S&T) Plan; this document updates the 2014 plan, incorporating learning and feedback from internal and external stakeholders. A number of enhancements are also present:

- Full alignment with our higher level S&T Programme [2] (which replaces our Technical Programme Document [3]); this plan supersedes part C of the previously published programme document and identifies a clear “golden thread” from the major products identified in the programme to individual task sheets presented in the plan.
- A ‘change control’ appendix, identifying and justifying changes to the previously published plan, including completion, deferral, deletion, etc.
- A number of new tasks, recognising the iterative development of the GDF project, whereby arising needs are included in the plan.

This document addresses the development of our generic science and technology knowledge base, i.e. those research and development activities which can be undertaken in advance of site selection, including those associated with our support of both Geological Disposal Facility (GDF) development and waste disposability assessment. It is recognised that the publication of this report is only one step in the ongoing refinement of our generic science and technology activities. By sharing our current views on these activities we aim to encourage dialogue, the outcome of which will be reflected in further iterations of this document (see below). The S&T Plan is structured as follows:

- **Section 1**: This introduction, setting the context of the S&T Plan.
- **Section 2**: A statement of the purpose of this document and identification of how it is intended to enable our stakeholders to better understand our Science and Technology research and development needs.
- **Section 3**: A review of the current status of our knowledge base, including its key documents, and the mechanisms for identifying the needs for, and mechanisms for delivery, of work which enhances our knowledge base.
- **Section 4**: A consideration of the need for a tool to evaluate the scientific maturity of our understanding now and at key points in the future and the introduction of such a tool (Scientific Readiness Levels (SRLs)) [2].
- **Section 5**: A description of the two key components of the S&T Plan, presented as appendices to this document: Appendix B contains task sheets formatted in a consistent and user-friendly manner and Appendix C summarises the scheduling of these tasks in a long-range graphic.

---

1 In Scotland, the policy for management of higher activity radioactive waste is long-term near-surface, near-site storage or disposal so that the waste can be monitored and is retrievable and the need for transporting it over long distances is minimal.

2 SRL is a registered trademark of the National Nuclear Laboratory Ltd.
Section 6: A brief consideration of the linkages between the generic work presented in this document and how it will interface with, and be influenced by, site-specific research, development and demonstration activities once a potential candidate site has been identified.

Section 7. A short summary of the process used to develop and review the S&T Plan.

Section 8. An invitation to readers to provide feedback on this document.

We intend to review the S&T Plan at least every three years and will continue to make changes to our previous plans transparent in a ‘change control’ Appendix (see Appendix D). It is anticipated that higher tier documents will require less frequent review and revision, however when significant milestones are achieved this is likely to prompt a review of the entire Science and Technology hierarchy (see Section 3.1).

2 Purpose of this Document

This report has been developed in order to present an analysis of the nature and timing of RWM’s future research and development activities. It is primarily an internal document used to plan and agree our research priorities. It is however intended that publication of the S&T Plan will provide opportunities for dialogue and involvement of interested parties in the development of our knowledge base for the safe geological disposal of radioactive waste. This plan also demonstrates how we will fulfil the stated aim of our business plan: “to continue to work with suppliers to effectively deliver the needs-driven technical programme (including research and development, design and assessments) to meet White Paper commitments, reduce uncertainties in advance of site specific work and support work on new build wastes using their expertise and knowledge to deliver solutions to issues.”

The S&T plan has been produced with a time-horizon of a decade, during which the vast majority of planned generic research will be completed, with the associated reduction in knowledge gaps. At the current stage in our programme, without an identified host site for a GDF, we have constrained its scope to those activities which can be conducted at this generic stage although, as recognised in Section 6, the identification of a specific geological environment, together with the proposed disposal system concept, will provide opportunities for optimisation of this plan.

The benefits of the S&T Plan are many; in the following list, in no particular order, the benefits are sorted by stakeholder:

- **RWM.** The potential benefits to RWM are:
  - Improved linkages between the need for research and the scope of work being carried out will drive improved clarity of the end-users’ requirements and hence deliver improved value for money.
  - Improved clarity in RWM’s science and technology needs is likely to lead to further economic efficiencies in the tendering of work (e.g. by tendering a bundle of related activities under a solution-based contract) and will also assist in internal technical resource planning.
  - Improved clarity of the specific research needs and objectives of each project in a more structured manner will not only foster better targeted research, but it will better enable improved knowledge capture via our internal processes following the completion of research. In a multi-generation project such effective knowledge capture is vital and is undertaken via RWM’s ‘change control’ process which provides a highly structured approach to the capture of data and understanding of features, events and processes of relevance to our safety case.
The added granularity of this plan will also provide improved clarity in the scheduling of particular activities, including the rationale for the deferral of specific tasks, should prioritisation be required.

Improved transparency and facilitation of dialogue with all stakeholders (see below) is of great value in providing confidence in the robustness of our plans.

- **Academia.** RWM operates a needs-driven research programme in that we commission research targeted at specific needs through our supply chain, where appropriate including academic input. As such, this work is often fully funded by us. However, we also collaborate with Research Councils UK (RCUK) in order to:
  - Build UK skills and capability in this area of strategic national importance. RWM’s remit includes supporting the development of the UK’s geological disposal skills base; while we are already supporting many PhD students, Post-Doctoral Research Assistants (PDRAs) and young academics, we believe the better engagement that will be facilitated through greater clarity of our research needs will enhance this capability.
  - Support some less needs-driven and more ‘curiosity-driven’ research, which can provide increased confidence to our stakeholders that we are undertaking an appropriately balanced research programme.

There is significant potential to improve the level of engagement with UK academia through the research activities we require. While the industrial supply chain will always play an important role in the development of our science base, we recognise there are many areas where universities, often utilising the UK’s world-leading facilities, can enhance our depth of understanding of the processes which will determine the performance of the disposal system. However, it is also clear from our engagement with academia that improved clarity of our longer-term generic research needs and objectives at a task level would enable them to engage with RWM in a more effective and proactive manner.

By improving the clarity of the timing and objectives of future research activities it is intended that RWM’s engagement with the academic community will lead to improved focus, better use of RCUK funding, opportunities for co-funded research and more opportunities for cutting-edge technical input to our programme. The universities should benefit by developing research proposals focussed on our broad needs and objectives with a higher likelihood of making a significant impact on the national challenge of radioactive waste disposal. As such, they are more likely to attract RCUK and/or RWM funding.

- **Potential host communities and other interested parties.** Under our principles of openness and transparency in engaging with the public we encourage dialogue with interested or concerned stakeholders. Anybody is able to raise issues with us via our website [4]. A number of issues have already been raised in relation to the science and technology of geological disposal; the technical programme document [3] addresses at a high level how issues will be dealt with as our programme progresses, however a significantly more detailed description of our research needs, objectives and potential scope will facilitate this dialogue.

- **Regulators.** Our regulators, the Office for Nuclear Regulation (ONR), the Environment Agency (EA) and Natural Resources Wales (Cyfoeth Naturiol Cymru), require appropriate safety-related research activities to be undertaken in support of our evolving safety case. Improved clarity of our longer-term plans for enlarging our knowledge base will enable early discussion with our regulators and improved focus on any areas of potential concern to them.
• **Supply chain.** Visibility of our longer term science and technology activities will provide our supply chain with improved visibility of our market and hence will enable them to recruit and resource plan more effectively.

• **NDA and the Committee on Radioactive Waste Management (CoRWM).** In the NDA Research Board’s annual report for 2012/13, recommendation 6 states that the NDA should better publicise its research needs as this will enable academia and industry to better dovetail to them; the publication of this report directly addresses this point. In the development of this S&T plan we have also engaged with RWM’s Technical Advisory Panel for advice. It is also intended that by increasing the resolution of our planned science and technology research and development through this document we will facilitate dialogue with the Government’s Committee on Radioactive Waste Management, who provide independent scrutiny.

• **Nuclear Innovation Research Advisory Board (NIRAB).** By identifying clear research needs and objectives we will support NIRAB’s objective of fostering greater cooperation and coordination across the nuclear landscape.

This recognition of the breadth of benefits in our stakeholder engagement and dialogue is directly aligned with our strategic imperative, “to engage with a wide range of stakeholders to maximise confidence in the programme.” [2]

### 2.1 How to Use this Document

From our experience of using this document within RWM it is recommended that the long-range graphic contained in Appendix C is used as the entry point to the programme. It contains concise, but self-explanatory, task titles and is structured by technical work area. Having identified tasks of interest in the graphic (and their task number) further details can be obtained by identifying the corresponding task sheet, using its unique number, in Appendix B.

The electronic version of this report contains hyperlinks from each task sheet to the relevant long-range graphic, and from each line on the graphic to the specific task sheet, to facilitate ease of use.

### 3 Development of Our Knowledge Base

#### 3.1 RWM’s Science and Technology Hierarchy of Documentation

In version 1 of the S&T Plan we identified a range of strategic documents underpinning our research activities. In this version 2 we have worked to develop a simpler suite of documentation that delineates our science and technology strategy, programme and plan in a clear and concise manner. This hierarchy of documents sets out RWM’s approach to carrying out the scientific and technical work required to support delivery of a GDF and the provision of waste management solutions. Figure 1 illustrates the document hierarchy, with a clear ‘golden thread’ from strategy to plan.

At the highest level is RWM’s Corporate Strategy [5]. This sets out RWM’s vision, mission and values, and identifies RWM’s key strategic drivers. It sets out the framework within which RWM’s scientific and technical work programme is carried out (and effectively replaces Part A of previous versions of the Technical Programme).

The S&T Programme [2] comprises the second tier; it describes the programme of scientific and technical work that RWM will carry out, and the main deliverables it will produce, in support of our Corporate Strategy. It sets out our technical work programme by describing a series of ‘Major Products’. The S&T Programme sets out comprehensive details of our work programme, in a ‘top-down’ approach, to enable RWM and our stakeholders to have a reference document that describes:
The S&T Programme is ‘needs-driven’, with R&D requirements identified primarily from the iterative development of the disposal system. As Figure 2 illustrates, the process of developing RWM’s knowledge base is a fundamental component of RWM’s business model in that it is the key means of addressing the needs of the disposal system specification, design development and safety assessments. Fundamental to addressing these needs is the delivery of the required research and technical development in the optimum cost effective manner, whilst mitigating risks of future delays to the programme and developing the complementary technical capability within RWM, our supply chain and academia. At a strategic level our S&T Programme document sets out this needs-driven approach and identifies the evolution of the technical programme as the siting process progresses. On the basis of our published prioritisation criteria our detailed scope is developed on an annual basis, within the framework of a longer term business planning cycle.

Other RWM planning documents, besides the S&T Plan, also sit below the S&T Programme, supporting the delivery of Major Products by detailing aspects of how they will be produced, along with supporting work required to feed into Major Product development. Some such documents have already been produced and are maintained internally by RWM. Others will be produced in future as part of planning the delivery of upcoming Major Products. RWM’s planning documents will be updated as necessary, and others, besides the S&T Plan, may

![Diagram of the 'Golden Thread' Underpinning RWM's Technical Documentation.](image-url)
be published in future, if there is a need for stakeholder engagement to inform their development.

It should also be noted that following feedback from CoRWM and other stakeholders on RWM's emphasis on 'needs driven' research, we have committed to a range of complementary ‘curiosity driven’ research, undertaken in collaboration with the UK Research Councils (RCUK). These tasks are shown in Appendix C in blue so as to discriminate them from the ‘needs driven’ activities shown in black.

The iterative development process shown in Figure 2 has been used to identify and organise the individual packages of technical work, or Major Products that need completing in order to realise a GDF. The detailed breakdown of Major Products within each of the four main work areas (specifications, designs, assessments and underpinning knowledge) is illustrated in Figure 3. The figure has been colour coded to show (in green) work areas that produce Major Products, where generic R&D tasks have been identified and are presented in this plan. These work areas form the basis of the structure presented in Appendix A; note that Page A1 shows those work areas with Major Products which, because of their emphasis on Development (rather than Research), are directly commissioned via the Major Product work areas. Page A2 shows the more research-oriented elements of the work programme which underpin the “Prioritised R&D Programme” Major Product. Figure 3 also shows those work areas that produce purely site-specific Major Products (in blue).

The timescales for production of the Major Products in relation to the phases in the development of a GDF are described in the S&T programme [2].

Figure 2. RWM's Iterative Development Process for the Development of the Disposal System

Development of the S&T work programme is a requirements-driven process. Broadly speaking, these requirements can be grouped into three types of inputs:

- The waste and waste packages that require disposal, i.e. the 'inventory' [6].

---

3 LoC: Letter of Compliance, the disposability assessment assessment process operated by RWM. WAC: Waste Acceptance Criteria, to be defined at an appropriate stage of GDF development.
• Applicable regulatory requirements and permissions.
• Stakeholder requirements, discussed in RWM’s strategy for public and stakeholder engagement and communication [2].

RWM uses these requirements to develop work that needs to be undertaken in the disposal system specification, disposal system design, assessments and knowledge base work areas. This process is described in more detail in the S&T Programme document [2].

Contactors are used to support project delivery via either task based\(^4\), solution based\(^5\) or integrated project based\(^6\) contracts. Recognising the cross-cutting nature of many of our information needs, and the associated requirement for horizontal integration across the organisation and our contractors, we have established a series of ‘integrated project teams’ (IPTs). RWM has established four IPTs focusing on the following, highest priority, topics:

• The influence of heat generated from certain radioactive wastes and materials on engineered barrier systems for the range of generic disposal concepts being considered by RWM, and the development of packaging solutions for these wastes / materials that take account of any thermal constraints (the ‘high-heat generating wastes IPT’).
• A holistic approach to management of the UK’s carbon-14 containing wastes (the ‘carbon-14 IPT’).
• The disposability and associated full lifecycle implications of managing the UK inventory of depleted, natural and low-enriched uranium (DNLEU) through geological disposal (the ‘uranium IPT’).
• The development of disposal concept options to support RWM decisions on concept selection, and identification of associated information needs (the ‘concept development IPT’).

The Disposal System Development Committee (DSDC), chaired by the Science and Technology Director, oversees integration of the technical work being delivered by the various project teams, ensuring that knowledge gaps are addressed to meet identified needs. The DSDC ensures that the benefits of the technical work programme are embedded in RWM’s knowledge base.

\(^4\) Addressing a specific knowledge gap.
\(^5\) Addressing a broader challenge to our understanding.
\(^6\) A larger, collaborative team approach; pooling the capabilities of our supply chain and internal experts.
Figure 3. Work Areas within the Science & Technology Programme, Highlighting Work Areas that Produce Major Products where R&D Activities are Undertaken. The Majority Product numbers associated with each work area are shown in parentheses.
3.2 Current Position

3.2.1 Status of Current Science & Technology Activities

Having undertaken three decades of research into the geological disposal of UK wastes, significant progress has been made in the fundamental understanding of features, events and processes impacting on the safety functions of the Geological Disposal Facility (GDF). Figure 4 is a representation of the evolution of the knowledge base underpinning geological disposal. It shows how challenges to the viability of geological disposal concepts have been overcome (although implementation may be subject to site-specific challenges) and the remaining key uncertainties, such as the fate of gaseous carbon-14 in the evolving post-closure disposal system and the long-term (post-one million years) radiological impact of the large quantity of uranium which may require disposal, are currently subject to large focused research projects due to their higher priority [7,8]. At the next lowest level of significance a considerable body of work is underway and planned in order to reduce the important areas of uncertainty associated with the generic DSSC [9], for example in the likelihood and consequences of criticality. The figure also indicates a current emphasis in work which demonstrates the applicability of a large body of international research and development to the UK inventory, e.g. spent fuel post-closure evolution and the durability of HLW vitrified wastes. Once a potential candidate site has been identified a programme of site investigation will be undertaken to ensure the site’s characteristics are within the bounding assumptions underpinned by the generic research programme, together with research, development and demonstration studies associated with the optimisation of the disposal system to the local geological environment.

Figure 4. Timeline for the Evolution of the Geological Disposal Knowledge Base, with Examples of Current Research Priorities

---

7 The isotopes of uranium of relevance here, $^{235}$U and $^{238}$U, have half-lives far in excess of any period for which the engineered disposal system can be considered to retain its integrity ($^{235}$U $t_{1/2} = 700$ million years and $^{238}$U $t_{1/2} = 4.5$ billion years). Both radionuclides generate a number of long-lived daughters which effectively lead to an increase in the radionuclide inventory over a period of millions of years. The multi-faceted work programme described in [8] is investigating the fate and options for managing the uranium inventory.
RWM currently deploys a balanced programme of generic research involving laboratory-based studies, modelling at the process and component level, \(^8\) natural / archaeological analogue studies and larger scale experiments and demonstration studies deployed in overseas Underground Research Laboratories (URLs). This enables us to undertake a comprehensive research programme which explores the mechanistic understanding of physical, chemical and biological processes governing the performance of the future GDF, together with research that investigates whether this understanding can be up-scaled to the real environment. Concept and design development activities are undertaken, either internally or via international collaborations. Work is also undertaken to investigate the social science aspects of planning and implementing effective public engagement, so as to build confidence in RWM’s capabilities to deliver a safe long-term solution to the management and disposal of higher activity radioactive wastes.

---

\(^8\) Process model: This type of model is typically very detailed and potentially very complex. It is focused on a specific technical area to provide underlying calculations or arguments that will support the component or total system model or the DSSC directly. A bottom-up approach is taken to its development. Uncertainty is addressed by considering alternative assumptions. Component model: This is a collection of process models that uses multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development. Some representation of uncertainty is usually required.
4 Assessment and Comparison of Scientific Maturity

The concept of Technology Readiness Levels (TRLs) is widely used across the NDA estate [10] and elsewhere [11,12], and has been successfully applied to process wiring diagrams in the NDA estate’s TBuRD documents (Technical Baseline and Underpinning Research and Development). In recent work by RWM the TRL scale has been used to assess the current maturity of the technology which could be applied to the UK GDF; a draft TBuRD is in development and is available internally. R&D undertaken under the TBuRD is also included in the S&T Plan; see, for example, task sheets in the ‘Design’ Major Product area where, as TRLs are the most appropriate tool, they have been used.

Figure 5. Schematic Representation of the Technical Readiness Level (TRL) Scale

The technology required for implementation of geological disposal in a range of environments in the USA, Sweden, Finland, France and Switzerland has been demonstrated in those specific environments at the higher end of the TRL scale. The wiring diagrams produced in the TBuRD are therefore well suited to the development of engineering design-based activities and we have in fact used TRLs in this document for design-based tasks. However, for the purposes of calibrating the scientific maturity of underpinning science, identifying the requisite level of scientific maturity and plotting a route to attaining that robustness in understanding, TRLs have proven intractable. A survey of possible alternatives was undertaken, together with consideration of a novel system and modification of the TRL scale. However, the most promising tool identified has been developed by the UK National Nuclear Laboratory (NNL) and utilises SRLs®; the definitions are shown in Figure 6. It should be noted that the term ‘SRL’ has also been used to denote System Readiness Levels.
however, since the term ‘SRL®’ has been registered as a trademark, RWM will continue to use this terminology.

**Figure 6. Schematic Representation of the Scientific Readiness Level (SRL®) Scale**

SRLs® are similar in organisation to the TRLs and complement their assessment of the ‘deployability’ of technology with their assessment of the scientific robustness of understanding of the underlying science [13]. In the case of TRLs a successful implementation of a new technology needs a high TRL. However, SRLs® are an indication of basic mechanistic understanding, and the SRL® required in any situation is determined by the level of extrapolation required beyond the area underpinned by experimental or plant data. It is therefore not necessary to achieve an SRL® of 6 for all applications. An SRL of 4 or 5 may be an appropriate end-point for generic research aimed at supporting the evolving DSSC, recognising that further site-specific research will extend the validity of conclusions to the potential candidate site; similarly, an SRL® of 3 for the science underpinning a set of differing disposal concepts may be sufficient to enable the selection of an illustrative concept which can be further developed in advance of a potential candidate site. Finally, an SRL of 2 may adequately support strategy or policy development in identifying a range of possible disposal concepts (for example, in developing concepts for the disposal of plutonium to an appropriate level of maturity to support policy decisions) without incurring undue expense in advance of the need. This tool therefore enables a structured analysis which has proven to be a very useful tool to RWM in populating the S&T Plan.

NNL developed ‘Scientific Readiness Levels®’ as a means of identifying and illustrating the value associated with scientific / technical debate and content and they have been utilised by RWM in this spirit; as a tool to prompt internal discussion over the current maturity of specific areas of underpinning science and of the likely scientific maturity that would result from
planned research activities. The definitions of the SRLs® that have been developed by NNL have broad applicability. The levels represent a logical progression through different stages of the maturity of the scientific/technical arguments that underpin system performance or prediction of complex technological phenomena. The value of utilising SRLs® is threefold:

- In the consistent assessment of scientific maturity and in the consistent comparison of maturity between different areas within our technical programme. In this way appropriate effort can be channelled to the development of the science underpinning less mature alternative disposal concepts to bring them to an appropriate scientific readiness to facilitate future concept selection, i.e. to close the gap between the current SRL and that required to make a decision.
- In providing a structure to enable the planned systematic development of understanding, coupled with the reduction in uncertainty in our knowledge base where it is leading to unhelpful over-conservatisms.
- In assisting us in the determination of the appropriate end-point of each line of generic research, this may be, for example:
  - The closure of all research needs, whether generic or site-specific, having closed the knowledge gap.
  - The conclusion of generic research, interfacing with site specific research and development activities.
  - The initiation of a long-term experiment validating our understanding of system performance, typically at component level although possibly at the process level.
  - A watching brief.

While the concept of a stepwise increase in SRL® could portray an idealistic scenario we do recognise that science does not always progress in a stepwise manner. Therefore it is likely, considering the breadth of our research activities, that progress will not be as anticipated in all areas. Nevertheless, the use of SRLs® will enable us to calibrate and record progress in a critical and structured manner.

<table>
<thead>
<tr>
<th>Robustness and Monitoring of SRL® Development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SRL® attribution:</strong> Following the identification of a research need RWM's internal procedure RWPR 15-01 is followed in order to gain end-user endorsement and task approval by RWM's Science and Technology Director. New tasks are periodically compiled into a revised S&amp;T Plan; during its development the Head of Research reviews every task sheet for consistency and the Chief Scientific Advisor undertakes a focussed review on the consistency of SRL® application.</td>
</tr>
<tr>
<td><strong>SRL® review:</strong> In order to facilitate review of the success, or otherwise, of each task in achieving its intent, the task sheets contain clearly defined objectives. These will provide the basis for future review and scrutiny. We will consider contracting an external body to provide a periodic audit of our application of the SRL® methodology.</td>
</tr>
</tbody>
</table>

5 Description of Science and Technology Plan Contents

5.1 Planning and Prioritisation of Research Projects

In Part C of our Technical Programme document [3] we described our approach to the prioritisation of our generic R&D in terms of its significance or potential impact on safety and/or delivery, and on our current level of understanding, in line with seven key questions:
1. What is the driver for the R&D? The seven drivers for our programme are outlined in Box 1.

2. What do we need to know by when?

3. How important or significant is this topic area?

4. What is our ‘knowledge gap’?

5. What do we need to do to fill it?

6. How long will it take?

7. How urgent is the task?

Box 1. High-level drivers for the R&D programme (in no specific priority order)

<table>
<thead>
<tr>
<th>There are seven main drivers determining the scope of the R&amp;D programme carried out by NDA RWM. These are described in greater detail below:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The Disposal System Specification and its supporting justification</strong> – some R&amp;D needs are identified through the development of the Disposal System Specification. Such activities support the clear identification and justification of the requirements set out in the specification and development of technical solutions to achieve these requirements.</td>
</tr>
<tr>
<td><strong>Support the assessment of packaging solutions</strong> – R&amp;D necessary to evaluate the disposability of specific waste streams and packaging solutions and to support development of optimum waste packaging solutions is identified through Disposability Assessments and through optioneering studies. Depending on the nature of activities required, R&amp;D may be carried out by waste producers or by the NDA (including RWM).</td>
</tr>
<tr>
<td><strong>Support the identification and development of GDF concepts</strong> – at this stage of our programme, specific disposal concepts for different types of wastes have not yet been decided and we are carrying out optioneering studies to evaluate the suitability and merits of different concepts. This will include work in preparation for a future site characterisation programme.</td>
</tr>
<tr>
<td><strong>The Disposal System Safety Case</strong> – demonstration of the safety of a GDF is a key driver for the R&amp;D programme. The DSSC and its supporting Status Reports describe the current state of the knowledge and identify important knowledge gaps which the research programme needs to address. This may include aspects relevant to a future site characterisation programme.</td>
</tr>
<tr>
<td><strong>Assessment of environmental impact and sustainability</strong> – the development of the Strategic Environmental Assessment and subsequent Environmental Impact Assessments will place requirements for R&amp;D that are different to those from the DSSC.</td>
</tr>
<tr>
<td><strong>Support strategic decisions</strong> – R&amp;D needs are identified to support Government policy on long-term waste management strategies. For example, this includes the long-term approach to the management of plutonium and uranium.</td>
</tr>
<tr>
<td><strong>The site-selection process based on partnership with a community</strong> – R&amp;D to meet good practice in working with a community stakeholder partnership.</td>
</tr>
</tbody>
</table>

As discussed in Section 5.2, we had intended to utilise these prioritisation questions in order to resource / cost level the schedule; however the unconstrained plan was considered achievable without the need to prioritise and we therefore intend to deliver all tasks at the earliest sensible juncture, bearing in mind internal and external inputs. Should prioritisation be required in the future we would however use these questions to re-structure the plan; the level of detail contained herein enabling us to document the justification for changes.

5.2 Task Descriptions and the Long-range Graphic

The Technical Programme document [3] introduced the product breakdown structure (PBS) that has been used to develop the S&T Plan. This PBS is shown schematically in Appendix...
A. Under each PBS element we have developed the knowledge gaps identified in the Technical Programme (Part C) [3] into specific tasks and have used a structured approach to clarify the specific research needs and objectives associated with each task, together with other parameters useful in scheduling the task. The following headings, utilised on the task sheets, are annotated here with the prioritisation questions introduced in Section 5.1:

- **Task number**
  - A unique identifier has been attributed to each task, enabling the cross-walk between the task sheets shown in Appendix B and the long-range graphic shown in Appendix C.

- **PBS descriptors**
  - As shown in Appendix A, the PBS has been developed to two levels.

- **Short Title**
  - A brief description of the scope which is also used in the long-range graphic (Appendix C).

- **Background** (*‘How important or significant is this topic area?’ & ‘How urgent is the task?’*)
  - A brief summary of background information is presented in the task sheets in Appendix B in order to provide the context for the task. Note that in successive tasks in the same PBS element some of this text is repeated, however the concept of self-contained task sheets was considered beneficial to end-users and stakeholders.

- **Research Need** (*‘What is our ‘knowledge gap’? & ‘What is the driver for the R&D?’*)
  - This provides a clear link from the knowledge gap to the RWM business requirement based on our business model (Figure 2), e.g. design concept development, disposal system specification, or assessments (the safety case, waste package disposability or environment & sustainability assessments).

- **Research Objective** (*‘What do we need to know by when?’*)
  - A clear statement of the required outcome(s) from the task which will increase our knowledge with respect to the specific research need.

- **Internal ‘Customer’**
  - This is a recognition of the requesting business function(s) or end-user(s) within RWM. Task sheets have been prepared in collaboration with these end-users.

- **Scope** (*‘What do we need to do to fill the knowledge gap?’*)
  - Where appropriate, a scope has been developed although, since a primary objective of the plan is to encourage innovation and dialogue with academia and our supply chain, in many cases the scope has been left deliberately brief.

- **SRL® at Task Start; SRL® at Task End; Target SRL®**
  - See Section 4 for a discussion of SRLs®.

- **End point**
  - The ultimate end point is identified for generic research, for example:
    - The closure of all research needs, whether generic or site-specific, having closed the knowledge gap.
    - The conclusion of generic research, interfacing with site specific research and development activities.
    - The initiation of a long-term experiment validating our understanding of system performance, typically at component level although possibly at the process level.
    - A watching brief.
  
  The end point of tasks will be kept under review as, owing to the nature of scientific research, they may be subject to change. We recognise that scientific knowledge will
always be incomplete; although expert opinion may be that we have sufficient knowledge to progress to the next phase.

- **Further Information**
  - Any other relevant text, references or suggestions for collaboration.

The remaining question raised in [3] is ‘How long will it take?’ This is dealt with in the long-range graphic (Appendix C), together with the question of what the linkage is between related tasks. This is a more visually intuitive representation of the schedule than the Gantt chart generated internally by our planning tool, Primavera P6, and has proven useful in internal planning discussions. It is hoped that this will be equally helpful to external stakeholders in delineating our schedule.

In addition to improving internal resource planning the greater resolution presented in the S&T Plan has enabled us to develop an improved cost profile of the identified generic research programme. A crude parametric cost estimation matrix was developed and populated with estimated average costs based on expert judgement; see Figure 7 for the redacted matrix; this has been redacted for commercial reasons.

The schedule was initially developed in an unconstrained manner, i.e. tasks were scheduled at their earliest appropriate juncture, taking into consideration outputs from other internal and external work programmes. In version 1 of the S&T Plan, upon reviewing the cost / resource profile (derived with the cost matrix) required to manage this unconstrained programme it was concluded that no prioritisation was required. However, available funding was reduced for 2015/16 during the planning round and so a number of tasks were deferred in line with the prioritisation criteria presented in Section 5.1 (see Appendix D). In developing version 2 we have again prioritised the plan and will continue to do so should further changes in funding arise.

<table>
<thead>
<tr>
<th>Scope</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simple</td>
</tr>
<tr>
<td>Archiving / storage</td>
<td>A1</td>
</tr>
<tr>
<td>Desk study / review</td>
<td>B1</td>
</tr>
<tr>
<td>Computational study</td>
<td>C1</td>
</tr>
<tr>
<td>Inactive laboratory based research / analogue study</td>
<td>D1</td>
</tr>
<tr>
<td>Active laboratory based research</td>
<td>E1</td>
</tr>
<tr>
<td>Hot-cell based research</td>
<td>F1</td>
</tr>
<tr>
<td>Large scale / URL experimental project</td>
<td>G1</td>
</tr>
</tbody>
</table>

Figure 7. Parametric cost estimation matrix (redacted) used to develop a crude cost profile for internal use.

### 6 Interfacing of Generic with Site Specific Research

Until a potential candidate site (or sites) is identified, the development of our knowledge base will continue on a generic basis. However, once a potential site (or sites) is identified the focus of the work will transition in three ways:

- The emphasis of our research will focus on developing the underpinning science of concepts, designs and safety / environmental assessments specific to the site or sites in question.
- Where appropriate, the scope of those research activities currently identified in the generic programme will be tailored to the site or sites in question. For example, where
water-rock interactions are being investigated the programme may transition from using a range of simulated groundwaters relevant to the range of generic concepts, to real samples of groundwater or rock cores extracted from the geological formation(s) in question.

- A range of site specific research tasks will be developed, aimed at:
  - Optimisation of the disposal concept and designs against the host geology;
  - Reflecting the real environment in the disposal system safety case (DSSC). Some parameters will be assessed in situ, via the site characterisation programme, while others will be more research-focussed and will utilise a range of laboratory-based techniques.

It is possible to discuss at length the respective definitions of ‘site characterisation’ and ‘research’ without delineating a clear division; the continuum might be better described as ‘development of the underpinning science base’. However, what is clear is that once a site, or sites, become available for investigation there will be a significant shift in focus. The contents of this generic S&T Plan will provide a firm foundation and a clear starting point for the review that will be necessary.

It is however clear from the level of research needs identified herein that there are no generic concept viability challenging issues within the underpinning science base, so development of a site is not impeded by any existing knowledge gaps. This point is well illustrated by Figure 4, which presents the overall maturity of geological disposal in terms of the pathway to implementation. Nevertheless, should a viable site not be identified in the near-term, it might be appropriate to continue generic research for the purposes of capability and knowledge maintenance.

7 Review and Scrutiny

In developing version 1 of the S&T Plan we sought further review and engaged widely via the following fora:

- We commissioned and attended two externally facilitated workshops [14,15] with invited experts from academia, sister waste management organisations and industry. These workshops focussed on the engineered barrier and the geosphere / biosphere respectively; reviewing the research needs, objectives and scope identified internally for completeness and validity.

- We consulted widely within RWM, in particular with the internal customers of our research programme (Safety Case, Disposability Assessments, Concepts, Design and Disposal System Specification).

- We shared our approach with the Nuclear Waste Research Forum (NWRF) and incorporated their feedback in this document, in particular in the discussion of TRLs and SRLs.

Furthermore, to support its development as a competent delivery organisation that will be subject to formal regulation, RWM has agreements with the regulators to allow “voluntary scrutiny” of key activities. As part of the scrutiny programme regulators have reviewed version 1 of the S&T Plan, which itself addressed a number of previous (August 2012) conclusions [7]. In their March 2015 review [8], the Environment Agency stated that: "The document provides a good overview of the R&D work that RWM plans to undertake over the next decade"; they went on to identify 12 recommendations and a number of detailed comments. Our intent in producing version 2, in addition to updating the schedule and incorporating new tasks, was to address these recommendations.

As stated above, version 1 was reviewed extensively, internally within RWM and externally by our independent Technical Advisory Panel; it was also subjected to a usability review by two leading UK academics. In addition to internal and supply chain scrutiny, version 2 has
been peer reviewed by one of the aforementioned academics and a recently retired and highly experienced employee of an overseas waste management organisation. This review was undertaken on both the S&T Programme and this S&T Plan to provide explicit review of the linkage and coherency between these documents.

8 Feedback

In this document we have presented our current understanding of our detailed science and technology requirements in support of the Higher Activity Waste disposal programme, together with an indicative schedule for undertaking the required generic research. We have identified over 350 individual tasks scheduled over a period of up to ten years. However, as discussed earlier, there are no generic concept viability challenging issues within the underpinning science base, so development of a site is not impeded by any existing knowledge gaps.

We would welcome your comments on our S&T Plan. Specifically, we would ask you to consider the Appendices to this document and answer the following questions:

- Do the areas we have listed in Appendix A as our Product Breakdown Structure reflect the full scope of the issues we need to address under each topic? Have we left out a major area?
- Are there areas to which you consider that we are giving an inappropriate emphasis?
- Are there areas where you consider the proposed R&D to be inappropriate or inadequate?
- Would you like to suggest any innovative approaches to addressing the research needs and objectives detailed in the appendices?

In each case please tell us your reasons for making the comment and if there are additional sources of information that you would like to bring to our attention, that would be very helpful. Comments should be provided to the Head of Stakeholder Engagement and Communications, as identified inside the front cover of this document.
9 References


3 Nuclear Decommissioning Authority, Geological Disposal: Technical Programme, NDA Technical Notes: 17903454 (Part A – Introduction); 17901313 (part B – Delivery); 18004261 (Part C – Research and Development), September 2013.


8 Nuclear Decommissioning Authority and Department of Energy and Climate Change, Radioactive Wastes in the UK: A Summary of the 2013 Inventory, URN 14D039, NDA/ST/STY (14) 0006, February 2014.


Appendix A – Product Breakdown Structure
Appendix A. Schematic of the relationship of Product Breakdown Structure (Levels 1 to 4) to the Detailed Structure (Levels 4 and 5) Addressed in this Plan

Detailed Product Breakdown Structure (Levels 4 & 5) for those Major Products that require generic R&D activities (also see over page)
Appendix B – Task Sheets
### BIOPROTA: Geosphere / Biosphere Interface Modelling

#### Background
Since long-term releases from disposal facilities involve transfers from the geosphere to the biosphere an important aspect is the combined effects of surface hydrology, near-surface hydrogeology and chemical gradients on speciation and radionuclide mobility in the zone in which the geosphere and biosphere overlap (the geosphere-biosphere interface - GBI).

A methodology was developed for characterising the geosphere-biosphere interface in a wide range of assessment contexts. Three illustrative climate and landscape evolution scenarios were then described and the methodology developed for characterising the geosphere-biosphere interface was applied to two of these three scenarios in order to define a set of geosphere-biosphere interface sub-systems for which conceptual models need to be developed. This then led into application of the second part of the methodology for creation of these conceptual models. Consideration has been given to the range of mathematical and computational tools that are available for implementing the conceptual models. Recommendations have been made for as to how work in this area could be developed in the future.

#### Research Need
To support the post-closure safety case and its supporting performance assessment by developing an improved understanding of the coupling between the geosphere and biosphere.

#### Research Objective
To determine whether an improved understanding of the geosphere-biosphere interface will support the simplified uncoupled approach used in the performance assessment.

#### Scope
The scope comprises:
- Preparation of a BIOPROTA report setting out the various types of GBI that have been considered in previous assessments, the factors distinguishing qualitatively different types of GBI and the ways in which these different types of GBI could be affected by environmental change.
- A two-day workshop to refine the descriptions of the various types of GBI and identify those to be studied in detail.
- Consideration of the scenarios that are to be taken forward for detailed study in Task 002.
- Continuing involvement in a possible successor project within BIOPROTA.

#### SRL at task start 3  SRL at task end 4  Target SRL 4

#### End point
Site Specific Application of Modelling Capability

#### Customer
Disposal System Safety Case

#### Further information
Relevant further information can be found in the following:
- [http://www.bioprota.org/](http://www.bioprota.org/)
Task Number 002

PBS level 4 Biosphere
PBS level 5 Biosphere Assessment Approach

Title
Updated Marine Model for Climate States Posing a Potential Challenge to the Risk Guidance Level

Background
It is important to consider long-term climate change when representing the biosphere in post closure assessments. The BIOCLIM project provided the basis for the climate change scenarios that RWM consider in biosphere assessments studies.

The science that underpins climate change modelling and the associated modelling capabilities continues to develop. Given recent developments in climate modelling there is an opportunity to build on the methodology developed in the BIOCLIM project. This would greatly improve the actual predictions made in BIOCLIM by utilising state-of-the-art climate modelling tools and techniques whilst also reviewing the representation of future biosphere scenarios.

We aim to increase our understanding of the expected evolution of the geosphere and biosphere, and associated consequences for a GDF, in response to natural processes. The objective being to provide an integrated description of the expected evolution of the surface and sub-surface environments over the timescale of around one million years relevant to geological settings in the UK. Our current marine model corresponds to the temperate terrestrial model used for the post-closure safety assessment. Since its development, further terrestrial models have been developed for other climate states (tropical, boreal and glacial). This task comprises the development of marine models for these alternative climate states.

Research Need
To support the post-closure safety case and its underpinning numerical performance assessment by developing an understanding of the consequences of potential impacts due to climate change on the safety performance of the GDF for different marine scenarios (sea level rise / fall, changes in estuaries, etc.).

Research Objective
To determine whether climate change will lead to a marine pathway which gives rise to doses of significance in comparison to the terrestrial pathway.

Scope
The scope comprises the development of marine models for alternative climate states (tropical, boreal and glacial) which could be used in conjunction with their corresponding terrestrial model.

SRL at task start 3 SRL at task end 4 Target SRL 4

End point Site Specific Application of Modelling Capability
Customer Disposal System Safety Case

Further information
The relevance of this work may be site specific and may be deferred until a site has been identified as requiring this study.

Relevant further information can be found in the following:
**Title**
BIOPROTA: Update of BIOMASS (BIOsphere Modelling and ASSessment) methodology

**Background**
RWM’s approach to representing the biosphere in long-term performance studies aligns with international guidance, notably the BIOMASS methodology developed within the context of an IAEA programme. The BIOMASS methodology sets out a structured approach based on good practice to defining biosphere systems that appropriately reflect the context for the assessment and that can then be used as a basis for quantitative calculations. This methodology was developed in 2003 and needs to be reviewed as a result of the findings of the MODARIA project and other developments in the biosphere area since 2003. The IAEA are considering a project to update the BIOMASS methodology as part of a MODARIA II programme.

**Research Need**
To ensure that the treatment of the biosphere in the post-closure safety assessment takes account of improvements in methodology and understanding of various biosphere processes that have occurred since publication of the IAEA BIOMASS methodology in 2003.

**Research Objective**
To ensure the RWM’s approach to representation of the biosphere in the post-closure safety case is consistent with current international guidance and practice.

**Scope**
Particular topics envisaged for the update to the BIOMASS methodology include:
- Practical experience of its application.
- Capturing experience in site characterisation and assessment.
- Addressing environmental change and associated radionuclide behaviour.
- Addressing radionuclide behaviour in the transition from the geosphere to the biosphere.
- Conceptual models for key radionuclides (e.g. C-14, Se-79 etc.).
- Current approaches to treatment of non-human biota.
- Enhancements to the methodology to specifically address impacts on the environment and non-radiological impacts linked to radioactive waste disposal.

**SRL at task start** | **5** | **SRL at task end** | **5** | **Target SRL** | **5**
--- | --- | --- | --- | ---
**End point** | Watching Brief
**Customer** | Disposal System Safety Case

**Further information**
Relevant further information can be found in the following:

---

**Appendix B - 3**
Environmental Impact Assessments (EIAs) will be carried out to support Development Consent applications for both deep boreholes and a GDF. The EIAs will include consideration of the environmental, socio-economic and health and well being effects associated with implementing geological disposal. The focus of the assessments for a GDF will be the operational and short-term post closure phases – extending to several hundred years.

Research is also being carried out to determine how the biosphere should be represented in the disposal system safety case. The timescales considered by this work extend to hundreds of thousands of years.

At least 12 months of baseline monitoring and survey work will be carried out at candidate sites to inform the EIAs. This work will help to define a baseline (the situation in the absence of geological disposal, at any defined point in time) which will provide a yardstick against which the predicted effects of a GDF can be compared. Defining the baseline involves collecting information about the current environment and predicting how it might change in the future. The baseline definition used for the EIAs needs to be consistent with the scenarios for long term environmental change and biosphere development used in the safety case.

A review of the approach to climate change between the biosphere research programme and the preparatory EIA work has been carried out. The review shows that over the timescale of common interest, which is the period spanning the short term (period of authorisation) and long term (post-closure) assessment (300-1,000 years), both programmes use the UKCP09 data projections (the MODARIA work uses these as lower boundary conditions for long-term climate projections), and hence are consistent.

To ensure consistency in the baseline definition used in EIA work and the scenarios for environmental change developed by the biosphere research programme for use in post-closure safety assessments.

To ensure that treatment of the biosphere in the early part of the period covered by the post-closure safety case is consistent with that described by the EIA work.

To review and compare specific areas in the biosphere and EIA work programmes and identify where significant differences in approaches and methodology exist. The review should map out a programme of future work to address any discrepancies.

Areas that might be covered in a review include climate change, as described above, and related issues such as biodiversity and landscape evolution, population and demographic change, land-use and environmental monitoring. Specific topics to consider might include:

1. Habitats, Sites of Special Scientific Interest (SSSIs) and ‘Natura 2000’ sites (which are internationally-designated nature conservation sites). These are relevant to the terrestrial biosphere model, land use and non-human biota considerations.
2. Biodiversity, flora and fauna - all individual species (e.g. plants, animals), their habitats and the interactions amongst them, particularly in terms of ecosystem function. Ecosystems are linked communities of organisms together with non-living components of their environment (such as air, water and soil). These are relevant to the biosphere work on non-human behaviour.
3. Human health, people and communities who could be affected by the effects from developing and operating a geological disposal facility, specifically as relates to their health and well-being. These are relevant to the biosphere Potentially Exposed Groups.
4. Population and economic projections and projected demographic changes (e.g. urban and rural population densities). These are relevant to the biosphere Potentially Exposed Groups, land use, habits and predictions of behaviour over long time scales.
5. Geology and soils: quantity and distribution of different soil types. These are relevant to the terrestrial biosphere model.
6. Water quality and resources: size, capacity, shape and location of a water body in relation to its users. Includes flood risk: the likelihood of a flood happening, plus the consequences that will result if the flood occurs. These are relevant to the terrestrial and freshwater biosphere model.

7. Hydromorphology /geomorphology: the relationship between landforms and water bodies, combined with the process of sediment transfer (erosion, transport and deposition). These are relevant to the terrestrial and freshwater biosphere model.

8. Climate change - climate emissions: the greenhouse gases which are emitted as a result of (in general) the use of natural resources; climate adaptation: the measures taken in order to help society and nature adapt to future changes in our climate. These are relevant to MODARIA work on the effects of climate change.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
<th>End point</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
<td>Consistency of Scientific Approaches within RWM</td>
<td>Environmental Impact Assessment</td>
</tr>
</tbody>
</table>

Further information

Relevant further information can be found in the following:
Jacobs, 2014, Geological Disposal and Climate Change, Report to RWM.
Appendix B - 6

Task Number | 011 | Status | Ongoing
--- | --- | --- | ---
PBS level 4 | Biosphere
PBS level 5 | Uptake of Radionuclides

Title
MODARIA: Review and Update of Radioecological Data

Background
We are supporting work being undertaken by international bodies to review the approaches adopted to represent the biosphere during future climate change. This includes developing our understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota).

International guidance recognises the importance of establishing the context and requirements for representing the biosphere. RWM contributes to collaborative work with sister Waste Management Organisations (WMO’s), including the International Atomic Energy Agency’s (IAEA) Modelling and Data for Radiological Impact Assessments (MODARIA) programme. The assessment of exposures in planned, existing and emergency exposure situations requires situation-specific models supported by appropriate datasets and input parameters. There are several recent IAEA Technical Reports Series (TRS) publications which contain basic data about the human food chain and radionuclide transfer in the terrestrial environment. There is also an earlier TRS report containing data on marine systems. There are however many data gaps in the three IAEA TRS publications, as well as considerable variation in many of the parameter values. This task comprises a review of these new publications and their significance to the GDF programme.

Findings of the review will be incorporated into an update of the biosphere assessment model currently used by RWM. The model update will enable new sources of information to be taken into account, along with updated guidance on the representation of potentially exposed groups and wildlife.

Research Need
To support the generic disposal system safety case and its underpinning numerical performance assessment by analysing recent IAEA TRS publications to identify key radionuclides and to collate those parameter values which are required for RWM assessments of both human and wildlife exposure.

Research Objective
- To identify the most important pathways and parameter values for different radionuclide source terms and exposure situations (human and wildlife) using the IAEA TRS publications.
- To identify key radionuclides so as to allow a process-based modelling approach to be developed which will enable the identification of the most radiologically sensitive species of wildlife and therefore to enable remedial actions, addressing those most vulnerable species, to be considered.

Scope
The scope comprises a critical evaluation of the TRS publications to identify which data gaps may be important in certain types of assessments (and which are not). The parameter value evaluations will be conducted using either: (a) Widely available tools for humans and for wildlife; or (b) MODARIA participants’ own models using a specific set of criteria for evaluating the importance of parameter values for humans and wildlife.

The analysis of the relative importance of different parameter values for different radionuclides will enable the identification and prioritisation of key radionuclides for which a future process based approach to modelling may be justified, as opposed to a simple empirical approach.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
</table>

End point
Site Specific Application of Understanding

Further information
Relevant further information can be found in the following:
http://www-ns.iaea.org/projects/modaria/default.asp?
f=116
Handbook of Parameter Values for the Prediction of Radionuclide Transfer to Wildlife (in preparation; to be
Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment,
APPENDIX B - 8

MODARIA: Biota Modelling and Parameter Update

Background
We are supporting work being undertaken by international bodies to review the approach adopted in representing the biosphere and its subsequent documentation. This includes developing understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota).

RWM contributes to the International Atomic Energy Agency’s (IAEA) MODARIA programme. The general aim of the MODARIA programme is to improve capabilities in the field of environmental radiation dose assessment by means of acquisition of improved data for model testing, model testing and comparison, reaching consensus on modelling philosophies, approaches and parameter values, development of improved methods and exchange of information.

Most modelling approaches for the distribution of radioactivity in non-human biota assume heterogeneity in the body, which may not be appropriate. In addition, the concentration ratio (CR) (equilibrium) approach is used in most radioecological models and assume the activity concentrations in the body of a selected plant or animal are in equilibrium with the surrounding medium, such an approach is used in the ERICA tool. However, there can be various physical, chemical and other environmental factors that affect equilibrium, as well as seasonal effects on biota such as changes in diet. In addition, equilibrium approaches have limited applicability in situations where environmental concentrations are changing rapidly with time and space, for example in the Fukushima accident. Predictions using the CR versus site-specific measurements can therefore vary by orders of magnitude. It is more appropriate to model the activity concentrations in selected biota using dynamic models. This task reviews the state-of-the-art on dynamic modelling.

Research Need
To support the environmental safety case by developing assessment capabilities for biota exposures which have not yet been considered and to improve dynamic modelling approaches to incorporate adequate assessment of site heterogeneity and improved dosimetry.

Research Objective
To produce a guidance handbook for biota dose assessments which will:
- Provide a more realistic representation of the exposure of organisms by representing radionuclide behaviour in the body.
- Develop approaches for biota spatial modelling as an alternative to the typical assessment approach, focusing upon the maximum exposed individual or the average exposed individual.
- Develop a dynamic biota model assessment approach as an alternative to the CR (equilibrium) approach which can be utilised for non-equilibrium situations such as Fukushima.

Scope
The scope comprises the development of a guidance handbook, its content covering:
- Model applications: scenarios will be carefully selected for model comparison purposes, such as emergency exposure situations, terrestrial naturally occurring radioactive material (NORM) sites, technologically enhanced naturally occurring radioactive material (TENORM) releases, tropical and permafrost environments.
- Improved modelling tasks: dealing with non-equilibrium situations (such as those resulting from accidents); guidance for assessments for heterogeneous distribution of radionuclides in environmental media; improved dosimetry (in close coordination with the ICRP); and the spatial and temporal scale of biota assessment.

Further information
Relevant further information can be found in the following:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>012</td>
<td>Ongoing</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>PBS level 4</td>
<td>Biosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Uptake of Radionuclides</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix B - 8
Appendix B - 10

MODARIA: Effects of Acute and Chronic Exposure on Wildlife

Background

We are supporting work being undertaken by international bodies to review the approach adopted in representing the biosphere and its subsequent documentation. This includes developing understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota).

RWM contributes to the International Atomic Energy Agency's (IAEA) MODARIA programme. The general aim of the MODARIA programme is to improve capabilities in the field of environmental radiation dose assessment by means of acquisition of improved data for model testing, model testing and comparison, reaching consensus on modelling philosophies, approaches and parameter values, development of improved methods and exchange of information.

Models should only be applied to representative wildlife species to assess population effects. Whilst there has been some work on defining Reference Animals and Plants (RAPs) there is still a need to reach consensus on a definition of a population (e.g. a sub-population) that is both scientifically relevant and appropriate from the viewpoint of radiological protection. This requires that exposure conditions, dose-response relationships for relevant life-history traits and life-history characteristics of the species over their entire lifecycles, are described and combined into population dynamics.

In assessing the effects of radiation on non-human biota there is a need for a conceptual model which considers effects data from both acute and chronic radiation exposures (instead of using acute effect data to predict chronic situations). Ideally a conceptual model would take account of both acute and chronic exposure situations (in order to make the best use of all available data). There is also a need for relevant chronic experimental and field data to calibrate such models so they are applicable to low dose exposure situations as well as to ‘middle range’ doses. This task, under the MODARIA project, focuses on improving the methodology for wildlife population dose assessment.

Research Need

To support the environmental safety case by improving our understanding of radiological consequences on populations of wildlife species considering: exposure conditions; the total, and time dependent, absorbed dose; and dose response relationships (for relevant assessment endpoints).

Research Objective

- To determine whether numeric criteria derived for individuals are representative of populations.
- To investigate whether the models that consider effects on populations, often based on acute effects data, are also applicable to chronic effects.

Scope

The scope comprises the development of a methodology for population modelling incorporating estimation of radiation effects at the population level, including comparison and analysis of radiation dose effect models for different taxonomic groups (including terrestrial and aquatic invertebrates, fish and mammals).

Also included is consideration of the modelling of acute versus chronic effects. It is important to distinguish between the two as one is significantly more likely to lead to permanent irradiation damage than the other.

An initial approach was developed using an index of the ratio between effects and exposure time over lifespan. Acute dose is largely delivered over a timescale and level where recovery is not possible, whereas chronic exposure relates more to a time and intensity where recovery processes are possible. A simple logistic population model has now been developed based on a single age category which allows consideration of chronic or acute exposure. For acute exposure, the healthy group reduce exponentially whilst the unhealthy group initially increase before succumbing to mortality, whereas for chronic exposure both repair and fecundity functions work to maintain the population.

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Biosphere</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Uptake of Radionuclides</td>
<td></td>
</tr>
</tbody>
</table>

Title

MODARIA: Effects of Acute and Chronic Exposure on Wildlife

Background

We are supporting work being undertaken by international bodies to review the approach adopted in representing the biosphere and its subsequent documentation. This includes developing understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota).

RWM contributes to the International Atomic Energy Agency's (IAEA) MODARIA programme. The general aim of the MODARIA programme is to improve capabilities in the field of environmental radiation dose assessment by means of acquisition of improved data for model testing, model testing and comparison, reaching consensus on modelling philosophies, approaches and parameter values, development of improved methods and exchange of information.

Models should only be applied to representative wildlife species to assess population effects. Whilst there has been some work on defining Reference Animals and Plants (RAPs) there is still a need to reach consensus on a definition of a population (e.g. a sub-population) that is both scientifically relevant and appropriate from the viewpoint of radiological protection. This requires that exposure conditions, dose-response relationships for relevant life-history traits and life-history characteristics of the species over their entire lifecycles, are described and combined into population dynamics.

In assessing the effects of radiation on non-human biota there is a need for a conceptual model which considers effects data from both acute and chronic radiation exposures (instead of using acute effect data to predict chronic situations). Ideally a conceptual model would take account of both acute and chronic exposure situations (in order to make the best use of all available data). There is also a need for relevant chronic experimental and field data to calibrate such models so they are applicable to low dose exposure situations as well as to ‘middle range’ doses. This task, under the MODARIA project, focuses on improving the methodology for wildlife population dose assessment.

Research Need

To support the environmental safety case by improving our understanding of radiological consequences on populations of wildlife species considering: exposure conditions; the total, and time dependent, absorbed dose; and dose response relationships (for relevant assessment endpoints).

Research Objective

- To determine whether numeric criteria derived for individuals are representative of populations.
- To investigate whether the models that consider effects on populations, often based on acute effects data, are also applicable to chronic effects.

Scope

The scope comprises the development of a methodology for population modelling incorporating estimation of radiation effects at the population level, including comparison and analysis of radiation dose effect models for different taxonomic groups (including terrestrial and aquatic invertebrates, fish and mammals).

Also included is consideration of the modelling of acute versus chronic effects. It is important to distinguish between the two as one is significantly more likely to lead to permanent irradiation damage than the other.

An initial approach was developed using an index of the ratio between effects and exposure time over lifespan. Acute dose is largely delivered over a timescale and level where recovery is not possible, whereas chronic exposure relates more to a time and intensity where recovery processes are possible. A simple logistic population model has now been developed based on a single age category which allows consideration of chronic or acute exposure. For acute exposure, the healthy group reduce exponentially whilst the unhealthy group initially increase before succumbing to mortality, whereas for chronic exposure both repair and fecundity functions work to maintain the population.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point

Site Specific Application of Understanding

Customer

Disposal System Safety Case
### Further information

Scope will be refined through the MODARIA project. Relevant further information can be found in the following:

NERC TREE: Development of a Mechanistic Undertaking of Acute and Chronic Low Dose Uptake and Transgenerational Effects in Non-human Biota.

Background

Radiological risk assessments are essential for safeguarding human and environmental health, but assessments often have to rely upon simplistic assumptions, such as the use of simple ratios which combine many processes, in risk calculations. This pragmatic approach has largely arisen due to the lack of data in key areas. The resultant uncertainty has been taken into account through conservative approaches which may tend to overestimate risk. Transfer-Exposure-Effects (TREE) is an integrated, multi-disciplinary, NERC project aiming to assess and reduce the uncertainty associated with radiological risk assessment so as to protect human health and the environment. RWM is co-funding this project under its initiative to support a portfolio of 'curiosity-driven' research which complements our 'needs-driven' programme.

Empirical studies of impacts of chronic radiation at low doses in the natural environment are rare. This Task aims to link laboratory and field studies in the Chernobyl exclusion zone (CEZ) to improve knowledge of chronic and transgenerational exposure. This will improve the quantification of radiation exposure and the understanding of the resultant short- and long-term biological effects by understanding the underlying mechanisms involved.

Research Need

To support the environmental safety case by developing a mechanistic understanding of acute and chronic dose uptake in non-human biota.

Research Objective

To investigate whether:
- Laboratory exposure data can be used to predict the effects of radiation exposure in the wild.
- Current environmental doses of radiation in the CEZ impact the health (somatic and reproductive development) of exposed individuals.
- Transgenerational impacts can be caused by chronic radiation exposure affecting populations.
- Biosystem models for euaryotes can be adapted to predict the effects of radiation-induced oxidative stress in organisms.

Scope

The scope comprises the following elements:
- Laboratory studies to optimise and validate a suite of radiation-sensitive biomarkers to predict physiological response. Samples collected from the CEZ will be used to assess the effects of chronic radiation exposure on DNA integrity.
- Long-term radiation exposure on populations of Drosophila (fruit flies) in the laboratory, irradiating the parents only, or both parents and their offspring, will be used to assess transgenerational impact.
- Eukaryote biosystem models will be adapted to predict the impact of anti-oxidants on Reactive Oxygen Species (ROS), which can be used to predict radiation damage by causing oxidative stress on organisms ranging from yeast to vertebrates.

Further information

RWM’s role in TREE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to the generic DSDC, including how this study interacts with projects on non-human biota such as the relevant MODARIA working groups.

Relevant further information can be found at: http://www.nerc.ac.uk/research/funded/programmes/rate/
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>015</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Biosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Uptake of Radionuclides</td>
</tr>
</tbody>
</table>

Title

NERC TREE: Spatial Behaviour of Non-human Biota Reference Species

Background

Radiological risk assessments are essential for safeguarding human and environmental health, but assessments often have to rely upon simplistic assumptions, such as the use of simple ratios which combine many processes, in risk calculations. This pragmatic approach has largely arisen due to the lack of data in key areas. The resultant uncertainty has been taken into account through conservative approaches which may tend to overestimate risk. Transfer-Exposure-Effects (TREE) is an integrated, multi-disciplinary, NERC project aiming to assess and reduce the uncertainty associated with radiological risk assessment so as to protect human health and the environment. RWM is co-funding this project under its initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

This Task aims to investigate how wildlife utilise the contaminated environments around Chernobyl and Fukushima within the radiologically well characterised exclusion zone. The resultant data will enable the actual external dose rates received to be compared with predicted dose rates.

Research Need

To support the environmental safety case by developing an understanding of the averaging effects of the spatial habits of non-human biota on doses. The current dose assessment approaches for wildlife do not consider how animals utilise their environment, leading to over-estimation of doses.

Research Objective

To determine whether:
- For non-human biota, the averaging affect of spatial roaming demonstrates that current overly pessimistic dose assessments need to be revised and made more realistic.
- The current assessed doses arising from the consumption of animals by humans are conservative and can be revised downward, if required, on a site-specific basis.

Scope

The scope comprises an investigation of how wildlife (e.g. deer, wolves, lynx, fox) utilise the contaminated environments around Chernobyl and Fukushima with a variety of tracking techniques (GPS collars, time-lapse photography, etc.) within the radiologically well-characterised exclusion zone. The resultant data will enable the actual external dose rates received to be compared with predicted dose rates. Internal dose rates will be estimated by collecting fresh faeces and using the DNA metabarcoding approach to determine the diet of the study species. As a result of this observational programme, a dose assessment methodology, based on more realistic scenarios than currently used, may be developed.

SRL at task start: 2  
SRL at task end: 4  
Target SRL: 4

End point: Site Specific Application of Understanding  
Customer: Disposal System Safety Case

Further information

RWM’s role in TREE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to the generic DSDC.

Relevant further information can be found in the following:
http://www.nerc.ac.uk/research/funded/programmes/rate

<table>
<thead>
<tr>
<th>Task Number</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>016</td>
<td>Biosphere</td>
<td>Uptake of Radionuclides</td>
<td></td>
</tr>
</tbody>
</table>

Title

Background
Radiological risk assessments are essential for safeguarding human and environmental health, but assessments often have to rely upon simplistic assumptions, such as the use of simple ratios which combine many processes, in risk calculations. This pragmatic approach has largely arisen due to the lack of data in key areas. The resultant uncertainty has been taken into account through conservative approaches which may tend to overestimate risk. Transfer-Exposure-Effects (TREE) is an integrated, multi-disciplinary, NERC project aiming to assess and reduce the uncertainty associated with radiological risk assessment so as to protect human health and the environment. RWM is co-funding this project under its initiative to support a portfolio of 'curiosity-driven' research which complements our 'needs-driven' programme.

This Task aims to determine whether the current empirical approach pessimistically assesses and extrapolates soil-plant transfer factors for key GDF-relevant radionuclides in soil-plant systems.

Research Need
To support environmental safety case by developing a mechanistic understanding of radionuclide uptake and incorporation which supplements empirical measurements of soil-plant transfer factors.

Research Objective
- To determine whether the current empirical approach conservatively assesses and extrapolates soil-plant transfer factors for key radionuclides.
- To investigate whether short-term measurements collected in controlled experiments can be used to predict the long-term availability of radionuclides in soils by testing the models in the Chernobyl exclusion zone.

Scope
The scope comprises the systematic evaluation of the results of short-term experimental studies in predicting the long-term biogeochemical behaviour and biological availability of key radionuclides (I-129, Se-79, Tc-99 and U-235) in soil-plant systems. These experiments include:
- Incubation experiments to follow changes (over a two and a half year period) in speciation / fractionation of isotopic spikes added to well-characterised soils;
- Measurements of current activity concentrations, the soil profile distribution and the fractionation and speciation of radionuclides in the Chernobyl exclusion zone (CEZ) soils.

Kinetic soil lability models will be developed to represent the time-dependent distribution between available and inaccessible forms, with rate coefficients parameterised using the measured distributions and related to readily measureable soil characteristics. These short-term models will be evaluated against observations of radionuclide fractionation in soils from the CEZ and, once assessed for uncertainty, will be tested for the viability of extending them for long-term prediction.

SRL at task start | 3 | SRL at task end | 4 | Target SRL | 4 |
End point | Site Specific Application of Understanding |
Customer | Disposal System Safety Case |

Further information
RWM’s role in TREE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to the generic DSDC.

Relevant further information can be found in the following:
http://www.nerc.ac.uk/research/funded/programmes/rate
Appendix B - 15

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>017</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

PBS level 4 | Biosphere
PBS level 5 | Uptake of Radionuclides

**Title**

NERC TREE: New Robust Approach to Predicting Radionuclide Activity Concentrations in Ecosystem-Food Transfer.

**Background**

Radiological risk assessments are essential for safeguarding human and environmental health, but assessments often have to rely upon simplistic assumptions, which combine many processes, such as the use of simple ratios, in risk calculations. This pragmatic approach has largely arisen due to the lack of data in key areas. The resultant uncertainty has been taken into account through conservative approaches which may tend to overestimate risk. Transfer-Exposure-Effects (TREE) is an integrated, multi-disciplinary, NERC project aiming to assess and reduce the uncertainty associated with radiological risk assessment so as to protect human health and the environment. RWM is co-funding this project under its initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

This task aims to utilise modern advances in plant sciences to develop an innovative and improved approach to ecosystem / food chain transfer relevant to waste disposal and contaminated land.

**Research Need**

To support the environmental safety case by improving the use of inter-species and inter-element relationships in order to better predict the radionuclide activity concentrations in foodstuffs or wildlife essential for input to human and non-human biota dose assessment models.

**Research Objective**

To use approaches and methods normally applied to describe the uptake of elements in plant nutrition to the study of radionuclide uptake in other organisms and human foods with the aim of making predictions for any plant or animal. This is of great value as it is impossible to measure uptake for all wildlife, crops and farm animals. The following hypotheses will therefore be tested:

- Radionuclide activity concentrations in crop plants and terrestrial and aquatic wildlife can be predicted using phylogenetically-derived relationships.
- Ionomic relationships can be established to enable knowledge of one radionuclide to improve predictions of the activity concentrations of other radionuclides in human foodstuffs and wildlife.

**Scope**

The scope is based upon utilisation of recent advances in plant sciences (phylogeny and ionomics) to develop a new scientifically robust approach to predicting radionuclide activity concentrations in human foodstuffs and wildlife, which is independent of site variables and generically applicable across species.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Application of Understanding

**Customer**

Disposal System Safety Case

**Further information**

Phylogenetics is the study of evolutionary relationships among groups of organisms (e.g. species and populations), through molecular sequencing and morphological data matrices.

Ionomics, the study of the ionome, involves the quantitative and simultaneous measurement of the elemental composition of living organisms and changes in this composition in response to physiological stimuli, developmental state, and genetic modifications.

Relevant further information can be found in the following:

http://www.nerc.ac.uk/research/funded/programmes/rate
<table>
<thead>
<tr>
<th>Task Number</th>
<th>018</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Biosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Uptake of Radionuclides</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Title</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NERC Lo-RISE: Studies of Speciation, Environmental Transport and Transfer of Key Radionuclides (C-14, U &amp; Ra) in Naturally Contaminated Environments and Laboratory Studies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Background</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The near-surface is a highly complex environment where many physical, chemical and biological processes influence radionuclide transport, both in the soil / sediment solution phase, and in transfers to biota. In developing our environmental safety case an improved understanding of the mechanisms governing radionuclide speciation and the subsequent impact on mobility and uptake by living organisms would reduce the uncertainty associated with the modelling of these complex environments. Particular radionuclides / chemicals are important where they may be environmentally mobile, are readily taken up by living organisms and are of chemo- / radio-toxicological interest. The NERC Lo-RISE project is an integrated, multi-disciplinary study with the aim of developing our understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms (including humans and non-human biota). RWM is co-funding this project under its initiative to support a portfolio of 'curiosity-driven' research which complements our 'needs-driven' programme. The primary focus of this project is on developing a process-based understanding of the speciation of radiologically important radionuclides (particularly C-14, U/Ra), and of transport and transfer phenomena through field-studies in four 'natural laboratories' in England and Scotland, spanning terrestrial, intertidal and marine systems, integrated with laboratory experiments, and leading to the development of quantitative models.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Research Need</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To support the environmental safety case by developing an improved understanding of the speciation of radiologically important radionuclides, and of transport and transfer phenomena, in the near-surface environment.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Research Objective</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To develop a process-based understanding of the speciation of radiologically important radionuclides (particularly C-14, U/Ra), and of transport and transfer phenomena through field studies in four ‘natural laboratories’ in the UK, spanning terrestrial, intertidal and marine systems, integrated with laboratory experiments, and leading to the development of quantitative models of key processes.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scope</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The scope comprises a series of laboratory experiments, investigating the way soil / sediment conditions influence radionuclide concentrations in solution, the chemical form of the radionuclides in solution, the way radionuclides are taken up into plants and animals, and the way they are distributed in plant tissues. The results from field and laboratory studies will be used to develop and test mathematical models of radionuclide transport and transfer processes, allowing for radionuclide behaviour prediction. The resulting models will be valuable in assessing environmental impacts, supporting the clean-up of contaminated land and prediction of the long-term impact of radioactive waste disposal.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SRL at task start</strong></td>
<td>3</td>
<td><strong>SRL at task end</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>End point</strong></td>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Customer</strong></td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Further information</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevant further information can be found in the following: <a href="https://bgs.ac.uk/rate/Lo-RISE.html">https://bgs.ac.uk/rate/Lo-RISE.html</a></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Further International Collaboration on Effects of Radiation on Non-human Biota

Background
We are contributing to work being undertaken by international bodies to review the approach adopted in representing the biosphere and its subsequent documentation. This includes developing understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms in the biosphere (including humans and non-human biota).

RWM contributes to the International Atomic Energy Agency's (IAEA) MODARIA programme. The general aim of the MODARIA programme is to improve capabilities in the field of environmental radiation dose assessment. One of the outcomes of the MODARIA programme will be to establish an agreed international approach on non-human biota by: collating existing datasets; defining populations; developing conceptual models which take account of both acute and chronic exposure situations; and, considering non-heterogeneous distributions of radioactivity in the body.

Such information will help in estimating the exposure of non-human biota to ionising radiation. There will be further interest in using such information to develop guidelines for the protection of non-human biota at national and international levels which may require further work. This task addresses such future development.

Research Need
To support the environmental safety case by providing an internationally agreed basis for the estimation of chronic radiological consequences on non-human biota.

Research Objective
To further develop models, laboratory techniques and field studies to increase our knowledge on the effects of radiation on non-human biota.

Scope
To revisit the effect of exposures to non-human biota when new data become available and models undergo significant development.

SRL at task start 4  SRL at task end 4  Target SRL 4

End point Site Specific Application of Understanding

Customer Disposal System Safety Case

Further information
Current work in this area is being undertaken through the MODARIA and BIOPROTA international collaborations. These collaborative programmes are highly cost-effective in sharing the financial burden of large studies and in developing international consensus in a potentially contentious area. It is assumed that this rationale will continue and will support this task.

Relevant further information can be found in the following:
http://www.bioprota.org/
Task Number 020  Status Ongoing

PBS level 4  Biosphere

PBS level 5  Uptake of Radionuclides

Title

Synthesis of NERC TREE and Lo-RISE Outputs

Background

The near-surface is a highly complex environment where many physical, chemical and biological processes influence radionuclide transport, both in the soil / sediment solution phase, and in transfers to biota. In developing our environmental safety case an improved understanding of the mechanisms governing radionuclide speciation and the subsequent impact on mobility and uptake by living organisms would reduce the uncertainty associated with the modelling of these complex environments. Particular radionuclides / chemicals are important where they may be environmentally mobile, are readily taken up by living organisms and are of chemo- / radio-toxicological interest.

RWM is co-funding the NERC Radioactivity and the Environment (RATE) programme under its initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. Two of the projects concern radionuclide mobility and uptake in the near-surface environment:

- The NERC Lo-RISE project is an integrated, multi-disciplinary study with the aim of developing our understanding of biosphere migration and accumulation mechanisms for key radionuclides and their subsequent uptake by living organisms (including humans and non-human biota).
- Transfer-Exposure-Effects (TREE) is an integrated, multi-disciplinary, NERC project aiming to assess and reduce the uncertainty associated with radiological risk assessment so as to protect human health and the environment.

This task integrates the outputs from the two research council led projects in the context of RWM’s safety case in order to realise the benefits of these significant programmes of work.

Research Need

To support development of the environmental safety case by integrating recent learning from studies into soil / plant / animal transfer factors.

Research Objective

To determine whether the current stylised approach used by RWM adequately represents soil / plant / animal transfer factors in the generic Disposal System Safety Case (gDSSC).

Scope

To integrate the learning from recently completed NERC co-funded research programmes (TREE and Lo-RISE (Tasks 014 - 018 inclusive and Tasks 786-789 inclusive) in the area of near-surface radionuclide mobility and uptake.

SRL at task start 4  SRL at task end 4  Target SRL 4

End point Site Specific Application of Understanding

Customer Disposal System Safety Case

Further information

Relevant further information can be found in the following:

http://www.nerc.ac.uk/research/funded/programmes/rate
MODARIA: Climate Change Review, Incl. UK Specific Application

Background

It is important to consider long-term climate change in representing the biosphere in post-closure assessments. The BIOCLIM project provided the basis for the climate change scenarios that RWM considers in biosphere assessment studies. The science that underpins climate change modelling and the associated modelling capabilities continues to develop; given recent developments in climate modelling there is an opportunity to build on the methodology developed in the BIOCLIM project. This will greatly improve the actual predictions made in BIOCLIM by utilising improved state-of-the-art climate modelling tools and techniques whilst also reviewing the representation of future biosphere scenarios.

The International Atomic Energy Agency (IAEA) has set up the Modelling and Data for Radiological Impact Assessments (MODARIA) programme which includes a working group addressing the environmental change in long-term safety assessments of radioactive waste disposal facilities. The working group has the specific aim of updating the predictions made in BIOCLIM by utilising improved state-of-the-art climate modelling tools and techniques. It has as its members recognised experts in climate modelling and biosphere development. RWM is playing a significant role and has set up a study to review UK climate change scenarios.

The aim of this task is to provide advice on what climate modelling calculations should be undertaken at a global level and how existing datasets from global model simulations should be used in a regional or local context for a defined area in the UK. A secondary aspect is then to downscale the global data to produce regional data and then develop a number of biosphere scenarios for various landscape types (and in the future potential GDF locations) and their associated communities.

Research Need

To support the environmental safety case for the distant post-closure phase by developing our understanding of the likely evolution of the UK climate, and specifically the location of a future GDF.

Research Objective

To capitalise on recent advances in long-term climate forecasting to give greater confidence to the selection of future biosphere scenarios for the safety case of a UK based GDF.

Scope

The scope comprises the:
- Analysis of the key processes which drive environmental change (mainly climate change), and how the future global climate may develop. These ‘futures’ are not predictions, but relevant examples that provide valuable input for solving specific questions in a safety assessment.
- Development of a conceptual framework for long-term climate change that is valid on a global scale, and consideration of how it can be downscaled to provide site-specific information.
- Application of the conceptual framework to a number of case studies, that will illustrate the interaction with site characteristics and the implications for dose assessment models.

Further information

Relevant further information can be found in the following:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>032</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PBS level 4 | Biosphere |
PBS level 5 | Landscape and its Evolution |

Title
Impact of Climate State Transitions

Background
It is important to consider long-term climate change in representing the biosphere in post-closure assessments. The BIOCLIM project provided the basis for the climate change scenarios that RWM considers in biosphere assessment studies. The science that underpins climate change modelling and the associated modelling capabilities continue to develop; given recent developments in climate modelling there is an opportunity to build on the methodology developed in the BIOCLIM project. This will improve the actual predictions made in BIOCLIM by utilising state-of-the-art climate modelling tools and techniques whilst reviewing the representation of future biosphere scenarios.

The International Atomic Energy Agency (IAEA) has set up the Modelling and Data for Radiological Impact Assessments (MODARIA) programme which includes a working group addressing environmental change in long-term safety assessments of radioactive waste disposal facilities. The working group has the specific aim of updating the predictions made in BIOCLIM by utilising improved state-of-the-art climate modelling tools and techniques. It has as its members recognised experts in climate modelling and biosphere development. RWM is playing a significant role and has set up a study to review UK climate change scenarios.

This task will assist in the development of robust long-term predictions of future climate using plausible sequences of climate scenarios (sub-tropical, temperate, boreal, glacial), including understanding the transitions between the scenarios. This will determine if the change from one climate scenario to another could lead to significant doses above those of the initial and subsequent climate states.

Research Need
To support the environmental safety case for the distant post-closure phase by developing our understanding of the potential radiological impacts of transitions between climate states (sub-tropical, temperate, boreal, glacial).

Research Objective
To determine whether the dose arising to a population from the transition between climate states is bounded by the temperate climate model as propounded in the generic Disposal Site Safety Case.

Scope
The scope comprises the activities of the collaborative international MODARIA working group on climate change, which will explore transitions between different climate states.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

End point
Site Specific Application of Understanding

Customer
Disposal System Safety Case

Further information
This task may need to be revisited circa 2025 unless radical new understanding challenges this approach. Relevant further information can be found in the following:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>033</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Biosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Landscape and its Evolution</td>
</tr>
</tbody>
</table>

**Title**

Periodic Review of Climate Change Understanding

**Background**

It is important to consider long-term climate change in representing the biosphere in post closure assessments. The BIOCLIM project provided the basis for the climate change scenarios that RWM considers in biosphere assessments studies.

The science that underpins climate change modelling and the associated modelling capabilities continue to develop and it is anticipated that future advances will require a periodic update to our understanding of climate change in the context of a UK GDF. This Task comprises such a review.

**Research Need**

To develop an understanding of how climate states (other than temperate) impact on biosphere assessments of the effects on human and non-human biota of radioactivity emerging from the geosphere in the vicinity of a GDF.

**Research Objective**

To develop an improved understanding of climate sequences and the associated land use, human habits, etc. in order to determine whether this will support the choice of a bounding climate state.

**Scope**

To revisit the analysis of climate sequences following significant development of climate change models.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Application of Understanding

**Customer**

Disposal System Safety Case

**Further information**

Relevant further information can be found in the following:
Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established an integrated project team to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes, which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Work has shown that better understanding could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. The impact of these wastes will be highly site-specific and one of the aims of the integrated project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely.

Our approach to modelling the behaviour of carbon-14 in the biosphere has been developed drawing on evidence from laboratory and field-scale experiments and modelling. Through the international collaborative biosphere forum, BIOPROTA, our modelling approach has been compared with other models developed elsewhere and this has given confidence in our approach. A follow-up study is proposed, in which model simulations could be compared with other available data.

Research Need

To determine the radiological consequences of any potential releases of carbon-14 in the biosphere (by testing the process understanding of how C-14 might behave in soil, be taken up by plants and aquatic species and enter the food chain) against available data.

Research Objective

To test the model of C-14 behaviour in the biosphere against additional field data and compare the outputs with other models in use internationally.

Scope

The scope comprises the next phase of the BIOPROTA C-14 work-stream, focusing on:
- A comparison of the results from simulations undertaken with models currently being used or developed to represent C-14 transport in soil-plant systems with available field and experimental data and in different ecological contexts (e.g. streams, rivers and lakes).
- Undertaking a modelling study of the Duke Swamp area at Chalk River in order to explore whether the observed changing distribution of C-14 in the swamp can be explained through application of physically-based mathematical modelling.

Further information

Development of Supporting Information for Post-closure Non-radiological Assessment

Background
The understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides within the near-field and in rocks surrounding a GDF is an important safety function in many concepts. Within the near-field the Engineered Barrier System (EBS) plays a critical role in all concepts in preventing the transport of most radionuclides into the geosphere. Once radionuclides have migrated into the geosphere their transport is influenced by rock composition and groundwater geochemistry (amongst other factors). The same principles apply to non-radioactive species, for example, small organic molecules, lead, mercury, cadmium, beryllium (and uranium). Additionally it is conceivable that degradation products from organic wastes and polymeric encapsulants could migrate from the EBS. Unlike the consideration of most radionuclides (i.e. excepting those such as U-235 and U-238 with half-lives of many millions of years) these non-radiological elements will never decay, hence on very long timescales some of this inventory will reach the geosphere.

Whether these species eventually reach the human and non-human receptors in the biosphere will depend on the geology of a site. Until a potential candidate site has been identified in the UK it is difficult to represent the beneficial role of the geosphere in our models, hence our safety assessments have previously ignored the role of the geosphere. Nevertheless, the result is an appropriately conservative assessment.

In order to support waste producers and the post-closure safety case (PCSC) it is necessary to enhance our understanding of the non-radiological inventory, its evolution and its mobility. This task will partially address the regulatory observation that RWM should, "develop criteria for protection of groundwater resources and human health against non-radiological chemotoxic or hazardous waste destined for disposal."

Research Need
To support the PCSC and to provide packaging advice by understanding the behaviour of non-radiological species in the geosphere.

Research Objective
To determine whether the disposal of non-radiological species within the inventory will give rise to concentrations in the surface environment which pose a hazard, e.g. lead, polymeric encapsulants, mercury, cadmium, beryllium and uranium. This task will feed into Task 053 – Further Development of Approach to Non-radiological Species in Post-closure Safety.

Scope
The scope is likely to include the development of data to help us to understand the migration of non-radiological species out of a GDF via the groundwater pathway. Where solubility and sorption data are identified as unavailable these data-gaps will be fed into other programmes of work, e.g. the development of our thermodynamic database (Tasks 806-809). The range of non-radiological species considered will reflect their presence in the UK inventory. The inventory of non-radiological species is considered in a separate task (Task 306).

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>052</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-radiological Species</td>
<td>Non-radiological Species</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consideration of Chemotoxic Non-radiological Species in Post-Closure Safety</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are components of the waste to be disposed of in a GDF which may, in addition to their radiotoxicity, contain non-radiological species which could also pose hazards to receptors (in terms of the groundwater, humans and non-human biota), or purely be chemically toxic to sensitive receptors. In order to make our safety case for a GDF we need to make sure that no receptors are adversely affected by these components. We have received a regulatory observation (reference GDF_RO_001) from the Environment Agency on the generic Disposal System Safety Case (DSSC) 2010 that required evaluation of the current post-closure methodology for the assessment of chemotoxic non-radiological species. RWM further identified the requirement to update this methodology to incorporate a wider regulatory context, specifically regarding chemotoxic non-radiological assessments in groundwater.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>To improve the robustness of our assessment of chemotoxic non-radiological species in the post closure period. Regulatory guidance requires RWM to &quot;demonstrate that the disposal system provides adequate protection against non-radiological hazards&quot; (requirement R10 of the Guidance on Requirements for Authorisation).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>To evaluate whether the methodology previously developed, as described in the Biosphere Status Report, is fit for purpose and develop new methodologies where required.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>- To undertake a scoping exercise to evaluate the current state of knowledge in the context of the prevailing regulatory setting.</td>
</tr>
<tr>
<td>- Based on the findings of the scoping exercise, propose additional work to satisfy knowledge gaps to support the future development of the DSSC (see Task 53).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Specific Application of Modelling Capability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposal System Safety Case</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Further information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant publications include:</td>
</tr>
<tr>
<td>Task Number</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>PBS level 4</td>
</tr>
<tr>
<td>PBS level 5</td>
</tr>
</tbody>
</table>

**Title**  
Further Development of Approach to Chemotoxic Non-radiological Species in Post-Closure Safety

**Background**  
There are components of the disposal system for a UK GDF which may be chemically toxic to human or non-human biota (known as ‘receptors’). Chemotoxic non-radiological species may be present within the wastes, as part of their packaging, or as components of the engineered barrier system (for example, a high pH backfill). In order to make our safety case for a GDF we need to make sure that no receptors (in terms of the groundwater, humans and non-human biota) are adversely affected by these components.

We have received a regulatory observation (reference GDF_RO_001) from the Environment Agency on the generic Disposal System Safety Case (DSSC) 2010 that required evaluation of the current post-closure methodology for the assessment of chemotoxic non-radiological species. RWM further identified the requirement to update this methodology to incorporate a wider regulatory context, in particular regarding the chemotoxic non-radiological assessment in groundwater.

Previous work has been undertaken by RWM regarding the assessment of chemotoxic non-radiological species in the post-closure period and the current validity of this work was investigated under Task 052. This task is assumed to be required as a successor of Task 052 in order to provide the foundations at the generic level for the full assessment of chemotoxic non-radiological species that will be required at the site-specific level.

**Research Need**  
To support the development of the environmental safety case by extending its coverage to include the assessment of chemotoxic non-radiological species in the post-closure period. Regulatory guidance requires RWM to "demonstrate that the disposal system provides adequate protection against non-radiological hazards", (requirement R10 of the Guidance on Requirements for Authorisation).

**Research Objective**  
To evaluate whether the methodology previously developed, as described in the Biosphere Status Report, is fit for purpose and where required develop new methodologies for the assessment of chemotoxic non-radiological species.

**Scope**  
Scope to be defined following the completion of Task 052. It is likely to comprise the development of an appropriate methodology for undertaking a full site-specific chemotoxic non-radiological assessment. This work will define which non-radiological species are important in terms of post-closure assessment and will input into the data required from the inventory (Task 306).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Modelling Capability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**  
Relevant publications include:


Appendix B - 26

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Non-radiological Species</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Non-radiological Species</td>
<td></td>
</tr>
</tbody>
</table>

Title

Potential Synergistic Effects Resulting from Exposures to Mixtures of Radiotoxic and Chemically-toxic Substances

Background

Some of the waste packages and materials used in the construction of the GDF will contain non-radiological species which may be chemically toxic to humans and/or non-human biota. The RWM generic environmental safety case for deep geological disposal focuses on the assessment of radiological impacts on the environment. In addition, some attention is also given to the potential for the release of non-radiological substances.

RWM have funded work on the assessment of human health issues arising from the combined release of chemically toxic and radiotoxic substances from ILW / LLW disposed in a GDF. The possibility of additive and synergistic effects resulting from exposures to mixtures of chemical contaminants or a combination of radiotoxic and chemically toxic substances was also considered. The outcome of this work suggested that releases of chemotoxic substances from a GDF will not have a significant adverse effect on safety in terms of the receptors of humans and non-human biota. However, it also suggested that for the potential combined effects of chemical and radiological hazards there is a relative lack of quantitative data available. We therefore need to develop our knowledge of the effect of other chemically toxic stressors on an organism’s uptake of radioactive material, the subsequent distribution within that organism, and on the radiosensitivity of a species.

Tasks 051-053 will review and develop our approach to the assessment of non-radiological species; an output from these tasks may inform this potential future study on synergistic effects.

Research Need

To support the environmental safety case by developing our understanding of whether radiotoxic and chemically toxic effects can produce synergistic detrimental effects.

Research Objective

To update our state of knowledge in respect of synergistic effects of radiotoxic and chemically toxic stressors on the basis of RWM work (Tasks 051-053) and international progress in this field.

Scope

To identify and review appropriate studies available in the open literature and to incorporate this knowledge in the context of the likely inventory and GDF design, developing our understanding of the significance of possible synergistic effects. If any potentially significant effects are identified, further work to quantify such effects should be considered.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

End point

Further Work to be Defined

Customer

Disposal System Safety Case

Further information

Relevant publications include:


https://wiki.ceh.ac.uk/display/star/Radiation+Protection+in+a+Mixed+Contaminant+Context?atl_token=66346a492415d59190d1d2676761f66a6a9c8e3c

https://wiki.ceh.ac.uk/display/star/Radiation+Protection+in+a+Mixed+Contaminant+Context?atl_token=66346a492415d59190d1d2676761f66a6a9c8e3c
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>056</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

**PBS level 4**  
Review of Options

**PBS level 5**  
Review of Options

**Title**  
Review of Alternative Waste Management Options

**Background**

Government policy for the management of radioactive waste in the long-term is through geological disposal, coupled with safe and secure interim storage and ongoing R&D to support its optimised implementation, as set out in the July 2014 White Paper on Implementing Geological Disposal. This document also outlines that the UK Government has noted that other long-term management options could emerge as practical alternatives to geological disposal for some wastes in the future. In line with this, the NDA and RWM shall continue to review appropriate solutions including learning from, and engaging with, overseas programmes which could have the potential to improve the long-term management of some of the UK’s higher activity radioactive wastes. This task supports RWM’s commitment to monitor alternatives to geological disposal.

**Research Need**

In support of Government policy, RWM needs to periodically review alternative radioactive waste management options to report relevant developments and, when required, align with specific activities or decision points in the site selection process.

**Research Objective**

To keep alternatives in radioactive waste management under review, including alternatives to geological disposal.

**Scope**

The scope will address the following aspects:
- Identification and explanation of recent, relevant developments in radioactive waste management options.
- Explanation of the significance of these developments for the UK inventory of higher activity waste.
- Discussion of any developments that merit more detailed attention.

The findings from RWM’s reviews of options will be published periodically; these publications will provide the basis for communicating developments in radioactive waste management options with Government and stakeholders. If an alternative disposal option is identified as sufficiently developed that the option potentially requires consideration relative to geological disposal, then RWM will provide this information to Government. It will then be the responsibility of Government to take such a decision and make any necessary changes to policy.

The scope of RWM’s review of alternatives to geological disposal (recognising that many of these alternatives do not offer complete solutions) includes:
- Long-term interim storage options (although research and consideration of interim storage prior to waste disposal is the responsibility of the wider NDA and nuclear site operators).
- Waste treatment techniques (e.g. partitioning and transmutation).
- Near-surface disposal (tens of metres to around 150 metres deep) for short-lived waste.
- Deep borehole disposal.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

**End point**  
Watching Brief

**Customer**  
Disposal System Specification

**Further information**

Note: This is a watching brief on keeping alternative options to geological disposal under review. RWM’s methods for keeping waste management options under review are:
- Reviews of technology and status updates for specific options.
- Dialogue with the wider NDA and nuclear site operators on developments in waste management options, technologies and solutions, including engagement through the Direct Research Portfolio (DRP) programme and through the disposability assessment process, and participation in the Nuclear Waste Research Forum (NWRF).
- Discussions with overseas waste management organisations, facilitated by the NDA’s bilateral agreements with such organisations and participation in international initiatives.
- Participation in international expert groups, studies and reviews.
- Participation in targeted international conferences.

Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>057</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Concept Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Concept Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>Concepts IPT: Development of a Range of Disposal Concepts</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Background**

A geological disposal concept is the engineered barrier system and its geometry (layout) required to deliver the safety functions and requirements defined in the disposal system specification, in a particular geological environment. A geological disposal concept is developed for a particular inventory or a particular type or group of waste and geological setting. A geological disposal facility for all UK higher activity waste will combine a number of geological disposal concepts for specific types of waste and function as one integrated system. A key feature of a geological disposal concept is that it must be tailored to site-specific characteristics.

RWM’s strategy for the use of geological disposal concepts is to increase the scientific maturity of the options available for consideration as part of the disposal system to an extent that is sufficient to enable selection decisions to be made, based on geological information that becomes available through the site selection process, and to enable sound decisions to be made regarding waste packaging proposals. Under this task the basic understanding of how a range of alternative concepts would work, and their limitations, will be developed.

**Research Need**

To develop the technical maturity of a range of alternative disposal concepts to a sufficient level of detail to support waste packaging and strategic advice and to fill gaps in disposal concept information for the inventory that may require geological disposal.

**Research Objective**

To support the GDF siting process and the provision of packaging advice for all waste groups in the inventory that may require geological disposal.

**Scope**

The scope comprises the development of our understanding of the benefits (e.g. smaller GDF footprint) and constraints of less mature disposal concepts (e.g. vaults for high-heat-generating wastes, mined borehole matrices, co-location and multi-level disposal concepts, storage / transport / disposal multi-purpose container layouts, silos for low heat-generating wastes and ‘supercontainers’). Factors requiring consideration include: review of international precedent, identification of engineered barrier system options and their associated operational and post-closure safety functions, engineering practicality and layout, criticality safety, thermal impacts, radiological impacts, operational safety, cost-estimation and scheduling and environmental impacts.

The output of this task will be a report that describes the range of disposal concepts and updates previous descriptions.

The improved understanding will support the selection of an underpinned range of geological disposal concepts for consideration during site assessment and selection.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
<th>SRL at task end</th>
<th>3</th>
<th>Target SRL</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Site Selection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:


Task Number | 058 | Status | Ongoing
--- | --- | --- | ---
PBS level 4 | Concept Development | 
PBS level 5 | Concept Development | 

Title

Background
A geological disposal concept is the engineered barrier system and its geometry (layout) required to deliver the safety functions and requirements defined in the disposal system specification, in a particular geological environment. A geological disposal concept is developed for a particular inventory or a particular type or group of waste and geological setting. A geological disposal facility for all UK higher activity waste will combine a number of geological disposal concepts for specific types of waste and function as one integrated system. A key feature of a geological disposal concept is that it must be tailored to site-specific characteristics.

There is a need for information on geological disposal concepts to support the provision of waste packaging and strategic advice; RWM has been proactive in identifying a number of radioactive material groups for which the current illustrative concepts may not be the optimum solution:

- Plutonium residues (defined as all that plutonium not converted to Mixed Oxide fuels (MOX)).
- Depleted, natural and low-enriched uranium (DNLEU) (this gap is being addressed by the uranium integrated project, see Tasks 796-798).
- Exotic spent fuels.
- Metallic spent fuels.
- Highly-enriched uranium (HEU).

Disposability advice has already been requested by waste producers for plutonium residues and is expected to be needed for the other waste groups. This task comprises the development of disposal concepts for these materials so as to support our advice and evaluation to waste owners in the development of packaging solutions for these materials.

Research Need
To support the waste disposability assessment process by developing an underpinned range of geological disposal concept options suitable for materials such as plutonium residues, exotic fuels, metallic spent fuels and highly-enriched uranium.

Research Objective
- To develop geological disposal concept descriptions for all the waste groups that may require geological disposal to a sufficient level to understand the constraints and potential benefits that they could offer.
- To identify what issues must be addressed to achieve operational and post-closure safety for each defined waste group in our three generic host geological environments.
- To identify waste groups for which benefits may be realised by allocating them to another category or by proposing the use of the same geological disposal concept as for another waste group.
- To understand the range of parameters that should be included in Level 2 Generic Specifications (i.e. a functional packaging specification rather than a detailed Level 3 waste package specification) for high-heat-generating wastes and fissile wastes, taking account of any sub-divisions of the waste groups, and how the disposal concepts will achieve operational and post-closure safety.
- To ensure that the parameters that might be used in Level 2 specifications take account of any disposal concept that could be suitable for implementation in the UK.
- To specify any geological environments that would be unsuitable for each concept.

Scope
Because waste characteristics influence safety concepts and functions so profoundly, an iterative process is needed to define waste groups on the basis of their characteristics and to describe what is required of disposal concepts for each type of waste. This task is split into the following iterative sub-tasks:

- Definition of waste groups and sub-groups: This will begin with the list of waste groups identified by a gap analysis and a description of their characteristics.
- For each waste group, the specific requirements that the waste group places on the disposal concept will
- Development of bounding parameters underpinning a Level 2 waste packaging specification.

For metallic spent fuels and HEU the characteristics that could influence their behaviour during and after emplacement within a GDF will be summarised. These characteristics will cover those that are potentially detrimental to GDF performance if not managed appropriately (e.g. relatively rapid gas generation) and characteristics that are potentially advantageous (e.g. the relatively low heat generation of these wastes compared to certain other kinds of spent fuel). Having reviewed and summarised the characteristics of the metallic fuel wastes, and the temporal variations in these characteristics, the task will next determine the limitations of existing spent fuel disposal concepts (e.g. those already developed for plutonium residues and spent fuel) with respect to the disposal of these particular materials and, where appropriate, new disposal concepts will be developed.

The output of this task will be used to support the report that describes the range of disposal concepts (Task 57).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
<th>SRL at task end</th>
<th>3</th>
<th>Target SRL</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Waste Package Disposability Assessments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

The plutonium wasteforms to be considered are: plutonium residues treated by hot isostatic pressing (HIP) and pyrochemical salts immobilised in calcium phosphate ceramic.

Relevant publications include:
Title
Concepts IPT: Development of the Concept Selection Process

Background
A geological disposal concept is the engineered barrier system and its geometry (layout) required to deliver the safety functions and requirements defined in the disposal system specification, in a particular geological environment. A geological disposal concept is developed for a particular inventory or a particular type or group of wastes and geological setting. A geological disposal facility for all UK higher activity waste will combine a number of geological disposal concepts for specific types of waste and will function as one integrated system.

The concept selection process has been described at a high level; however the level of detail is insufficient for planning data acquisition and management, for resource planning and for communication of how decisions will be made during the site selection process. Therefore, this task comprises the development of more detail on how the process will operate in practice.

Research Need
To provide more clarity on the process for selecting geological disposal concepts as part of the GDF siting process.

Research Objective
To develop a more detailed description of the concept selection process and to test the process to be used in selecting concepts during the early stages of the site-selection process.

Scope
The scope of this task will include:

Stage 1: Develop Principles for Detailed Approach to Concept Selection Process: In this stage the principles that will guide disposal concept selection will be defined. These will address the decision-making process to be used, and the information that will be required to support decision making. Issues to be addressed are:
- The methodology for identification of disposal concepts.
- How concepts can be compared when the level of information and understanding on the concepts differs.
- Understanding which attributes in RWM’s standard attribute list will be used in decision making on disposal concepts, what information is required for each attribute and how attributes will be evaluated (e.g. scored or compared).
- The range of disposal concepts to be considered during site characterisation needs to be defined.
- How the process could be communicated and the potential roles of stakeholders (e.g. the role of local communities in determining weightings).

Stage 2: Preliminary Drafting of the Concept Selection Process Manual: The principles that will have been developed will be tested through a trial application of the concept selection process and used to develop a draft manual explaining how the process will be undertaken. Information to be included in the manual will include, for example, a specific description of the attributes that would be considered, the data required for assessment of these attributes and how these data would be acquired, and the method to be used to compare disposal concepts.

Stage 3: Completion of the Concept Selection Process Manual: The manual will include development of an integrated activity schedule for the concept selection process which recognises inputs from, and interactions with, RWM functions. This will provide a better understanding of the resources required to select disposal concepts during the site-selection process. It will include identification of who will be involved in the evaluation of disposal concepts, what length of time is required to undertake the work and how the outcomes of work would be reported and communicated.

The output of this task will be an update to the concept selection process description.
<table>
<thead>
<tr>
<th>End point</th>
<th>No Further Research Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>Site Selection</td>
</tr>
</tbody>
</table>

Further information

Relevant publications include:


As this task comprises the development of a methodology it is not appropriate to present SRLs or TRLs.
**Background**

This task is complete, but final reports are still in the peer review process.

To date, most of RWM’s Criticality Safety Assessment (CSA) studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low [1,2].

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to support and evaluate changes to the design of the disposal system, for example the potential use of multi-purpose containers (MPCs) for spent fuel, Pu and U disposal.

This task will identify and document the factor(s) which may be relied upon in order to provide criticality control for an MPC containing legacy spent Pressurised Water Reactor (PWR) or Advanced Gas Reactor (AGR) fuel.

**Research Need**

To support transport and disposal safety case development by identifying and documenting the factor(s) which may be relied upon in order to provide criticality control for an MPC containing legacy spent Pressurised Water Reactor (PWR) or Advanced Gas Reactor (AGR) fuel.

**Research Objective**

To undertake a design feasibility study to determine the preferred solution / design required to achieve criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in an MPC.

**Scope**

To evaluate the balance between neutron production and absorption that needs to be managed in order to construct and document a criticality safety assessment in support of the transport and disposal of legacy PWR and AGR spent fuel disposed of in an MPC.

The output will be a design feasibility study to determine the preferred solution / design required to achieve criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in an MPC.

**Further information**

The post-closure phase is already being covered within the RWM Concepts Integrated Project Team (IPT) (Tasks 057-059 inclusive), hence the scope for this task is restricted to transport and operational phases of GDF. Relevant publications include:

Title
Spent Fuel - Criticality Control Options

Background
To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to support and evaluate changes to the design of the disposal system, for example the potential use of multi-purpose containers for spent fuel, Pu and U disposal. RWM’s current understanding has been used in the generic Disposal System Safety Case.

In future, site-specific work will provide robust assurance of criticality safety for specific container designs and facility layouts. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. This task will provide a review of the options available for administrative and design options for assuring criticality safety of legacy spent fuels.

Research Need
To support the safety case and design process by developing a hierarchy of administrative controls and design measures (for example burn-up credit, neutron absorbing materials and flux traps, void fillers / water barriers in transport and/or disposal container design) to assure criticality safety of legacy spent fuel.

Research Objective
To review whether the use of one, or a combination of:
- neutron-absorbing materials;
- burn-up credit arguments;
- void fillers or multiple water barriers,
can be implemented to facilitate disposability of spent fuel.

Scope
To review the feasibility of various options (e.g. neutron absorbing materials, burn-up credit, void filler / water barriers (amongst others) in support of the potential disposability of spent fuels.

This will build on work previously completed by the design (transport) function of RWM (e.g. to expand criticality safety arguments for disposal of spent fuel from just transport, to operational and post-closure phases of the GDF). Outputs will include the preferred design developments.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>3</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
</table>

End point
No Further Research Planned

Customer
Disposal System Safety Case

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>069</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Criticality Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety Assessment for Spent Fuel Disposal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Disposal Container - Criticality Control Options Study

**Background**

To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to support and evaluate changes to the design of the disposal system, for example the potential use of multi-purpose containers for spent fuel, Pu and U disposal.

This task will identify and document the factor(s) which may be relied upon in order to provide criticality control for a UK disposal container containing legacy spent pressurised water reactor (PWR) or advanced gas-cooled reactor (AGR) fuel.

**Research Need**

To support transport and disposal safety case development by identifying and documenting the factor(s) which may be relied upon in order to provide criticality control for a UK disposal container containing legacy spent fuels (PWR and AGR) if disposed of in a UK disposal container.

**Research Objective**

To undertake a design feasibility study to determine the preferred solution / design required to achieve criticality safety of existing legacy spent fuels (PWR and AGR) if disposed of in a UK disposal container.

**Scope**

To evaluate the balance between neutron production and absorption that needs to be managed in order to construct and document a criticality safety assessment in support of the transport, operations and disposal of legacy PWR and AGR spent fuel disposed of in a UK disposal container.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Design, Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

RWM has recently developed two illustrative designs of disposal containers for legacy spent fuel, one featuring a copper-shell with a cast iron insert (Variant 1, based on the KBS-3 Swedish design) and one featuring a carbon steel single body (Variant 2, similar to a design considered in Switzerland). Both designs now consider disposal of 16 ‘slotted cans’ of AGR fuel (48 fuel elements) and 4 PWR assemblies in each container. Relevant publications include:


Background
To date, most of RWM’s criticality safety assessment studies have been made for the transport of intermediate level waste (ILW) to a geological disposal facility and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, high level waste (HLW), spent fuel, Pu and U during transport, operations and following facility closure. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. This task comprises a concept selection exercise for a range of scenarios for the disposal of exotics (a large number of spent fuels, with varying levels of enrichment, from research and experimental reactors, typically of low volume and with varied, currently unstudied disposal characteristics), including the potential use of neutron-absorbing materials.

Research Need
To support concept development by identifying the leading concept option for the disposal of exotics.

Research Objective
To conduct a review of the feasibility of various disposal options for the proportion of the UK inventory classified as exotics and to select / justify the leading option.

Scope
To undertake a feasibility study in order to consider available design measures, and potential administrative controls, to ensure criticality safety of disposed exotics in a range of potential disposal concepts.

Further information
This work is being conducted as part of RWM’s ongoing Concepts integrated project - phase 2.
### Background

To date, most of RWM’s criticality safety assessment studies have been made for the transport of intermediate level waste (ILW) to a geological disposal facility and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, high level waste, spent fuel, Pu and U during transport, operations and following facility closure. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. This task comprises a concept selection exercise for selected scenarios for the disposal of metallic fuel, including the potential use of neutron-absorbing materials.

### Research Need

To support concept development by identifying the leading concept option for the disposal of metallic fuel.

### Research Objective

To conduct a review of the feasibility of various disposal options for metallic fuel and to select / justify the leading option.

### Scope

To undertake feasibility study in order to consider administrative controls and design measures to ensure criticality safety of disposed metallic fuel in a range of potential disposal concepts.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Concept Development, Disposal System Safety Case

### Further information

This work is being conducted as part of RWM’s ongoing Concepts integrated project phase 2. Relevant publications include:


Background

To date, most of RWM’s criticality safety assessment studies have been made for the transport of intermediate level waste (ILW) to a geological disposal facility, and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to optimise the disposal of spent fuel, where credit can be taken for the reduction in nuclear reactivity due to burn-up of some of the fissile component.

Research Need

To support the design, safety case and waste disposability processes by optimising the disposal of legacy UK spent fuels (from advanced gas-cooled reactors and pressurised water reactors) by maximising the quantity that can be accommodated safely in each disposal container.

Research Objective

To develop and document burn-up credit arguments such that they can be implemented in RWM’s designs, safety case and waste disposability assessments.

Scope

To review and extend international knowledge of the effect of burn-up credit on the long-term reactivity of the range of anticipated fuel types and irradiation histories. This will be achieved by derivation of methodologies, including loading curves.

The results will facilitate regulatory discussion and allow subsequent identification of further research required to validate the application of burn-up credit in the operational and disposal safety cases (N.B. the scope excludes transport, as multiple water barriers are being pursued in this area).

SRL at task start | SRL at task end | Target SRL
---|---|---
3 | 4 | 6

End point | No Further Research Planned
Customer | Disposal System Safety Case, Design

Further information

It is assumed for higher-enriched fuels that the application of burn-up credit will be necessary to ensure disposability. If Task 068 concludes otherwise, different work streams may be required.

The operational safety case is likely to require a Scientific Readiness Level (SRL) of 5. The generic post-closure safety case is also envisaged to require an SRL of 5. Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>074</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Criticality Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety Assessment for Spent Fuel Disposal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Disposal Container – CSA for Legacy Fuels

**Background**
To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to support and evaluate changes to the design of the disposal system, for example the potential use of multi-purpose containers for spent fuel, Pu and U disposal.

Having identified the factor(s) which may be relied upon in order to provide criticality control for a UK disposal container containing legacy spent pressurised water reactor (PWR) or advanced gas-cooled reactor (AGR) fuel in Task 069, this task will comprise a criticality safety assessment which can be used to demonstrate criticality safety.

**Research Need**
To support safety case development by identifying and documenting the factor(s) relied upon in order to provide criticality control for a UK disposal container containing legacy spent PWR and AGR fuel.

**Research Objective**
To undertake a full criticality safety assessment to demonstrate criticality safety for the disposal of legacy spent fuels (e.g. PWR and AGR) in the UK disposal container.

**Scope**
Now that UK disposal container designs have been developed and after a criticality control options study has been completed (under Task 378), a full criticality safety assessment is required to demonstrate criticality safety for the disposal of legacy spent fuels (e.g. PWR and AGR) in the UK disposal container design.

The criticality safety assessment should comprise a computational study conducted on a set of normal operation and accident condition scenarios (covering transport, operation and post-closure phases of GDF), likely utilising the MCNP or MONK criticality codes.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>6</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
</table>

**End point**
No Further Research Planned

**Customer**
Disposal System Safety Case, Design

**Further information**
RWM has recently developed two illustrative designs, one featuring a copper-shell with a cast iron insert (Variant 1, based on a Swedish design) and one featuring a carbon steel single body (Variant 2, similar to a design considered in Switzerland). Both designs now consider disposal of 16 ‘slotted cans’ of AGR fuel (48 fuel elements) and 4 PWR assemblies in each container. Relevant publications include:


Criticality Safety Assessment for Exotics

Background

To date, most of RWM's criticality safety assessment studies have been made for the transport of intermediate level waste (ILW) to a geological disposal facility (GDF) and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, high level waste (HLW), spent fuel, Pu and U during transport, operations and following facility closure. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. A leading candidate for the disposal of exotics (a large number of spent fuels from research and experimental reactors, typically of low volume and with varied, currently unstudied disposal characteristics), will be identified through RWM's ongoing Concepts integrated project, Phase 2: Feasibility of Disposal Concepts for exotics (See Task 070). This task comprises a criticality safety assessment of the identified preferred disposal concept for exotics.

Research Need

To support concept development by developing a criticality safety assessment for a preferred disposal concept for exotics. This task is conditional on the preceding Concepts IPT task (Task 070) demonstrating that it is required.

Research Objective

To assess the criticality safety of the preferred disposal concept for exotics (see Task 070).

Scope

To undertake a computational study based on a set of normal operation and accident condition scenarios (covering transport, operations and post-closure phases, likely utilising the MCNP (Monte Carlo N-Particle Code) or MONK (Criticality Software developed and licensed by AMEC) codes) for the leading disposal concept for exotics.

Further information

This work will be conducted either as a follow-on task to RWM’s ongoing Concepts integrated project, or potentially as a stand-alone design for criticality safety task.


Task Number | 076 | Status | Start date in future
---|---|---|---
PBS level 4 | Criticality Safety
PBS level 5 | Criticality Safety Assessment for Spent Fuel Disposal

Title
Criticality Safety Assessment for Metallic Fuel

Background
To date, most of RWM’s criticality safety assessment studies have been made for the transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, spent fuel, Pu and U during transport, operations and following facility closure. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. A leading candidate for the disposal of metallic fuel will be identified through RWM’s ongoing Concepts integrated project, Phase 2: Feasibility of Disposal Concepts for Metallic Fuel (See Task 071). This task comprises a criticality safety assessment of the identified preferred disposal concept for metallic fuel.

Research Need
To support concept development by developing a criticality safety assessment for a preferred disposal concept for metallic fuel. This task is conditional on the preceding Concepts IPT task (Task 071) concluding that it is required.

Research Objective
To assess the criticality safety of the preferred disposal concept for metallic fuel (see Task 071).

Scope
To undertake a computational study based on a set of normal operation and accident condition scenarios (covering transport, operations and post-closure phases, likely utilising the MCNP (Monte Carlo N-Particle Code) or MONK (Criticality Software developed and licensed by AMEC) codes) for a disposal concept for metallic fuel.

SRL at task start | 4 | SRL at task end | 6 | Target SRL | 6
End point | No Further Research Planned
Customer | Concept Development, Disposal System Safety Case

Further information
This work will be conducted either as a follow-on task to RWM’s ongoing Concepts integrated project, or potentially as a stand-alone design for criticality safety task. Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>077</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Criticality Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety Assessment for Spent Fuel Disposal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Spent Fuel - Implementation / Validation of Burn-up Credit Arguments

**Background**

To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to optimise the disposal of spent fuel, where credit can be taken for the reduction in nuclear reactivity due to burn-up of some of the fissile component.

**Research Need**

To support the design, safety case and waste disposability processes by optimising the disposal of legacy UK spent fuels (advanced gas-cooled reactor / pressurised water reactor) by maximising the quantity that can be accommodated safely in each disposal container.

**Research Objective**

To develop and document burn-up credit arguments such that they can be implemented in RWM’s designs, safety case and waste disposability assessments.

**Scope**

To use criticality modelling codes and our understanding of the evolution of the post-closure system for the development and validation of burn-up credit arguments such that they can be used in the operational and post-closure safety cases.

| SRL at task start | 4 | SRL at task end | 6 | Target SRL | 6 |

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case, Design

**Further information**

It is assumed for higher enriched fuels that the application of burn-up credit will be necessary to ensure disposability. If Task 073 concludes otherwise, different work streams may be required.

Relevant publications include:


Appendix B - 44

Task Number | 078 | Status | Start date in future
PBS level 4 | Criticality Safety
PBS level 5 | Criticality Safety Assessment for Spent Fuel Disposal

Title
Disposal Container – Criticality Safety Assessment for Future Higher Enriched New Build Fuels

Background
To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to support and evaluate changes to the design of the disposal system, for example the potential use of multi-purpose containers for spent fuel, Pu and U disposal.

Having identified the factor(s) which may be relied upon in order to provide criticality control for a UK disposal container containing legacy spent fuel in Task 074, this task will comprise expanding the existing criticality safety assessment to demonstrate criticality safety of future higher enriched fuels (e.g. some exotics or mixed oxide (MOX) spent fuels) in this container.

Research Need
To support safety case development by identifying and documenting the factor(s) relied upon in order to provide criticality control for a UK standardised disposal container containing legacy spent pressurised water reactor, advanced gas-cooled reactor and higher enriched spent fuels.

Research Objective
To undertake a full criticality safety assessment (CSA) to demonstrate criticality safety for the disposal of higher enriched spent fuels in the UK disposal container.

Scope
To expand the scope of the existing criticality safety assessment (produced under Task 074) to spent fuels with higher enrichments, e.g. mixed oxide fuel (MOX)).

The new or revised criticality safety assessment will again comprise a computational study conducted on a set of normal operation and accident condition scenarios (covering transport, operations and post-closure phases of GDF) likely utilising the MCNP or MONK criticality codes.

SRL at task start | 4 | SRL at task end | 6 | Target SRL | 6

End point | No Further Research Planned

Customer | Design, Disposal System Safety Case

Further information
RWM has recently developed two variant designs for the UK disposal container, one featuring a copper-shell with a cast iron insert (Variant 1, based on a Swedish design) and one featuring a carbon steel single body (Variant 2, similar to a design considered in Switzerland). Both designs now consider disposal of 16 ‘slotted cans’ of AGR fuel (48 fuel elements) and 4 PWR assemblies in each container. Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>079</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Criticality Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety Assessment for Spent Fuel Disposal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Spent Fuel - Extending Burn-up Credit Arguments to Future Higher Enriched New Build Nuclear Fuels and Low Burn-up Fuels.

**Background**

To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work is needed to optimise the disposal of spent fuel, where credit can be taken for the reduction in nuclear reactivity due to burn-up of some of the fissile component. Burn-up credit arguments will also need to be expanded to support / facilitate the disposability of non-legacy spent fuels, for example, potential future higher-enriched spent fuels (e.g. mixed oxide fuel). Furthermore, alternative criticality control options may also be required to demonstrate disposability of low burn-up or fresh (i.e. non-irradiated) fuels.

**Research Need**

To support the design, safety case and waste disposability processes by optimising the disposal of non-legacy UK spent fuels (e.g. mixed oxide fuel) by maximising the quantity that can be accommodated safely in each disposal container.

**Research Objective**

To develop burn-up credit arguments to support / facilitate the disposability of non-legacy spent fuels, for example highly enriched spent fuels (e.g. mixed oxide fuel).

To develop alternative criticality control options which may be utilised in order to optimise the disposability of low-burn-up, or fresh (non-irradiated) spent fuels.

**Scope**

To use criticality modelling codes and our understanding of the evolution of the post-closure disposal system to extend our understanding of the role of burn-up credit in the post-closure safety case to incorporate higher enriched and / or lower burn-up fuels; this may require assessing an agreed range of scenarios for the evolution of the disposal system.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>6</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

It is assumed that for highly enriched fuels the application of burn-up credit will be necessary in order to ensure disposability.


Develop the Transport Criticality Safety Assessment for the Disposal Container Transport Container

Background

The transport of radioactive waste to a geological disposal facility must meet the requirements of national legislation deriving from the International Atomic Energy Agency's (IAEA) Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety.

In respect of criticality safety, the Transport Regulations require that packages containing fissile material must be demonstrated to be safely subcritical in routine, normal and accident conditions of transport and approved by a Competent Authority (the Office for Nuclear Regulation in the UK). Preliminary work has shown that a Disposal Container Transport Container containing spent fuel with higher uranium-235 enrichments cannot be shown to remain safely sub-critical. The preferred solution has been identified to incorporate multiple high-standard water barrier features in the Disposal Container Transport Container design. Criticality safety analysis has shown that such features would enable a demonstration that the packages remain safely sub-critical. A concept design for a Disposal Container Transport Container incorporating multiple high-standard water barriers features has been developed. The use of multiple high-standard water barrier features is novel in the UK and further work is required to demonstrate that the concept design can be licensed.

Research Need

To determine whether the concept design for the Disposal Container Transport Container incorporating multiple high-standard water barriers features can be licensed.

Research Objective

To develop a transport criticality safety assessment for the Disposal Container Transport Container demonstrating that it can be licensed.

Scope

Specific concerns on the licensing of the Disposal Container Transport Container incorporating multiple high standard water barriers features are:

- The transport regulations do not include a quantified acceptance criterion for a high-standard water barrier. A quantified criterion must be developed, agreed with the Competent Authority and the concept package design demonstrated to meet the criterion.

- The concept design of Disposal Container Transport Container relies upon the concept of the disposal container providing the function of one of the high-standard water barriers. This is a novel approach. Research is needed to identify if there are any licensing issues with the proposed concept design and to resolve any identified issues.

Further information

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Criticality Safety</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety Assessment of Spent Fuel Disposal</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Develop the Disposal Container Transport Container Criticality Safety Assessment for New Fuels in the 2013 Derived Inventory

**Background**

The transport of radioactive waste to a geological disposal facility must meet the requirements of national legislation deriving from the International Atomic Energy Agency’s (IAEA) Regulations for the Safe Transport of Radioactive Material (Transport Regulations). The Transport Regulations place controls on the design and operation of transport packages to ensure safety.

In respect of criticality safety, the transport regulations require that packages containing fissile material must be demonstrated to be safely subcritical in routine, normal and accident conditions of transport and approved by a Competent Authority (the Office for Nuclear Regulation in the UK). Preliminary work has shown that a Disposal Container Transport Container (DCTC) containing spent fuel with higher uranium-235 enrichments cannot be shown to remain safely sub-critical. A preferred solution has been identified to incorporate multiple high-standard water barriers features in the Disposal Container Transport Container design. Criticality safety analysis has shown that such features would enable a demonstration that the packages remain safely sub-critical. A concept design for a Disposal Container Transport Container incorporating multiple high-standard water barriers features has been developed. However, further work is required to demonstrate the criticality safety of the Disposal Container Transport Container incorporating multiple high-standard water barriers for the transport of new fuels introduced in the 2013 Derived Inventory.

**Research Need**

To determine whether the concept design for the Disposal Container Transport Container incorporating multiple high-standard water barriers features can used for the transport of new fuels introduced in the 2013 Derived Inventory.

**Research Objective**

To develop a transport criticality safety assessment for the Disposal Container Transport Container incorporating multiple high-standard water barriers features when used for the transport of new fuels introduced in the 2013 Derived Inventory.

**Scope**

Specific concerns on the licensing of the Disposal Container Transport Container incorporating multiple high-standard water barriers features are that previous work to demonstrate the criticality safety might not be valid for new fuels introduced in the 2013 Derived Inventory. This is particularly so for PFR fuel where fast fission neutrons are more relevant.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

Watching Brief

**Customer**

Disposal System Safety Case

**Further information**

### Task Number: 092
**Status:** Ongoing

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Criticality Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety for ILW Disposal</td>
</tr>
</tbody>
</table>

**Title:** Fissile Limits for ILW Transported in an SWTC

#### Background

To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. At this current generic phase, RWM plan to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work will be needed to support and evaluate changes to the design of the disposal system. RWM’s current understanding has been used in the generic Disposal System Safety Case.

In future, site-specific work will provide robust assurance of criticality safety for specific container designs and facility layouts. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. This task comprises an assessment in support of the transport safety case in order to demonstrate that criticality cannot happen during the transport of ILW containers within a standard waste transport container (SWTC).

#### Research Need

To support concept development by identifying waste package fissile material limits for ILW packages transported in a SWTC.

#### Research Objective

To demonstrate criticality safety during ILW transport in an SWTC by the derivation of appropriate waste package fissile material limits.

#### Scope

To undertake a computational study on a set of normal operation and accident condition scenarios utilising the MCNP or MONK criticality codes in order to derive appropriate waste package fissile material limits for a range of unshielded ILW waste packages, starting with 500L drums.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>5</th>
<th>SRL at task end</th>
<th>6</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>End point</strong></td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Customer</strong></td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Further information

Work is being undertaken by RWM’s design team and International Nuclear Services (INS). Relevant publications include:

Task Number | 093 | Status | Ongoing
---|---|---|---
PBS level 4 | Criticality Safety
PBS level 5 | Criticality Safety for ILW Disposal
Title
Transport Fissile Exception Test Case

Background
To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. At this current generic phase, RWM plan to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. Additional work will be needed to support and evaluate changes to the design of the disposal system. RWM’s current understanding has been used in the generic Disposal System Safety Case.

In future, site-specific work will provide robust assurance of criticality safety for specific container designs and facility layouts. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. This task comprises an assessment in support of the transport safety case in order to demonstrate that criticality cannot happen during the transport of ILW containers within a standard waste transport container (SWTC).

The 2012 edition of the IAEA transport regulations introduced a provision permitting a Competent Authority to approve material as fissile excepted. Such material is then excepted from the requirements for the transport of fissile material, notably controls on the design and approval of transport packaging for criticality safety, package accumulation control and implicitly the need for additional criticality safety assessment. This task aims to make a ‘test’ application to the UK regulators for approval of material containing a low concentration of fissile nuclides as fissile excepted. If successful, the application could be invoked by waste producers to demonstrate the transport criticality safety of a broad range of waste.

Research Need
To support concept development by identifying and testing the new waste package fissile exception and competent authority approval route for ILW transport under the revised 2012 edition of the IAEA transport regulations.

Research Objective
To make a ‘test’ application to the UK regulators (and respond to their comments/challenges) for approval of material containing a low concentration of fissile radionuclides as fissile excepted.

Scope
To produce a test case fissile exception against Paragraph 417 of the 2012 edition of the transport regulations. The scope of the test application is envisaged to cover material that is safe by virtue of its low fissile radionuclide concentration. The case should aim to demonstrate that non-fissile material in the waste acts as a parasitic neutron absorber such that material is sub-critical in any accumulation. Limits should be identified on the composition of the material and disposition of the fissile nuclides to ensure that the material remains safely subcritical in conditions that could reasonably occur during routine, normal and accident conditions of transport.

SRL at task start | 5 | SRL at task end | 6 | Target SRL | 6
End point | No Further Research Planned
Customer | Disposal System Safety Case, Design, Assessment of Packaging Solutions

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>102</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PBS level 4**  
Criticality Safety

**PBS level 5**  
Criticality Safety Assessment for Plutonium and Uranium Disposal

**Title**  
Criticality Safety Considerations for Hot Isostatic Pressed (HIPed) Pu Wasteforms

**Background**

To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. Task 101 identified that a leading candidate for the disposal of plutonium residues is to blend the material with neutron-absorbing ceramics and then to utilise Hot Isostatic Pressing (HIP) to create a highly durable and inherently criticality-safe wasteform. Furthermore, there are also research requirements arising from RWM’s disposability assessment process that may also require us to consider disposal of ceramic-immobilised Pu wasteforms within our low-heat generating waste disposal concept. This task comprises a scoping-level criticality safety assessment of HIPed product disposed of in potentially both the high-heat-generating waste and low-heat-generating waste disposal concepts.

**Research Need**

To support concept development and disposability assessments by developing a scoping-level criticality safety assessment for both a preferred plutonium residues disposal concept and a more traditional LHGW disposal concept for plutonium (both assumed to involve a HIPed wasteform).

**Research Objective**

To assess the criticality safety of the preferred plutonium disposal concept (see Task 101) to support concept development and of a more traditional low-heat-generating waste concept to support ongoing disposability assessment work.

**Scope**

To undertake a computational study based on a set of normal operation and accident condition scenarios covering transport, operations and post-closure phases, likely utilising the MCNP (Monte Carlo N-Particle Code) or MONK (Criticality Software developed and licensed by AMEC) codes) for a HIPed wasteform for the disposal of plutonium residues and selected plutonium-contaminated materials (intended to be immobilised in ceramic wasteforms).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>6</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>End point</strong></td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Customer**  
Concept Development, Disposal System Safety Case

**Further information**

This work is being conducted as part of RWM’s ongoing Concepts integrated project.


Title
Concepts IPT: Feasibility of Separated Highly-enriched Uranium (HEU) Disposal

Background
To date, most of RWM’s criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. This task comprises a concept selection exercise for selected scenarios for the disposal of highly-enriched uranium (HEU) wasteforms, including the potential use of neutron-absorbing materials.

Research Need
To support concept development by identifying the leading concept option for the disposal of HEU.

Research Objective
To conduct a review of the feasibility of various disposal options for the disposal of HEU.

Scope
To undertake a feasibility study in order to consider administrative controls and design measures to ensure criticality safety of disposed HEU in a range of potential disposal concepts

SRL at task start 4 SRL at task end 5 Target SRL 6

End point No Further Research Planned

Customer Concept Development, Disposal System Safety Case

Further information
This work is being conducted as part of RWM’s ongoing Concepts integrated project. Relevant publications include:


Task Number: 104
Status: Start date in future

PBS level 4: Criticality Safety
PBS level 5: Criticality Safety Assessment for ILW Disposal

Title: Criticality Safety Assessment for HIPed HEU Wasteforms

Background
To date, most of RWM's criticality safety assessment studies have been made for transport of ILW to a GDF and its subsequent emplacement and disposal. A significant component of this work programme is to assess the safety of operations and disposal of spent fuel and separated uranium (U) and plutonium (Pu), which will also be disposed of if declared as waste. Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are both very low.

At this current generic phase, RWM plans to demonstrate the principles that are used to assure criticality safety of ILW, HLW, spent fuel, Pu and U during transport, operations and following facility closure. During this phase the number of options under consideration will reduce which, together with any optioneering, will result in refinement of the final design of the disposal system. A leading candidate for the disposal of plutonium residues is to blend the material with neutron-absorbing ceramics and then to utilise Hot Isostatic Pressing (HIP) to create a highly durable and inherently criticality-safe wasteform. It is assumed in compiling this task sheet that the HIPed wasteform will be identified in Task 103 as the leading candidate for the disposal of Highly Enriched Uranium (HEU) residues. This task comprises a criticality safety assessment of HEU product.

Research Need
To support concept development by developing a criticality safety assessment for a preferred HEU disposal concept (assumed to involve a HIPed wasteform). This task is conditional on the preceding Concepts IPT task (Task 103) concluding that it is required.

Research Objective
To assess the criticality performance of the preferred HEU disposal option (defined by the feasibility task, Task 103) in support of concept development, including consideration of criticality safety arguments for a waste package containing multiple HEU wasteforms (if applicable).

Scope
To undertake a computational study on a set of normal operation and accident condition scenarios covering transport, operations and post-closure phases, likely utilising the MCNP (Monte Carlo N-Particle Code) or MONK (Criticality Software developed and licensed by AMEC) codes) for an HEU-containing wasteform.

SRL at task start: 5
SRL at task end: 6
Target SRL: 6

End point: No Further Research Planned

Customer: Concept Development, Disposal System Safety Case

Further information
Depending on the outcome of Task 103, this task may or may not be required. Relevant publications include:


Applying the Likelihood of Criticality Models to Future Concepts, Facility Designs and Inventories

Background
RWM has a good understanding of the processes that contribute to the low likelihood of fissile material in a GDF accumulating to give a critical configuration at some time after the closure of the facility. Immediately after closure there is no greater risk of criticality than that during the operational phase, which is very low. However, as the waste packages deteriorate over long periods of time there is the need to develop a methodology to estimate the likelihood of criticality (for all of the higher activity wastes in the three illustrative disposal geologies) over the time period covered by the environmental safety case. Historically, RWM’s low likelihood work focused predominantly on ILW in higher strength rock GDFs. More recent work has extended the knowledge base and RWM’s capability/toolkit to cover all of the higher activity wastes (e.g. LLW, ILW, DNLEU, HLW, spent fuel, Pu and HEU) in the three illustrative geologies.

This task has been developed to recognise that RWM will need to apply these new likelihood and consequences of post-closure criticality assessment capabilities to future concepts, facility designs and / or revised inventories, as they become available.

Research Need
To support the environmental safety case by applying RWM’s methodology for estimating the likelihood of criticality (e.g. to underpin our low likelihood position).

Research Objective
The environmental safety case needs to be able to demonstrate, substantiate and communicate its position that post-closure criticality is a low likelihood event.

Scope
To be defined on the basis of future waste disposal concepts, facility designs and / or revised inventories e.g. the recently updated Derived Inventory.

SRL at task start 5 SRL at task end 6 Target SRL 6

End point Application of Models to Revised Inventories / Concepts

Customer Disposal System Safety Case, Assessment of Packaging Solutions, NDA Strategy

Further information
Relevant publications include:
## Task Number

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>131</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### PBS level 4

- Criticality Safety

### PBS level 5

- Criticality Safety - Models of Consequences of Hypothetical Criticality

## Title

Types of Critical Systems and the Credibility of Rapid Transient Criticality During Post-closure

## Background

Historically RWM has assessed Features, Events and Processes that might lead to a post-closure criticality for ILW in a higher-strength rock GDF. It was concluded that, although a criticality would not be expected based on best estimate data (which will soon be replaced with likelihood results), the possibility of a criticality could not be entirely discounted. In response, RWM initiated a programme called Understanding Criticality Under Repository Conditions in order to obtain a better understanding of the processes that would control the nature and magnitude of a post-closure criticality. The programme involved the development and benchmarking of models that predict the evolution of critical systems, including the effects on the surroundings. Coupled with knowledge of the transport of radionuclides within and from the vicinity of the disposal facility, these models can be used to predict the consequences of a criticality.

More recently, further consequences of post-closure criticality work has sought to expand its coverage out to all of the higher activity wastes (e.g. not just ILW) in the three illustrative concept geologies (i.e. not just higher strength rock).

This task has been developed to further document RWM's knowledge of the types of critical systems that may develop and the credibility of rapid transient critical systems developing during the post-closure phase of GDF.

## Research Need

To support the packaging and safe disposal of fissile wastes by underpinning RWM's evolving post-closure criticality safety methodology (low likelihood and low consequences) that has recently concluded that a rapid transient criticality can be shown to be not credible within a UK GDF.

RWM is aware of previous international work and fundamental nuclear physics calculations (particularly considering highly enriched uranium systems/or over moderated systems) that may challenge the above conclusion. A position paper will be produced that documents the credibility of post-closure rapid transient criticality.

## Research Objective

The objectives of this task are:

- to bring together RWM’s knowledge of the types of criticality and the conditions required for their development; and
- To consider the credibility of rapid transient critical systems during the post-closure phase of a GDF.

## Scope

The scope of this desk-based literature review task comprises the following:

- A discussion on how a criticality could start, evolve and end. Initially from a purely fundamental nuclear physics viewpoint, before later considering the restriction of credible scenarios by imposing conditions and constraints applicable to a UK GDF.
- Consideration of key aspects of previous international work that has considered the development of post-closure critical systems and in particular the possibility of rapid transient critical systems. This should draw on the recent consequences of hypothetical post-closure criticality international review, where relevant.
- Clarify the lines of argument as to why (if this is indeed the conclusion of the task) rapid transient critical systems are not thought to credible and/or identify any areas where it is technically possible but incredible in a UK GDF and document why.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End point</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Further Research Planned</td>
<td>Waste Package Disposability Assessments</td>
</tr>
</tbody>
</table>

Further information:

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>132</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Criticality Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety - Models of Consequences of Hypothetical Criticality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Further Understanding of Types of Critical Systems and the Credibility of Rapid Transient Criticality During Post-closure.

**Background**

Historically RWM has assessed Features, Events and Processes that might lead to a post-closure criticality for ILW in a higher-strength rock GDF. It was concluded that, although a criticality would not be expected based on best estimate data (which will soon be replaced with likelihood results) the possibility of a criticality could not be entirely discounted. In response, RWM initiated a programme called Understanding Criticality Under Repository Conditions in order to obtain a better understanding of the processes that would control the nature and magnitude of a post-closure criticality. The programme involved the development and benchmarking of models that predict the evolution of critical systems, including the effects on the surroundings. Coupled with knowledge of the transport of radionuclides within and from the vicinity of the disposal facility, these models (see Further Information) can be used to predict the consequences of a criticality.

More recently, further consequences of post-closure criticality work has sought to expand its coverage out to all of the higher activity wastes (i.e. not just ILW) in the three illustrative concept geologies (i.e. not just higher strength rock). Relevant reports are listed in Further Information.

This task has been developed to progress the recommendations of Task 131 (i.e. to address any identified knowledge gaps following the completion of a position paper titled 'Types of critical systems and the credibility of rapid transient criticality during post-closure')

**Research Need**

To support the packaging and safe disposal of fissile wastes by underpinning RWM's evolving post-closure criticality safety methodology (low likelihood and low consequences) that has recently concluded that a rapid transient criticality can be shown to be not credible within a UK GDF.

RWM is aware of previous international work and fundamental nuclear physics calculations (particularly considering highly enriched uranium systems/and or over moderated systems) that may challenge the above conclusion. A position paper will be produced that documents the credibility of post-closure rapid transient criticality.

**Research Objective**

The objective of this task is to address any outstanding research needs that are identified by RWMs position paper entitled 'Types of critical systems and the credibility of rapid transient criticality during post-closure' (i.e. Task 131).

**Scope**

The scope of this task will be defined following completion of Task 131.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Waste Package Disposability Assessments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>136</th>
<th>Status</th>
<th>Complete, pending publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Criticality Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Criticality Safety - Assessment of Consequences of Hypothetical Criticality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Update To The Post-Closure Criticality Consequence Assessment (PCCCA)

**Background**

This task is complete, but final reports are still in the peer review process. To date a generic post-closure criticality consequences assessment (PCCCA) has been conducted using calculations from the Understanding Criticality under Repository Conditions work programme. The consequences used as a baseline for estimates of risk are based on information produced in the 2003 generic Performance Assessment for ILW in a higher strength rock GDF. Criticality is treated as a variant scenario, to be considered in the context of existing detailed assessment of potential post-closure consequences already derived for a set of baseline scenarios. These baseline scenarios cover the gradual release of radionuclides from a GDF to the biosphere over timescales of up to one million years.

Recent work by RWM has demonstrated that, for any materials potentially requiring disposal, the likelihood and consequences of a criticality event over the next million years are very low for the full range of spent fuel, HLW, plutonium and highly-enriched uranium. This task will apply the recent results generated through the recent 'consequences' work package (and to a lesser extent the recent 'likelihood' work package) to expand the PCCCA out to all of the higher activity wastes disposed of in the three illustrative geologies. Furthermore, the PCCCA will also now include the expanded likelihood understanding.

**Research Need**

To support the environmental safety case by using the results from the consequences and likelihood of post-closure criticality projects to conduct a generic post-closure criticality consequence assessment.

**Research Objective**

To provide a post-closure criticality safety assessment for the generic designs of the GDF.

**Scope**

The results generated in the likelihood and consequences research contracts need to be jointly applied to demonstrate that criticality in a GDF following closure of the facility is not a significant concern, by showing that the impacts on pathways that give rise to risk in the post-closure safety assessment are negligible.

The scope will comprise work to assess the consequences of the impacts of a range of criticality events on the safety performance of a GDF. In particular, this task will use the new consequences and likelihood of post-closure criticality results to update the existing PCCCA, updating the ILW consequences results and adding in the new spent fuel, HLW, Pu and highly-enriched uranium results. The deliverable will be the safety arguments and calculations for use in an update to the generic environmental safety case and post-closure safety assessment that demonstrate that post-closure criticality is not a significant concern.

| SRL at task start | 4 | SRL at task end | 6 | Target SRL | 6 |
| End point | No Further Research Planned |
| Customer | Disposal System Safety Case, NDA Strategy |

**Further information**

Relevant publications include:


### Background

It is likely that a geological disposal facility will use a number of conventional materials for construction purposes including: concrete, shotcrete and grout, rock bolts and mesh amongst many others. The principal function of these materials is to stabilise the excavations and enable a safe working environment to be maintained during the construction and operational phases of a geological disposal facility. They are currently considered to be a permanent feature of a geological disposal facility and would remain after closure.

Currently, only limited consideration has been given to the composition and quantity of materials required in construction of a geological disposal facility. Although the exact compositions of materials can only be determined once site specific conditions are known, work can be carried out to increase RWM’s knowledge and to identify areas that may require site-specific development in the future.

RWM is currently undertaking a two year study to evaluate the composition of typical construction materials that could be used within a geological disposal facility to ensure that they are fit for purpose and will not prejudice other aspects of the disposal system. The temporal evolution of construction materials is being considered to determine impact on the evolution of the Engineered Barrier System (EBS) or the host rock after closure of a geological disposal facility and how these interactions could impact on the post-closure safety functions of the multi-barrier system. It is therefore important that the construction materials used within a geological disposal facility:

- Do not increase the migration of radionuclides from the EBS and through the geosphere to an unacceptable degree;
- Are sufficiently physically and chemically compatible with the components of an EBS that they do not adversely affect the performance of an EBS; and
- Are sufficiently physically and chemically compatible with the host geological formation for the required operational period of a geological disposal facility.

Any of the above possible impacts is not only determined by the composition of the construction materials but also by their volume and spatial distribution relative to waste packages, EBS components and the host rock. It is possible that they may complement those safety features afforded by the EBS and the host rock, or they could result in a negative impact.

### Research Need

Understand the impact of construction materials on the multi-barrier system, to meet the demands of the safety cases.

### Research Objective

To evaluate and demonstrate the feasibility of a number of different materials for construction purposes, which are suitable for application within a geological disposal facility and will not prejudice other aspects of the disposal system.

### Scope

The scope includes the following activities, including to:
- Review construction materials used and developed by other waste management organisations and analogous industries.
- Identify the range of construction materials that could be used within a geological disposal facility including their performance requirements to determine whether the materials considered are fit for purpose.
- Determine the feasibility of using the identified construction materials within a geological disposal facility.
- Develop our understanding of the long-term performance of the materials, and any potential impacts on the multi-barrier system.
- Identify future development needs of material specifications for construction materials. Formulation development may need to be undertaken and will require an appropriate testing programme.
- Demonstrate the effectiveness of application under conditions that replicate geological disposal facility
<table>
<thead>
<tr>
<th>Conditions.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>TRL 2</th>
<th>SRL at task end</th>
<th>TRL7</th>
<th>Target SRL</th>
<th>TRL7</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**


Watching Brief on Technology and Techniques for Safeguards Verification

Background
Nuclear safeguards are measures to verify that countries comply with their international obligations to use nuclear materials (plutonium, uranium and thorium) from their civil nuclear programmes for peaceful uses. These measures will apply to the disposal of safeguarded material within a geological disposal facility.

Work is continuing internationally on the application of safeguards to GDFs. As in other areas of safeguards, the technology and techniques that are used to verify the contents of waste packages, the as-built condition of facilities and to detect attempted diversion are subject to continued development.

Research Need
To maintain and develop understanding of technology and techniques for the application of nuclear safeguards to geological disposal facilities with input of this knowledge and understanding into:
- The development of RWM's approach to safeguards and discussions with key stakeholders.
- Application of knowledge to inform the design, operation and closure of a GDF.

Research Objective
To ensure that techniques and technology are available for the efficient application of nuclear safeguards to the design, operation and closure of a geological disposal facility.

Scope
To maintain an understanding of available data acquisition techniques through liaison with Office for Nuclear Regulation Safeguards, Euratom, overseas sister organisations and involvement in international fora such as the International Atomic Energy Agency expert group on the Application of Safeguards to Geological Repositories (ASTOR).

Relevant publications include:
Develop and Maintain the Disposal Container Designs

Background

RWM develops and maintains a range of disposal container designs to demonstrate the feasibility of disposal of spent fuel, high level waste, high enriched uranium and separated plutonium in a range of geological environments.

Two variants of disposal container have been developed:
- The variant one disposal container is a copper disposal container with a cast iron structural insert based on the SKB / Posiva spent fuel disposal concept. The content of a variant one disposal container is located in lodgements cast into the insert.
- The variant two disposal container is a steel disposal container based on the Nagra spent fuel disposal concept. The contents of a variant two disposal container are located in a carbon steel tube, rod and plate basket assembly.

The disposal container designs have a common diameter and lifting features, but have varying lengths depending on their contents.

In addition, RWM considers the development of other concept designs for the disposal of spent fuel. For instance, the development of multi-purpose containers.

Research Need

Develop and maintain disposal container designs to demonstrate that spent fuel, high level waste, highly enriched uranium and separated plutonium can safely be disposed of in a geological disposal facility.

Research Objective

To provide continued confidence in container designs for the disposal of spent fuel, high level waste, high enriched uranium and separated plutonium in a geological disposal facility.

Scope

The task scope is kept under review and evolves in response to needs identified from; the iterative design process and safety integrated design, peer review, regulatory scrutiny, decisions regarding the type of new nuclear build reactor types to be used in the UK, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon.

The task comprises a series of work packages, including to:
- Demonstrate that the disposal container designs can accommodate additional materials identified in the 2013 Derived Inventory (that is spent fuel from possible new nuclear build reactors, mixed oxide spent fuel, Magnox spent fuel and Prototype Fast Reactor spent fuel).
- Design a disposal container for spent fuel from Advanced Boiling Water Reactors.

These work packages will comprise desk based studies, often supported by computational studies. In limited circumstances prototype manufacture and testing may be required to underpin the technical readiness level. The output of the work packages feeds into update of the generic disposal facility designs.

Further information

Title
Geological Disposal Facility (GDF) investigations and construction

Background
At the current generic phase of work RWM has developed illustrative engineering designs for a GDF based on mature, overseas disposal concepts. These designs enable planning and also demonstrate the feasibility to construct, operate and maintain a GDF within three generic geological environments, namely: higher strength rock, lower strength sedimentary rock and evaporite. At present we consider the use of construction methods and materials that have been used in the overseas disposal concepts.

There is also a need to understand the investigations that will be required to support development of a GDF. At this generic phase we have identified some of the investigations that would need to be undertaken during siting, construction and operation. It is necessary to explore the range of investigation methods available and the data that can be collected, and to ensure that the data collected are appropriate to support the design process.

Research Need
Understand the range of investigations required to support development of a geological disposal facility and demonstrate that it is both feasible and safe to construct using available methods, technologies and materials.

Research Objective
To provide continued confidence in the feasibility to conduct investigations for, to construct and to maintain a geological disposal facility.

Scope
The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon.

The task comprises a series of work packages to satisfy the objectives, including to:

- Consider the range and timing of investigations that will need to be undertaken to support the development of a geological disposal facility and associated facilities. This will respond to the requirements derived from Task 494. This task would include identifying the investigations that will need to be undertaken during the siting process to enable designs to become tailored to the geology of a specific site.

- Evaluate construction methods that could be used in development of a geological disposal facility, including consideration of new and emerging technologies that could be used to support development of a geological disposal facility (e.g. new hard-rock tunnel boring machines, wire-cutting etc.).

- Consider the properties of the host geological environment and identify the possible impacts on excavations and the associated rock support system, in preparation for site-specific work. This objective is linked to Task 167.

- Review the implications of an extended operational period on a geological disposal facility. Consider the examination, inspection, maintenance and testing needed to demonstrate that a geological disposal facility fulfills its safety functions.

These work packages will comprise desk-based studies, often supported by computational studies. The output of the work packages feeds into update of the generic disposal facility designs.

Further information
### Background

At the current generic phase of work RWM has developed illustrative engineering designs for a GDF based on mature, overseas disposal concepts. These designs enable planning and also demonstrate the feasibility to construct, operate and maintain a geological disposal facility within three typical UK geological environments, namely; higher strength rock, lower strength sedimentary rock and evaporite.

The current illustrative designs and operational programme are underpinned by a number of assumptions regarding the throughput and emplacement rates for different waste types. For our illustrative designs, these rates are currently consistent with the assumptions used in the overseas disposal concepts, upon which the illustrative designs are based. These activities are on the critical path for the emplacement of waste packages. The drift capacity is assumed to be up to 3,900 journeys a year and this is assumed to be the same for the waste emplacement shaft in an evaporite rock. These rates have been underpinned in previous studies and are consistent across all three host geological environments but it is necessary to explore the range of assumptions underpinning these rates to ensure that they remain appropriate.

### Research Need

Understand the package handling and throughput capacity, including any associated activities, for a geological disposal facility in different host geological environments and understand the impacts on the operational programme.

### Research Objective

To provide continued confidence in the feasibility to operate and maintain a geological disposal facility.

### Scope

The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon.

The task comprises a series of work packages, including to:

- Review the drift throughput in terms of total waste packages, personnel and materials required and identify any issues with capacity and the differences in terms of using a waste emplacement shaft rather than a drift (as currently assumed in the evaporite illustrative design).

- Review the unshielded intermediate level waste inlet cell design and throughput for the safe unloading and processing for different waste package types and in the different host geological environments.

- Review the throughput for the safe unloading and processing of packages in the vault reception area and identify any additional issues relating to different waste package types.

- Review the disposal rate of 200 disposal containers a year for each of the three host geological environments to provide confidence in adopting this rate for different host geological environments considering the different emplacement approaches.

- Consider the examination, inspection, maintenance and testing needed to demonstrate that the package handling and transfer systems fulfill their safety functions.

These work packages will comprise desk based studies, often supported by computational studies. The output of the work packages feeds into update of the generic disposal facility designs.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>TRL 4</th>
<th>SRL at task end</th>
<th>TRL 6</th>
<th>Target SRL</th>
<th>TRL 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Watching Brief</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Design</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Disposal System Facility Designs</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Geological Disposal Facility (GDF) Disposal Vault and Tunnel Design

**Background**
At the current generic phase of work, RWM has developed illustrative engineering designs for a geological disposal facility and its key elements and facilities based on mature, overseas disposal concepts. These illustrative designs demonstrate that it is feasible and safe to handle and emplace waste packages within underground excavations using currently available technologies, and then backfill, seal and close the disposal vault or tunnel.

Enhancements may be made to the existing illustrative designs for geological disposal facility disposal vaults and tunnels to improve operational safety and reduce risk. It may be necessary to undertake studies to evaluate various aspects of the existing designs including; waste package handling and emplacement systems, remote operation and monitoring equipment, and backfilling approach, amongst others.

**Research Need**
Develop engineering designs of disposal vaults and tunnels suitable for disposal of various radioactive wastes and package types.

**Research Objective**
To provide continued confidence in the feasibility to construct, operate, maintain, backfill and close disposal vaults and tunnels.

**Scope**
The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon.

The task comprises a series of work packages, including to:
- Review and enhance existing disposal vault and tunnel designs (e.g. floor slab design underlain by peripheral NRVB in higher strength rock).
- Evaluate the handling and emplacement technologies including evaluating the use of new technologies that have been developed for analogous industries/environments.
- Enhance the understanding of the backfill requirements including identifying the requirements for minimising voidage (e.g. the need for backfilling of the crown space in disposal vaults), the use of Magnesium Oxide for chemical conditioning in the evaporite concept and also determining appropriate backfill ratios within disposal vaults and tunnels.
- Evaluate the backfill materials assumed for use in the existing disposal concepts to demonstrate feasibility (e.g. constructing bentonite blocks and rings) as well as considering materials not currently considered in the illustrative designs.
- Further development of the backfill emplacement processes for the existing illustrative designs to demonstrate feasibility. This would include determining the time required to undertake backfilling processes and reviewing the assumption that one backfill gallery is required for every two disposal vaults in higher strength rock.
- Review backfill timings and implications on reversibility within the context of the geological disposal facility system and the potential implications on safety during operations and post-closure.
- Assess the thermal impact on systems within a geological disposal facility (e.g. handling and monitoring equipment).
- Extend the Process Flow Diagram to include the processes required for backfilling, decommissioning, sealing and closure of disposal areas.
- Consider the examination, inspection, maintainence and testing needed to demonstrate that the vaults and tunnels fulfill their safety functions.
- Extend the Process Flow Diagram to include maintenance operations required (e.g. rock support in...
roadways, and then in disposal areas filled with waste) and the process for recovery of a GDF if a fault occurred.

These work packages will comprise desk based studies, often supported by computational studies. The output of the work packages feeds into update of the generic disposal facility designs.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>TRL 4</th>
<th>SRL at task end</th>
<th>TRL 6</th>
<th>Target SRL</th>
<th>TRL 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Watching Brief</td>
<td>Customer</td>
<td>Design</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

Geological Disposal Facility (GDF) utilities and services

Background
At the current generic phase of work RWM has developed illustrative engineering designs for a geological disposal facility and its key elements and facilities based on mature, overseas disposal concepts. These designs enable planning and also demonstrate the feasibility to construct, operate and maintain a geological disposal facility within three typical UK geological environments, namely; higher strength rock, lower strength sedimentary rock and evaporite. At present, in our illustrative designs we consider the use of typical utilities and services that have been used in the overseas disposal concepts and other similar non-nuclear facilities.

Research Need
Understand the utilities and services for a geological disposal facility in different host geological environments.

Research Objective
To provide continued confidence in the feasibility to construct, operate and maintain the utilities and services for a geological disposal facility.

Scope
The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon.

The task comprises a series of work packages, including to:
- Evaluate the use of new/novel transfer systems, for the movement of goods that could be modified for use at a geological disposal facility to transport construction materials to a geological disposal facility and to export excavated spoil out of a geological disposal facility.
- Demonstrate the feasibility of the nuclear ventilation system required for the waste emplacement ventilation circuit, noting the requirements to manage gas and temperature, fire suppression systems, security and safe operations.
- Assess how the volumes of water that could arise from both the host rock and from construction and operation activities could be managed and treated. This objective is linked to Task 164.
- Produce an integrated waste strategy for the geological disposal facility and identify how secondary wastes (including both nuclear and non-nuclear) should be managed.
- Consider the examination, inspection, maintenance and testing needed to demonstrate that the utilities and services fulfill their safety functions.

These work packages will comprise desk based studies, often supported by calculation studies. The output of the work packages feeds into update of the generic disposal facility designs.

SRL at task start | TRL 4 | SRL at task end | TRL 5 | Target SRL | TRL 5
--- | --- | --- | --- | --- | ---
End point | Watching Brief | 
Customer | Design | 

Further information
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Design</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Disposal System Facility Designs</td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>Geological Disposal Facility (GDF) Sealing and Closure</td>
<td></td>
</tr>
</tbody>
</table>

**Background**

At the current generic phase of work RWM has developed illustrative engineering designs for a geological disposal facility and its key elements and facilities based on mature, overseas disposal concepts. These designs enable planning and also demonstrate the feasibility to construct, operate and maintain a geological disposal facility within three typical UK geological environments, namely; higher strength rock, lower strength sedimentary rock and evaporite. At present we consider the use of typical sealing and backfilling approaches in our illustrative designs that have also been used in the overseas disposal concepts.

The current geological disposal facility illustrative designs assume a 10 year closure phase once all waste has been emplaced for all three host geological environments. During this closure phase, disposal vaults (depending upon the host geology) and roadways are backfilled and all surface facilities dismantled and decommissioned.

**Research Need**

Understand the sealing and closure activities for a geological disposal facility in different host geological environments.

**Research Objective**

To provide continued confidence in the feasibility to decommission and close a geological disposal facility.

**Scope**

The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements, learning from external events or changes to the overseas disposal concepts that the designs are based upon.

The task comprises a series of work packages:

- Review the logistics and activities for sealing and closure activities for all three host geological environments to identify potential changes to the programme duration currently assumed, this could include backfilling disposal vaults and tunnels and decommissioning buildings prior to the closure period.
- Assess the mass backfill material types for the different illustrative designs and how emplacement technologies and requirements on the post-closure performance affects duration and the ease of implementation.
- Identify how dismantling and decommissioning of the surface facilities would be undertaken, the timings and the process for how any secondary wastes could be managed.
- Identify the types of materials and equipment that could be left in-situ within a geological disposal facility once closed.
- Participate in the European Full-Scale Demonstration of Plugs and Seals (DOPAS) project and identify lessons learnt that could be incorporated in to the UK programme.

These work packages will comprise desk based studies, often supported by computational studies. The output of the work packages feeds into update of the generic disposal facility designs.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>TRL 3</th>
<th>SRL at task end</th>
<th>TRL 5</th>
<th>Target SRL</th>
<th>TRL 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Watching Brief</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Design</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Disposal System Facility Design</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Technology and Techniques for Nuclear Security

**Background**

The Conceptual Security Arrangements (CSA) have been developed and address the relevant security objectives, National Objectives, Requirements and Model Standards (NORMS), that are applicable to all three generic illustrative designs for a geological disposal facility. It follows that the designs will be further affected by site-specific considerations.

The Conceptual Security Arrangements (CSA) inform the development and production of the site layouts that will form part of the Construction Site Security Plan (CSSP) and later the Nuclear Site Security Plan (NSSP) for a geological disposal facility that will require regulatory approval. These plans should detail all aspects of the integrated security system throughout the site that provides security measures to counter threats.

The different waste types to be transported and disposed of in a geological disposal facility could range from Category I to Category IV materials for physical protection purposes to prevent theft. There will also be a requirement to carry out a process known as Vital Area Identification to determine if an act of sabotage against specific equipment, systems or devices comprising part of the site’s infrastructure could potentially create a radiological hazard to the public and/or the environment.

Work will continue to apply nuclear security to the geological disposal facility. As in other areas of geological disposal facility development, the technology and techniques used to verify the contents of waste packages, the as built condition of facilities, the transport systems and potential security threats will be used to maintain the CSA.

**Research Need**

Maintain and develop an understanding of the technology and techniques for the application of nuclear security to the transport system and the geological disposal facility.

**Research Objective**

To ensure that techniques and technology are available for the efficient application of nuclear security to the design, operation and closure of a geological disposal facility with input of this knowledge and understanding into:

- The development of RWM’s approach to nuclear security and discussions with key stakeholders.
- Application of knowledge to inform the design, operation and closure of a geological disposal facility, including the:
  - Transport system.
  - Surface facilities and above-ground areas.
  - Tunnels or shafts leading to the underground operational areas and disposal vaults and tunnels (both during construction and during operational use).
  - Underground operational areas and disposal vaults and tunnels.

**Scope**

To maintain an understanding of available data acquisition techniques through liaison with waste packaging and storage organisations for nuclear material that is packaged for transport and disposal in a GDF.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Watching brief
Customer: Design

**Further information**

During 2002 to 2005, Nirex updated the 1993 security plan for the ‘Phased Geological Repository Concept’ (PGRC) for ILW/LLW disposal and to align with the Nuclear Industry Security Regulations (2003) Technical Requirements Document, which set out prescriptively what duty-holders should do to ensure security standards are met and maintained. To supplement this, Nirex produced a ‘Reference repository concept for UK HLW/SF security plan’ in 2007 for a standalone HLW/SF repository and also to (a) consider the impact
of including Pu and (b) co-locating HLW/SF with the PGRC. The 2005 PGRC security plan assumed the GDF would be a Category III facility. The 2007 plan assumed that a GDF would be upgraded to become a Category II facility before receipt of HLW/SF and would be further upgraded to become a Category I before receipt of Pu/HEU.

In 2010 the illustrative designs were produced for all UK higher activity wastes which assumed the same nuclear material categorisations; i.e. a GDF would be a Category III facility until upgrading to Category II before receipt of HLW/SF in 2075 and Category I before receipt of Pu/HEU. In 2012, ONR issued new security guidance, ‘National Objectives, Requirements and Model Standards’ or ‘NORMS’. The generic security plan, which is titled ‘Conceptual Security Arrangements for a Geological Disposal Facility’ (or ‘CSA’) is an update of the 2005 generic security plan to include all UK higher activity wastes and compliance with the NORMS guidance.

Relevant publications include: National Objectives, Requirements and Model Standards (NORMS) for the Protective Security of Civil Licensed Nuclear Sites, Other Nuclear Premises and Nuclear Material in Transit, Office for Nuclear Regulation, Civil Nuclear Security, Issue 1, October 2012.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Design</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Transport System Designs</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Develop and Maintain Transport Container Designs

**Background**

RWM develops and maintains a range of transport container designs to demonstrate that higher activity radioactive wastes can be safely packaged, transported and disposed of in a geological disposal facility. Included in that range is the Standard Waste Transport Container (SWTC) and Disposal Container Transport Container (DCTC) and Transport Overpack designs as described below.

The SWTC family is intended for the transport of Intermediate Level Wastes as Type B fissile transport packages. The SWTC family are cuboidal packages with a steel flask body and bolted steel lid. The family includes three shielding thickness variants, the SWTC-70, SWTC-150 and SWTC-285, incorporating 70, 150 and 285 mm of steel shielding, respectively.

The DCTC designs are developed to demonstrate the feasibility of transporting a disposal container containing spent fuel, high level waste, highly enriched uranium or separated plutonium. The DCTC designs are composed of a steel flask body, a bayonet content retention system, a bolted steel lid, neutron shielding and wood impact limiters.

A transport overpack design based upon a 6 metre ISO freight container is proposed to transport a range of ILW packages, including the concrete drums and the robust shielded waste packages introduced in the 2013 Derived Inventory. These waste packages types may be transported as an Industrial Package Type 2 transport package in their own right, but require an overpack to facilitate handling.

In addition, RWM considers the development of other transport container designs to support other concept options for the transport and disposal of higher activity radioactive wastes.

**Research Need**

Develop and maintain a range of transport container designs to demonstrate that higher activity wastes can safely be transported to a geological disposal facility.

**Research Objective**

To provide continued confidence that higher activity waste can be safely transported to a geological disposal facility.

**Scope**

The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements or learning from external events.

The task comprises a series of work packages, including to:

- Review and update the user and detailed requirements for the SWTC family of transport containers and review the technical readiness levels of the existing SWTC design variants against those requirements.
- Develop a SWTC-150 variant to demonstrate that it can safely transport a 500 litre robust shielded drum.
- Develop the DCTC design to demonstrate that it can be safely used to transport additional materials identified in the 2013 Derived Inventory (that is spent fuel from possible new nuclear build reactors, mixed oxide spent fuel, Magnox spent fuel and Prototype Fast Reactor spent fuel).
- Develop the concept designs for a transport overpack for concrete drums and robust shielded waste packages.
- Develop a new transport and disposal overpack design as a potential concept option for the disposal of depleted, natural and low enriched uranium.

These work packages will comprise desk-based studies, often supported by computational studies. In limited circumstances prototype manufacture and testing may be required to underpin the technical readiness level. The output of the work packages feeds into update of the generic transport system designs.

<p>| SRL at task start | TRL 3-5 | SRL at task end | TRL 5 | Target SRL | TRL 5 |</p>
<table>
<thead>
<tr>
<th>End point</th>
<th>Watching Brief</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>Design</td>
</tr>
</tbody>
</table>

Further information

Title
Transport Infrastructure Constraints on the Geological Disposal System

Background
The disposal of higher activity waste in a geological disposal facility will require transport of radioactive waste from sites of interim storage to a geological disposal facility. In addition, construction of a geological disposal facility will require transport of construction materials to the site of a geological disposal facility and transport of spoil away from a geological disposal facility. At this generic stage in development of a geological disposal facility it is assumed that transport could be by road, rail or sea.

The existing UK transport infrastructure, particularly the road and rail infrastructure, will impose constraints on the vehicles used to transport materials to and from a geological disposal facility, for example, limits on the maximum mass or the maximum dimensions of road or rail vehicles. In turn, these infrastructure constraints indirectly impose limits on the radioactive waste transport packages used to transport waste to a geological disposal facility, for instance, on the maximum mass or maximum dimensions.

RWM develops and maintains designs of road vehicles and rail wagons for the transport of higher activity waste to a geological disposal facility in order to determine any constraints imposed on radioactive waste transport packages.

Research Need
Maintain an understanding of the constraints of the UK transport infrastructure on the geological disposal system.

Research Objective
To provide continued confidence that higher activity waste, construction materials and spoil can be transported to and from a geological disposal facility.

Scope
The task scope is kept under review and evolves in response to needs identified from the iterative design process and safety integrated design, peer review, regulatory scrutiny, feedback from stakeholders, maturity analysis of the designs, identification of new and emerging technologies, change management of the designs, changes to regulatory requirements or learning from external events.

The task comprises a series of work packages, including to:
- Develop an updated design for a rail wagon for the transport of radioactive waste transport packages on the UK rail network.
- Maintain road vehicle designs to current regulatory requirements and technologies.
- Maintain a watching brief on sea transportation systems.

These work packages will comprise desk-based studies, often supported by computational studies. The output of the work packages feeds into update of the generic transport system designs.

Further information
Maintain Up-to-date Cost Estimates for the Geological Disposal Facility Programme

**Background**
RWM is required to calculate the lifetime cost of the geological disposal facility for internal budgeting purposes and to support Government in determining the waste transfer price for new nuclear power station operators.

**Research Need**
Maintain an understanding of latest cost estimation tools and techniques.

**Research Objective**
To ensure that fit-for-purpose techniques are used in calculating geological disposal facility cost estimates.

**Scope**
Maintain an understanding of cost estimation tools and techniques that are applicable to geological disposal facility cost estimation.
Liaise with overseas sister organisations on cost estimation approaches, standards and data, for example the International Association for Environmentally Safe Disposal of Radioactive Materials (EDRAM) cost estimation working group.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Models</td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Design</td>
<td></td>
</tr>
</tbody>
</table>
### Title
EC CAST: WP2 Measurement of the C-14 Release Rate and Speciation from Irradiated Steels (Stainless, Mild and Inconel) in a Range of Aqueous Conditions

### Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an integrated project team to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST (Carbon-14 Source Term), which includes experimental programmes, which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

After graphite, steels provide the largest inventory of C-14 associated with irradiated material in ILW. Recent work has shown that a better understanding of the speciation and rate of corrosion could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. The impact of these wastes will be highly site-specific and one of the aims of the integrated project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely. As there is little information on the form of C-14 released from irradiated steels an improved understanding of the rate and speciation of C-14 associated releases would enable us to better parameterise assessment models.

### Research Need
To support the development of the Transport, Operational and Environmental Safety Cases by developing an appropriate strategy.

### Research Objective
- To determine whether the speciation and rate of C-14 release from irradiated steels can be determined accurately and used as a basis for better parameterised assessment models.
- To determine whether C-14 is released from irradiated stainless steel under high pH conditions at a rate that challenges the post-closure risk guidance level.

### Scope
EC CAST contains a work package that will provide an up-to-date review of the release of carbon and C-14 from steels by corrosion (in particular it will seek to draw together all the knowledge on this topic held by contributors to CAST), followed by a detailed experimental programme addressing knowledge gaps in the data for rate and speciation of the release of C-14 from irradiated stainless steels.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Disposal System Safety Case, Assessment of Packaging Solutions

Further information

Relevant publications include:
- S.W. Swanton et al, 2015, Rates of Steel Corrosion and Carbon-14 Release from Irradiated Steels – State of the Art Review (D2.1), EC CAST. Available at www.projectcast.eu/cms-file/get/iFileId/2501
## Task: Manufacture and Commission Experimental Rig for CAST Stainless Steel Experiments

### Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the experimental design and commissioning of apparatus capable of resolving this uncertainty.

### Research Need

To support the development of the operational and environmental safety cases by gaining an appropriate understanding of the rate and speciation of C-14 release from irradiated stainless steels.

### Research Objective

- To determine whether the speciation and rate of C-14 release from irradiated steels can be determined accurately and used as a basis for better parameterised assessment models.
- To determine whether C-14 is released from irradiated stainless steel under high pH conditions at a rate that challenges the post closure risk guidance level of 10^-6 y^-1.

### Scope

To develop and commission an apparatus for the measurement of the rate of gaseous C-14 release from the corrosion of irradiated steels samples in experiments within a shielded-cell facility that has the ability to differentiate 14CO2, 14CO and 14C-hydrocarbon / organic gaseous species.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Disposal System Safety Case, Assessment of Packaging Solutions

### Further Information

Relevant publications include:
### Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes, which will fill knowledge gaps in data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Work has shown that better understanding could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. The impact of these wastes will be highly site-specific and one of the aims of the integrated project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely.

### Research Need
To support the development of the transport, operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 release from irradiated stainless steels.

### Research Objective
To determine whether, by integrating an improved understanding of the inventory with consideration of corrosion rates and speciation of C-14 release from irradiated stainless steels, it will be possible to demonstrate a reduction in the calculated risk.

### Scope
To update the model of carbon-14 release from irradiated stainless steel, using improved inventory data and consideration of corrosion rates and speciation of C-14 release.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
</table>

### End point
Feeds into Task 213

### Customer
Disposal System Safety Case, Assessment of Packaging Solutions

### Further information
Relevant publications include:

www.projectcast.eu
Appendix B - 78

Title
C-14 IPT: Measurement of C-14 Release from Irradiated Reactive Metals (Magnox and Aluminium) to the Gas Phase

Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an integrated project team to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST (CArbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

After graphite and steels, reactive metals provide the largest inventory of C-14 associated with irradiated material in ILW.

Recent work has shown that a better understanding of the speciation and rate of corrosion could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. The impact of these wastes will be highly site-specific and one of the aims of the integrated project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely. As there is little information on the form of C-14 released from irradiated steels an improved understanding of the rate and speciation of C-14 associated releases would enable us to better parameterise assessment models.

Research Need
To support the development of the transport, operational and environmental safety cases by developing an appropriate understanding of the release and speciation of C-14 from the corrosion of reactive metals.

Research Objective
To measure the speciation and rate of C-14 release from reactive metals to the gas and solution phase, for use as a basis for better parameterised assessment models.

Scope
To undertake experiments to measure gaseous and dissolved C-14 releases from irradiated reactive metals: Magnox and aluminium.

The scope may be expanded to include measurements at higher chloride concentrations if required.

SRL at task start | 2 | SRL at task end | 4 | Target SRL | 5
End point: No Further Research Planned
Customer: Disposal System Safety Case, Assessment of Packaging Solutions

Further information
There are currently no published data on C-14 releases from the corrosion of reactive metals to either gas or solution phase.

Relevant publications include:
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes, which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Recent work has shown that a better understanding of the speciation and rate of corrosion of irradiated reactive metals could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through treatment, packaging or design options. As there has in the past been little information on the form of C-14 released from reactive metals an updated model of the rate and speciation of C-14 associated releases is required.

Research Need
To support the development of the transport, operational and environmental safety cases by developing an appropriate model of the release of C-14 from the corrosion of reactive metals. In particular, there is a need to understand the uncertainties around the timing of the peak risk and to consider whether this can be mitigated using alternative treatment, packaging or design options.

Research Objective
- To determine whether by integrating an improved understanding of the inventory with data on the speciation of releases from irradiated reactive metals, together with consideration of package-scale effects, it will be possible to develop an improved understanding of the rate and timing of the release of gaseous C-14 from reactive metals that leads to a decrease in the calculated risk.
- To determine whether, if required, the peak risk associated with the release of C-14 from reactive metals in the early post closure period can be mitigated using bespoke treatment, packaging and emplacement solutions.

Scope
To undertake a study, informed by experiments and package scale modelling, to develop understanding of the likely timing and rate of release of C-14 and incorporate this understanding into a new model. This will include the impact of water and chloride availability. The benefits of selective treatments for reactive metals, including dissolution, bespoke packaging arrangements, gradual backfilling, etc. will be considered as a means of mitigating potentially high peak risk.

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>206</td>
<td>Ongoing</td>
<td>Gas Pathway</td>
<td>C-14 Release from Irradiated Metals</td>
</tr>
</tbody>
</table>

**Title**

EC CAST: WP3 Measurement of the C-14 Release Rate and Speciation from Irradiated Zircaloy in a Range of Aqueous Conditions

**Background**

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes, which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. Ziracaloy, the clad for PWR fuel, is a minor C-14 bearing waste stream resulting from the reprocessing of overseas fuels at Sellafield. This task comprises an experimental investigation of the rate and speciation of C-14 release from the corrosion of Ziracaloy in the post-closure GDF.

**Research Need**

To support the development of the operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 releases from Zircaloy.

**Research Objective**

To understand whether the speciation and rate of C-14 release from irradiated Ziracaloys (Zr) can be determined accurately and be used as a basis for better parameterised assessment models.

**Scope**

The scope comprises the following:
- To review the current status of knowledge of C-14 release from Zircaloy wastes. This will consider the origins and inventories of C-14 in hulls (from measurement and calculation), Zr corrosion rates, Zr oxide-layer dissolution rates and C-14 release mechanisms and speciation under disposal conditions.
- To develop analytical methodologies to determine the forms of released C-14 (organic / inorganic, partitioned in the solution and gaseous phases).
- To undertake leaching of Zr wastes under a range of conditions to determine the released C-14 chemical forms and to measure the rates of release.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions

**Further information**

This task forms part of the CAST project (Work Package 3, which has no direct UK involvement), which is an international collaboration co-funded by the European Commission.

Relevant publications include:

www.projectcast.eu

Task Number 207
Status Start date in future
PBS level 4 Gas Pathway
PBS level 5 C-14 Release from Irradiated Metals
Title
EC CAST WP2 (UK Component): C-14 Release and Speciation from 316N (High Nitrogen) Stainless Steel Under pH12 Conditions

Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task follows on from Task 202 (the experimental design and commissioning of apparatus capable of resolving this uncertainty) by conducting these measurements.

Research Need
To support the development of the operational and environmental safety cases by gaining an appropriate understanding of the rate and speciation of C-14 release from irradiated stainless steels.

Research Objective
To determine whether the speciation and rate of C-14 release from irradiated steels can be determined accurately and used as a basis for better parameterised assessment models.

To determine whether C-14 is released from irradiated stainless steel under high pH conditions at a rate that challenges the post closure risk guidance level of 10^-6 y^-1.

Scope
To measure the rate of gaseous C-14 release from the corrosion of irradiated stainless steel samples in alkaline solution and to understand the distribution between 14CO2, 14CO and 14C-hydrocarbon / organic gaseous and C-14 aqueous species.

SRL at task start 3
SRL at task end 4
Target SRL 5
End point No Further Research Planned
Customer Disposal System Safety Case, Assessment of Packaging Solutions

Further information
Relevant publications include:
www.projectcast.eu

This is an ongoing task procured through our supply chain under the rules of the EC 7th Framework.
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer-term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the interpretation of data obtained from Task 204 on the rate and speciation of reactive metal (Magnox and aluminium) corrosion and release to the gas phase.

**Research Need**

To support the development of the operational and environmental safety cases and disposal concept development by gaining an appropriate understanding of the rate and speciation of C-14 releases from intermediate level wastes containing irradiated Magnox and aluminium.

**Research Objective**

To develop an improved understanding of the rate, speciation and timing of the release of gaseous C-14 from reactive irradiated metals, together with consideration of package-scale effects, in order to determine whether the calculated post-closure risk is reduced.

**Scope**

The scope comprises a desk-based and modelling study updating our understanding of the likely timing, rate of release and speciation of C-14 to the gas phase using the output from Task 204.

**Further information**

This task will be procured through our supply chain or undertaken with internal resources.

Relevant publications / sources of further information:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>209</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Pathway</td>
<td>C-14 Release from Irradiated Metals</td>
</tr>
</tbody>
</table>

**Title**

C-14 IPT: Experimental Study on Rate and Speciation of C-14 Release to the Gas Phase from Irradiated Uranium

**Background**

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer-term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the measurement of the rate and speciation of C-14 released to the aqueous and gaseous phases by irradiated uranium (a reactive metal) due to its corrosion upon GDF resaturation.

**Research Need**

To support the development of the operational and environmental safety cases and disposal concept development by developing an appropriate understanding of the rate and speciation of C-14 releases from irradiated uranium.

**Research Objective**

To measure the rate and speciation of C-14 release from irradiated uranium to the gas and solution phase, for use as a basis for better parameterised assessment models.

**Scope**

To measure the rate of gaseous C-14 release from the corrosion of irradiated stainless steel samples in alkaline solution and to understand the distribution between $^{14}$CO$_2$, $^{14}$CO and $^{14}$C-hydrocarbon / organic gaseous and C-14 aqueous species.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions

**Further information**

The need for this study will depend on the outcome of the C14 IPT.

There are currently no published data on C-14 releases from the corrosion of irradiated uranium to either gas or solution phase.

Relevant publications / sources of further information:

Synthesis of Recent EPSRC and EC CAST Outputs in UK Context

Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer-term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the synthesis of separate research programmes funded by the EPSRC and the EC with the objective of improving our understanding of the release and speciation of C-14 from the ILW inventory. The outputs may enable a revision to our safety case and/or facilitate the design of improved packaging and disposal concepts.

Research Need

To support the development of the operational and environmental safety cases and disposal concept development by gaining an appropriate understanding of the rate and speciation of C-14 releases from intermediate level wastes.

Research Objective

To understand the final output from the EC-funded CAST project and the EPSRC-funded C14-BIG project in the UK context.

Scope

To summarise the results from CAST on C-14 release from steels, zirconium alloys, ion-exchange resins and graphite and results from C14-BIG for C-14 behaviour in irradiated graphite in the context of RWM’s operational and post-closure safety cases. Areas requiring updating in our safety cases and any further work required will be identified.

SRL at task start 4  SRL at task end 4  Target SRL 5

End point No Further Research Planned

Customer Disposal System Safety Case, Assessment of Packaging Solutions

Further information

Relevant publications include:
www.projectcast.eu
www.hud.ac.uk/c14-big/
## Task Number

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>211</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Gas Pathway</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>C-14 Release from Irradiated Metals</td>
</tr>
</tbody>
</table>

## Title

Update Task with New Understanding of C-14 Release from Irradiated Uranium

## Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14-bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer-term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task follows the experimental measurement of the rate and speciation of C-14 released to the aqueous and gaseous phases by the reactive metal uranium upon its corrosion following resaturation (Task 209). It integrates these new data with our existing parametric models and understanding of the package scale evolution of C-14 bearing gases.

## Research Need

To support the development of the operational and environmental safety cases and disposal concept development by developing an appropriate understanding of the rate and speciation of C-14 releases from irradiated uranium.

## Research Objective

To develop an improved understanding of the rate, speciation and timing of the release of gaseous C-14 from irradiated uranium based on new data (Task 209), together with consideration of package-scale effects, in order to determine whether the calculated post-closure risk is reduced.

## Scope

The scope comprises a desk-based and modelling study updating our understanding of the likely timing, rate of release and speciation of C-14 to the gas phase using the output from Task 209.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

## End point

No Further Research Planned

## Customer

Disposal System Safety Case, Assessment of Packaging Solutions

## Further information

Relevant publications include:

Appendix B - 86

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>C-14 Release from Irradiated Metals</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Mechanistic Study on C-14 Release and Speciation from Zircaloy (if shown from EC CAST to be of Safety Case Significance)

**Background**
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. Ziracaloy, the clad for PWR fuel, is a minor C-14 bearing waste stream resulting from the reprocessing of overseas fuels at Sellafield. CAST will have provided information on the speciation and rate of release of C-14 from irradiated Zircaloys relevant to overseas WMOs (Task 206) and this task comprises any further work required in the UK context.

**Research Need**
To support the development of the operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 releases from Zircaloy.

**Research Objective**
To better understand the speciation and rate of C-14 release from irradiated Zircaloys relevant to UK ILW under conditions appropriate to UK disposal concepts as a basis for better parameterised process and assessment models.

**Scope**
The need and scope of this experimental and / or modelling study will be defined by Task 210 ('Synthesis of recent EPSRC and EC CAST outputs in UK Context'), following the completion of the EC CAST WP3 project (Task 206).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Further Work to be Defined (Aqueous)
No Further Research Planned (Gas-Pathway)

**Customer**
Disposal System Safety Case, Assessment of Packaging Solutions

**Further information**
The outcome is likely to be that at the end of this task no further work will be required with respect to the gas pathway. Work related to the aqueous pathway might continue under site-specific conditions and would thus form part of the radionuclide behaviour research programme.

Relevant publications include:
www.projectcast.eu
Further Update Model of C-14 Release from Irradiated Stainless Steel

Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC funded project, CAST, which includes experimental programmes which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the incorporation of data and understanding gained from Tasks 203 and 210 in our model of the release of C-14 from irradiated steels.

Research Need
To support the development of the operational and environmental safety cases by gaining an appropriate understanding of the rate and speciation of C-14 release from irradiated stainless steels.

Research Objective
To determine whether, by integrating an improved understanding of the inventory with consideration of corrosion rates and speciation of C-14 released from irradiated stainless steels it will be possible to demonstrate a reduction in the calculated risk.

Scope
To update, as necessary, the model of carbon-14 release from irradiated stainless steel (developed in Task 203) using the understanding gained in Task 210 from WP2 of the EC-CAST project.

Further information
Relevant publications include:
www.projectcast.eu
Appendix B - 88

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>C-14 Release from Irradiated Metals</td>
<td></td>
</tr>
</tbody>
</table>

Title

Carbon-14 release from AGR steels

Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established an integrated project team (IPT) to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST (CArbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

After graphite, steels provide the largest inventory of C-14 associated with irradiated material in ILW.

Recent work has shown that a better understanding of the speciation and rate of corrosion could reduce the calculated radiological consequences for these wastes. Work is being undertaken within CAST to determine the release of C-14 from a number of irradiated steels as there is little information on the form of C-14 released from irradiated steels. Work within the C-14 IPT has shown that the release from irradiated AGR stainless steel hulls may be an important contributor to the rate of release of C-14 from steels in ILW after closure of a GDF. In addition, it is possible that any carbon deposits on AGR steel components (although these are unlikely to have remained on hulls that have been through the dissolver in the Thermal Oxide Reprocessing Plant (THORP) or may have been leached of C-14 during pond storage) or carburisation during reactor operation may affect the rate of corrosion and C-14 release from steel AGR components.

Research Need

To support the development of the transport, operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 release from irradiated AGR steels.

Research Objective

To determine the rate of release of C-14 from irradiated AGR hulls and steel components.

Scope

Measurements of corrosion rates, rate of release of C-14 and speciation from irradiated AGR stainless steel hulls, steel components and associated carbon deposits (if present).

SRL at task start | SRL at task end | Target SRL |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Disposal System Safety Case

Further information

Relevant publications include:
www.projectcast.eu
Task Number | 226 | Status | Ongoing
--- | --- | --- | ---
PBS level 4 | Gas Pathway | --- | ---
PBS level 5 | C-14 Release from Irradiated Graphite | --- | ---

Title
EPSRC Geowaste: C14-BIG – Micro-distribution, Release and Fate of C-14 in Irradiated Graphite

Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species.

RWM has established an Integrated Project Team to develop an holistic approach to C-14 management in the disposal system. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Work has shown that better understanding could reduce the calculated radiological consequences for these wastes. While only a minor component of the C-14 inventory of irradiated graphite is thought to be labile, graphite comprises the largest inventory of C-14 associated with irradiated material in ILW in the UK. In conjunction with the Research Councils’ Energy Programme, this task represents RWM’s co-funded project investigating the micro-structural distribution and availability of C-14 in irradiated graphite (under the C14-BIG programme, through the Geological Disposal of Nuclear Waste Programme of the EPSRC). RWM is co-funding this project under its initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. The primary focus of this project is on developing a process-based understanding of the speciation of radiologically important radionuclides (particularly C-14, U/Ra), and of transport and transfer phenomena through field-studies in four ‘natural laboratories’ in England and Scotland, spanning terrestrial, intertidal and marine systems, integrated with laboratory experiments, and leading to the development of quantitative models.

Research Need
To support the development of the Environmental Safety Case (ESC) by determining the impact of releases of C-14 from irradiated graphite

Research Objective
To characterise the C-14 distribution in irradiated Magnox graphite.
To determine the release rate, speciation and fate of C-14 in a post-disposal environment using both real samples and C-13 simulants.
To develop a biogeochemical source term model and an improved understanding of C-14 / graphite influence on calculated doses using generic biosphere representations.

Scope
The scope is based on the work packages (WP) for C14 BIG as summarised below:

- WP1. Characterisation of Reactor Graphite. Characterisation of pristine and irradiated graphite materials taken from different reactor locations to identify the concentration and distribution of C 14 and their relationship with the porosity and weight loss using a range of techniques, including XRD, X-ray tomography, FIB sectioning, SEM / TEM, EDX and SIMS.
- WP2. The near-field behaviour of C-14. Investigation of the near-field behaviour of C-14 containing graphite including inorganic degradation in simple aqueous systems and investigation of the behaviour of graphite and associated C-14 under microbially-active near-field conditions using irradiated Magnox graphites, C-13 doped un-irradiated graphites (prepared by vapour deposition) and un-irradiated graphites.
- WP3. C-14 Biogeochemical Code Development. This work package will develop a flexible biogeochemical transport code which will implement isotope fractionation within a code able to model the full range of microbial degradation processes likely to occur within a deep geological repository. The model will be used to produce a set of reference repository evolutions which can provide gaseous source terms for C-14 labelled gases in biosphere modelling.
- WP4. C-14 Biosphere Modelling. This will assess the impact of an improved C-14 understanding on
potential biosphere dose calculations. Release profiles generated by the code developed in WP3, will be processed via the Advanced RIMMERS biosphere models developed for the NDA’s involvement in the CARBOWASTE programme. RIMMERS will be coded up in a commercial modelling package.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRL at task end</td>
<td>4</td>
</tr>
<tr>
<td>Target SRL</td>
<td>5</td>
</tr>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
</tr>
</tbody>
</table>

Further information

Relevant publications include:


www.hud.ac.uk/c14-big/
### Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team to develop an holistic approach to C-14 management in the disposal system. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Work has shown that better understanding could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. While only a minor component of the C-14 inventory of irradiated graphite is thought to be labile, graphite comprises the largest inventory of C-14 associated with irradiated material in ILW in the UK.

### Research Need

To support the development of the environmental safety case by determining the release of C-14 from irradiated graphite (this may also support the transport and operational safety cases).

### Research Objective

To determine the inventories and release rates of C-14 from a range of irradiated graphites to the solution and gaseous phases in simulated post-closure conditions.

### Scope

The scope comprises the:

- Collation of existing information on the C-14 inventory in irradiated graphite, its form and leaching behaviour and treatment and packaging for geological disposal.
- Development of approaches to the characterisation of the C-14 inventory of irradiated graphites and studies on the release of C-14 from irradiated graphites to solution and gas.
- Development of an interpretation of C-14 behaviour in, and release from, irradiated graphites.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
</table>
### End point

No Further Research Planned

### Customer

Disposal System Safety Case

### Further information

This task forms part of the CAST (Carbon-14 Source Term) project (Work Package 5), which is an international collaboration co-funded by the European Commission.

Relevant publications include:


www.projectcast.eu
## Task Number

**228**

## Status

Complete, pending publication

### PBS level 4

Gas Pathway

### PBS level 5

C-14 Release from Irradiated Graphite

### Title

C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite

### Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes, which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Graphite provides the largest inventory of C-14 associated with irradiated material in ILW. Recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through treatment, packaging or design options. The impact of these wastes will be highly site-specific and one of the aims of the project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely. Only limited work, recently reported by RWM, has been undertaken on the form of C-14 released from irradiated graphite and an improved understanding of the rate and speciation of C-14 associated releases would enable us to better parameterise assessment models.

### Research Need

To support the development of the environmental safety cases by determining the release of C-14 from irradiated graphite (it may also support the transport and operational safety cases).

### Research Objective

To measure the rate and speciation of C-14 release in both the dissolved and gaseous phase from Oldbury graphite for use as an input to a revised model of graphite leaching and to update scoping calculations of the risk associated with C-14 release from irradiated graphites.

### Scope

The scope includes:

- An experimental programme measuring dissolved and gaseous releases from irradiated graphite.
- Updating the existing graphite release model using the data collected from the experimental programme.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site / Concept Specific Application of Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Concept Development, Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Further information

Relevant publications include:


Appendix B - 93

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>229</td>
<td>Ongoing</td>
<td>Gas Pathway</td>
<td>C-14 Release from Irradiated Graphite</td>
</tr>
</tbody>
</table>

Title

C-14 IPT: Further Measurements on Release of C-14 from i-Graphite

Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes, which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Graphite provides the largest inventory of C-14 associated with irradiated material in ILW. Recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. The impact of these wastes will be highly site-specific and one of the aims of the project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely. Only limited work, recently reported by RWM, has been undertaken on the form of C-14 released from irradiated graphite and an improved understanding of the rate and speciation of C-14 associated releases over longer times and from a broader range of irradiated graphite would enable us to better parameterise assessment models.

Research Need

To support the development of the post-closure safety case by developing the understanding of the behaviour of irradiated graphite over longer times than previously investigated.

Research Objective

To develop an improved understanding of the behaviour of irradiated graphite in a GDF by carrying out experiments with irradiated graphite over timescales of two to three years.

Scope

The scope includes:

- To undertake an experimental programme measuring both dissolved and gaseous releases from irradiated Oldbury Magnox reactor graphite over timescales of two to three years as an extension of the work previously reported.

SRL at task start | 4 | SRL at task end | 5 | Target SRL | 5

End point: Site / Concept Specific Application of Model

Customer: Concept Development, Disposal System Safety Case

Further information

Relevant publications include:


### Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Graphite provides the largest inventory of C-14 associated with irradiated material in ILW. Recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through treatment, packaging or design options. One potential option is to segregate high C-14 waste streams from materials which will corrode to produce large volumes of bulk gas which may facilitate the migration of the C-14 bearing gases from the GDF. This task investigates such options.

### Research Need

To support the future development of emplacement strategies by determining the extent of any benefit resulting from segregating the larger graphite waste streams so they are removed from materials that generate bulk gas.

### Research Objective

- To determine whether segregating large graphite waste streams so as to reduce the influence of materials which generate bulk gas would reduce the overall release of gaseous C-14 from the GDF.
- To determine whether segregation strategies and/or alternative packaging strategies have the potential to significantly reduce post-closure risk.

### Scope

To undertake an assessment to review the potential benefit of segregating the larger graphite waste streams and of packaging the wastes in non-metallic containers to further reduce risk by removing the influence of materials that generate bulk gas.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

### Customer

Concept Development, Disposal System Safety Case

### Further information

Relevant publications include:

Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. RWM has established an Integrated Project Team to develop an holistic approach to C-14 management in the disposal system. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Work has shown that better understanding could reduce the calculated radiological consequences for these wastes. While only a minor component of the C-14 inventory of irradiated graphite is thought to be labile, graphite comprises the largest inventory of C-14 associated with irradiated material in ILW in the UK. This task comprises the interpretation of and synthesis of the outputs of the EC-funded CAST (Carbon-14 Source Term) project (Task 227), the EPSRC-co-funded C14-BIG research programme (Task 226) and the output of further measurements on rate and speciation of release of C-14 from irradiated graphite (Task 229).

Research Need

To support the development of the environmental safety case by determining the release of C-14 from irradiated graphite (this may also support the transport and operational safety cases).

Research Objective

To develop an improved understanding of the rate, speciation and timing of the release of gaseous C-14 from irradiated graphite on new data.

Scope

The scope comprises an update to RWM’s model of C-14 release from irradiated graphite using new data and understanding arising from Tasks 226, 227 and 229.

SRL at task start 5  SRL at task end 5  Target SRL 5

End point Site / Concept Specific Application of Model

Customer Disposal System Safety Case

Further information

Relevant publications include:

www.projectcast.eu
www.hud.ac.uk/c14-big/

Task Number | 232 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Gas Pathway |
PBS level 5 | C-14 Release from Irradiated Graphite |
Title
Studies of C-14 Release from Irradiated Graphite from Reactors Other Than Oldbury

Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM is leading a collaborative EC-funded project, CAST, which includes experimental programmes, which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).
Graphite provides the largest inventory of C-14 associated with irradiated material in ILW. Recent work has shown that a better understanding of the speciation and rate of release could reduce the calculated radiological consequences for these wastes. Only limited work, recently reported by RWM, has been undertaken on the form of C-14 released from irradiated graphite. An understanding of the rate and speciation of C-14 associated releases from a broader range of irradiated graphite would enable us to better parameterise assessment models.

Research Need
To support the development of the post-closure safety case by better underpinned parameterisation of the model of carbon-14 release from irradiated graphite through investigation of the behaviour of irradiated graphites with a wider range of characteristics and irradiation histories than previously studied.

Research Objective
To develop an improved understanding of the behaviour of irradiated graphites in a GDF by carrying out experiments on a wider range of irradiated graphite samples.

Scope
The scope includes:
- Depending on the outcomes of the C-14-BIG project (Task 226) and the EC CAST project (Task 227), measure dissolved and gaseous C-14 releases from UK graphite samples with different characteristics and irradiation histories than the Oldbury and BEP0 samples studied previously.

| SRL at task start | 5 | SRL at task end | 5 | Target SRL | 5 |
--- | --- | --- | --- | --- | --- |
End point | Site / Concept Specific Application of Model |
Customer | Concept Development, Disposal System Safety Case |

Further information
This task may not be required, depending on the importance of the related uncertainties in the safety case.

Relevant publications include:
Task Number: 241
Status: Ongoing

PBS level 4: Gas Pathway
PBS level 5: C-14 Release from Other Sources

Title: EC CAST: WP4 Measurement of the C-14 Release Rate and Speciation from Spent Ion-Exchange Resins from Light Water Reactor Systems in a Range of Aqueous Conditions

Background
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated radiological consequences of gaseous C-14 bearing species. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by the corrosion of irradiated reactive metals, irradiated stainless steel and leaching of irradiated graphite. Light Water Reactors, such as Sizewell B in the UK, utilise ion-exchange resins for the clean-up of aqueous wastes and this wastestream comprises a further high specific activity inventory of C-14.

A better understanding of the inventory and post-closure behaviour of these wastes could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. RWM is leading a collaborative EC-funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. This task comprises the element of CAST concerning the characterisation of spent ion-exchange resins (SIERs) and their post-closure behaviour.

Research Need
To support the development of the environmental safety case by developing an appropriate understanding of the rate and speciation of C-14 release from SIERs.

Research Objective
To determine the inventories and release characteristics of C-14 from a range of SIERs in simulated post-closure conditions.

Scope
The scope comprises the:
- Review of the current knowledge of C-14 in SIERs and identification of the C-14 inventory, its speciation and its distribution among SIERs from different origins (BWR, PWR and CANDU).
- Evaluation of the leaching of C-14 under clay, granitic and alkaline (cementitious) conditions representative of a range of deep geological facilities. The inorganic / organic partitioning, C-14 speciation and any gaseous releases will be investigated.
- Synthesis of the experimental studies to develop an interpretation of C-14 behaviour from SIERs.

SRL at task start: 1
SRL at task end: 4
Target SRL: 5
End point: No Further Research Planned
Customer: Disposal System Safety Case

Further information
This task forms part of the CAST project (Work Package 4, which has no UK direct involvement) which is an international collaboration co-funded by the European Commission.

Relevant publications / sources of further information:
www.projectcast.eu
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>C-14 Release from Other Sources</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Mechanistic Study on C-14 Release and Speciation from Ion-Exchange Resins (if shown from EC CAST to be of Safety Case Significance)

**Background**
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by the corrosion of irradiated reactive metals and leaching of irradiated graphite. Light Water Reactors, such as Sizewell B in the UK, utilise ion-exchange resins for the clean-up of aqueous wastes and this wastestream comprises a further high specific activity inventory of C-14.

A better understanding of the inventory and post-closure behaviour of these wastes could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. RWM is leading a collaborative EC-funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. The outputs from CAST will be reviewed in the UK context under Task 210 to identify any further research that is required for the UK programme. This task comprises any required follow-on work on Spent Ion-Exchange resins (SIERs) arising from the review.

**Research Need**
To support the development of the operational and environmental safety cases by developing an appropriate understanding of the rate and speciation of C-14 release from UK spent ion-exchange resins.

**Research Objective**
To determine the release and speciation of C-14 from SIERs relevant to the UK (if necessary).

**Scope**
The scope of this task will be defined based on the findings from Task 210. The outcome is likely to be that at the end of this task no further work will be required with respect to the gas pathway. Work related to the aqueous pathway might continue under site-specific conditions and would thus form part of the radionuclide behaviour research programme.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
- Further Work To Be Defined (Aqueous)
- No Further Research Planned (Gas-Pathway)

**Customer**
Disposal System Safety Case

**Further information**
Relevant publications include:
www.projectcast.eu
**Background**

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM is leading a collaborative EC-funded project, CAST (Carbon-14 Source Term), which includes experimental programmes that will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials. We have also established an Integrated Project Team (IPT) to develop an holistic approach to C-14 management in the disposal system.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:

- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Work has shown that better understanding could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through alternative treatment, packaging or design options. The impact of these wastes will be highly site-specific. This collaborative task investigates the safety case implications of the new knowledge developed under CAST (Tasks 201, 207, 206, 227 and 241).

**Research Need**

To evaluate and incorporate the new understanding from CAST in the context of safety cases.

**Research Objective**

To combine the results from CAST WP2 to 5 to deliver a sound scientific basis and safety relevant information in the context of national programmes and safety cases.

**Scope**

The scope comprises the:

- Review of the treatment of C-14 in current safety assessments of CAST-participating Waste Management Organisations and related organisations and placing the basis of these safety assessment against the context of the current knowledge of C-14 containing wastes.

- Integration of the results from Work Packages 2 to 5 of CAST into safety case approaches and calculations.

**Further information**

This task forms part of the CAST project, which is an international collaboration co-funded by the European Commission.

Relevant publications include:


www.projectcast.eu
<table>
<thead>
<tr>
<th>Task Number</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
<th>Status</th>
<th>Complete, pending publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>252</td>
<td>Gas Pathway</td>
<td>System Modelling for C-14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

C-14 IPT: Integrate Revised Data & Understanding & Determine Impact on Operational & Post-Closure Safety Cases

**Background**

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Work has shown that better understanding could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through treatment, packaging or design options. The impact of these wastes will be highly site-specific and one of the aims of the integrated project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely.

The operational safety environmental assessment uses a general approach (using the model PC-Cream) which currently leads to doses above the design target of the GDF.

**Research Need**

To determine the impact of the revised data and understanding developed through the C-14 project on the calculated radiological consequence for C-14 bearing wastes.

**Research Objective**

To refine the calculated radiological assessment for the operational and post-closure periods by integrating improved data and understanding in revised scoping calculations and models.

**Scope**

The scope will include:
- Demonstrating that the calculated dose during the operational phase could be reduced by using more appropriate assumptions (in particular that the chemical form of C-14 vented from the stack is in the form of CH₄ rather than CO₂) leading to substantially lower uptake by plants and an associated reduction of off-site dose during the operational phase of the GDF life cycle.
- Running scoping calculations of gas generation to reflect revised data and understanding.
- Developing a total system model for C-14 in a higher strength rock environment to provide an improved understanding of the impact of key uncertainties on system behaviour.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:


www.projectcast.eu
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of the UK GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. We are also leading a collaborative EC funded project, CAST, which includes experimental programmes which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (longer term).

It is likely that a better understanding could reduce the calculated radiological consequences for these wastes by eliminating the conservatisms necessarily taken when there is a lack of data. This task comprises the incorporation of data and understanding gained throughout the entire C-14 project.

Research Need
There is a need to synthesise the understanding gained in the C-14 project to summarise our progress in developing an holistic approach to C-14 management in the disposal system.

Research Objective
The overall aim of the C-14 project is “To support geological disposal of UK wastes containing C-14, by integrating our evolving understanding from current and pre-existing projects, in order to develop an holistic approach to C-14 management in the geological disposal system”. This task will integrate the understanding and present it in a final report.

Scope
This work will integrate the outputs from tasks in the C-14 integrated project and will include:
- An update of calculations of the consequences of release of gaseous C-14, reflecting the understanding developed in the project.
- A view regarding the potential benefits of developing alternative treatment, packaging, design or disposal options for specific wastes.
- Consideration of the envelope of geological conditions under which wastes containing C-14 could be managed in different geological environments.

Relevant publications include:
www.projectcast.eu
<table>
<thead>
<tr>
<th>Task Number</th>
<th>261</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Other Radioactive Gases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>Radon Emanation from Polymer Encapsulated Wastes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Background**

In the generic operational environmental safety assessment (OESA), the radiological consequences of gases containing carbon-14 (C-14) and radon-222 (Rn-222) are potentially significant. There is however considerable uncertainty over the extent to which Rn-222 decays as it migrates within and from waste packages, and the manner it is transported through the engineered systems in a GDF during the operational period.

The retention of Rn-222 within a waste package is expressed in terms of an ‘emanation coefficient’, which corresponds to the fraction of Rn-222 that is released from a waste package in comparison to the in-package Rn-222 generation rate.

The dose arising from radon in the OESA is currently calculated using an assumed radon emanation coefficient of 2x10^-3. The calculated dose has the potential to exceed safety limits during the operational period. This emanation coefficient was however calculated using conservative data, for a grout-encapsulated waste within a 500 l steel drum, and applied holistically to the entire inventory.

Guidelines for radium containing wastes now suggest it is packaged using an encapsulant with a greater hold-up factor, for example polymer, facilitating the radioactive decay of the short-lived (3.8 day) Rn-222 radionuclide within the package. Recent Disposability Assessment (Letter of Compliance) submissions have implied an emanation coefficient several orders of magnitude lower can be achieved using bespoke packaging methods, utilising polymer, for particularly high radium containing waste streams. It is therefore necessary to review the models and parameters used to ensure they are appropriate.

**Research Need**

To support the operational environmental safety assessment by proposing radon emanation coefficients for a range of encapsulants, including polymers.

**Research Objective**

To determine appropriate radon emanation coefficients for use in updates to the OESA.

**Scope**

To experimentally derive radon hold-up factors for bespoke encapsulants for radium containing wastes (e.g. polymer formulations), and corresponding radon emanation coefficients to be used to update the estimated dose arising from radon within the OESA.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

## Appendix B - 103

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Bulk Gas Generation</td>
<td></td>
</tr>
</tbody>
</table>

### Title
Gas Generation from Microbial Degradation of Organic Wastes Including Cellulose

### Background
Gas generation from the microbial degradation of cellulose is an important contributor to the overall gas generation from ILW. The SMOGG gas generation tool incorporates two models for gas generation from cellulose – one applicable to near-neutral pH conditions and the other applicable to highly alkaline conditions.

Review of these models and the availability of suitable data (Small and Dutton, 2010) for calibration and validation identified that there were no data available for the calibration or validation of the high-pH model and also suggested some possible refinements to SMOGG itself. In general, there are uncertainties in the viability, activity and distribution of microbial activity at high-pH and corresponding uncertainties in gas generation. There is therefore uncertainty regarding whether or not the current SMOGG model leads to an overestimate of the rate of gas production from cellulosic wastes under high-pH conditions.

### Research Need
To support the disposal system safety case and the LoC process by determining the rate of gas generation from the microbial degradation of cellulose in a high pH environment.

### Research Objective
To determine whether the rate of bulk gas generation from the microbial degradation of grout-encapsulated cellulosic material in the UK ILW concept:
- is compatible with the safety functions of the concept and whether or not it is significantly affected by the dose rate present in the vault.
- may be simply bounded by a suitably conservative gas generation rate incorporating credible microbial population evolution scenarios.

### Scope
The scope will involve, where necessary, acquisition of experimental data relevant to bulk gas generation rates arising from the microbial degradation of cellulosic materials in high pH environments.

Additionally, the output of "Effects of Radiation on Microbial Survival and Activity" (a recently-completed Ph.D. with University of Manchester and National Nuclear Laboratories (NNL)), in which further understanding on related gas generation processes was gained, will inform our knowledge base such that suitable gas generation rate assumptions are incorporated in a gas generation modelling tool (i.e. SMOGG).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

### Customer
Disposal System Safety Case

### Further information
Relevant publications include:
- Effects of Radiation on Microbial Survival and Activity, (Ph.D. with University of Manchester and National Nuclear Laboratories (NNL)).
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Bulk Gas Generation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review of Bulk Gas Generation from Corrosion, Radiolysis and Microbial Action</td>
</tr>
</tbody>
</table>

**Background**

Bulk gas generation is of interest in all phases of a GDF with the relative importance of some of the aspects dependent on the concept (e.g. potential pressurisation of a GDF in the post-closure phase in a clay environment). Corrosion of metals in ILW packages (whether as waste or containers) is a significant contributor to gas generation. The mechanisms and rates of corrosion (and hence hydrogen generation) from steels, Zircaloy (Zr), Magnox, uranium (U) and aluminium (Al) have been reviewed for high-pH conditions and these data input to our SMOGG gas generation model.

Other contributors to bulk gas generation are radiolysis and microbial degradation of some organic materials (e.g. cellulosic wastes), reviews of which have also been carried out in the context of data input parameters to SMOGG.

**Research Need**

To provide support to the safety case and disposability assessment by maintaining and developing, as necessary, an up-to-date understanding of bulk gas generation in a range of geologies and disposal concepts.

**Research Objective**

- To update the understanding of metal corrosion rates, radiolytic yields and microbial degradation under GDF-relevant conditions to ensure our understanding of bulk gas generation in a range of geologies and disposal concepts is developed and maintained.
- To determine the rate of bulk gas generation from the corrosion of steels, Zircaloy, Magnox, uranium and aluminium under GDF-relevant conditions, noting existing data and understanding on mechanisms and rates of corrosion (and H2 generation) from steels, Zircaloy, Magnox, uranium and aluminium under high pH conditions.
- To consider the impact of gas generation on the safety functions of the disposal system.'

**Scope**

The scope comprises a review of the input corrosion rate, radiolytic yield and microbial degradation data to SMOGG for an appropriate range of disposal concepts to recommend any changes to these input data that may be required and to identify where additional data may be required.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:


Progress Understanding of G-values in Relation to Gas Generation from Radiolysis.

Background
A recent review report ("Determination of G-values for use in SMOGG Gas Generation Calculations") reviewed data required to calculate gas generation by radiolysis in relation both to materials present in the UK Radioactive Waste Inventory (UK RWI) and to the operational and post-closure evolution of a UK Geological Disposal Facility. The relationship between the amount of gas, typically hydrogen gas, and the radiation dose is usually formulated in terms of a G value (also known as radiation chemical yield or yield). The report:
- Reviewed the current approach to gas generation by radiolysis, described the use of G values and analysed the most recent gas generation results in order to understand the breakdown of radiolysis by waste material type.
- Analysed the UK RWI for relevant materials that generate gas by radiolysis to help determine the most sensible waste category groupings.
- Critically reviewed the available information on G values using expert input for water, cementitious materials and organic materials.
- Present a summary of the findings and their uncertainties and data gaps, including tables of best estimate and upper bound G values for relevant waste materials.

Research Need
To support the disposal system safety case by determining the rate of gas generation from radiolysis of water and inventory components.

Research Objective
There are several data gaps identified in the above-noted recent review report, where further information would aid the assessment of gas generation by radiolysis. However, it is recognised that the benefit of additional data needs to be considered relative to the overall uncertainties given the current range of G values, and the expected inventory mass of the material in question. Furthermore, enhancements to the Simple Model of Gas Generation (SMOGG) gas generation tool are recommended:
- Include separate G values for each type of radiation for water and each of the different organic materials listed.
- Assign a single G value for each type of radiation for cementitious grout and its pore water regardless of its state of water saturation, rather than the current simple approach that considers a G value for the fraction of (pure) water contained within the cementitious encapsulant. It is suggested that cementitious backfill and its pore water could similarly be assigned a single G value for each radiation type.

Scope
To progress RWM’s position on data gaps and uncertainties in the review of G-values and to develop the SMOGG tool based on the outcomes from the review.

Further information
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Complete, pending publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td>Gas Migration Through Cement-Based EBS Materials</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Gas Migration Through Cement-Based EBS Materials</td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>C-14 IPT: C-14 Migration Through the Cementitious EBS</td>
<td></td>
</tr>
</tbody>
</table>

**Background**
Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

Recent work has shown that a better understanding of the speciation and rate of corrosion could reduce the calculated radiological consequences for these wastes. Alternatively, it may be possible to mitigate the impact of these wastes through treatment, packaging or design options. One potential option is to segregate high C-14 waste streams from materials which will corrode to produce large volumes of bulk gas which may in turn facilitate the migration of the C-14 bearing gases from the GDF. This task investigates the impact of bulk gas on the ability of C-14 bearing gases to migrate through the engineered barrier system.

**Research Need**
To support safety case development by determining whether C-14 bearing gas generated in the post-closure phase will be entrained within a bulk gas phase and whether it is able to migrate through the engineered facility.

**Research Objective**
To underpin the scientific basis for the assessment calculations by collating and documenting results from relevant near-field projects.

To determine whether:
- CO₂ will undergo a carbonation reaction in the cementitious materials of the engineered barrier system and will therefore not enable C-14 to migrate out of the GDF.
- C-14 bearing methane levels will be enhanced by the reaction of CO₂ with H₂ in the GDF.
- Microbes are able to metabolise H₂ gas, thereby reducing the volume of bulk gas in the engineered barrier system (Task 766).

**Scope**
This task aims to incorporate the understanding from relevant modelling projects to inform scoping calculations and development of the total system model (including the gas pathway) and includes:
- An ongoing task to determine how effectively CO₂(g) released from waste packages will react with Nirex Reference Vault Backfill (NRVB) to form carbonates.
- Ongoing work within the EC FORGE project (by the British Geological Survey) to investigate the reaction of carbon dioxide as gas, and in solution in the NRVB porewater, to understand the impact of the reaction on the evolution of permeability.
- To investigate the interaction of gas and cement during / following backfilling.
- A PhD project at the University of Manchester to investigate the microbiological metabolism of hydrogen within a GDF (Task 443).
Relevant publications include:
Experimental Study on Gas Interactions with the Package Vent and Curing Backfill

Background
Cement-based buffers are permeable and allow gas to pass through. If cement contains free water, carbon dioxide will react with it and form solid calcium carbonate. This is an important mechanism for removing carbon-14 (C-14) bearing CO2 from the gas phase in the UK’s cementitious GDF concept. RWM needs an understanding of how gas will affect transport properties of the backfill through processes such as carbonation, pressurisation and the potential for cracking.

This task will investigate whether the backfilling of vaults needs to be managed to prevent disruption of the backfill above the vents of drums that may generate gas rapidly on backfilling due to the exotherm from backfill curing. Such disruption may comprise:

- Gas pressurisation (e.g. by bulk hydrogen), which could lead to disruption or cracking of the backfill above package vents.
- An increase in porosity or an absence of backfill above vents, which offers possible preferential pathways to radionuclide release.
- Effects of high gas flows on cement properties during curing which, were this to occur, are not yet understood sufficiently.

The output of this task will inform operational decisions during backfilling and closure.

Research Need
To support the safety case by determining the physical effects of gas flowing through a drum vent on the backfill as it is emplaced and to determine whether there is the potential for gas generated rapidly on backfilling (due to the exotherm from the backfill curing) to re-initiate a reaction between reactive metals and the grout encapsulant.

- Understand if free water from Nirex Reference Vault Backfill (NRVB) can pass through the vent in a vented 500 litre drum under GDF conditions.
- Understand if gas generated in a vented 500 litre drum with high gas generation potential (e.g. Magnox swarf) under GDF conditions can pass through this vent, coupling with any concurrent water ingress.
- Understand the effects of gas release from vented packages during NRVB emplacement and curing on physical properties of the NRVB under conditions relevant to the GDF in the post-closure period.
- Identify a bounding gas generation rate above which the effects of gas release on the physical properties of the NRVB are unacceptable in comparison to NRVB assumed to have cured to steady state in the absence of a gas release.

Research Objective
To determine whether:

- The physical effect of gas generated within a vented drum during curing, and passing through the backfill as it is emplaced, is of a magnitude that will influence the homogeneity of the backfill properties.
- There is a need for managed backfilling of vaults where a significant thermal gradient exists.

Scope
To conduct a laboratory-scale experiment to determine the physical effects of gas flowing through a drum vent on the backfill as it is emplaced and to determine whether there is the potential for gas generated rapidly on backfilling (due to the exotherm from the backfill curing) to re-initiate a reaction between reactive metals and the grout encapsulant.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Gas Pathway</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Gas Migration Through Cement-Based EBS Materials</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Review of Approaches to the Management of Gas During the Operational and Post-Closure Phases

**Background**

The generation, accumulation and migration of gas in a GDF will vary with waste inventory and with GDF concept (itself a function of the geological setting). Different design strategies aiming to reach one or several of the following objectives may be adopted:

- Ensure that the release of any gases to the biosphere does not challenge regulatory limits.
- Prevent the degradation of the performance of GDF barriers.
- Reduce uncertainties on factors controlling the generation and migration of gases.
- Limit adverse consequences of gas release in case of the variant human intrusion scenario.

The optimum strategy is directly dependent on the waste inventory and disposal concept, as well as on the boundary conditions associated with the host rock and its environment. These boundary conditions include the availability of water and the chemical conditions (controlling the corrosion processes and the free gas phase), gas entry pressure (controlling the gas accumulation and the subsequent pressurisation) and sealing capacities (controlling the resilience of the host-rock).

With respect to GDF-derived gas, the EC FORGE (Fate Of Repository GasEs) project has considered gas generation and gas migration, with migration concerning both clay-based and cement-based engineered barrier system (EBS) materials, and disturbed and undisturbed host rock. Significant new numerical modelling has also been undertaken at the cell, module and GDF scale to better understand how gas could interact with GDF infrastructure (e.g. plugs and seals, interfaces) and how migration of waste-derived gas could occur over the post-closure period. Interaction with groundwater has been considered (both in the desaturation period occurring whilst the GDF is open, and in the re-saturation period after the GDF is closed).

**Research Need**

To support the disposal system safety case by developing concept and design solutions to potential issues posed by GDF gas generation.

**Research Objective**

- To develop mitigation approaches to ensure waste-derived gas is managed so as not to be a safety case-relevant concern.
- To demonstrate surface radiological or flammability hazards potentially posed by GDF-derived hydrogen in the form of bulk gas can be managed by appropriate choice of EBS for a given geosphere.

**Scope**

To ensure benefits from EC FORGE project are integrated into the RWM knowledge base on gas, and are utilised in safety case and design studies. This task is a desk study identifying gas issues for the UK Radioactive Waste Inventory and the range of potential mitigation approaches through concept and design measures (covering GDF construction, operation, closure and sealing).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point | Site Specific Validation
Customer | Disposal System Safety Case

**Further information**

Relevant publications include:
http://www.bgs.ac.uk/forge/
Appendix B - 110

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>282</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Gas Pathway</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Gas Migration Through Cement-Based EBS Materials</td>
</tr>
</tbody>
</table>

Title
Implications of Understanding from Task 277 for Conceptual Model of Gas Interactions with the Package Vent and Curing Backfill

Background
Cement-based buffers are permeable and allow gas to pass through. If cement contains free water, carbon dioxide will react with it and form solid calcium carbonate. This is an important mechanism for removing carbon-14 (C-14) bearing CO2 from the gas phase in the UK’s cementitious GDF concept. RWM needs an understanding of how gas will affect transport properties of the backfill through processes such as carbonation, pressurisation and the potential for cracking.

Task 277 investigated whether the backfilling of vaults needs to be managed to prevent disruption of the backfill above the vents of drums that may generate gas rapidly on backfilling due to the exotherm from backfill curing. Such disruption may comprise:
- Gas pressurisation (e.g. by bulk hydrogen), which could lead to disruption or cracking of the backfill above package vents.
- An increase in porosity or an absence of backfill above vents, which offers possible preferential pathways to radionuclide release.
- Effects of high gas flows on cement properties during curing which, were this to occur, are not yet understood fully.

The current task will consider the implications of understanding derived from Task 277 on the conceptual model of gas interactions with the package vent and curing backfill, and will recommend any updates necessary.

Research Need
To support the disposal system safety case by determining the conceptual model of how any gas flowing through a drum vent interacts with backfill as the backfill is emplaced and cures, for a range of gas flow rates.

Research Objective
To determine whether the physical effect of gas generated within a vented drum during curing, and passing through the backfill as it is emplaced, is of a magnitude that will influence the homogeneity of the backfill properties.

Scope
This is a desk-based study, building on the output from, and understanding derived by, Task 277. If backfill homogeneity above a vent in a gas-generating package is not maintained, on the basis of output from Task 277, to derive a conceptual model of gas flow / backfill interaction, and assess the implications of this new / revised conceptual model in the context of the DSSC.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

End point
Further Work to be Defined

Customer
Disposal System Safety Case

Further information
Relevant references include:
Appendix B - 111

Task Number | Status | Ongoing
--- | --- | ---
PBS level 4 | Gas Pathway
PBS level 5 | Gas Migration Through Clay-Based EBS Materials
Title
EPSRC GEOWASTE: Gas Flow in Saturated Bentonite at Elevated Temperature

Background
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

This task comprises such an academic study. It is co-funded by RWM and the Engineering and Physical Sciences Research Council (EPSRC) under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

Research Need
To support concept development by developing a mechanistic understanding of the impact of elevated temperatures on gas flow in saturated bentonite.

Research Objective
Across eight work packages in the SAFE consortium, to deploy and refine advanced monitoring techniques for simultaneous imaging of THMC variables (pH, temperature, pore-water pressure, swelling, etc.) within the laboratory, and to integrate these monitoring techniques with experiments to gain a predictive understanding of the THMC evolution of clay-based engineered barriers, and their interfaces, up to the upper-bound of realistic environmental conditions.

Scope
To undertake a series of high precision experiments on pre-compacted bentonite cores subject to elevated temperatures (<150°C), to investigate the effect of temperature on multi-phase flow with particular emphasis placed on issues related to gas entry, breakthrough, evolution of flow and the coupling between stress and porewater pressure.

Experiments will be undertaken under constant volume conditions. Axial and radial total stresses, and internal porewater pressure, will be continuously monitored to provide detailed hydro-mechanical data in response to changes in gas / water flow and thermal load. Experiments will be undertaken on intact blocks of rock, and the role of interfacial flow along joint planes will be investigated.

SRL at task start | 3 | SRL at task end | 4 | Target SRL | 4
End point | Watching Brief
Customer | Research (‘Curiosity Driven’), Disposal System Safety Case
Further information
RWM’s role in SAFE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case. The SAFE consortium comprises the universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff and Oxford, together with the British Geological Survey.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>288</td>
<td>Ongoing</td>
<td>Gas Pathway</td>
<td>Gas Migration Through Clay-Based EBS Materials</td>
</tr>
</tbody>
</table>

**Title**

Experimental Study of Gas Migration Through Clay to Investigate the Gas Migration Mechanism in Bentonite

**Background**

In the current phase of preparatory studies, RWM is undertaking a programme of experiments and models of gas migration in clays and the effects of pressurisation on clay barrier performance in order to develop a capability in this area. Such work will also feed into the development of GDF concepts in the future. If gas were to form in a GDF its subsequent migration would be dependent on the properties of the host rock, properties of the surrounding rock, and the extent of dissolution in groundwater. If the rate of gas generation were to become sufficiently high there would be a potential for over-pressurisation and cracking of very low permeability rocks, which have no significant natural fractures that would allow gas to escape. Clays typically have very small inter-granular pores which make it difficult for gas to migrate. The presence of gas in clay environments could therefore cause damage due to over-pressurisation, leading to preferential pathways for contaminated groundwater migration through the engineered barrier system or clay host rocks. The mechanisms of movement and healing properties of clay require additional understanding.

Work carried out on such rock types in other countries’ waste management programmes has shown that a gas over-pressure can be relieved by the formation of micro-fissures in the rock. In the cases studied, the micro-fissures 'heal' after the pressure is relieved because of the rock’s intrinsic properties and the compressive forces acting on the rocks at depth. In addition, there are also international studies to assess the potential for gas to be transported along the engineered disturbed zone at the tunnel / rock interface. This task comprises an experimental mechanistic study on gas migration in clay systems.

**Research Need**

To build an understanding of gas generation in a GDF, and its subsequent fate, in order to identify any consequences that need to be considered in safety cases.

**Research Objective**

To investigate the detailed process of fluid flow in clay to determine whether the interaction of waste-derived gas and clay that may be present in the engineered barrier system negatively impacts on the safety functions provided by the clay.

**Scope**

Following the injection of gas or water, work in this PhD project will comprise a series of novel experiments using a Hele-Shaw cell, with a transparent surface, packed with a clay mixture, into which liquid or air may be injected from a point or line source. The experimental system will enable visualisation of the flow path of the gas or liquid through the clay pack in order to determine the processes by which the clay develops permeability and allows for flow. Video image analysis will be used to follow the flow, and track the formation and healing of fractures within the formation.

Time evolution of the fractures by progressively injecting fluid with different colours will enable monitoring of the evolution of the flow pattern with time. As well as monitoring the fluid / gas motion, as described above, the deformation of the surface of the Hele-Shaw cell will be tracked, again using video, and by measuring the distortion of lines on the surface of the cell.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Watching Brief

**Customer**

Disposal System Safety Case

**Further information**

This is an ongoing PhD project being conducted jointly by the BP Institute, University of Cambridge, and the British Geological Survey.
In the current phase of preparatory studies, RWM will continue with a programme of experiments and models of gas migration in clays and the effects of pressurisation on clay barrier performance in order to develop a capability in this area. Such work will also feed into the development of GDF concepts in the future. Much of this work will involve participation in international collaborative projects such as LASGIT (LArge Scale Gas Injection Test) at Åspö in Sweden and the EC FORGE project conducted under the EC 7th Framework to investigate the fate of gases generated in a GDF.

If gas were to form in a GDF its subsequent migration would be dependent on the properties of the host rock, properties of the surrounding rock, and the extent of dissolution in groundwater. In the absence of a migrating free gas phase the only transport of trace radioactive gases, e.g. carbon-14 (C-14) bearing methane, would be as dissolved species. If the rate of gas generation were to become sufficiently high there would be a potential for over-pressurisation and cracking of very low permeability rocks, which have no significant natural fractures that would allow gas to escape. Clays typically have very small inter-granular pores which make it difficult for gas to migrate. The presence of gas in clay environments could therefore cause damage due to over-pressurisation, leading to preferential pathways for contaminated groundwater migration through the EBS or clay host rock. The mechanisms of movement and healing properties of clay require additional understanding.

Work carried out on such rock types in other countries’ waste management programmes has shown that a gas over-pressure can be relieved by the formation of micro-fissures in the rock. In the cases studied, the micro-fissures 'heal' after the pressure is relieved because of the rock’s intrinsic properties and the compressive forces acting on the rocks at depth. In addition, there are also international studies to assess the potential for gas to be transported along the Engineering Disturbed Zone at the tunnel / rock interface.

This task comprises RWM’s participation in the aforementioned LASGIT project, which is a field scale experiment operated by the British Geological Survey (BGS) located at approximately 420m depth in Svensk Kärnbränslehantering AB’s (SKB’s) Åspö Hard Rock Laboratory in Sweden. LASGIT has yielded high quality data relating to the hydration of the bentonite and the evolution in hydrogeological properties adjacent to the deposition hole.

**Research Need**

To support concept development by developing an understanding of gas migration through a bentonite buffer.

**Research Objective**

To determine whether the interaction of waste-derived gas and bentonite material present in the engineered barrier system has a negative impact on the safety functions provided by the bentonite.

**Scope**

LASGIT has been designed to study the impact of gas build up and subsequent migration through the engineered barrier system of the Swedish KBS-3 disposal concept for high level radioactive waste via a full-scale in situ experiment.

**Further information**

Relevant publications include:

### Background

Carbon-14 (C-14) is a key radionuclide in the assessment of the safety of a GDF for radioactive waste because of the calculated assessment of the radiological consequences of gaseous C-14 bearing species. RWM has established a project to develop an holistic approach to C-14 management in the disposal system. RWM is also leading a collaborative EC-funded project, CAST, which includes experimental programmes which will fill knowledge gaps in the data for the rate and speciation of C-14 release from key materials.

Using the current modelling basis, but ignoring any potential benefits from the geosphere in retarding or preventing gas from reaching the surface, the calculated release of C-14 is dominated by:
- Corrosion of irradiated reactive metals (in the operational and early post-closure time frame).
- Corrosion of irradiated stainless steel and leaching of irradiated graphite (in the longer term).

The impact of these wastes will be highly site-specific and one of the aims of the integrated project is to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely.

### Research Need

To support the safety case by developing an understanding of the envelope of geological environments in which C-14 bearing wastes can be managed safely.

### Research Objective

To document an understanding of the implications of C-14 containing gases for site characterisation.

### Scope

The geological environment could be very important in determining whether C-14 bearing gases reach the biosphere. The geosphere may have features, such as cap rocks, that retard or prevent the breakthrough of gas at the surface. In an evaporite or lower strength sedimentary rock, there is unlikely to be a significant release of C-14 bearing gas to the biosphere. In regions of higher groundwater flow, gas may be dissolved. Therefore there is a need to understand the envelope of geological environments in which C-14 bearing wastes can be managed safely.

This task will consider how features such as cap rocks and aquifers can influence gas migration and will also identify analogues relevant to gas release. The impact of the assumed gas release area on the calculated risk will also be considered. No detailed development of gas migration models is expected during this task; it will however be necessary to consider how the understanding developed will be used to inform the requirements for site characterisation.

### SRL at task start | SRL at task end | Target SRL
---|---|---
3 | 4 | 4

### End point

Site Specific Application of Understanding

### Customer

Disposal System Safety Case

### Further information

Relevant publications include:


Appendix B - 115

Task Number 298  Status Ongoing

PBS level 4 Gas Pathway

PBS level 5 Gas Migration Through the Geosphere

Title Holistic Review of Gas Consumption / Sinks in the Geosphere

Background

RWM recognises that gas migration is strongly site-specific, being dependent on host geology and the availability of water, in combination with the nature of the emplaced waste and its chemical composition. Although radioactive gases can be generated in a GDF, the volumes generated are calculated to be small and potentially could dissolve in any groundwater present. The consideration of gases in the safety case would then be as part of the groundwater pathway. Depending on site-specific features, groundwater travel time could be long-enough that significant decay of C-14 bearing gases can be assumed. This would then act to reduce the radiological impact of such species and their significance in the safety case.

For radioactive gases to pose a greater radiological hazard in the safety case, their entrainment in a bulk free gas phase would need to occur, with the volume of the bulk gas phase being such that it persists and does not dissolve completely in any groundwater. Migration of a free gas phase, under buoyancy, could then result in a travel time from GDF to surface environment that, depending on site-specific properties, could be quicker than the groundwater pathway travel time. The radiological hazard associated with any entrained radioactive gases would be greater than in the case where complete dissolution can be argued.

Research Need

To support safety case development by building an understanding of gas generation in a GDF and its subsequent fate in order to identify consequences that need to be considered in the safety case.

Research Objective

To develop a “cradle-to-grave” understanding encompassing the migration and fate of bulk hydrogen gas generated in a GDF.

Scope

To consider processes occurring in the engineered barrier system and the geosphere that could affect the bulk gas balance, here taken to be hydrogen (volumetrically the most significant non-radioactive gas from UK Higher Activity Wastes (HAW)), including:

- Utilisation of hydrogen by microbiology present in the engineered barrier system and geosphere.
- Dissolution / exsolution.
- Gas trapping in the EBS and in the host rock (including the role of the surrounding geology); to include dissolution or re-mobilisation of trapped gas over prolonged periods of time.
- Processes that could act to re-mobilise trapped gas.

SRL at task start 3  SRL at task end 4  Target SRL 4

End point Site Specific Application of Understanding

Customer Disposal System Safety Case

Further information

Relevant publications include:


Further Development of the Derived Inventory

Background
Quantified estimates of the inventory for geological disposal are needed to support development of the geological disposal system for the UK's higher activity radioactive wastes. The UK Radioactive Waste Inventory (UK RWI) provides the basis for these estimates and contains an extensive amount of data. These data require some modification or enhancement before they can be used in RWM's generic design and safety assessment at the waste package level. A Derived Inventory has therefore been developed from the UK RWI to provide the required dataset.

This task involves further development of the methodologies and tools used to prepare the Derived Inventory to ensure it remains fit for purpose, and to improve and expand the data as required by design and safety assessments.

Research Need
To support disposal system development and communication of inventory to stakeholders.

Research Objective
To maintain and further develop the Derived Inventory.

Scope
The scope of this task will include:
- Maintenance of the methodology and tools used to prepare the Derived Inventory.
- Ongoing review of the nuclear data used to support the Derived Inventory.
- Reducing inventory uncertainty in priority areas based on feedback from the generic DSSC and waste packaging disposability assessment.

The output of this task will support updates to the Derived Inventory.

SRL at task start | SRL at task end | Target SRL
--- | --- | ---
5 | 6 | 6

End point: Further Development Throughout UK Nuclear Lifecycle


Further information
Relevant publications include:


### Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

One such task (under the HydroFrame project) is being undertaken under our collaboration with the Natural Environment Research Council (NERC), investigating the possibility of collecting and processing seismic and THM data in order to develop a capability for monitoring the evolution of the GDF throughout its construction and operational phases. We are co-funding this project under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

### Research Need

To support the safety case for operations and post-closure by developing new and / or improved methodologies, codes and protocols for analysing hydromechanical and geochemical processes (in fractured rock mass).

### Research Objective

To develop new / improved methodology to characterise and model the properties of fractured rock masses with regards to the influence of these properties on the performance of a GDF.

### Scope

The scope is to investigate the opportunity to develop an integrated seismic and thermo-hydro-mechanical methodology for time-lapse monitoring of repository sites by exploring seismic monitoring strategies and developing data processing methodologies.

### SRL at task start | SRL at task end | Target SRL
--- | --- | ---
4 | 5 | 5

### End point

- Site Specific Application of Models

### Customer

- Disposal System Safety Case

### Further information

RWM’s role in HydroFrame is in supporting the academic cohort by reviewing the technical output of the project and its applicability to RWM.

Relevant further information can be found in the following:

http://www.nerc.ac.uk/research/funded/programmes/rate
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>332</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geosphere</td>
<td>Tectonics &amp; Seismicity</td>
</tr>
</tbody>
</table>

Title
NERC RATE (HydroFrame) WP3: Seismic Modelling of Fracture Response to Inform Survey Designs for Repositories

Background
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

One such task (under the HydroFrame project) is being undertaken under our collaboration with the Natural Environment Research Council (NERC), investigating the opportunity to develop new or improved methodology for the characterisation and modelling of the properties of fractured rock masses with regards to the influence of these properties on the performance of a GDF. We are co-funding this project under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

Research Need
To support site characterisation by investigating innovative micro-seismic approaches.

Research Objective
To develop a new or improved methodology for the characterisation and modelling of the properties of fractured rock masses with regards to the influence of these properties on the performance of a GDF.

Scope
The scope is to investigate the potential of seismic forward modelling of fracture response to inform survey design for repositories. The output could be a technique for utilising natural seismic activity or man-made pulses to characterise the fracture fields of a rock mass in order to assess its suitability for a GDF. The work will include the development of models of discrete fracture networks to explore seismic attributes diagnostic of fracture properties and to use fracture models to design acquisition strategies that enhance observations and interpretation of fractured systems.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point  Site Specific Application of Models
Customer  Site Characterisation

Further information
RWM’s role in HydroFrame is in supporting the academic cohort by reviewing the technical output of the project and its applicability to RWM.

Relevant further information can be found in the following:
http://www.nerc.ac.uk/research/funded/programmes/rate
Background

The geosphere is a key component of a multi-barrier disposal concept. As noted in the geosphere status report, the geosphere is continually evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety.

The UK is a relatively stable tectonic environment, well removed from major plate boundaries. Therefore consideration of tectonic activity, and related phenomena such as earthquakes, is of much lower significance in the UK geological disposal programme than in those of some other organisations in countries such as Japan.

In 2013 we published a major review of the potential impact of natural processes on a GDF, “Potential Natural Changes and Implications for a UK GDF”, produced under contract for us by the British Geological Survey. We recognise however that further UK-based research (such as work co-funded by us, the Environment Agency and the Natural Environment research Council (Tasks 331 and 332) or undertaken internationally, may make it necessary to update this aspect of our knowledge base. This task comprises such a review.

Research Need

To support the post-closure safety case by maintaining an up-to-date understanding of the potential impact of tectonism and earthquakes in a UK context, and related impacts on the geosphere and biosphere, on a timescale of a million years.

Research Objective

In relation to tectonism and earthquakes in a UK context:
- To review our understanding of the related evolution of geosphere processes so as to underpin safety case studies for a UK GDF.
- To review whether the impact of tectonism and earthquakes, over the post-closure period, could have a significant impact on a UK GDF and surrounding geology.
- To review whether the magnitude of earthquakes expected in the UK over the post-closure period, including glacially-induced seismicity, could have a significant impact on the performance of a UK GDF and surrounding geology.

Scope

The scope of this task comprises a periodic review of the UK and international understanding of tectonism and earthquakes, building on the recent BGS project. The impact of these natural processes and events over the lifetime of the GDF will be considered with respect to their potential to influence GDF performance.

Further information

Relevant publications include:
### Task Number

**336**

### Status

Start date in future

### PBS level 4

Geosphere

### PBS level 5

Uplift, Erosion & Subsidence

### Title

Periodic Review of the Potential Impact of Natural Processes on a GDF – Uplift, Erosion & Subsidence

### Background

The geosphere is a key component of a multi-barrier disposal concept. As noted in the geosphere status report, the geosphere is continually evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety.

In 2013 we published a major review of the potential impact of natural processes on a GDF, “Potential Natural Changes and Implications for a UK GDF”, produced under contract for us by the British Geological Survey. We recognise however that further research, contracted either by RWM or undertaken elsewhere, may make it necessary to update this aspect of our knowledge base. This task comprises such a review.

### Research Need

To support our post-closure safety case by maintaining an understanding of the potential impact of the evolution of the geosphere from the natural processes of uplift, subsidence, erosion and deposition.

### Research Objective

To review whether uplift, subsidence, erosion and deposition processes will be of a magnitude deemed to pose a significant risk to the performance of the GDF over post-closure time scales.

### Scope

The scope of this task comprises a periodic review of the UK and international understanding of the impact of the natural processes of uplift, subsidence, erosion and deposition with respect to their potential to influence GDF performance.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Further information

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>341</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Impacts of Future Climate Change</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Title</strong></td>
<td>Application of Permafrost Modelling Methodology: Consideration of Implications</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Background**

The geosphere is a key component of a multi-barrier disposal concept and it is continually evolving. In order to build confidence in the performance of the geosphere barrier, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the required isolation and containment. While current predictions indicate the next period of glaciation is unlikely to occur for approximately 200,000 years, it is important to consider the effects of glaciation upon the GDF. A number of processes may occur during a glaciation event, including the mechanical deformation of the geosphere in response to ice-sheet loading, surface erosion and the subsequent changes to groundwater flow patterns as the ice-sheet grows and retreats (including the effects of permafrost).

The disposal system specification currently identifies a suitable GDF depth to be in the range 200m to 1000m. Dependent on the location in the UK, it is possible that permafrost formation / decay associated with climate change could affect performance of the geological barrier and engineered barrier system (EBS). This may lead to a requirement to increase the minimum depth of a GDF at a specific UK location to take account of the effects of permafrost. This is an issue that can be progressed in the absence of a site, as permafrost will affect the whole of the UK. The learning from this task will inform whether or not site-specific considerations of permafrost may subsequently need to be undertaken.

**Research Need**

To support the siting process and the environmental safety case by determining the significance on the post-closure system performance of the formation, presence and decay of permafrost at a UK GDF site over a time period of the next one million years (including impacts on the EBS and geosphere safety functions).

**Research Objective**

To identify likely depths of permafrost penetration across the UK, in order to inform the siting process and thereby manage - by choice of suitable depth - the potential for permafrost to significantly affect the performance of at least some of the geological barrier, and the performance of the EBS (e.g. as a result of changing groundwater pathways).

**Scope**

- Desk-based study to model the depth of penetration of permafrost based on historical climatic conditions and the thermal properties of rocks to the order of 1 km depth below the surface. The output will be a contour map showing the depth of permafrost penetration in a reference case and in cases considering uncertainties in rock thermal properties and climate change.
- Desk-based study to model how evolving and decaying permafrost could affect the chemistry of groundwater beneath the permafrost layer, and to investigate if any e.g. salinity increases could detrimentally impact on a GDF (host rock or engineered barrier system), even if below permafrost depth.
- Desk-based study to consider gas hydrate stability in the vicinity of a GDF, related to permafrost conditions.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

**Task Number**: 342  
**Status**: Start date in future

**PBS level 4**  
Geosphere

**PBS level 5**  
Impacts of Future Climate Change

**Title**  
Periodic Review of the Potential Impact of Natural Processes on a GDF - Climate Change

**Background**

The geosphere is a key component of a multi-barrier disposal concept and it is continually evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety.

The most significant aspect of climate change affecting the performance of the GDF is likely to arise in future periods of glaciation; current predictions indicate the next such period is unlikely to occur for approximately 200,000 years. A number of processes may occur during a glaciation event, including the mechanical deformation of the geosphere in response to ice-sheet loading, surface erosion and the subsequent changes to groundwater flow patterns as the ice-sheet grows and retreats (including the effects of permafrost).

In 2013 we published a major review of the potential impact of natural processes on a GDF, “Potential Natural Changes and Implications for a UK GDF”, produced under contract for us by the British Geological Survey. We recognise however that further research, contracted either by RWM (such as our work on permafrost (Task 341)) or undertaken elsewhere, may make it necessary to update this aspect of our knowledge base, particularly in the field of climate science. This task comprises such a review.

**Research Need**

To support the environmental safety case by determining the significance on the post-closure system performance of a UK GDF of climate change over a time period of the next one million years (including impacts on engineered barrier system and geosphere safety functions).

**Research Objective**

To review UK and international developments in the understanding of climate science, and its effect on the geosphere.

**Scope**

The scope of this task comprises a periodic review of the UK and international understanding of climate evolution over the next million years and application of this understanding to consider how climate change might impact the performance of the geosphere, and potentially the engineered barrier system of a UK GDF.

**SRL at task start**: 4  
**SRL at task end**: 4  
**Target SRL**: 4

**End point**: Site Specific Application of Understanding  
**Customer**: Disposal System Safety Case

**Further information**

Relevant publications include:

## Task Number 343

<table>
<thead>
<tr>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geosphere</td>
<td>Impact of Future Climate Change</td>
</tr>
</tbody>
</table>

### Title
PhD to Investigate Signatures of Past Permafrost in Rocks

### Background
The geosphere is a key component of a multi-barrier disposal concept and it is continually evolving. In order to build confidence in the performance of the geosphere in a multi-barrier disposal concept, RWM needs to demonstrate that evolution of the geosphere will not compromise its ability to provide the isolation and containment that are fundamental to ensuring safety. While current predictions indicate the next period of glaciation is unlikely to occur for approximately 200,000 years, it is important to consider the effects of glaciation upon the GDF. A number of processes may occur during a glaciation event, including the mechanical deformation of the geosphere in response to ice-sheet loading, surface erosion and the subsequent changes to groundwater flow patterns as the ice-sheet grows and retreats (including the effects of permafrost).

The disposal system specification currently identifies a suitable GDF depth to be in the range 200m to 1000m. Dependent on the location in the UK, it is possible that permafrost formation / decay associated with climate change could affect performance of the geological barrier and engineered barrier system (EBS). This may lead to a requirement to increase the minimum depth of a GDF at a specific UK location to take account of the effects of permafrost. This is an issue that can be progressed in the absence of a site, as permafrost will affect the whole of the UK. The learning from this task will inform whether or not site-specific considerations of permafrost may subsequently need to be undertaken.

### Research Need
To support the siting process and the environmental safety case by determining the significance on the post-closure system performance of the formation, presence and decay of permafrost at a UK GDF site over a time period of the next one million years (including impacts on EBS and geosphere safety functions).

### Research Objective
- To identify likely depths of past permafrost penetration across the UK, in order to inform the siting process and thereby manage - by choice of suitable depth - the potential for permafrost to significantly affect the performance of at least some of the geological barrier, and the performance of the EBS.
- To investigate if past permafrost has impacted on groundwater chemistry (in the region affected by permafrost and beneath permafrost) and if any signal relating to the potential past presence of gas hydrates can be detected.

### Scope
The scope comprises a PhD study to investigate if historical permafrost has left ‘signatures’ in affected geological media, complemented by a study to build confidence in our understanding of the depth of permafrost penetration as derived from modelling studies and its effect on groundwater chemistry. The PhD will have laboratory-based experimental, field work and modelling aspects.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

### End point
Site Specific Application of Understanding

### Customer
Disposal System Safety Case

### Further information
## Background

The heat generated from high-heat-generating waste will lead to a temperature rise in the surrounding rocks. One of the issues identified in RWM's Issues Register (Issue 142-25) concerns the expansion of the rocks as a result of the temperature rise, and the potential for uplift of the ground surface above the GDF as a result.

Work has been carried out within the High-heat Generating Wastes project to estimate the magnitude of the uplift for the three generic geological environments under consideration by RWM. The analyses performed in the report were simplified in order that the calculations were mathematically tractable, and to provide appropriate insight into the main factors affecting the uplift. This task extends these simple scoping calculations to more appropriately represent the geometry of a GDF and to consider time-dependent behaviour of the GDF material and rocks, such as creep. Following on from this, assessment of the safety case and/or design implications of the potential uplift is required.

## Research Need

To support concept development and the post-closure safety case by developing sufficient understanding of the extent of any expansion of the geosphere (host rock and surrounding rocks) as a result of the thermal evolution of disposed waste in a GDF.

## Research Objective

- To understand the consequences of heterogeneity and variability in relation to rock properties on any thermal uplift and to determine possible implications of any thermal expansion and uplift of the ground surface.
- To identify the main factors that could be used as mitigation measures if it is determined there are any significant consequences of uplift.

## Scope

To conduct a desk based assessment of the potential for thermal uplift considering the properties of real geological environments as well as the physics of thermal expansion.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Further Work to be Defined</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Customer

Disposal System Safety Case, Design

## Further information


NOTE – this report is currently (July 2015) undergoing external peer review, and will need to be raised to Issue 2 in response to peer review comments.
Background

In the Environment Agency (EA) Guidance on Requirements for Authorisation for Geological Disposal Facilities on Land for Solid Radioactive Wastes (EA 2009), the regulator recognises the potential for deep boreholes, such as could be drilled as part of a site investigation process, to affect the integrity of a site area. This potential impact will need to be assessed prior to undertaking any intrusive investigations, and RWM will need to demonstrate that boreholes can be appropriately and adequately sealed. As part of the environmental permitting process, an Initial Site Evaluation (ISE) must be prepared by the developer and approved by the Environment Agency prior to commencement of the site characterisation programme.

In early 2011, we commissioned an initial phase of work to develop illustrative concepts for sealing and abandonment of investigation boreholes. In February 2011, a workshop, facilitated by Jacobs, was convened and attended by international experts in drilling and sealing. A number of reports were subsequently produced, which are available on the RWM bibliography. Phase 1 (let in FY13/14) developed and delivered a contractor-approved report to RWM that presents reasoned and prioritised plans for a structured programme of work that will be delivered in Phase 2 of the project.

Research Need

To support the Initial Site Evaluation (ISE) by demonstrating our ability to meet the requirements of the disposal system safety case in consideration of sealing site investigation boreholes.

Research Objective

To provide scientific evidence and technological demonstration that site investigation boreholes will be sealable to appropriate criteria in a UK context sufficient to support a successful ISE.

Scope

This scope is broken down into two phases. Phase 1 work (now complete) was desk-based and informed the programme of work proposed for Phase 2 by developing reasoned and prioritised plans. Phase 2 consists of further desk-based studies, numerical analysis and experimental studies on materials that could be used in borehole sealing. The project considers the performance of borehole seals both in the short-term and the long-term, covering the GDF operations and post-closure phases respectively. Potential methods of material emplacement to seal site investigation boreholes are also being considered in Phase 2; these are based on current practice where precedent exists.

SRL at task start 5  SRL at task end 6  Target SRL 6
End point  No Further Generic Research Planned
Customer  Site Characterisation, Disposal System Safety Case

Further information

Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>358</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

**PBS level 4**
Geosphere

**PBS level 5**
Hydrogeological Processes

**Title**
Development of Generic Geological Environments

**Background**
RWM has developed a range of disposal system concepts and design specifications, and these are used to support our generic Disposal System Safety Case (gDSSC).

The geosphere, here taken as the geological and hydrogeological environment, provides isolation and containment safety functions to the GDF concept. Generic geological environments have previously been developed as examples of approaches that could be applied to post-closure assessments (see references in Further Information below), but were developed for specific purposes and not integrated more widely across the organisation.

Development of generic geological environments that incorporate potential flow pathways that link to the three generic host rock environments (higher strength, lower-strength sedimentary and evaporite) would aid organisation-wide consistency during the current generic phase of the programme. The term ‘geological’ in this context also represents the hydrogeological and hydrological setting.

**Research Need**
To support design development, disposal system specification development and the disposal system safety case by:
- Promoting consistency across RWM (and in the supply chain) regarding geosphere-dependent assumptions.
- Providing generic geological environments and flow path descriptions for use the gDSSC.

**Research Objective**
To develop generic geological environments for subsequent use across RWM. These models and descriptions will not be based on specific geographical locations, but will relate to geological and hydrogeological settings that are UK-relevant.

**Scope**
The scope of works comprises:
- Review current geosphere-related assumptions used by RWM (i.e. in the disposal system specification, design and gDSSC).
- Where practicable, adapt existing generic geological and hydrogeological conceptual models and narrative descriptions to incorporate the existing geosphere assumptions.
- Develop generic geological environments for a range of typical geological / hydrogeological scenarios relevant to England, Wales and Northern Ireland (incorporating cross-sections, supporting narrative descriptions and potential flow path routes).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
No Further Generic Research Planned

**Customer**
Disposal System Safety Case, Design, Concept Development

**Further information**
This activity will be undertaken in supply chain.

Relevant publications include:
Using Isotopes for Groundwater Ageing and Development of a Site Descriptive Model

Background

The hydrogeological component of site descriptive models (SDM) is developed through evaluation of multiple lines of qualitative and quantitative evidence that cross-correlate the groundwater composition with the geological, structural and geomechanical site setting. Results of geochemical analysis for reactive, non-reactive and isotopic components inform on the nature of water-rock interactions encountered along the flow-path and can be used to ‘date’ groundwater - either by setting time boundaries such that water is ‘older’ or ‘younger’ than a certain value (i.e. has been in the rock for a longer / shorter time), or by quantifying an ‘age’ for groundwater (based on some component within the groundwater such as Eh or pH).

Isotope analysis techniques continually evolve, achieving lower detection limits and improved resolution. In addition, new techniques are developing whilst existing techniques that were previously fundamental in groundwater dating become obsolete to the UK groundwater context (i.e. tritium from bomb testing in 1950’s which has now decayed to below detection limits).

Through research and groundwater testing carried out at Sellafield in the mid-1990’s, the state of knowledge regarding collection of samples and interpretation and use of isotopes is mature. However, the state of knowledge has not been re-visited since then and a knowledge gap regarding available techniques and supply chain capabilities now exists.

Research Need

To support site characterisation by:
- Understanding, and satisfying the knowledge gap regarding the current state-of-the art in the collection of deep groundwater samples and the use of isotope data to develop SDMs.
- Enabling RWM and our supply chain to make use of site-specific groundwater data.

Research Objective

- To evaluate the current state of knowledge regarding groundwater isotope techniques currently adopted by RWM and overseas waste management organisations (WMOs).
- To engage with supply chain to understand emerging and obsolete isotope techniques.
- For RWM and our supply chain / universities to gain experience of applying groundwater sampling techniques and laboratory analysis of isotopes relevant to the UK GDF using groundwater collected from settings analogous to a UK GDF (e.g. an underground rock laboratory (URL)).

Scope

The scope comprises:
- Undertaking a review of the literature regarding groundwater sampling / dating techniques appropriate to the characterisation of the hydrogeology of a GDF, which will be followed by a watching brief of the state-of-knowledge.
- To undertake groundwater sampling and analysis for isotopic (and standard geochemical) components in groundwater collected from an URL.
- Development of an SDM for the URL enabling the use of site-specific data to strengthen supply chain capability and underpin our capability in using real data.

Further information

This task will be undertaken under a studentship at the University of Strathclyde.
Task Number | 360 | Status | Ongoing
---|---|---|---
PBS level 4 | Geosphere | PBS level 5 | Hydrogeological Processes
Title | Specification of Parameter Values Relevant to Generic Geological Environments

Background
In Task 358, generic geological environments were developed to aid consistency of assumptions adopted for the geosphere across RWM and in our supply chain. The physical and chemical attributes of the geosphere (here taken as the geological and hydrogeological environment) have significant bearing on the safety case for geological disposal, including how radionuclides travel and sorb in the geosphere and the role of groundwater chemistry in canister corrosion / barrier system design.

At this current generic phase there is not currently a 'list' detailing a consistent set of assumed geological and hydrogeological parameters. Similarly, illustrative flow paths linking the GDF and surface environments have not been parameterised based on a generic environment.

Research Need
To support design development, disposal system specification development and the disposal system safety case by:
- Promoting consistency across RWM and in the supply chain regarding geosphere-dependent assumptions.
- Generating a consistent set of robustly underpinned parameter values for the geosphere and potential flowpaths linking the GDF to the surface environment.

Research Objective
To develop a standardised, geosphere parameter list representing the physical and hydrogeological attributes defined in the generic geological environments from Task 358.

Scope
The scope of works comprises:
- Reviewing the generic geological environments in Task 358 to identify geological and hydrogeological attributes for which standard parameter values (ranges) are required. The list of parameters to be defined will be agreed in a collaboration between RWM and our contractors.
- Identification of potential pathways for the migration of groundwater or solutes between the GDF and the surface environment for each generic geological environment.
- Reviewing current literature (including from other Waste Management Organisations (WMO)) and the RWM knowledge base to identify appropriate values to populate the parameter list.
- Providing recommendations for further research and development for parameters for which underpinned values are not identified.

| SRL at task start | 4 | SRL at task end | 5 | Target SRL | 5 |
---|---|---|---|---|---|
End point | No Further Generic Research Planned |
Customer | Disposal System Safety Case, Design, Concept Development |

Further information
This activity will be undertaken in supply chain.
### Field-scale Borehole Sealing Experiment: Demonstration of Practicability of Approaches

**Background**

In the Environment Agency (EA) Guidance on Requirements for Authorisation for Geological Disposal Facilities on Land for Solid Radioactive Wastes (EA 2009), the regulator recognises the potential for deep boreholes, such as could be drilled as part of a site investigation process, to affect the integrity of a site. This potential impact will need to be assessed prior to undertaking any intrusive investigations, and RWM will need to demonstrate that boreholes can be appropriately and adequately sealed. As part of the environmental permitting process, an Initial Site Evaluation (ISE) must be prepared by the developer and approved by the Environment Agency prior to commencement of the site characterisation programme.

In early 2011, we commissioned an initial phase of work to develop illustrative concepts for sealing and abandonment of investigation boreholes. In February 2011, a workshop was attended by international experts in drilling and sealing. A number of reports were subsequently produced, which are available on the RWM bibliography. Phase 1 (let in FY13/14) developed and delivered a contractor-approved report to RWM that presents reasoned and prioritised plans for a structured programme of work that will be delivered in phase 2 of the project. Phase 2 itself (Task 356) is now let and in progress, and will run from FY14-15 to FY16-17. This task sheet covers phase 3 of the project.

**Research Need**

- To demonstrate our understanding of the requirements relating to the sealing of site investigation boreholes in the context of the ISE and long-term performance of the site, such as is considered in the environmental safety case.
- To ensure that, if required, a programme of research is developed and undertaken to meet the requirements of the disposal system safety case in consideration of sealing site investigation boreholes.

**Research Objective**

To provide scientific evidence and technological demonstration that site investigation boreholes will be sealable to appropriate criteria in a UK context sufficient to support a successful ISE.

**Scope**

Phases 1 and 2 of the current borehole sealing project are desk- and laboratory-based, and the laboratory-based work is small scale. This task covers phase 3 of the project, and extends the scale of demonstration of competence and practicability of approaches regarding sealing site investigation boreholes to the field scale. Learning from phases 1 and 2 of the project will be the starting point; interactions with sister companies (e.g. SKB and Posiva) in relation to knowledge, capability and experience exchange will be progressed as an integral component of this phase of the project.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>5</th>
<th>SRL at task end</th>
<th>6</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Site Characterisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

- Jacobs, 2013, Factors Influencing Borehole Design
- AMEC, May 2014, Sealing Deep Site Investigation Boreholes: Phase 1 Report, AMEC report to RWM, 201257/002 Issue B.
Status of Knowledge Review of Groundwater and Groundwater Chemistry Research

Background

Groundwater movement and chemistry have safety relevance to a GDF and have been studied in the UK for over three decades. In addition, this research is complemented by that undertaken by international WMOs. Whilst RWM is currently in a generic phase, from early 2017 communities can engage with us regarding prospects for hosting a GDF. Our research therefore needs to forward look, being able to transition from a generic and site-specific programme.

A state of the knowledge review is required to understand what gaps and outstanding questions (if any) exist relating to groundwater movement and chemistry specific to the development of a GDF. This needs to consider evolving research needs for a site-specific programme. The findings of the review will inform RWM’s needs driven research programme but will also provide confidence to internal and external stakeholders that research (undertaken and proposed) addresses knowledge gaps and outstanding questions.

Research Need

- To record outstanding groundwater movement and groundwater chemistry knowledge gaps and outstanding questions relevant to GDF programmes (UK and overseas), at both generic and site specific stages (considering each host environment separately (i.e. strength sedimentary rocks (LSSR), Higher Strength Rock (HSR) and Evaporites)).
- To produce a strategy through which identified knowledge gaps and questions are closed-out within RWM’s needs driven research programme.

Research Objective

To understand what knowledge gaps and outstanding questions regarding groundwater movement and chemistry currently exists relating to GDF programmes based on a review of research completed, in progress or planned by RWM and international WMOs.

Scope

A contractor report will be prepared to:
- Document and summarise the knowledge gaps and questions being addressed by current research within RWM and international WMOs relating to generic and site specific stages (considering each host environment separately).
- Record knowledge gaps and questions closed-out by past research undertaken by RWM and international WMO’s.
- Identify research needs relevant to RWM’s programme (at both generic and site specific stages for each host environment). This will be based on:
  • review of recommendations / conclusions in published reports, papers or technical notes by RWM and WMOs.
  • identification of knowledge gaps and outstanding questions considered by WMOs not historically considered by RWM, and which are not currently planned to be evaluated.
  • identification of research activities by WMOs that have advanced the knowledge base beyond RWM’s currently documented understanding.

The findings of the report will be used by RWM to identify future research needs.

<table>
<thead>
<tr>
<th>Task Number</th>
<th>363</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Hydrogeological Processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SRL at task start 4  | SRL at task end 5  | Target SRL 5  |
End point          | Further Work to be Defined |
Customer           | Disposal System Safety Case |

Further information
Stress-induced anisotropy in crustal rocks and its influence on underground excavations

Background
Shallow underground excavations are engineered for numerous reasons, from hydroelectric stations to deep level underground railways. Whilst the challenges are generally understood in short timescales expected in a civil engineering context, the stability of such structures over geological timescales (of thousands to hundreds of thousands of years) is poorly known. However, such data are now gaining new importance for the purposes of Geological Disposal Facilities, both in the UK and overseas.

Well-controlled laboratory studies have the potential to provide the required information. The approach has the advantage that key parameters of stress, temperature and strain may be directly monitored and controlled. As a result of recent technological advances this can now be achieved using the synergy created by the new generation of rock physics testing apparatus and acoustic emission instrumentation that can operate in both passive and active mode. In such studies, emphasis should be placed on the complex interplay between the pressure and temperature of the formation and the influence of these variables on the deformation of the rock in "creep" mode – where the rock fails at a stress level far below its nominal strength due to being loaded at temperature over an extended time in the presence of active fluids (a process called "stress corrosion").

Developing a knowledge of this overall bulk anisotropy and stress corrosion will allow RWM greater understanding of the long term evolution of the rock mass around the GDF and is important in developing monitoring methods of the repository via long-term active or passive seismic surveys. Further, this research will elucidate the feedback between rock mass damage evolution at elevated temperature/stress (if any) and the fluid permeability (and permeability anisotropy) of the rock mass.

Research Need
To support the development of the safety case and the engineering design of the disposal facility, and to demonstrate confidence to stakeholders that the geosphere of a potential disposal facility site is adequately understood, there is a requirement to build understanding of the stability of underground excavations over timescales of thousands to hundreds of thousands of years.

Research Objective
To build an understanding of the short-term and long-term stability of rock caverns through a well-controlled laboratory approach in which recent technological advances are employed.

Scope
This laboratory-based task will investigate the influence of externally-applied stress fields as a function of the natural anisotropy using several rock types. New rock physics laboratory investigation techniques will be utilised to establish stress corrosion of rock over long time scales. This will be achieved by measuring the overall anisotropy of the rock mass, using P-wave tomography methods, as it changes due to the overprinted mechanical stresses (from overburden and due to cavity excavation) and the inherent anisotropy in the rock mass itself.

The changing P-wave anisotropy will then be used as a diagnostic tool and related to other rock physics parameters, principally the evolving permeability along the sample symmetry axis. These parameters are fundamental in all branches of rock mechanics, allowing rock physical properties to be used with confidence when they are otherwise unavailable.

SRL at task start 4  |  SRL at task end 5  |  Target SRL 5  |
End point  Site Specific Application of Understanding  |
Customer  Site Characterisation  |

Further information
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>372</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PBS level 4**  
Geosphere

**PBS level 5**  
Chemical Processes

**Title**  
Review of Understanding and Approach to Modelling Rock Matrix Diffusion (RMD)

**Background**
Most groundwater flow in higher-strength rocks takes place through a network of interconnected fractures. The radionuclides are transported ('advected') through these fractures by the flowing groundwater. The fractures provide surfaces on which radionuclides being transported by this flowing groundwater can sorb. However, much of the porosity and mineral surfaces in fractured rocks occur not in the fractures but in the rock between the fractures (the rock 'matrix'). Radionuclide migration through the geosphere would be further slowed if this additional porosity and surface can be accessed. The mechanism by which radionuclides are transported through the pore water into the low permeability rock matrix is diffusion. In the context of diffusive transfer between fracture and rock matrix, the process is termed 'rock-matrix diffusion'.

**Research Need**
To support the post-closure safety case by ensuring that RWM is aware of the current knowledge base that could be relevant to a GDF in a UK higher-strength rock drawing learning from SKB and Posiva (in particular) in relation to their respective ongoing studies.

**Research Objective**
To develop a review report that can subsequently underpin the consideration of rock-matrix diffusion in the disposal system safety case (DSSC).

**Scope**
The scope comprises a desk based review drawing on the learning from e.g. “SKB Task Force on Modelling of Groundwater Flow and Transport of Solute” Task 9: Increasing the realism in solute transport modelling – Modelling the field experiments of REPRO and LTDE-SD” and other expert sources, as available. To acknowledge that rock-matrix diffusion behaviour in situ and in laboratory-based experiments can differ, e.g. due to relaxation of rock core on extraction, and to consider approaches to dealing with the extrapolation of laboratory-based knowledge to the field-scale at a specific site.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**  
Site Specific Validation

**Customer**  
Disposal System Safety Case

**Further information**
Task Number | 373 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Geosphere | | |
PBS level 5 | Chemical Processes | | |

**Title**
Knowledge Capture - Summary Paper Collating Learning and Experience from EC PADAMOT Project (Palaeohydrogeology-basis)

**Background**
Chemical composition and groundwater flow are the key factors influencing containment within a GDF, affecting radionuclide mobility. Climate changes occurring during the Quaternary resulted in large areas of Britain and northern Europe being covered by ice sheets. This could have significantly influenced both chemistry and flow of deep groundwaters:

- Glacial meltwater recharge beneath ice sheets is fresh and highly oxidising (up to 300 mg/l dissolved O₂), and may penetrate to GDF depth, driven by the high glacial head;
- Periglacial conditions existed for much of the Quaternary, during which permafrost may have restricted freshwater recharge leading to a rise in deeper saline groundwater;
- Lowering of sea level during glacial periods may increase hydraulic gradient and freshwater flow in coastal regions;
- The saline-freshwater interface may rise and move landward as a result of sea level rise during interglacial periods.

An important requirement of the safety assessment for a geological disposal facility (GDF) for radioactive waste is to be able to demonstrate the long-term chemical stability of the groundwater system at GDF-relevant depth over the period of time during which the waste will be a hazard, typically up to one million years. The potential impact of future climate change on deep groundwater systems is therefore relevant to the safety assessment for a GDF. The last one million years (Quaternary Period) saw the climate in northern Europe vary between extremes of ice ages and conditions warmer than today. The present-day climate is not representative of that which existed for much of the Quaternary. Observations of the impacts of past Quaternary climate changes (i.e. ‘palaeohydrogeology’) may therefore provide valuable information on how the modern groundwater system might respond to future climate changes. Of particular concern in the UK is the potential for oxidising groundwater to penetrate to GDF depth during periods of glaciation, thereby increasing the mobility of some transuranic radionuclides.

**Research Need**
To support the post-closure safety case by documenting the current understanding of UK palaeohydrogeology, in the context of deep geological disposal, in a peer reviewed academic journal.

**Research Objective**
- To collate precedent information relating to palaeohydrogeological studies and the learning that can be gained for deployment in a UK context, and to prepare an academic paper.
- To progress the paper to journal publication, therefore providing a peer-reviewed reference for subsequent use in the RWM programme as appropriate.

**Scope**
In relation to palaeohydrogeological studies, considerable work was carried out under the EC Framework IV and V PADAMOT (Palaeohydrogeological Data Analysis and Model Testing) and EQUIP projects, and the BGS Core Research programme, with additional information from the United Kingdom Nirex Limited site investigation programme at Sellafield, UK. This work has not been reported in a peer-reviewed, accessible state, and hence a reference for precedent UK palaeohydrogeological work is not available. This task rectifies this situation; an academic paper for publication in a peer-reviewed scientific journal will be produced.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**
<table>
<thead>
<tr>
<th>Task Number</th>
<th>381</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Long-term Cement Study (LCS) at Grimsel Test Site, Including Consideration of the Cyprus Natural Analogue Project Dataset

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent, in space and time, of the impact of a GDF is influenced by the host rock properties and properties of the surrounding geosphere, as well as the GDF design and operations. One of the most significant impacts of the GDF on the chemistry of the host rock is expected to be the effect of high-pH water from cement-based materials used in the engineered barrier system (EBS). The interaction between high-pH waters and a number of different rock types was extensively studied in the 1990s. RWM has a good understanding of the expected mineralogical changes that will occur when Ca-rich high-pH water (typically pH 12 and above) contacts the surrounding rock, such as the formation of secondary calcium-silicate-hydrate (CSH) phases. However, the spatial extent of the interaction and the consequences for groundwater movement remain uncertain. The understanding of the effect of interactions between rocks and lower-pH water (in the pH range 10–11) is also less well-developed.

As this is an area where there is a need to increase our process-level understanding, RWM is participating in the LCS international collaborative research programme on cement-rock interaction, based at the Grimsel Test Site in Switzerland. We have also participated in the Cyprus Natural Analogue Project (CNAP) - an international collaborative research programme on alkali plume-clay interaction at a natural analogue site where an alkaline plume has been interacting with clay rocks for hundreds of thousands of years - as well as similar investigations of Maqarin and Tournemire (see further information). This task supports our continued participation in the LCS project and aims to combine our learning from the Grimsel Test Site and natural analogue studies.

**Research Need**

To support the post-closure safety case and concept development through a more robust understanding of how cement leachates, derived from the EBS, will interact with the host rock and bentonite components within a GDF system.

**Research Objective**

- To determine whether the evolution of cementitious materials in the EBS will affect the surrounding geology in the post-closure phase, for example by modifying the permeability of fractures through precipitation of secondary mineral phases or by releasing an alkali plume that may interact with other GDF components.
- To determine whether any such changes will challenge the safety case.'

**Scope**

The scope comprises our participation in the LCS project at the Grimsel URL. Further utilisation of the CNAP dataset will consider interactions of a low alkali plume and a clay medium, to understand if field and laboratory observations can be replicated in a numerical-modelling based approach using existing toolkits, thereby validating our mechanistic understanding.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

Relevant publications include:

Blind Reactive-Transport Modelling of the LCS In Situ Experiment, Quintessa report to RWM, In preparation.


DECOVALEX: Laboratory Study of the Interaction of a Groundwater with a Fresh Fracture

Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as 'THMC coupled processes' to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM's geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

THMC coupled processes for fractured rocks is an extremely complex area of scientific research which may have a significant bearing on the potential design and performance of radioactive waste disposal facilities. The DECOVALEX project (DEvelopment of COupled models and their VALidation against Experiments) is an international research and model comparison collaboration, initiated in 1992, for advancing the understanding and modelling of coupled THM and THMC processes in geological systems. Prediction of these coupled effects is an essential part of the performance and safety assessment of geological disposal systems. Through this collaborative work, in-depth knowledge has been gained of coupled THM and THMC processes, as well as the suitability of numerical simulation models for their quantitative analysis. This task represents RWM's participation in DECOVALEX, with the aim of develop understanding, knowledge and experience relevant to THMC processes in fractured rock.

Research Need

To support safety case development by maintaining an understanding of international developments relating to the modelling of THMC processes and their relevance to UK disposal concepts.

Research Objective

To develop and validate our THMC modelling approach in fractured rock by modelling two experiments which observe coupled THMC responses in single fractures. To develop the UK skills base and awareness of international modelling capabilities in this field.

Scope

The scope comprises the:

- Investigation, development and testing of robust process models for the representation of coupled THMC processes in fractured rock by using the experimental data.

Further information

Relevant publications include:

http://www.decovallex.org/task-c1.html


H. Yasuhara, N. Kinoshita, H. Ohfuji, D.S. Lee, S. Nakashima, and K. Kishida, 2011, Temporal Alteration of Fracture Permeability in Granite under Hydrothermal Conditions and Its Interpretation by Coupled Chemo-
mechanical Model. Applied Geochemistry 26: 2074–2088.
DECOVALEX: SEALEX Experiment at Tournemire URL Investigating Resaturation of Bentonite Plugs (Hydro-mechanical)

Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

THMC coupled processes in lower strength sedimentary rocks is an area of scientific research which may have a significant bearing on the potential design and performance of radioactive waste disposal facilities. The DECOVALEX project (DEvelopment of COupled models and their VALidation against Experiments Task ) is an international research and model comparison collaboration, initiated in 1992, for advancing the understanding and modelling of coupled THM and THMC processes in geological systems. Prediction of these coupled effects is an essential part of the performance and safety assessment of geological disposal systems. Through this collaborative work, in-depth knowledge has been gained of coupled THM and THMC processes, as well as the suitability of numerical simulation models for their quantitative analysis.

The SEALEX experiment was built at the Institute for Radiological Protection and Nuclear Safety (IRSN) Underground Research Laboratory (URL) at Touremire, France, with a specific focus on sealing systems’ efficiency (cell seals, gallery seals, shaft seals) via limited-size in-situ experiments focused on performance in the long-term (i.e. under isothermal and water-saturated conditions) utilising clay cores. The project aims to identify parameters (technical specifications, design, construction, defects, etc.) that will control the performance of swelling clay-based sealing systems in the long-term. This task represents RWM’s participation in the DECOVALEX SEALEX project whereby the experimental data are provided to international participants as a basis for their model development and validation.

Research Need

To support safety case development by maintaining an understanding of international developments relating to the modelling of THMC processes and their relevance to UK disposal concepts. To develop the UK skills base and awareness of international modelling capabilities in this field.

Research Objective

- To test the long-term hydraulic performance of sealing systems (in normal conditions, i.e. not chemically or thermally altered) for different core compositions (pure MX80, sand / MX80 mixtures) and conditioning (pre-compacted blocks or in situ compacted powder).
- To quantify the impact of intra-core geometry (construction joints in the case of pre-compacted blocks) on the hydraulic properties of sealing systems.
- To quantify the effect of altered conditions (i.e. incomplete saturation of the swelling clay or an incidental decrease of the swelling pressure caused by a failure of the concrete confining plugs) on sealing system performance so as to test concept robustness with respect to the hydraulic characteristics of the system.

Scope

The scope is organised in a progressive manner in terms of complexity of the computations to be performed, targeting the full HM understanding of the SEALEX experiment, which is the final objective of this task.

<p>| SRL at task start | 3 | SRL at task end | 4 | Target SRL | 5 |</p>
<table>
<thead>
<tr>
<th>End point</th>
<th>Site Specific Application of Understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

- [http://www.decovalex.org/task-a.html](http://www.decovalex.org/task-a.html)


Appendix B - 140

<table>
<thead>
<tr>
<th>Task Number</th>
<th>386</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Ongoing</td>
</tr>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
</tr>
<tr>
<td>Title</td>
<td>EPSRC GEOWASTE WP2: Behaviour of the Clay-Grout-Rock Interfaces</td>
</tr>
</tbody>
</table>

Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

This task comprises such an academic study. It is co-funded by RWM and the Engineering and Physical Sciences Research Council (EPSRC) under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. The task aims to investigate novel monitoring techniques to investigate the mechanism of the interactions at the interface between clay, grout and rock surfaces.

Research Need

To support the post closure safety case by developing an improved understanding of the impact of coupled THMC processes on engineered barrier systems.

Research Objective

Across eight work packages in the SAFE consortium, to deploy and refine advanced monitoring techniques for simultaneous imaging of THMC variables (pH, temperature, pore-water pressure, swelling, etc.) within the laboratory, and to integrate these monitoring techniques with experiments to gain a predictive understanding of the THMC evolution of clay-based engineered barriers, and their interfaces, up to the upper-bound of realistic environmental conditions.

Scope

The scope comprises the development of a mechanistic understanding of the clay-grout-rock interface, investigating the effect of sharp gradients in pH across the interfaces of the engineered barrier system.

SRL at task start 3  SRL at task end 4  Target SRL 4

End point Site Specific Application of Understanding

Customer Research (‘Curiosity Driven’), Disposal System Safety Case

Further information

RWM’s role in SAFE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case. The SAFE consortium comprises the universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff and Oxford, together with the British Geological Survey.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>387</td>
<td>Ongoing</td>
<td>Geosphere</td>
<td>Coupled Processes</td>
</tr>
</tbody>
</table>

**Title**

EPSRC GEOWASTE WP3: Thermal-Hydraulic-Mechanical-Chemical (THMC) Processes in Bentonite at Temperatures in Excess of 100°C (up to 150°C)

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

This task comprises such an academic study. It is co-funded by RWM and the Engineering and Physical Sciences Research Council (EPSRC) under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. The task aims to investigate the role of THMC processes in bentonite at temperatures above 100°C, where structural degradation resulting in inhibition of the swelling capacity of the clay (an important safety function) may occur.

**Research Need**

To support concept development and the post-closure safety case by developing a mechanistic understanding of the impact of elevated temperatures on the behaviour of bentonite.

**Research Objective**

Across eight work packages in the SAFE consortium, to deploy and refine advanced monitoring techniques for simultaneous imaging of THMC variables (pH, temperature, pore-water pressure, swelling etc.) within the laboratory, and to integrate these monitoring techniques with experiments to gain a predictive understanding of the THMC evolution of clay-based engineered barriers, and their interfaces, up to the upper-bound of realistic environmental conditions.

**Scope**

Uncertainty exists in relation to the effects of temperature up to 150°C on smectite to illite decomposition and the coupled hydraulic processes: theoretical models exist, but experimental data are sparse. In this task, theoretical formulation development, solution algorithms and numerical simulations of processes occurring under elevated temperatures will be investigated; particular attention will be paid to moisture redistribution and pore-gas behaviour, with reference to preferential moisture redistribution and direct thermal impacts. Chemical / geochemical changes will be induced due to both moisture /gas movements and direct diffusion processes. The experimental work will involve non-isothermal elevated temperature experiments, with temperatures up to 150 °C at one face of the clay barrier and moisture inflow at a fixed low temperature on the opposing face of the bentonite barrier.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Application of Understanding

**Customer**

Disposal System Specification, Disposal System Safety Case

**Further information**

RWM’s role in SAFE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case.

---

Appendix B - 141
Appendix B - 142

<table>
<thead>
<tr>
<th>Task Number</th>
<th>388</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>EPSRC GEOWASTE WP5: THMC Behaviour of Bentonite Along Block Interfaces</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. Therefore the approach during the current phase is to maintain an understanding of the key processes and their expected impacts and significance on the different potential host rocks so that this understanding can be used appropriately in decision-making. RWM is currently participating in a number of collaborative projects which seek in part to address the potential impact of a GDF on the surrounding environment. Once site(s) and concepts(s) have been developed, site-specific processes will be studied in more detail. The coupling of these processes, rather than their individual impacts, is particularly significant for the performance of a GDF.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled (referred to frequently as ‘THMC’ Processes). As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in the current preparatory studies phase RWM is developing its understanding of the expected couplings and developing appropriate modelling capabilities.

**Research Need**

To support the post-closure safety case by developing an improved understanding of the impact of coupled THMC processes on engineered barrier systems.

**Research Objective**

To determine whether understanding of coupled THMC processes of relevance to a GDF can be enhanced through development and deployment of novel monitoring techniques to investigate components of the engineered barrier systems and their evolution.

**Scope**

THM behaviour of bentonite blocks at block to block interfaces, to ascertain how interfaces (gaps) respond to e.g. bentonite resaturation and increasing temperature conditions, as present in the early stage of a GDF post-closure evolution (as the engineered barrier system evolves towards a long term steady state).

To be undertaken by SAFE consortium (Universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff, Oxford, and BGS)

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
<th>SRL at task end</th>
<th>3</th>
<th>Target SRL</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Research ('Curiosity Driven'), Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

RWM’s role in SAFE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case. The SAFE consortium comprises the universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff and Oxford, together with the British Geological Survey.
### Background

An important consideration for the evolution of the disposal system is that many processes are coupled. These are frequently referred to as 'THMC coupled processes' to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. Our reference concept for the disposal of HLW / Spent Fuel in higher strength and lower strength rock utilises a bentonite buffer in contact with a disposal container in order to maintain the chemical and physical conditions necessary to protect the metallic container from corrosion. The primary safety function of the bentonite requires it to maintain a specified swelling pressure upon resaturation; however, a number of coupled processes (such as its possible thermal degradation and hydrochemical erosion) could challenge its performance.

As we continue to develop our knowledge base on the evolution of bentonite buffer material via in-situ and laboratory experiments the ability to monitor key physical parameters would be beneficial. This task is co-funded by RWM and the Engineering and Physical Sciences Research Council (EPSRC) under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. The task aims to develop detailed numerical mechanistic formulations based on experimental evidence (as produced from other work packages in the SAFE consortium), and to simulate the impact on field-scale behaviour.

### Research Need

To support the post-closure safety case by developing an improved understanding of the impact of coupled THMC processes on engineered barrier systems.

### Research Objective

Across eight work packages in the SAFE consortium, to deploy and refine advanced monitoring techniques for simultaneous imaging of THMC variables (pH, temperature, pore-water pressure, swelling etc.) within the laboratory, and to integrate these monitoring techniques with experiments to gain a predictive understanding of the THMC evolution of clay-based engineered barriers, and their interfaces, up to the upper-bound of realistic environmental conditions.

### Scope

This work package aims to improve existing THMC models relating to bentonite to include the processes and phenomena investigated experimentally in other work packages of the SAFE consortium.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
</table>

### End point

Site Specific Application of Understanding

### Customer

Research ('Curiosity Driven'), Disposal System Safety Case

### Further information

RWM’s role in SAFE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case. The SAFE consortium comprises the universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff and Oxford, together with the British Geological Survey.
Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects, are central to RWM’s geosphere research. In our current phase of the programme we are supporting international collaborations and academic studies in this field.

One such task (under the HydroFrame project) is being undertaken under our collaboration with the Natural Environment Research Council (NERC) and the Environment Agency, with the objective of extending previously developed methodology to rheologically realistic, three-dimensional networks. The main outcomes will be a set of new and/or improved methodologies, codes and protocols for analysing various processes that occur during the lifetime of a GDF. We are co-funding this project under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

Research Need

To build up expertise and capability in modelling hydromechanical and biogeochemical processes that occur in fractured rock masses in the vicinity of a GDF. The main outcomes will be a set of new and/or improved methodologies, codes and protocols for analysing various processes that occur during the lifetime of a GDF.

Research Objective

To extend previously developed methodology to rheologically realistic, three-dimensional networks, to give a quantitative understanding of how transmissivity of a volume of rock depends on transmissivities of individual fractures and their degree of interconnectivity.

Scope

A simple methodology for estimating overall transmissivity of a two-dimensional fracture network will be extended to three dimensions, with particular emphasis on incorporating as much ‘geological realism’ into the fracture network geometry as possible.

Further information

RWM’s role in HydroFrame is in supporting the academic cohort by reviewing the technical output of the project and its applicability to RWM.

Relevant further information can be found in the following:

http://www.nerc.ac.uk/research/funded/programmes/rate

For further information on the previous EPSRC/NDA case studentship (2009-2012) see:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Geosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
</tr>
</tbody>
</table>

**Title**

NERC RATE (HydroFrame) WP4: Hydro-thermo-mechanical and Fracturing Processes in Fractured Rocks Around a Repository

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as 'THMC coupled processes' to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings, and a capability to model those effects, is central to RWM's geosphere research. In our current phase of the programme we are supporting international collaborations and academic studies in this field.

This task, under the Hydroframe project, is being undertaken under our collaboration with the Natural Environment Research Council (NERC) and the Environment Agency, with the objective of developing a 3D-THM-coupled model of geomechanically-driven 3D-flow behaviour in fractured rock systems. The main outcomes will be a set of new and/or improved methodologies, codes and protocols for analysing various processes that occur during the lifetime of a GDF. We are co-funding this project under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

**Research Need**

To support the safety case for operations and post-closure by developing new and/or improved methodologies, codes and protocols for analysing hydromechanical and geochemical processes (in fractured rock mass) that occur during the lifetime of a GDF.

**Research Objective**

To develop new / improved methodology to model the properties of fractured rock masses with regards to the influence of these properties on the performance of a GDF.

**Scope**

The scope comprises the following:

- Development of a highly accurate discrete fracture and matrix flow model that incorporates mesh refinement within realistic 3D-fracture networks, and includes fracture-matrix coupling.
- At the <1m scale, apply 3D-modelling to study fracture tip behaviour and fracture coalescence.
- At the 1-10m scale, apply 3D-fracture modelling and alternative network creation methods to generate fully 3D-fracture and matrix models to study geomechemically-driven 3D-flow behaviour.
- Development of a thermal element so that the effects of radioactive decay heating, in both the near-field and far-field of a repository, can be modelled.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point** Site Specific Application of Understanding

**Customer** Research ('Curiosity Driven'), Disposal System Safety Case

**Further information**

RWM’s role in HydroFrame is in supporting the academic cohort by reviewing the technical output of the project and its applicability to RWM.

Relevant further information can be found in the following:

http://www.nerc.ac.uk/research/funded/programmes/rate

---

Appendix B - 145
<table>
<thead>
<tr>
<th>Task Number</th>
<th>392</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**
NERC RATE Hydroframe Project WP6: Do Microbes and Natural Organic Matter Lead to Increased Actinide Mobility in Fractured Rocks?

**Background**
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings, and a capability to model those effects, is central to RWM’s geosphere research. In our current phase of the programme we are supporting international collaborations and academic studies in this field.

This task, under the HydroFrame project, is being undertaken under our collaboration with the Natural Environment Research Council (NERC) and the Environment Agency, with the objective of extending a standard chemically coupled reactive transport model to include microbial processes. The main outcomes will be a set of new and / or improved methodologies, codes and protocols for analysing various processes that occur during the lifetime of a GDF. We are co-funding this project under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

**Research Need**
To support the safety case for operations and post-closure by developing new and / or improved methodologies, codes and protocols for analysing hydromechanical and geochemical processes (in fractured rock mass) that occur during the lifetime of a GDF.

**Research Objective**
- To develop a new and improved methodology that can model the properties of fractured rock masses with regards to the influence of these properties on the performance of a GDF.
- To extend a standard chemically coupled reactive transport model to include microbial processes such that it can represent actinide mobility.
- To determine whether biological processes need explicit inclusion in process-level models or whether they are bounded by existing chemical models.

**Scope**
The scope comprises:
- Undertaking studies with uranium and neptunium in order to improve our understanding of sorption processes, the extent of sorption and the effect of microbial processes.
- Development of a verified reactive transport model for the modelling of coupled THMC&B (i.e. biological) processes in the geosphere at a potential GDF site.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Research (‘Curiosity Driven’), Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**
RWM’s role in HydroFrame is in supporting the academic cohort by reviewing the technical output of the project and its applicability to RWM. Relevant further information can be found in the following:
http://www.nerc.ac.uk/research/funded/programmes/rate
**Task Number**: 393  
**Status**: Ongoing

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Geosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
</tr>
</tbody>
</table>

**Title**
Review of Implications of Extended GDF Operations on Geosphere Properties

**Background**
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

Understanding the perturbation to the evolution of the host rock and the surrounding geosphere as a result of the construction and operation of a GDF is a topic that we are progressing within our programme and through our involvement in international collaborations such as the ongoing DECOVALEX project. This complementary task considers how properties of the geosphere in the zone of rock affected by the introduction, operation and closure of GDF infrastructure (access tunnels, shafts, vaults, etc.) evolves with time, from undisturbed state prior to GDF construction to a long-term steady state in the post-closure period. This knowledge of this evolution will facilitate communication with scientists and engineers familiar with the evolution of voids (from e.g. a construction and mining perspective) and will provide input to the safety case. Evolving geosphere properties may also need to be considered quantitatively in post-closure performance assessment calculations, dependent on the likely significance of impact. As well as potential changes to the hydrogeological properties (e.g. permeability and porosity) of the disturbed zone, mechanical and chemical changes need to be considered (including Eh, pH, oxygen profile, temperature, presence of groundwater, presence of gas and microbiological changes).

This task is of particular significance when considering a possible period of extended retrievability.

**Research Need**
To support the disposal system safety case by developing a better understanding of the implications of extended GDF operations on the safety functions provided by the geosphere.

**Research Objective**
- To determine whether an extended period of retrievability could have a detrimental impact on the subsequent post-closure performance of the geosphere.
- To determine whether an operational phase of in excess of 100 years could have a detrimental impact on the subsequent post-closure performance of the geosphere and how any such effects should be mitigated.

**Scope**
The scope comprises a review of the possible impact of prolonged opening on the surrounding geosphere, and identification of processes of possible impact on the performance of the disposal system requiring further investigation.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**  
Site Specific Review of Analogue Application

**Customer**  
Disposal System Specification, Disposal System Safety Case

**Further information**
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
<th>Status</th>
<th>Complete, pending publication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geosphere</td>
<td>Coupled Processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Co-locating Disposal Modules of a GDF – Derivation of Approach to Determine Separation Distances

**Background**

The UK Higher Activity Waste inventory requiring disposal comprises distinct waste types, requiring distinct disposal concepts. Any interaction between such different concepts needs consideration in GDF research and assessment studies to understand if there is a possibility of one concept detrimentally affecting another as the GDF as a whole evolves post-closure via e.g. the groundwater pathway. As an example, the concept for the disposal of HLW and Spent Fuel (SF) is based on containing wastes for many millennia (achieved by the choice of appropriate container material and use of a bentonite clay buffer), whereas the disposal concept for ILW (and Long Lived LLW) is based on providing a highly alkaline cementitious chemical barrier that reduces the mobility of any radionuclides that migrate from thinner walled / vented waste packages. Considering the HLW / SF and ILW concepts, an issue concerns the potential for a plume of alkaline groundwater to migrate from the ILW / LLW module of a GDF to the HLW / SF module, where it could disrupt the ability of the bentonite clay buffer to fulfil its safety functions.

Consideration is therefore required in relation to a range of coupled THMC process interactions that could potentially be sourced in one module of a GDF, yet affect another module to the extent that the disposal concept is unable to maintain its desired purpose.

The preference for a co-located facility for waste categories does however allow for disposal in geographically-separated modules accessed from a common surface facility. This task has been commissioned with the objective of deriving a potential methodology for determining a tolerable separation distance between disposal areas containing different types of waste.

**Research Need**

To support concept and design development by identifying robustly derived parameters for the separation distance between GDF disposal modules.

**Research Objective**

- To underpin / revise the assumed minimum separation distance of 500m between GDF modules for specific waste categories.
- To identify appropriate tolerability limits for model parameters used in the coupled model.

**Scope**

The scope comprises a review of previous work on co-location, development of a coupled model, investigation of the sensitivity of the model to input parameters and identification of bounding limits.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Further Work to be Defined

**Customer**

Design

**Further information**


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>395</td>
<td>Ongoing</td>
<td>Geosphere</td>
<td>Coupled Processes</td>
</tr>
</tbody>
</table>

**Title**

LASMO: Hydrogeochemical Modelling in Response to Rock-mass Perturbations (Loading / Unloading) at the Grimsel Test Site

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. One particular uncertainty relates to how the mechanical and hydraulic characteristics of disposal vaults will respond to ongoing construction activities elsewhere in the GDF.

RWM is currently participating in a number of collaborative projects which seek, in part, to address the potential impact of a GDF on the surrounding environment. One such collaboration is through our membership of the Swiss-led collaborative research programme at their Grimsel Underground Research laboratory. Future hydro-electric generation related construction activities at Grimsel have required the overlying lake to be partially drained; development of a further neighbouring tunnel is being considered. Not only does this provide an opportunity to observe the effect within a GDF of the changing stress fields introduced by such changes, but it also provides an opportunity for the testing of innovative detection technologies. This task covers such studies.

**Research Need**

To the disposal system safety case and site characterisation by developing technologies suitable for monitoring the response of a potential host rock volume to construction of a GDF, and by developing techniques for passive host rock characterisation respectively.

**Research Objective**

- To develop and utilise the current Grimsel site descriptive model (SDM) to determine whether regional hydrogeological and hydrochemical conditions are affected by significant perturbations in rock mass.
- To utilise the unloading of overlying rock mass from the draining of Grimsel Lake as a proxy for the disturbance induced during GDF construction, to identify implications for a GDF safety case.

**Scope**

The scope comprises RWM’s participation in this international multi-partner project located at the Grimsel Test Site in Switzerland. Our contribution will involve supporting a PhD project providing an update to the Grimsel Test Site area hydrogeological and hydrochemical SDM using real geoscientific data, including e.g. microseismicity data.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Application of Understanding

**Customer**

Disposal System Safety Case

**Further information**

As well as helping to develop the UK skills base and awareness of international capabilities in this field, this task also supports the development of RWM’s competencies in the real-time handling of geoscientific data.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>396</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Title
Natural Analogue and Modelling Study of the Implications of GDF Operations on Geosphere Host Rock Properties

### Background
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

Understanding the perturbation to the evolution of the host rock and the surrounding geosphere as a result of the construction and operation of a GDF is a topic that we are progressing within our programme and through our involvement in international projects such as the ongoing DECOVALEX project. This complementary task considers how properties of the geosphere in the zone of rock affected by the introduction, operation and closure of GDF infrastructure (access tunnels, shafts, vaults, etc.) evolve with time, from undisturbed state prior to GDF construction to a long-term steady state in the post-closure period. Knowledge of this evolution will facilitate communication with scientists and engineers familiar with the evolution of voids from e.g. a construction and mining perspective, and will provide input to the safety case. As well as potential changes to the hydrogeological properties (e.g. permeability and porosity) of the disturbed zone, mechanical and chemical changes need to be considered (including Eh, pH, oxygen profile, temperature, presence of groundwater, presence of gas and microbiological changes). This task may follow the previous review of learning from natural analogues (Task 398 and 397) and includes modelling of the information gained from the previous task.

This task is of particular significance when considering a possible period of extended retrievability.

### Research Need
To support the disposal system safety case by developing a better understanding of the implications of extended GDF operations on the safety functions provided by the geosphere.

To consider changes to the geosphere that occur in going from an unperturbed state (pre-GDF) to a perturbed state (during construction and in the presence of a GDF), and for the latter to demonstrate an understanding pre- to post-closure evolution for incorporation in the environmental safety case, with emphasis on the incorporation of processes on sub-year, year and 10's-100's years timescale (noting this timescale is short-term in consideration of the environmental safety case yet will be of significant interest to stakeholders and regulators).

### Research Objective
To understand the effect the opening of access tunnels, shafts, vaults, etc. (GDF underground infrastructure) has on the geosphere, including the generation and evolution of the excavated disturbed zone (EDZ) with respect to hydrogeological, chemical, mechanical, biological and thermal properties, and the impact this can have on disposal system performance.

### Scope
The scope comprises a desk-based study on the disturbed zone, its evolution and its safety case significance. A modelling component will include analysis of information derived from natural and industrial analogues and will include an investigation of what can be learned from existing underground voids to inform GDF-relevant studies (for example, the evolution of rock-bolting; evolution of the EDZ; and the relationship between vault construction methodology, its resulting EDZ, and how that EDZ has evolved).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

End point: Site Specific Review of Analogue Application

Customer: Disposal System Safety Case

Further information
Task Number | 397 | Status | Start date in future
---|---|---|---
PBS level 4 | Geosphere | PBS level 5 | Coupled Processes

**Title**
Consolidation of Knowledge Gained from Natural Analogue Studies, based on our Natural Analogue Catalogue

**Background**
In order to validate our understanding of the natural and engineered environments, we complement our laboratory-based modelling and underground research laboratory (URL)-based research with studies of natural analogues.

Many natural and industrial analogues of relevance to the study of radwaste disposal exist and much information of use in the safety case, both quantitative and qualitative, has been provided to date. However, a large number of these studies were undertaken many years ago, and in the meantime the relevant disposal concepts and associated needs of the safety case have evolved, as have scientific techniques and modelling toolkits. This task systematically revisits analogue studies undertaken by the radwaste disposal industry in the context of the current regulatory requirements to ascertain if modern "mining" of earlier studies could, in a cost-effective manner, derive new data and understanding, and hence further enhance confidence in the safety case.

**Research Need**
To support the disposal system safety case by identifying whether existing data from analogue studies could further enhance the confidence in the safety case.

**Research Objective**
- To review existing natural and industrial analogue studies in the context of current disposal concepts to provide additional data and understanding in a cost-effective manner that enhances confidence in the safety case.
- To identify opportunities where limited additional natural and industrial analogue research could benefit the safety case.

**Scope**
The scope comprises a review of analogue studies undertaken for the radwaste industry over approximately the last 30 years in the context of the current disposal concepts and safety case requirements. An example, in the context of analogue studies focussed on bentonite, could include:
- Obtaining relevant information by data mining published natural analogue studies with a new focus of current safety case requirements.
- Obtaining relevant information by revisiting known bentonite analogue sites and conducting investigations with modern analytical techniques.
- Identifying novel study sites where, for example, the long-term stability of bentonite in very low salinity groundwaters can be studied.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Review of Analogue Application</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**
Relevant publications include:
Further Modelling and Benchmarking of Hydrochemical Processes in the Real Fractured Rock Environment (DECOVALEX D-2019)

Background

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

THMC coupled processes for fractured rocks is an extremely complex area of scientific research which may have a significant bearing on the potential design and performance of radioactive waste disposal facilities. Through our participation in projects such as DECOVALEX (DEvelopment of COupled models and their VALidation against EXperiments), we have been developing our modelling capability. This task represents a potential future study, to follow from Task 384.

Research Need

To support safety case development by maintaining an understanding of international developments relating to the modelling of THMC processes and their relevance to UK disposal concepts.

Research Objective

To improve understanding of THMC processes in a fractured host rock via participation in international collaborative inter-comparison studies involving modelling of data collected from URL-based or laboratory-based experimental studies.

Scope

This is a future task to follow up on the output from Task 384 to expand our understanding of THMC processes in the real environment.

SRL at task start 4 SRL at task end 5 Target SRL 5

End point Site Specific Application of Understanding

Customer Disposal System Safety Case

Further information

Relevant further information can be found at:
http://www.decovalex.org/
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Further Modelling and Benchmarking of Clay THMC Processes in a Clay-based Environment (DECOVALEX D-2019)

**Background**
The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

THMC coupled processes in lower strength sedimentary rocks is an area of scientific research which may have a significant bearing on the potential design and performance of radioactive waste disposal facilities. The DECOVALEX project (DEvelopment of COupled models and their VALidation against EXperiments) is an international research and model comparison collaboration, initiated in 1992, for advancing the understanding and modelling of coupled THM and THMC processes in geological systems. Prediction of these coupled effects is an essential part of the performance and safety assessment of geological disposal systems. Through our participation in projects such as DECOVALEX (DEvelopment of COupled models and their VALidation against Experiments), we have been developing our modelling capability. This task represents a potential future study, to follow from Task 385.

**Research Need**
To support safety case development by maintaining an understanding of international developments relating to the modelling of THMC processes and their relevance to UK disposal concepts.

**Research Objective**
To improve our understanding of THMC processes in a clay host rock or clay-based engineered barrier system via participation in international collaborative inter-comparison studies involving the modelling of data collected from URL-based or laboratory-based experimental studies.

**Scope**
This is a future task to follow up on the output from Task 385 to expand our understanding of THMC processes in the real environment.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Application of Understanding

**Customer**
Disposal System Safety Case

**Further information**
Relevant further information can be found at:
http://www.decovalex.org/
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Geosphere</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Modelling the Evolution of the Alkali-disturbed Zone in Fractured Rock

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. The disposal concept for ILW / LLW in higher strength rock (HSR) requires a hyper-alkaline backfill in order to provide a long-term chemical barrier to the mobilisation of radionuclides. This safety function is achieved by conditioning the pore-water within the backfill to a very high pH. Inevitably, this pore water will migrate through the surrounding host rock in an alkaline plume to create an alkali-disturbed zone (ADZ).

The effect of the alkaline plume on the geochemistry of the host rock, and the consequent effects on its properties is an area of some uncertainty, particularly in terms of the spatial and temporal distribution of the plume. For a number of years the ‘Long-Term Cement Study (LCS) (see Task 381) has been in place at the Grimsel Test Site underground research laboratory with the aim of providing data in a real higher strength rock (HSR) environment. This task concerns the development of a model, on the basis of LCS data, which can be applied at a potential UK GDF site in HSR.

**Research Need**

To support the post-closure safety case by developing a more robust understanding of how cement leachates derived from the engineered barrier system will interact with the host rock.

**Research Objective**

To determine whether learning from the evolution of the alkali-disturbed zone gained through the LCS project at the Grimsel Test Site can be applied within a UK relevant environment.

**Scope**

The scope comprises the development of a model of the evolution of the alkali-disturbed zone within a fractured host rock by taking the learning from the LCS project into a UK relevant environment.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Application of Model

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:

- Quintessa report to RWM, Blind Reactive-Transport Modelling of the LCS In Situ Experiment, In preparation.
- C. Watson, D. Savage and J. Wilson, 2012, Long-term Cement Studies Maqarin Natural Analogue, Quintessa QRS-1523B-1.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>402</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geosphere</td>
<td>Coupled Processes</td>
</tr>
</tbody>
</table>

**Title**

Impact of Ductile Cast Iron Containers and Polymer Encapsulants on Geosphere Performance

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. The implications of the water composition leaching from specific wastes are dependent on the waste composition, the choice of package, the choice of buffer / backfill and the presence of any groundwater pathway in combination with geosphere properties.

Some recent waste packaging proposals have identified the use of self-shielded packages in order to facilitate the more rapid and cost-effective clean-up of legacy sites. These proposals differ from our standard disposal concept in three key aspects: the non-encapsulation of wastes, the use of polymer encapsulants and the introduction of large quantities of shielding materials (predominantly iron and/or lead). There is some uncertainty over the effect that these aspects may have on the performance of the disposal system, and indeed the design of the disposal system (e.g. the ratio of backfill to packages). This task initiates work on these uncertainties.

**Research Need**

To support the development of the disposal system technical specification by identifying how the materials used for waste packages and buffer / backfill could affect the composition of groundwater moving into the geosphere from the engineered barrier system and the effect that such groundwater could have on 'geosphere performance'.

**Research Objective**

To determine whether:

- The use of specific packages, e.g. Ductile Cast Iron Containers, in a cementitious environment will have any significant effect on groundwater composition moving from the engineered barrier system to the geosphere (e.g. the relative increase in the total quantity of ferrous materials).
- The use of certain package materials, e.g. those made from cast iron or polymer, may actually result in an improvement in post-closure performance by, for example, promote reducing conditions.

Additionally, the task will consider how, for a range of packaging materials, a decision-making process could ascertain appropriate complementary backfilling material properties, including the volume of backfill that would be necessary.

**Scope**

The scope comprises a desk-based study of the anticipated inventory of innovative waste packages and an analysis of their potential to alter our understanding of geosphere performance. Specific waste package types requiring consideration are the Ductile Cast Iron Container (DCIC) Type II-15E1 (MOSAIK flask); and Ductile Cast Iron Container (DCIC) Type VI-15.

**SRL at task start** | **SRL at task end** | **Target SRL**
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Application of Understanding

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:

Appendix B - 157

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>404</td>
<td>Start date in future</td>
</tr>
</tbody>
</table>

PBS level 4  
Geosphere

PBS level 5  
Coupled Processes

Title  
EC Modern 2020 Project: Approaches to Monitoring Relevant to GDF Operational Period

Background  
The European Commission Modern2020 project, which is led by ANDRA, aims to provide the means for developing and implementing an effective and efficient repository operational monitoring programme, taking into account the requirements of specific national programmes. The work allows advanced national radioactive waste disposal programmes to design monitoring systems suitable for deployment when repositories start operating in the next decade and supports less developed programmes and other stakeholders by illustrating how the national context can be taken into account in designing dedicated monitoring programmes tailored to their national needs. The EC Modern2020 project is a successor to the EC MoDeRn (Monitoring Developments for safe Repository project operation), in which RWM also participated.

Research Need  
To support the operational safety case by ensuring that RWM is informed in relation to approaches to monitoring during the GDF operational period.

Research Objective  
Modern2020 has been established to understand what parameters should be monitored within operational safety cases, and to provide methodology on how monitoring information can be used to support decision making and to plan for responding to monitoring results.

Scope  
This task will be undertaken as a multi-year (2015 to 2019) international project, illustrating how a national context can be taken into account in designing dedicated monitoring programmes tailored to national needs.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

End point  
Site Specific Application

Customer  
Disposal System Safety Case

Further information  
http://cordis.europa.eu/project/rcn/196921_en.html
http://www.modern-fp7.eu/
MODERN project final report, 2014.
UK Nirex Ltd, 2005, Context Note 4.2: Monitoring, Number 484080.
UK Nirex Ltd, 2005, Summary Note for CoRWM on Building Confidence in Repository Long-term Safety Through Monitoring, Number 484078.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>405</th>
<th>PBS level 4</th>
<th>Geosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Ongoing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Coupled Processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>EPSRC GEOWASTE: Application and Development of MEMS Wireless Technologies for Experimental Monitoring in Bentonite</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Background**

An important consideration for the evolution of the disposal system is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. Our reference concept for the disposal of HLW / Spent Fuel in higher strength and lower strength rock utilises a bentonite buffer in contact with a disposal container in order to maintain the chemical and physical conditions necessary to protect the metallic container from corrosion. The primary safety function of the bentonite requires it to maintain a specified swelling pressure upon resaturation; however a number of coupled processes (such as its possible thermal degradation and hydrochemical erosion) could challenge its performance.

As we continue to develop our knowledge base on the evolution of bentonite buffer material via in situ and laboratory experiments the ability to monitor key physical parameters wirelessly would provide data without disrupting the integrity of the clay along connecting wires. Micro Electro Mechanical Systems (MEMS) comprise tiny sensor nodes that can form rapidly deployed, massive distributed networks to allow unobtrusive, spatially dense sensing and communication.

This task is co-funded by RWM and the Engineering and Physical Sciences Research Council (EPSRC) under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. The task aims to investigate the potential for MEMS wireless technologies for such monitoring.

**Research Need**

To support concept development by providing sensor technology capable of wirelessly instrumenting in situ experiments so as not to bias their results.

**Research Objective**

Across eight work packages in the SAFE consortium, to deploy and refine advanced monitoring techniques for simultaneous imaging of THMC variables (pH, temperature, pore-water pressure, swelling, etc.) within the laboratory, and to integrate these monitoring techniques with experiments to gain a predictive understanding of the THMC evolution of clay-based engineered barriers, and their interfaces, up to the upper-bound of realistic environmental conditions.

**Scope**

The scope comprises the application and development of MEMS wireless technology to enable experimental monitoring in bentonite. Initially MEMS will be embedded in small samples of bentonite, under confined conditions to generate high swelling pressures. Once a suite of small-scale tests is complete, MEMS will be embedded into interfaces between bentonite blocks, see Task 388.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Concept Development, Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

RWM's role in GEOWASTE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case. The SAFE consortium comprises the universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff and Oxford, together with the British Geological Survey.
Appendix B - 159

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>406</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

PBS level 4 | Geosphere
PBS level 5 | Coupled Processes

Title
EPSRC GEOWASTE: Development of Magnetic Sensors for Monitoring Bentonite Resaturation

Background
An important consideration for the evolution of the disposal system is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. Our reference concept for the disposal of HLW / Spent Fuel in higher strength and lower strength rock utilises a bentonite buffer in contact with a disposal canister in order to maintain the chemical and physical conditions necessary to protect the metallic container from corrosion. The primary safety function of the bentonite requires it to maintain a specified swelling pressure upon resaturation, however a number of coupled processes (such as its possible thermal degradation and hydrochemical erosion) could challenge its performance.

As we continue to develop our knowledge base on the evolution of bentonite buffer material via in situ and laboratory experiments, the ability to monitor key physical parameters wirelessly would provide data without disrupting the integrity of the clay along connecting wires. To this end, this project considers the inclusion of magnetic grain minerals within bentonite, with the intention of investigating if their magnetic properties vary when the bentonite resaturates, and whether or not such a change in magnetic properties is remote-monitorable.

This task is co-funded by RWM and the Engineering and Physical Sciences Research Council (EPSRC) under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. The task aims to investigate the potential for magnetic sensors for the monitoring of bentonite resaturation.

Research Need
To support concept development by providing sensor technology capable of wirelessly instrumenting in situ experiments and monitoring how properties of the magnetic minerals embedded in bentonite evolve in conditions designed to mimic a resaturating GDF.

Research Objective
Across eight work packages in the SAFE consortium, to deploy and refine advanced monitoring techniques for simultaneous imaging of THMC variables (pH, temperature, pore-water pressure, swelling etc.) within the laboratory, and to integrate these monitoring techniques with experiments to gain a predictive understanding of the THMC evolution of clay-based engineered barriers, and their interfaces, up to the upper-bound of realistic environmental conditions.

Scope
This scope comprises the application and development of magnetic mineral signatures to sense the reaction of ingressing fluids within the engineered barrier system, focussing on the bentonite buffer. The ability to monitor key parameters of bentonite during its resaturation in experiments on the scale of e.g. underground research laboratories, will be considered.

Further information
RWM's role in SAFE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case. The SAFE consortium comprises the universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff and Oxford, together with the British Geological Survey.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>416</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

**PBS level 4**
Near-Field Evolution

**PBS level 5**
Evolution of Cement Based EBS

**Title**
Hydrothermal Ageing of NRVB

**Background**
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. This task is investigating the hydrothermal alteration of Nirex Reference Vault Backfill (NRVB) and its reaction with waste encapsulation grouts over a ten year period.

**Research Need**
To support the post-closure safety case by developing a sufficiently detailed understanding of mechanisms and chronology of NRVB evolution over long timescales.

**Research Objective**
To determine whether changes to NRVB mineralogy over hundreds of thousands of years will compromise its ability to act as a chemical buffer.

**Scope**
Over a ten year period the project scope is to use hydrothermal ageing to attempt to accelerate the chemical evolution of NRVB over durations beyond those previously studied. The scope covers temperatures up to 80°C and will utilise appropriate techniques to determine mineralogical changes and will compare these to samples aged at lower temperatures. This task is expected to run until 2018 / 2019 with the potential to extend if required. This may include additional scope to involve other members of the supply chain and universities in the final sample analyses and characterisation. Long-term alteration of NRVB will be evaluated via data and sample characterisation from long-term hydrothermal ageing on NRVB and waste encapsulation grouts.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Validation

**Customer**
Disposal System Safety Case

**Further information**
This is an ongoing study let through existing supply chain arrangements.

Relevant publications include:


Experimental Design: High Temperature Backfill Functional Requirements

Background
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. Over several decades waste management organisations internationally have undertaken a significant programme of R&D on cementitious backfills for use in ILW disposal concepts.

Recent work to develop disposal concepts for high heat generating wastes has introduced the possibility of temperatures well in excess of 100°C where alternative buffers / backfills to bentonite clay may be required. Cement-based systems may be one such alternative, but there is currently inadequate understanding of their performance and evolution at such high temperatures in a geological disposal context.

This task concerns the development of a scope for an experimental programme to identify and characterise potential cement-based systems for use in this context. A significant input is the review currently being undertaken by the high heat generating waste integrated project team (HHIPT) on performance of cements and concretes at high temperature, which will lead to an evaluation of the viability of such an approach and, if so, identify potential research needs.

Research Need
To support concept development by building an understanding of the effect of elevated temperatures (>100°C) on backfill performance in a cavern concept for spent fuel.

Research Objective
To develop an experimental programme which will inform the testing and development of cementitious backfills to meet the safety functional requirements for a cement based disposal system for spent fuel.

Scope
- To identify the safety functions required from a cementitious backfill in spent fuel disposal concepts.
- To identify a range of possible cement formulations for investigation.
- To identify processes which are likely to affect the performance of the backfill in achieving its safety functions at high temperatures.
- To develop the scope for an experimental and modelling programme to underpin alternative backfill performance.'

SRL at task start 2  SRL at task end 2  Target SRL 4

End point Site Specific Validation
Customer Concept Development, Design

Further information
This task draws the relevant outcomes of the high heat generating waste IPT and the concepts IPT into the near-field research programme.

Relevant publications include:
**Task Number**: 418  
**Status**: Ongoing

**PBS level 4**  
Near-Field Evolution

**PBS level 5**  
Evolution of Cement Based EBS

**Title**  
Impact of Ductile Cast Iron Containers (DCICs) and Vitrified ILW on Cement Backfill Performance

**Background**

One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

In recent years a number of waste producers have proposed alternative packaging solutions, such as Ductile Cast Iron Containers (DCIC) and vitrified ILW wasteforms. This has led to a need to develop a better understanding of the possible impact of these wasteforms on the near-field environment, in particular the effectiveness of the backfill in providing chemical containment.

This task is part of a project on long-term evolution of cement backfills relevant to near field evolution and addresses the impact of DCICs and vitrified ILW on the performance of backfills (Nirex Reference Vault Backfill (NRVB) and in addition, for vitrified ILW, a generic 'low-pH' cement).

**Research Need**

To support concept development, the Disposal System Safety Case and the waste package assessment process by improving the understanding of backfill alteration through its reaction / interactions with new waste packages such as Ductile Cast Iron Containers or vitrified ILW.

**Research Objective**

To determine whether:
- Potential new waste packaging solutions will significantly impact the safety functions provided by a cement-based backfill and if so, whether the amount of backfill can be adjusted to ameliorate these effects.
- Assumptions can be developed on backfill ratios and repository chemistry for use in the Change Control assessment relating to DCICs.

**Scope**

Review and modelling of expected interactions between corroding iron and NRVB and between vitrified ILW and NRVB or a low pH backfill. Evaluation of the effect on safety functions provided by a cementitious backfill and the impact on planning assumptions.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
</table>

**End point**  
Site Specific Validation

**Customer**  

**Further information**

Tasks 418, 419 and 423 are let under a single contract

Relevant publications include:


Effect of Groundwater Solutes on Physical Properties of Cementitious Backfill

Background
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

There is a need to understand the interaction of cement backfill with common groundwater solutes and the impact this has on the physical properties of the backfill, e.g. reduced permeability or porosity due to pore clogging by precipitation of mineral phases.

This task forms part of a project on the long-term evolution of cement backfills relevant to near-field evolution - this task addresses the impact of groundwater ions on the long-term behaviour of the Nirex Reference Vault Backfill (NRVB).

Research Need
To support the post-closure safety case by developing an improved understanding of the changes in physical and chemical transport properties of NRVB and the consequent effect on the safety functions provided by the backfill.

Research Objective
- To determine whether changes in the permeability of the backfill reduce advective transport of water through a vault (e.g. does the backfill 'seal').
- To determine whether armouring of cracks within the backfill inhibits the conditioning of pore water within such cracks and influences the long-term pH buffering behaviour.

Scope
Experimental and modelling studies of the interaction of common groundwater solutes with NRVB, changes in transport properties of the NRVB and pore-water chemistry.

Further information
Tasks 418, 419 and 423 are let under a single contract.

Relevant publications include:
## Task Number 421

### Status
Start date in future

### PBS level 4
Near-Field Evolution

### PBS level 5
Evolution of Cement Based EBS

### Title
Effect of High Temperatures (>100°C) on Cement Backfill for Spent Fuel (SF) / Multi-Purpose Containers (MPC)

### Background
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

Over several decades waste management organisations internationally have undertaken a significant programme of R&D on cementitious backfills for use in ILW disposal concepts. Recent work to develop disposal concepts for high heat generating wastes has introduced the possibility of temperatures well in excess of 100°C where alternative buffers / backfills to bentonite clay may be required. Cement-based systems may be one such alternative but there is currently inadequate understanding of their performance and evolution at such high temperatures in a geological disposal context. This task implements the scope defined in the previous task.

### Research Need
To support concept development by building an understanding of the effect of elevated temperatures (>100°C) on backfill performance in a cavern concept for spent fuel.

### Research Objective
To determine whether high temperatures affect the long-term performance of a cement backfill and its ability to deliver the required safety functions (e.g. its ability to condition porewater to the required pH range, to enable gas migration to the far field, and to sorb radionuclides).

### Scope
The experimental scope will be defined in the predecessor task (Task 417).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

### End point
Site Specific Validation

### Customer
Concept Development, Disposal System Safety Case, Design

Further information
This Task draws the outcomes of the high heat generating waste Integrated Project Team (IPT) and the Concepts IPT into the near-field research programme.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Cement Based EBS</td>
</tr>
</tbody>
</table>

**Title**
Ageing of Nirex Reference Vault Backfill (NRVB) and Impact on Safety Functions

**Background**
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

There is a need to understand the formation of long-term stable phases in cementitious backfills and the impact of crystallisation of calcite silicate hydrate (CSH) gel on the long-term pH and sorption properties of Nirex Reference Vault Backfill (NRVB).

This task forms part of a new project on the long-term evolution of cement backfills relevant to near-field evolution - this part addresses the long-term evolution of the NRVB.

**Research Need**
To support the post-closure safety case by improving our understanding of the long-term (tens to hundreds of thousands of years) evolution of cement based materials e.g. NRVB.

**Research Objective**
To determine whether the evolution of the long-term behaviour of NRVB can be informed by examination of changes in microstructure on laboratory timescales and by an improved understanding of the long-term evolution processes and the resulting phases.

**Scope**
Laboratory study of the microstructural and phase evolution in NRVB and in synthesised CSH gels on ageing using transmission electron microscopy (TEM), nuclear magnetic resonance (NMR) spectroscopy, X-ray diffraction (XRD) and thermal analysis. Evaluation of any implications of the results for the performance of NRVB.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Validation

**Customer**
Disposal System Safety Case

**Further information**
Tasks 418, 419 and 423 are let under a single contract.

Relevant publications include:


Note synergy with Task 206 - Mechanism of Chemical Containment - Scoping Study.
Appendix B - 166

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Cement Based EBS</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Pilot Backfill Leaching and Migration Experiment in Overseas Underground Research Laboratories (URL)

**Background**

One of the safety functions provided by a cementitious backfill, such as the Nirex Reference Vault Backfill (NRVB) in the UK ILW disposal concept, is its contribution to chemical containment by maintenance of alkaline pore water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

In order to increase our understanding of the evolution of cement-based systems and their performance in providing chemical containment, it will be necessary to move towards demonstrations in real GDF-relevant environments. Through our relationship with overseas Waste Management Organisations (WMOs) we will investigate the opportunity to commission a pilot study in an Underground Research Laboratory (URL). This pilot study may be a prelude to a larger scale demonstration (Task 425).

**Research Need**

To support the safety case by validating our understanding of the behaviour of NRVB and its role in providing chemical containment in a real GDF-relevant environment, including the presence of cellulose degradation products (CDP) and their effect on dissolved metal ions.

**Research Objective**

- To develop our capability to design and undertake experiments in a URL environment.
- To demonstrate chemical containment in a real GDF-relevant environment. This would include the presence of potential complexing species such as CDP and superplasticisers that could increase the mobility of some dissolved metal ions in the cement components of an engineered barrier (EBS), e.g. the NRVB or waste encapsulation grouts.
- To understand the evolution of NRVB and encapsulant grouts in a real GDF-relevant environment as a precursor to a larger scale demonstration experiment in an overseas URL.
- To identify appropriate instrumentation and sampling regimes for a future larger scale experiment and to inform its experimental design (Task 425).

**Scope**

To commission a pilot backfill leaching and migration experiment (e.g. multiple 5 to 10 litre scale samples) within an overseas URL. Cylindrical casts of NRVB, wasteform grout or combinations thereof will be emplaced into a borehole drilled in a suitable higher strength fractured host rock in the vicinity of flowing features to facilitate resaturation and to allow advective flow. A small source term would be placed in the centre of most cylindrical samples. A cocktail of tracers, selected to represent a spectrum of radionuclide behaviours, is envisaged.

Porewater chemistry could be monitored from adjacent boreholes as an indicator of the movement of radionuclides or other tracers. Local site characterisation would be conducted to identify areas of water ingress and locations where suitable advective flows through the experimental samples could be achieved.

The overall scope includes work to gain improved understanding of:

- Mobility and retention of radionuclides in a cement-based EBS under real GDF relevant conditions.
- Cellulose degradation and its effect on the migration of radionuclides.
- Possible release of superplasticisers and their effect on the migration of radionuclides.
- Evolution of the physical and chemical properties of backfill and encapsulation grout in a real environment.
- Flow through cracks in backfill and potential for crack armouring and crack healing in a real GDF relevant environment.
- The evolution and interaction of NRVB with the host rock and porewater and alkali plume evolution in the host rock (as these would be a by-product of the experiment).
- Identification of instrumentation and sampling methodologies for incorporation in subsequent large scale experiments.
- Initial modelling of expected evolution of the NRVB and radionuclide migration to aid the experimental
- Comparison of modelling results with experimental observations.

Experiments would be left with minimal periodic sampling for a period of up to 5 to 20 years. Samples could be recovered at the end of the experiment (e.g. with overcoring of the surrounding rock) or it may be possible to recover samples on a periodic basis, depending on the experimental design. Complementary laboratory controls may be run in parallel to allow more frequent monitoring and validation of models (e.g. the near-field component model).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Disposal System Safety Case

Further information

This task builds on knowledge obtained through the laboratory demonstration of chemical containment (Task 736) and applies it in a real environment.

Relevant publications include:

M. Felipe-Sotelo, J. Hinchcliff, N. Evans, P. Warwick and D. Read, 2012, Sorption of Radionuclides to a Cementitious Backfill Material under Near Field Conditions, Min Mag 76, 3401-3410.

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Cement Based EBS</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Demonstration Backfill and Leaching Experiment in Overseas URL

**Background**

One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

In order to increase our understanding of the evolution of cement-based systems and their performance in providing chemical containment, it will be necessary to move towards demonstrations in real environments. Through our relationship with overseas Waste Management Organisations (WMOs) we will build on the pilot study (Task 424) by undertaking a larger scale demonstration of backfill performance and chemical containment in an Underground Research Laboratory (URL).

**Research Need**

To support the safety case by validating our understanding of the behaviour of Nirex Reference Vault Backfill (NRVB) and its role in providing chemical containment in a larger scale real environment, including the presence of cellulose degradation products (CDP) and their effect on dissolved metal ions.

**Research Objective**

To demonstrate chemical containment in a larger scale real (e.g. cubic metre) environment, including the presence of cellulose degradation products (CDP) and their effect on dissolved metal ions, over an extended timescale.

To validate the evolution of NRVB at a larger scale in a real environment, over an extended timescale, in an overseas URL, including the effects of scale-up and heterogeneity.

To demonstrate placement of NRVB using the current formulation at a cubic metre scale in an underground environment.

**Scope**

To commission a large scale backfill leaching and migration experiment (e.g. cubic metre scale) within an overseas URL. NRVB, wasteform grout or combinations thereof will be emplaced directly into the host rock (e.g. in a large diameter horizontal borehole) in the vicinity of a flowing feature to facilitate resaturation and to allow advective flow. The scope could include:

- The evolution and interaction of cements and host rock; pore-water and alkali plume evolution and the evolution of the physical properties of cement.
- Cellulose degradation and its effect on the migration of metal ions.

Experiments will be instrumented and monitored over a decade or more.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**Further information**

- Relevant publications include:
  - M. Felipe-Sotelo, J. Hinchcliff, N. Evans, P. Warwick and D. Read, 2012, Sorption of Radionuclides to a Cementitious Backfill Material under Near Field Conditions, Min Mag 76, 3401-3410.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>426</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Cement Based EBS</td>
</tr>
</tbody>
</table>

**Title**

Further Experimental / Modelling Study (to be Defined from Task 446)

**Background**

One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. This includes development and application of a near-field component model that builds confidence that the individual components within the near-field, such as the various waste modules or individual barriers, work together to provide a system that functions correctly (see Tasks 441, 444 and 446).

It is expected that application of the near-field component model may identify further research needs and this task has been created as a place holder recognising a likely need for further studies in this area.

**Research Need**

To provide further data and understanding on individual processes shown via application of the near-field component model to have significant knowledge gaps with respect to the safety case.

**Research Objective**

To undertake experimental and modelling studies as defined by Task 446.

**Scope**

To be defined from Task 446.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRL at task end</td>
<td>5</td>
</tr>
<tr>
<td>Target SRL</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Cement Based EBS</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Effect of Crack Armouring on Groundwater Conditioning for Backfill Under Advective Flow Conditions

**Background**

One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function. This includes development and application of a near-field component model that builds confidence that the individual components within the near field, such as the various waste modules or individual barriers, work together to provide a system that functions correctly (see Tasks 441, 444 and 446).

It is expected that application of the near-field component model may identify crack armouring and its effect on conditioning of groundwater as a further research need. Crack armouring is a process believed to occur in cements, whereby groundwater solutes form precipitates in the high pH environment on the surfaces of cracks; these may impede the migration of hydroxyl ions from the bulk cement into the water within the crack.

**Research Need**

To provide further data and understanding on crack armouring and its influence on groundwater conditioning and impact on the safety case.

**Research Objective**

- To improve our understanding, developed in Task 419 and applied in Task 446, on the factors influencing crack armouring (e.g. rate of formation, transport properties of such layers, dependence on groundwater composition and rate of flow).
- To apply this understanding to determine the effect crack armouring has on ground water conditioning for backfill under advective flow conditions.

**Scope**

Experimental and modelling task (e.g. reactive transport modelling using PHREEQC and TOUGHREACT). The scope will be further defined depending on the outcomes of Tasks 419 and 446.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:


## Task Number

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near-Field Evolution</td>
<td>Evolution of Cement Based EBS</td>
</tr>
</tbody>
</table>

### Title

Novel experimental approaches to understanding long-term evolution of water-saturated cement

### Background

One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

Ageing of cement involves both phase changes and textural modifications that may change the way in which fluid can move through the cement and the effectiveness with which it can provide chemical conditioning. These reactions may arise because the initial cement phases are intrinsically unstable, but may also be driven by the infiltration of fluid which is out of equilibrium with the phases that first develop in the cement. Understanding the long-term ageing of cement is challenging because it is difficult to increase the reaction rates without changing the nature of the ageing reactions. This pilot study aims to employ novel experimental approaches to address the rates of individual steps in the ageing process, and to do this in a way that will facilitate extrapolation to longer time periods. By looking further into the ageing process, we will also gain insights into the effect of the ageing cement on other backfill and vault wall materials.

This task interfaces closely with existing work on long-term evolution of cement backfills relevant to near field evolution, in particular Tasks 416, 419, 423 and 430. It specifically addresses the rate of recrystallisation of CSH phases to more stable reaction products via the medium of a static portlandite-saturated pore water and explores the effect of these reactions on permeability, thereby providing an end-member of the range of reactions from closed-system to infiltration.

### Research Need

To support the post-closure safety case by developing an improved understanding of the changes in physical and chemical transport properties of the Nirex Reference Vault Backfill (NRVB) and the consequent effect on the safety functions provided by the backfill. To develop approaches that would enable rapid characterisation of the ageing of other cements.

### Research Objective

- To determine whether rates of hydrothermal ageing reactions can be measured independently of rates of reactions arising from the infiltration of groundwater.
- To investigate whether novel experimental approaches can be used to monitor changes in cement texture and permeability in situ and with only small amounts of reaction.

### Scope

Initial experimental studies of the interaction of groundwater solutes with NRVB, changes in transport properties of the NRVB, cement phases and pore-water chemistry at elevated temperature. Two types of experiments are envisaged:

Batch kinetic experiments would be performed at a range of temperatures up to about 200°C to determine the rate of transformation of phases in NRVB to more stable phases in the presence of water that has been pre-saturated with NRVB. While water chemistry will be monitored, the primary measure of reaction progress will be changes in the relative proportions of product and original NRVB phases, determined at the end of batch experiments. The rates determined from these experiments will be extrapolated to lower temperatures based on an Arrhenius relationship. This approach, which ignores the different reaction products that may appear under different conditions, is valid provided that the reaction rate is controlled by dissolution at the surface of the reactant NRVB material rather than growth of products, as has been documented in kinetic studies for CCS, for example.

The influence of the evolution of NRVB on its transport properties will be determined in petrophysics-style experiments in which a core of NRVB is sealed into a core holder and water of various compositions (including pre-saturated with NRVB) is flowed through the core at constant flow rate so that pressure changes reflect changes in permeability. Once the initial protocols are established, experiments may also be set up which involve extended periods in which the core sits in a static fluid, permeability is measured episodically and the distribution of porosity periodically measured in a CT scanner capable of taking the entire assembly.

If these scoping studies are successful the methodologies will be applied more extensively in a subsequent
<table>
<thead>
<tr>
<th>Task</th>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

Task Number | 429 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Near-Field Evolution
PBS level 5 | Evolution of Cement Based EBS

Title
Application of Novel Experimental Approaches to Understanding Long-term Evolution of Water-Saturated Cements

Background
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work supporting our understanding of this safety function.

Ageing of cement involves both phase changes and textural modifications that may change the way in which fluid can move through the cement and the effectiveness with which it can provide chemical conditioning. These reactions may arise because the initial cement phases are intrinsically unstable, but may also be driven by the infiltration of fluid which is out of equilibrium with the phases that first develop in the cement. Understanding the long-term ageing of cement is notoriously difficult because it is difficult to increase the reaction rates without changing the nature of the ageing reactions. This study applies novel techniques developed in a previous task to a wider range of cements and groundwater solutes.

Research Need
To support the post-closure safety case by developing an improved understanding of the changes in physical and chemical transport properties during evolution of the Nirex Reference Vault Backfill (NRVB) and other cementitious backfills and grouts of relevance to geological disposal in the UK.

Research Objective
To measure rates of “wet” ageing reactions independently of rates of reactions arising from the infiltration of groundwater.
To use novel experimental approaches to monitor changes in cement texture and permeability in situ and with only small amounts of reaction.

Scope
The scope will be defined in the future and will depend on the outcome of Task 428. It could include a range of cement samples and a wider variety of groundwater solutes than Task 428 and kinetic and thermodynamic modelling.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information
Title
Participation in EC project CEBAMA

Background
One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work to support understanding of this safety function. There is a need to understand the interaction of cement backfill with common groundwater solutes and the impact this has on the physical properties of the backfill, e.g. reduced permeability or porosity due to pore clogging by precipitation of mineral phases.

The HORIZON 2020 EURATOM Collaborative Project "Cement-based materials, properties, evolution, barrier functions (CEBAMA)" is a four year project with 27 partners that commenced in Summer 2015. The specific objectives of Cebama are (i) experimental studies of interface processes between cement-based materials and host rocks or bentonite, and assessing the specific impact on transport properties (WP1), (ii) quantifying radionuclide retention under high pH cement conditions (WP2), and (iii) developing comprehensive modelling approaches to support interpretation of results and prediction of the long-term evolution of key transport characteristics such as porosity, permeability and diffusion parameters (WP3).

RWM are supporting two partners (Universities of Sheffield and Loughborough) participating in WP1. This work is complementary to Task 419. In addition, RWM are members of the End User group of CEBAMA.

Research Need
To support the post-closure safety case by developing an improved understanding of the changes in physical and chemical transport properties of the Nirex Reference Vault Backfill (NRVB) and other cements as a result of reaction with groundwater solutes.

Research Objective
To build a mechanistic understanding of the alteration of selected cements of relevance to international GDF concepts at the cement/groundwater interface and how this influences transport through changes to porosity, permeability and cement mineral phase assemblages.

Scope
The scope is to build a mechanistic understanding of how interactions at the cement / groundwater interface are likely to influence transport through their impact on porosity, permeability and cement mineral phase assemblages as a function of carbonation, pH, salinity and groundwater composition. It will be undertaken by two PhD students in collaboration at the Universities of Sheffield and Loughborough. The PhD studentship at the University of Loughborough will focus primarily on the chemical characterisation of these interactions, while the student at the University of Sheffield will focus on the physical characterisation.

Cement formulations representative of: low strength, high-pH cement (NRVB); low-pH, PC - silica fume cement (representative of Swedish and Finnish concepts); and low pH, PC - silica fume - FA blended cement (representative of the French concept) will be studied. These will be exposed to groundwater solutions representative of crystalline rock, Corallian-Oxfordian Clay, and a higher ionic strength solution representative of sea water or saline groundwater. Porosimetry and permeability techniques, μ-XCT, electron microscopy and neutron radiography and tomography will be applied to identify changes in porosity, permeability, tortuosity and microstructure. Porewaters will be recovered by porewater squeezing and analysed. The datasets generated will be applied in chemical speciation and transport modelling.

SRL at task start 4  SRL at task end 5  Target SRL 5
End point Site Specific Validation
Customer Disposal System Safety Case

Further information
Task Number | 431 | Status | Start date in future
---|---|---|---
PBS level 4 | Near-Field Evolution | PBS level 5 | Evolution of Cement Based EBS

<table>
<thead>
<tr>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate and Extent of Reactions between NRVB and Robust Shielded Containers or Vitrified ILW.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the safety functions provided by a cementitious backfill is its contribution to chemical containment by maintenance of alkaline pore-water over timescales of tens to hundreds of thousands of years. RWM is undertaking work to support understanding of this safety function. In recent years a number of waste producers have proposed alternative packaging solutions, such as robust shielded containers (formerly known as Ductile Cast Iron Containers, DCICs) and vitrified ILW wasteforms. This has led to a need to develop a better understanding of the possible impact of these wasteforms on the near-field environment, in particular the effectiveness of the backfill in providing chemical containment. This task is an experimental investigation of the evolution of the interfaces between the Nirex Reference Vault Backfill (NRVB) and robust shielded containers or vitrified ILW to build confidence in the conclusions of Task 418 and to determine the likely rates and extents of reaction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>To support concept development, the Disposal System Safety Case and the waste package assessment process by improving the understanding of backfill alteration through its reaction / interactions with new waste packages such as robust shielded containers or vitrified ILW.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>To determine whether: - Potential new waste packaging solutions will significantly impact the safety functions provided by a cement-based backfill and if so, whether the amount of backfill can be adjusted to ameliorate these effects. - Assumptions can be developed on backfill ratios and repository chemistry for use in the Change Control assessment relating to DCICs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental study of rate, products and extent of interactions between corroding cast iron and NRVB and between vitrified ILW and NRVB. Impact on physical and chemical properties of the altered NRVB.</td>
</tr>
</tbody>
</table>

| SRL at task start | 4 | SRL at task end | 5 | Target SRL | 5 |

| End point | Site Specific Validation |
| Customer | Concept Development |

**Appendix B - 175**
### Task Number

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>432</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### PBS level 4

- Near-Field Evolution

### PBS level 5

- Evolution of Cement Based EBS

### Title

Support to the Development and Implementation of Strategy for Management of NDA-owned Materials and Samples

### Background

Physical items have been collected as part of research, tests and experiments to assist decommissioning and waste management activities at NDA sites, or to underpin relevant safety cases. Due to the wide range of testing activities that have happened across the estate, these materials and samples exist in a variety of formats. Typical examples include graphite, steel and cemented samples. The items may be asset samples, fuel samples or waste samples. They may be active or inactive, and can be any size, weight or shape. The items may also be encapsulated or packaged. The items may have been produced recently or a very long time ago. The NDA are developing a strategy for archiving materials and samples, collecting baseline data and developing procedures for assessing the value of samples and for disposal or transfer. Routine analytical samples that are taken for operational purposes, such as effluent discharge samples, are excluded from the scope of the study.

### Research Need

To maintain access to key materials and samples for future research.

### Research Objective

To develop an archiving strategy for key materials and samples.

### Scope

RWM input to, and review of, an over-arching NDA strategy for the management of materials and samples consisting of:

- Improved inventory of archived materials/samples held at RWM.
- RWM participation and contribution to the development of procedures for value assessment process and disposal/transfer of materials/samples.
- Application of value assessment process (as necessary) to determine which samples managed by RWM are of value to the NDA estate
- Provision of technical support/guidance on RWM managed materials and samples, as required
- Facilitate and support the compliant transfer of materials and samples to third parties, where there is an identified need supported by RWM/NDA

It is expected that RWM will be required to feed into this work well into financial year 2016/17 with longer-term engagement as decisions are made regarding the options for management of existing stores.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End point</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDA Strategy</td>
</tr>
</tbody>
</table>

### Further information
### Task Number
441

### Status
Ongoing

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Near-Field Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Cement-Based EBS Model and System Interactions</td>
</tr>
</tbody>
</table>

### Title
Acceptance Test and Further Devel. of the Near Field - Component Model

### Background
Ensuring that an engineered barrier system will perform its desired functions requires integration – of an iterative nature – of site-specific information, information on the waste properties, understanding of material properties and performance, and in-situ and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM’s programme develops it will be important to build confidence that the individual parts of the near field, such as waste packages and backfill, work together to provide a system that achieves its safety functions.

In order to demonstrate adequate long-term performance of a cement-based disposal system RWM is developing and applying a near-field component model. In RMW's modelling hierarchy we define a component model as a collection of process models that use multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development, some representation of uncertainty is usually required.

A near-field component model considers the relevant processes (and associated uncertainty) that affect near-field evolution and radionuclide behaviour and that could impact on the performance of the system, e.g. heterogeneity, carbonation and pH evolution. During the period 2012-2014 RWM developed a prototype near-field component model.

### Research Need
To apply the prototype component model for the near-field of a cementitious ILW GDF in order that it can be used to support the disposal system safety case and to identify further research needs.

### Research Objective
To ensure that the near-field component model:
- Includes a robust treatment of uncertainty.
- Can be used to provide a number of key inputs to the total system model.
- Can be used to demonstrate understanding of near-field processes that will affect the post-closure safety of the UK ILW disposal concept.
- Is able to supply information to aid design.
- Can support the representation of the near field in performance assessments.
- Can support the development of safety function indicator criteria for the near field.

To identify research needs through application of the near-field component model with respect to cement buffer / backfill performance over time.

### Scope
The scope of this task is to use the near-field component model developed in the earlier tasks to research the nature of the uncertainties around the evolution of a cementitious GDF for ILW, and to identify further required development of the model.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

End point
Input into Design Development & Disposability Assessments

Customer

### Further information
Relevant publications include:
## Task Number

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>442</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## PBS level 4

**Near-Field Evolution**

## PBS level 5

**Cement-Based EBS Model and System Interactions**

### Title

**Effect of Ionising Radiation on Engineered Barrier System (EBS) Performance**

### Background

Ensuring that an engineered barrier system (EBS) will perform its desired functions requires integration of the following: site-specific information; information on the waste properties; understanding of material properties and performance, and in-situ / laboratory testing and modelling relating to key processes that will affect near-field evolution. Within this research sub-topic RWM considers additional processes (such as radiation effects) that overlap with other key research areas.

The impacts of radiation on waste package performance (e.g. corrosion of metals) and wasteform degradation (dissolution of spent fuel and HLW) are each discussed in the Package Evolution and Radionuclide Behaviour status reports. Within the near-field evolution research topic, radiation concerns have been focused on understanding the impact of radiation on the long-term performance of buffer / backfill materials and pore-water chemistry with respect to radiolysis.

In general, cementitious materials have good resistance to physical degradation upon irradiation, although some wasteforms associated with specific wastes (e.g. those containing large proportions of organic material) are less resistant. Similarly the effects of radiation on clay alteration and radiolysis of porewater have been studied. In general for typical HLW and spent fuel concepts it is considered that radiolysis of pore-water in a clay-based buffer would be insignificant, as the dose rate outside the container would be too low to have any significant effect. Similar conclusions were reached for the effects of radiation damage and radiolysis in the backfill (as the radiation field is even lower in these regions). Work considering long-term redox evolution has also investigated the impacts of radiolysis on redox conditions with respect to spent fuel dissolution and bentonite pore-water conditions. For cement-based ILW concepts, the potential effects of radiolysis were surveyed a number of years ago as part of the UK Nirex research programme. Since then work has been undertaken to improve understanding of the radiolysis of organic complexing agents and organic polymers, such as PVC.

### Research Need

To inform safety case development by improving our understanding of the expected ionising radiation doses within the EBS and whether these have a significant impact on the evolution of the near-field environment.

### Research Objective

To determine whether radiation is likely to impact on the performance of the engineered barrier system at expected dose rates and accumulated doses.

### Scope

- To review and model radiation doses in the low-heat-generating waste (LHGW) and high-heat-generating waste (HHGW) disposal areas of a GDF, including spatial variability.
- To discuss possible effects of such radiation doses on post-closure evolution and any impact on safety functions, including any such considerations by other Waste Management Organisations
- To identify possible future needs-driven research.'

### SRL at task start | SRL at task end | Target SRL
---|---|---
3 | 4 | 5

**End point**

No Further Research Planned

### Customer

Disposal System Safety Case

### Further information

Output would feed into defining the scope of Task 445 (if required). Relevant publications include:

Further Development of Near-field Component Model

Background

Ensuring that an engineered barrier system will perform its desired functions requires integration – of an iterative nature – of site-specific information, information on the waste properties, understanding of material properties and performance, and in-situ and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM’s programme develops it will be important to build confidence that the individual parts of the near field, such as waste packages and backfill work, together to provide a system that achieves its safety functions.

In order to demonstrate adequate long-term performance of a cement-based disposal system we are developing and applying a near-field component model. In our modelling hierarchy we define a component model as a collection of process models that use multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development, some representation of uncertainty is usually required.

A near-field component model considers the relevant processes (and associated uncertainty) that affect near-field evolution and radionuclide behaviour and that could impact on the performance of the system, e.g. cracking, heterogeneity, carbonation and pH evolution. During the period 2012-2014 we developed a prototype near-field component model and this task will support further development subsequent to initial application (in Task 441).

Research Need

- To further develop the component model for the near field of a cementitious ILW Geological Disposal Facility (GDF) to include consideration of additional processes, such as cracking, carbonation and crack armouring, and alternative data inputs.
- To develop the interface requirements between the near-field component model and the total system model, based on the understanding gained from Task 441.

Research Objective

- To further develop a component model to determine whether the effects of differing boundary conditions, such as groundwater flow and chemistry, on the long term buffer / backfill performance can be modelled effectively.
- To identify research needs through application of the near-field component model with respect to cement buffer / backfill performance over time.
- To ensure that the near-field component model interfaces appropriately with the total system model.'

Scope

The scope comprises the further development of the near-field component model, informed by application (in Task 441). This includes the development of the interface between the near-field component model and the total system model, e.g. to support the current representation, evaluate 'response surfaces' for solubility and sorption, or direct data transfer.

Further information

Relevant publications include:

Further Investigation of the Effects of Ionising Radiation on Engineered Barrier System (EBS) Performance in Cement and Clay Systems (e.g. Effects on Redox, Organic Degradation Products, Microbial Processes, etc.)

Ensuring that an engineered barrier system (EBS) will perform its desired functions requires integration – of an iterative nature – of the following: site-specific information; information on the waste properties; understanding of material properties and performance, and in-situ / laboratory testing and modelling relating to key processes that will affect near-field evolution. Within this research sub-topic RWM considers additional processes (to those already discussed) that overlap with other key research areas (such as radiation effects) that impact on near-field evolution.

In general, cementitious materials have good resistance to physical degradation upon irradiation although some wasteforms associated with specific wastes (e.g. those containing large proportions of organic material) are less resistant. Similarly the effects of radiation on clay alteration and radiolysis of pore-water have been studied. In general for typical HLW and spent fuel concepts it is considered that radiolysis of pore-water in a clay-based buffer would be insignificant, as the dose rate outside the container would be low. Similar conclusions were reached for the effects of radiation damage and radiolysis in the backfill (as the radiation field is even lower in these regions). Work considering long-term redox evolution has also investigated the impacts of radiolysis on redox conditions with respect to spent fuel dissolution and bentonite porewater conditions. For cement-based ILW concepts, the potential effects of radiolysis were surveyed a number of years ago as part of the UK Nirex research programme.

This task will address any research needs identified by the outcome of Task 442 to develop our understanding of the potential impact of ionising radiation on the post closure safety functions provided by cement-based and clay-based EBS.

Research Need
To inform safety case development by improving our understanding of whether ionising radiation has a significant impact on the evolution of the near-field environment by undertaking required experimental or modelling studies identified in the previous review.

Research Objective
To determine whether uncertainties can be reduced relating to radiation impacts on the performance of the engineered barrier system as a result of further investigation.

Scope
The scope for this task will be defined by the outcome of task 442.

SRL at task start | SRL at task end | Target SRL
--- | --- | ---
4 | 5 | 5

End point
No Further Research Planned

Customer
Disposal System Safety Case

Further information
This task may be partly addressed by a university research study.
Application of Near-field Component Model Using Updated Understanding of Backfill Evolution

Background
Ensuring that an engineered barrier system will perform its desired functions requires integration – of an iterative nature – of site-specific information, information on the waste properties, understanding of material properties and performance, and in-situ and laboratory testing and modelling relating to key processes that will affect near-field evolution. As RWM’s programme develops it will be important to build confidence that the individual parts of the near-field, such as waste packages and backfill, work together to provide a system that achieves its safety functions.

A near-field component model considers the relevant processes (and associated uncertainty) that affect near-field evolution and radionuclide behaviour and that could impact on the performance of the system, e.g. cracking, heterogeneity, carbonation and pH evolution. During the period 2012-2014 we developed a prototype near-field component model and this task will support further development subsequent to initial application (Tasks 442 and 444).

Research Need
To further develop the component model for the near field of a cementitious ILW GDF taking account of new information from work on the evolution of cement-based engineered barrier system.

Research Objective
To ensure that the near-field component model takes account of new information provided by Tasks 418, 419, 423 and 424, as well as current awareness.

Scope
To be defined based on tasks 418, 423 and 419, as well as current awareness.

Further information
Relevant publications include:
Title
High Heat IPT: Data Collation for the Thermal Analysis of UK Design Concepts

Background
Currently there is very well-developed modelling capability with respect to heat generation and heat transfer processes for both the HLW / spent fuel disposal area and the ILW / LLW disposal area, but further work remains to understand fully the thermal evolution of the disposal system for a wide range of engineered barrier systems’ design and material options.

The tools and modelling capability developed internationally to calculate the thermal evolution of a HLW and spent fuel disposal area are well developed, however only limited calculations have been conducted using UK waste data. Work has recently been completed to develop a thermal dimensioning tool to evaluate the thermal evolution profiles for a range of potential GDF concepts and designs, to inform the specification of thermal targets. This task addresses the requirement to evaluate and derive suitable UK-specific data that can be used in the thermal dimensioning tool.

Research Need
To support concept development by identifying suitable data to calculate acceptable waste package loading and spatial configurations of those packages and thereby to enable heat-generating waste to be successfully disposed in a GDF.

Research Objective
To gather suitable data to allow subsequent thermal dimensioning studies to be carried out which are representative of the UK inventory and design concepts.

Scope
A basic dataset will be developed for use in the thermal dimensioning analysis. This information will be incorporated into the project database. Data will come from:
- Engineering designs for all of the outline concepts (e.g. disposal container dimensions and the basic geometry/layout of the disposal modules).
- Inventory information (and corresponding power curves).
- Thermal properties of the key engineered barrier system components (e.g. the specific heat capacity and thermal conductivity of the buffer materials).

Ranges on the thermal conductivity of the generic rock environments will be recorded and justified.

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>457</td>
<td>Complete, pending publication</td>
<td>Near-Field Evolution</td>
<td>Thermal Modelling of Heat-generating Processes</td>
</tr>
</tbody>
</table>

**Title**
High Heat IPT: 3D-Thermal Analysis Verification of Analytical Model

**Background**
Currently there is very well-developed modelling capability with respect to heat generation and heat transfer processes for both the HLW / spent fuel disposal area and the ILW / LLW disposal area, but further work remains to understand fully the thermal evolution of the disposal system for a wide range of engineered barrier system design and material options.

The tools and modelling capability developed internationally to calculate thermal evolution of a HLW and spent fuel disposal area are well developed, however only limited calculations have been conducted using UK waste data. Work has recently been completed to develop a thermal dimensioning tool to evaluate the thermal evolution profiles for a range of potential GDF concepts and designs, to inform the specification of thermal targets. This task utilises a small number of more complex 3D-modelling calculations in order to verify the analytical thermal dimensioning tool.

**Research Need**
To support concept development, design studies and waste package disposability assessments by verifying the thermal dimensioning tool previously developed against a small number of more complex 3D-modelling calculations.

**Research Objective**
To perform 3D-modelling calculations to justify the use of the simplifications used in the analytical thermal dimensioning tool previously developed.

**Scope**
The 3D-modelling task will:
- Identify the key calculations to be performed.
- Identify a suitable modelling platform.
- Perform the verification calculations.
- Identify whether additional calculations need to be performed and conduct these, as appropriate.
- Produce a technical report describing the conclusions of the study, and in particular identifying limits of applicability of the analytical model.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
No Further Research Planned

**Customer**
Disposal System Specification

**Further information**

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>459</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near-Field Evolution</td>
<td>Thermal Modelling of Heat Generating Processes</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Thermal Modelling of Low-heat-generating Waste (LHGW) Disposal Areas

**Background**

Currently there is very well-developed modelling capability with respect to heat generation and heat transfer processes for both the HLW / spent fuel disposal area and the ILW / LLW disposal areas, but further work remains to understand fully the thermal evolution of the disposal system for a wide range of Engineered Barrier System (EBS) design and material options.

Modelling of the temperature evolution of an ILW/LLW disposal area after backfilling and closure has considered the short–term exotherm from the hydration of a cement backfill and the contribution of the decay of radionuclides over a period of a few tens of years. There is a need to examine the sensitivity of these results to model input parameters and to account for radioactive decay heat over longer timescales.

**Research Need**

To support design, post-closure assessment, Disposal System Safety Case and concept development by improving the understanding of the temperature profile resulting from the cement hydration exotherm during backfilling and closure and heat generation from radioactive decay of ILW.

**Research Objective**

To evaluate the uncertainty in the LHGW disposal temperature profile, including that associated with the exotherm from the curing of the backfill, radioactive decay, placement of packages (UILW) and background temperature at depth.

**Scope**

Thermal modelling of the Low-heat-generating Waste (LHGW) disposal area to address details of thermal modelling of ILW vaults and to evaluate the uncertainty in the thermal profile.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Specification

**Further information**

Relevant publications include:

Background
Currently there is very well-developed modelling capability with respect to heat generation and heat transfer processes for both the HLW / spent fuel disposal area and the ILW / LLW disposal area, but further work remains to understand fully the thermal evolution of the disposal system for a wide range of engineered barrier system design and material options.

The tools and modelling capability developed internationally to calculate thermal evolution of a HLW and spent fuel disposal area are well developed, however only limited calculations have been conducted using UK waste data. This task utilises the data identified in Task 456 in the thermal dimensioning tool, previously developed to further our understanding of the constraints that the thermal output of high-heat-generating wastes pose on the disposal system.

Research Need
To support concept development, design studies and waste package disposability assessments by developing a strategy to enable acceptable waste package loading and spatial configurations of those packages to be determined such that the understanding gained enables heat-generating waste to be successfully disposed in a GDF.

Research Objective
To carry out thermal analysis which will:
- Define the relationship between the number of assemblies per waste package and the surface storage time, for a given temperature constraint for each of the disposal concepts.
- Inform option development by allowing refinement of the range of concepts by identifying constraints on each design.
- Inform waste package requirements (maximum power output) to ensure waste producers are provided with sufficient guidance in the context of the range of waste disposal concepts.
- Support cost estimations on the basis of credible disposal configurations (i.e. spacing of waste packages), voidage, backfill volumes and footprint.
- Identify the consequences of assumptions related to changes in burn-up and cooling period of the higher-heat generating waste.

Scope
The thermal analysis task will include:
- Identification of the calculations to be performed and suitable sensitivity calculations to inform the final selection of cases.
- Performing the thermal analysis, generating summary plots (e.g. peak temperature versus. spacing plots) and producing a technical report describing the conclusions of the study.

Relevant publications include:
Task Number | 461 | Status | Ongoing
---|---|---|---
PBS level 4 | Near-Field Evolution |  
PBS level 5 | Evolution of Clay-Based EBS |  

Title

Modelling of Bentonite Resaturation using Data Provided from Aspo Underground Research Laboratory Under SKB Engineered Barrier System (EBS) Task Force and the FEBEX Dismantling Project

Background

Resaturation is a complex process, especially in low permeability materials such as those comprising typical clay-based and cement-based engineered barriers. Resaturation will be a heterogeneous process because of variations in the properties of the engineered barrier system (EBS) components and heterogeneity in the host rock. However, the ways in which interactions between disposal system components will affect the rate of resaturation are not yet adequately understood. Our planned R&D on EBS resaturation is focused on developing a good understanding of barrier performance to support the development of GDF concepts and the Disposal System Safety Case (DSSC). The rate and manner in which the near field resaturates controls the evolution of many of the components and affects the long-term performance.

Work is ongoing within several Waste Management Organisations (WMOs) and international collaboration projects to improve the understanding of resaturation for specific sites and to improve modelling capabilities for resaturation.

In the longer term, once site-specific information becomes available, research on understanding and modelling the expected resaturation processes will become central to developing an understanding of near-field evolution in a HLW and spent fuel disposal area (providing a clay-based barrier remains a candidate material). This will be important as resaturation controls the onset of any clay-based backfill swelling process and gas generation and heat transfer properties. All of these processes will require detailed understanding to inform the development of site-specific designs, and the optimeering and, in particular, the planning of installation of EBS materials (e.g. appropriate backfill emplacement procedures). It will therefore be necessary to develop a comprehensive modelling capability to illustrate detailed understanding of the key processes of importance for resaturation and its heterogeneity for a specific site(s).

This task includes using data from experiments at the Åspö URL through the international collaborative SKB EBS Task Force and the FEBEX DP project in order to further develop and test our models.

Research Need

To support the safety case by developing an understanding of the evolution of bentonite-based buffers and the achievement of the required safety functions through modelling of the thermal, hydraulic, mechanical and chemical processes during water resaturation in buffer, backfill and the near field (in a crystalline rock environment).

Research Objective

To develop understanding and modelling capability of the resaturation of bentonite after container emplacement.

Scope

- To undertake modelling of bentonite resaturation using field-test data from Åspö URL as part of the SKB EBS Task force and the FEBEX Dismantling project.
- To participate in modelling test cases identified by the SKB EBS Task Force.'

| SRL at task start | 4 | SRL at task end | 5 | Target SRL | 5 |
|---|---|---|---|---|

End point | Site Specific Validation |

Customer | Disposal System Safety Case, Design |

Further information

Tasks 461, 462, 464 and 466 (part) are let under a single contract. Relevant publications include:

D. Holton, S. Baxter and A.R. Hoch, 2012. Modelling Coupled Processes in Bentonite; Recent Results from the UK’s Contribution to the Åspö EBS Task Force, Min Mag 76, 3033-3043.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>462</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Near-Field Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Evolution of Clay-Based EBS</td>
</tr>
</tbody>
</table>

**Title**

Study on Diffusion Processes in Saturated Bentonite (e.g. Chloride, Sulphide) with Relevance to Corrosion

**Background**

One of the roles of a bentonite buffer is to control the migration of species to the surface of a spent fuel canister once the buffer has resaturated. This is an important control on the corrosion and long-term integrity of the container. Diffusion in saturated bentonite systems is not yet fully understood.

Work is ongoing within several Waste Management Organisations (WMOs) and international collaboration projects to improve the understanding of resaturation for specific sites and to improve modelling capabilities for resaturation. In the current phase RWM is developing its understanding of the implications of major resaturation processes for the UK context through participation in international collaboration projects. Work has been undertaken within several WMOs and international collaboration projects to develop the understanding of transport processes in bentonite. In this task RWM will develop its understanding of diffusion within bentonite in the UK context, considering typical groundwater solutes.

**Research Need**

To understand the diffusion of groundwater solutes in saturated bentonite to inform consideration of the impact of corrosion on long term container performance.

**Research Objective**

To understand how saturated bentonite restricts the diffusion of dissolved solutes to and from a spent fuel container.

**Scope**

To undertake modelling studies and measurement of diffusive transport processes in saturated bentonite as part of the SKB EBS Task Force. This task may use data provided from the EBS Task Force in addition to laboratory measurements undertaken as part of this task.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**

Tasks 461, 462, 464 and 466 (part) are let under a single contract

Relevant publications include:

D. Holton, S. Baxter and A.R. Hoch, 2012. Modelling Coupled Processes in Bentonite; Recent Results from the UK’s Contribution to the Åspö EBS Task Force, Min Mag 76, 3033-3043.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>463</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Clay-Based EBS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

EC BELBaR Study on Bentonite Erosion

**Background**

Resaturation is a complex process, especially in low permeability materials such as typical clay-based and cement-based engineered barriers. Resaturation will also be a heterogeneous process because of variations in the properties of the engineered barrier system (EBS) components and heterogeneity in the host rock.

Evolution of clay-based engineered barrier materials in the longer term can impact on the ability of a clay-based barrier to provide containment. Work has been carried out to determine the extent of these processes for several candidate clay buffer materials in a range of geological settings. Such processes include clay alteration through interactions with other EBS materials, for example cement-clay, iron-clay, and waste-clay interactions, mechanical alteration of clays as a consequence of gas breakthrough, and clay-groundwater interactions, including understanding the impact of external conditions such as glacial erosion processes. Such processes were considered as part of the EC NF-PRO (Near-field Processes) project; consideration of the geochemical aspects and implications for performance assessment of the work completed within this project were reported in 2008.

RWM has recently completed a review of UK-specific factors influencing bentonite barrier performance. This included consideration of cement-bentonite, iron-clay, and waste-clay interactions (specifically magnesium-rich wasteforms, such as Magnox swarf), in addition to thermal alteration and erosion and piping of clays. This task addresses uncertainty associated with the potential erosion of bentonite under evolving hydrological conditions.

**Research Need**

To support the post-closure safety case and concept optimisation by developing an understanding of the controlling processes of the potential erosion of bentonite as a buffer.

**Research Objective**

To determine whether erosion of bentonite may occur to the extent that it will impact on the safety function of the clay buffer.

**Scope**

BELBaR is a project within Euratom FP7. Management of Radioactive Waste - Geological Disposal. It aims to investigate bentonite erosion, its effects on the long term performance of the engineered barrier and radionuclide transport. The collaborative project will improve the understanding of when bentonite colloids are unstable, improve quantitative models of erosion of the bentonite barrier for the cases where colloids are stable, and improve the understanding of how radionuclides attach to clay colloids. This information will be used to formulate improved models for the assessment of radionuclide transport in the geosphere. Experimental programmes and quantitative models will be developed, tailor-made to resolve issues that are important in safety assessments.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:


NF-PRO website, http://www.nf-pro.org/
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Clay-Based EBS</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Study of Bentonite Thermal Alteration, Including Participation in SKB ABM (Alternative Buffer Materials) Project

**Background**
Evolution of clay-based engineered barrier materials in the longer term can impact on the ability of a clay-based barrier to provide containment. Work has been carried out to determine the extent of these processes for several candidate clay buffer materials in a range of geological settings.

Of particular importance in the disposal of high heat generating wastes such as future spent fuels / MOX, is the thermal stability of buffer materials. The impact of temperature-induced precipitation of cementing agents (silica, sulphates, carbonates and iron precipitates) on the stress / strain properties of clay buffers may be significant. This is of importance particularly if buffer temperatures higher than 100°C, but below the boiling point of water at in situ pressures, are considered. Above such temperatures steam can be formed and this has been reported to have deleterious effects on bentonite properties. This task addresses alteration of bentonites because of elevated temperatures and includes the effect of increased corrosion of steels.

**Research Need**
To support concept development and the post-closure safety case by determining whether high-heat generating wastes affect the safety functions provided by the bentonite and to identify what constraints may need to be imposed on the emplacement of heat-generating wastes.

**Research Objective**
- To understand the impact of long-term thermal alteration of bentonite buffers at temperatures around 100°C.
- To develop UK expertise through participation in overseas collaborative programmes.

**Scope**
- Participation in the Alternative Buffer Materials (ABM) experiment at the Äspö underground research laboratory. The participation in the ABM programme will allow RWM to develop the UK supply chain skills for analysing the mineral phases present in bentonite, and also help it to develop a knowledge base of alternative buffer materials that could be optimised for safety, availability and cost once a site has been selected.
- Studies of altered bentonite from the FEBEX DP project.
- Laboratory studies of effects of bentonite alteration at temperatures of around 100°C, utilising mineralogical analyses and measurement of hydromechanical properties.
- Modelling of bentonite alteration at elevated temperatures.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Application of Understanding

**Customer**
Disposal System Safety Case

**Further information**
Tasks 461, 462, 464 and 466 (part) are let under a single contract

Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>465</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

**PBS level 4**  
Near-Field Evolution

**PBS level 5**  
Evolution of Clay-Based EBS

**Title**  
EPSRC GEOWASTE SAFE PROJECT WP 1: Development of a Mechanistic Understanding of the Steel-Clay Interface

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operations and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock.

An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many processes are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings and a capability to model those effects is central to RWM’s geosphere research. The specific couplings of significance depend on the details of the concept, design and host geology and cannot be investigated at a site-specific level until site-specific and concept-specific information are available. However, in our current phase of the programme we are supporting international collaborations and academic studies in this field.

This task comprises such an academic study. It is co-funded by RWM and the Engineering and Physical Sciences Research Council (EPSRC) under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme. The task aims to investigate novel monitoring techniques to investigate the mechanism of the interactions at the interface between steel waste containers and clay backfill / buffer.

**Research Need**

To support the post-closure safety case by developing an improved understanding of the impact of coupled THMC processes on engineered barrier systems.

**Research Objective**

Across eight work packages in the SAFE consortium, to deploy and refine advanced monitoring techniques for simultaneous imaging of THMC variables (pH, temperature, pore-water pressure, swelling etc.) within the laboratory, and to integrate these monitoring techniques with experiments to gain a predictive understanding of the THMC evolution of clay-based engineered barriers, and their interfaces, up to the upper-bound of realistic environmental conditions.

**Scope**

To assess the behaviour and integrity of the interface between steel HLW / spent fuel waste containers and bentonite, combining geotechnical integrity testing with physico-chemical characterisation. To understand likely non-linear increases in reaction kinetics under temperatures and salinities that could reasonably be considered appropriate for UK GDF settings. This work is being progressed by the University of Newcastle.

**SRL at task start**  
4

**SRL at task end**  
5

**Target SRL**  
5

**End point**  
Site Specific Application of Understanding

**Customer**  
Research (‘Curiosity Driven’), Disposal System Safety Case

**Further information**

RWM’s role in SAFE is in supporting the academic cohort by reviewing the technical output of the project and its applicability to concept development and the safety case. The SAFE consortium comprises the universities of Strathclyde, Edinburgh, Nottingham, Newcastle, Glasgow, Cardiff and Oxford, together with the British Geological Survey.
Title

Modelling and Laboratory Studies on Bentonite Homogenisation Upon Resaturation

Background

Resaturation is a complex process, especially in low permeability materials such as those comprising typical clay-based and cement-based engineered barriers. Resaturation will be a heterogeneous process because of variations in the properties of the engineered barrier system (EBS) components and heterogeneity in the host rock. However, the ways in which interactions between disposal system components will affect the rate of resaturation are not yet fully understood. Our planned R&D on EBS resaturation is focused on developing a good understanding of barrier performance to support the development of GDF concepts and the Disposal System Safety Case (DSSC). The rate and manner in which the near field resaturates controls the evolution of many of the components and affects its long-term performance.

Work is ongoing within several Waste Management Organisations (WMOs) and international collaboration projects to improve the understanding of resaturation for specific sites and to improve modelling capabilities for resaturation.

In the longer term, once site-specific information becomes available, research on understanding and modelling the expected resaturation processes will become central to developing an understanding of near-field evolution in a HLW and spent fuel disposal area (providing a clay-based barrier remains a candidate material). This will be important as resaturation controls the onset of any clay-based backfill swelling process, together with gas generation and heat transfer properties. All of these processes will require detailed understanding to inform the development of site-specific designs and the optioneering and, in particular, the planning of installation of EBS materials (e.g. appropriate backfill emplacement procedures). It will therefore be necessary to develop a comprehensive modelling capability to illustrate detailed understanding of the key processes of importance for resaturation and its heterogeneity for a specific site(s). This task investigates the homogenisation of bentonite upon resaturation and the effect of compaction in order to support the achievement of the requisite swelling pressure and uniform properties.

Research Need

To support safety case development by demonstrating sufficient understanding of bentonite homogenisation on resaturation and its impact on the safety functions achieved by the buffer.

Research Objective

To develop an understanding of the resaturation and swelling of bentonite blocks and pellets, and the development of a homogeneous buffer system.

Scope

The scope will be undertaken by two PhD students.

Part of this task will review the current understanding of bentonite homogenisation from the programmes of other WMOs and will then undertake a modelling programme of work that will develop our understanding of the processes controlling homogenisation. This is expected to include participation in the SKB EBS Task Force and will also be able to draw on results of other experimental work at Imperial College.

The other part of this task will study the effect of the compaction process on the hydraulic, mechanical and thermal behaviour of bentonite with the aim of optimising its ability to resaturate while ensuring that its thermo-mechanical behaviour (e.g. swelling potential) is not compromised. This will be undertaken as a PhD under the EPSRC Centre for Doctoral Training initiative being coordinated by the Imperial Cambridge Open (ICO) Universities Consortium.

SRL at task start 3  SRL at task end 4  Target SRL 5
End point Site Specific Validation
Customer Disposal System Safety Case, Concept Development

Further information

Tasks 461, 462, 464 and 466 (part) are let under a single contract. Relevant publications include:
D. Holton, S. Baxter and A.R. Hoch, Modelling Coupled Processes in Bentonite; Recent Results from the UK’s Contribution to the Åspö EBS Task Force, Min Mag 76, 3033-3043, 2012.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>467</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

PBS level 4: Near-Field Evolution
PBS level 5: Evolution of Clay-Based EBS

**Title**
Study on Microbial Processes in Bentonite Systems, Including the Effect of Ionising Radiation and Swelling Pressure

**Background**
One of the roles of a bentonite buffer is to restrict microbial activity within the buffer and at the surface of a spent fuel container once the buffer has resaturated. Under sufficient swelling pressures microbial activity is expected to be suppressed due to low free water and the small pore-size restricting transport of microbes and nutrients. This is an important control on the corrosion and long term integrity of the container. It is important to demonstrate that bentonite at the required swelling pressure achieves this function and that the influence of ionising radiation is understood.

**Research Need**
To support development of the post-closure safety case by reducing uncertainty associated with potential microbial activity within a bentonite buffer, including the development of microcosms under realistic dose-rate conditions.

**Research Objective**
To understand the impact of swelling pressure and ionising radiation on microbial activity within a bentonite buffer.

**Scope**
This experimental study on microbial processes in bentonite systems will examine the effect of swelling pressure in restricting microbial activity within resaturated bentonite. It will then examine if there is any influence of ionising radiation at dose rates expected at the surface of a spent fuel disposal container. This task will capitalise on international understanding of bentonite performance, through analysis of samples from the FEBEX DP, and extend this understanding through microbial studies under simulated GDF conditions in the laboratory.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRL at task end</td>
<td>5</td>
</tr>
<tr>
<td>Target SRL</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Validation

**Customer**
Disposal System Safety Case

**Further information**
This is an ongoing PhD study at the University of Manchester.

Relevant publications include:
Appendix B - 193

Review of International Work on Bentonite Erosion to Identify Future Research Needs

Background

Resaturation is a complex process, especially in low permeability materials such as typical clay-based and cement-based engineered barriers. Resaturation will be a heterogeneous process because of variations in the properties of the Engineered Barrier System (EBS) components and heterogeneity in the host rock. However, the ways in which interactions between disposal system components will affect the rate of resaturation are not yet fully understood. The rate and manner in which the near-field resaturates controls the evolution of many of the components and affects the long-term performance of the disposal system.

Evolution of clay-based engineered barrier materials in the longer term can therefore impact on the ability of a clay-based barrier to provide containment. Work has been carried out to determine the extent of these processes for several candidate clay buffer materials in a range of geological settings. Such processes include clay alteration through interactions with other EBS materials, for example cement-clay, iron-clay and waste-clay interactions, mechanical alteration of clays as a consequence of gas breakthrough, and clay groundwater interactions, including understanding the impact of external conditions such as glacial erosion processes. Such processes were considered as part of the EC NF-PRO (Near-Field Processes) project; consideration of the geochemical aspects and implications for RWM's safety case performance assessment were reported in 2008.

RWM has recently completed a review of UK-specific factors influencing bentonite barrier performance. This included consideration of cement-bentonite, iron-clay, and waste-clay interactions (specifically magnesium-rich wasteforms, such as Magnox swarf), in addition to thermal alteration and erosion and piping of clays. RWM will continue to keep up-to-date with research being conducted as part of international and other WMOs’ programmes and to participate in collaborative projects.

This task comprises a review of the output from Task 463 and other international research on bentonite piping and erosion in order to define future RWM research requirements.

Research Need

To support concept optimisation by developing an understanding of the controlling processes on the potential erosion of bentonite as a buffer.

Research Objective

To identify the need for, and scope of, a future work programme on bentonite piping and erosion relevant to UK HLW / SF disposal concepts.

Scope

Review output from Task 463 and other international research to define a future work programme on bentonite piping and erosion relevant to UK HLW / SF disposal concepts.

Further information

Relevant publications include:


### Background
Resaturation is a complex process, especially in low permeability materials such as those comprising typical clay-based and cement-based engineered barriers. Resaturation will be a heterogeneous process because of variations in the properties of the engineered barrier system (EBS) components and heterogeneity in the host rock. However, the ways in which interactions between disposal system components will affect the rate of resaturation are not yet fully understood. Our planned R&D on EBS resaturation is focused on developing a good understanding of barrier performance to support the development of GDF concepts and the Disposal System Safety Case (DSSC). The rate and manner in which the near-field resaturates controls the evolution of many of the components and affects its long-term performance.

Work is ongoing within several Waste Management Organisations (WMOs) and international collaboration projects to improve the understanding of resaturation for specific sites and to improve modelling capabilities for resaturation.

In the longer term, once site-specific information becomes available, research on understanding and modelling the expected resaturation processes will become central to developing an understanding of near-field evolution in a HLW and spent fuel disposal area (providing a clay-based barrier remains a candidate material). This will be important as resaturation controls the onset of any clay-based backfill swelling process, together with gas generation and heat transfer properties. All of these processes will require detailed understanding to inform the development of site-specific designs, and the optioneering and in particular, the planning of installation of EBS materials (e.g. appropriate backfill emplacement procedures). It will therefore be necessary to develop a comprehensive modelling capability to illustrate detailed understanding of the key processes of importance for resaturation and its heterogeneity for a specific site(s).

### Research Need
To support the safety case by developing a detailed understanding of the evolution of bentonite-based buffers and the achievement of the required safety functions through modelling the thermal, hydraulic, mechanical and chemical processes during water transfer in buffer, backfill and near field (in a crystalline rock environment).

### Research Objective
To develop, and validate our understanding of bentonite resaturation after container emplacement against data from in situ experiments and the output from alternative models.

### Scope
- Modelling and validation of bentonite resaturation using field test data from SKB as part of the EBS Task Force.
- Participation in modelling test cases identified by the EBS Task Force. Scope will be informed by the results of task 461 and input from the EBS Task Force.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>5</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This task links with studies on bentonite homogenisation (Task 473).

Relevant publications include:
D. Holton, S. Baxter and A.R. Hoch, 2012 Modelling Coupled Processes in Bentonite; Recent Results from the UK’s Contribution to the Äspö EBS Task Force, Min Mag 76, 3033-3043.
Title
Development of Mechanistic Understanding of Diffusion in Saturated Bentonite

Background
One of the roles of a bentonite buffer is to control the migration of chemical species to the surface of a spent fuel canister once the buffer has resaturated. This is an important control on the corrosion and long term integrity of the canister. Diffusion in saturated bentonite systems is not yet fully understood.

Work is ongoing within several Waste Management Organisations (WMOs) and international collaboration projects to improve the understanding of resaturation for specific sites and to improve modelling capabilities for resaturation. Work has been undertaken within several WMOs and international collaboration projects to develop the understanding of transport processes in bentonite. In this task RWM would continue to develop its understanding of diffusion within bentonite in the UK context, considering typical groundwater solutes. This task is a future extension to Task 462, aimed at delivering sufficient mechanistic understanding of diffusive transport processes to underpin the use of MX80 bentonite (or a suitable alternative).

Research Need
To determine whether corrosive species e.g. chloride, diffuse through the buffer at a rate which prejudices the safety function provided by the container under realistic conditions.

Research Objective
To understand how saturated bentonite restricts the diffusion of dissolved corrosive species, which may be present in the groundwater, to a spent fuel container and how it controls the rate of corrosion.

Scope
To undertake modelling studies and measurement of diffusive transport processes in saturated bentonite as part of SKB EBS Task Force. This task may use data provided from the EBS Task Force in addition to laboratory measurements directly commissioned as part of this task.

The scope for this task will be defined by the findings of task 462.

SRL at task start  4  SRL at task end  5  Target SRL  5

End point  Site Specific Validation

Customer  Disposal System Safety Case

Further information
Relevant publications include:
D. Holton, S. Baxter and A.R. Hoch, 2012. Modelling Coupled Processes in Bentonite; Recent Results from the UK’s Contribution to the Åspö EBS Task Force, Min Mag 76, 3033-3043.
Resaturation is a complex process, especially in low permeability materials such as typical clay-based and cement-based engineered barriers. Resaturation will be a heterogeneous process because of variations in the properties of the engineered barrier system (EBS) components and heterogeneity in the host rock. However, the ways in which interactions between disposal system components will affect the rate of resaturation are not yet fully understood. The rate and manner in which the near field resaturates controls the evolution of many of the components and affects the long-term performance of the disposal system.

Evolution of clay-based engineered barrier materials in the longer term can therefore impact on the ability of a clay-based barrier to provide containment. Work has been carried out to determine the extent of these processes for several candidate clay buffer materials in a range of geological settings. Such processes include clay alteration through interactions with other EBS materials, for example cement-clay, iron-clay and waste-clay interactions, mechanical alteration of clays as a consequence of gas breakthrough, and clay groundwater interactions, including understanding the impact of external conditions such as glacial erosion processes. Such processes were considered as part of the EC NF-PRO (Near-Field Processes) project; consideration of the geochemical aspects and implications for RWM’s safety case performance assessment were reported in 2008.

RWM has recently completed a review of UK-specific factors influencing bentonite barrier performance. This included consideration of cement-bentonite, iron-clay, and waste-clay interactions (specifically magnesium-rich wasteforms, such as Magnox swarf), in addition to thermal alteration and erosion and piping of clays. RWM will continue to keep up-to-date with research being conducted as part of international and other WMOs’ programmes and to participate in collaborative projects. This task is assumed to arise from the review of research requirements identified under Task 468.

**Research Need**
To support concept optimisation by developing an understanding of the controlling processes on the potential erosion of bentonite as a buffer.

**Research Objective**
To investigate the potential for, and impact of, bentonite piping and erosion in UK HLW / Spent Fuel (SF) disposal concepts.

**Scope**
Scope to be defined by output of Task 468.

<table>
<thead>
<tr>
<th>End point</th>
<th>Site Specific Validation</th>
</tr>
</thead>
</table>

**Customer**
Disposal System Safety Case

**Further information**

Relevant publications include:


Background

Evolution of clay-based engineered barrier materials in the longer term can impact on the ability of a clay-based barrier to provide containment. Work has been carried out to determine the extent of these processes for several candidate clay buffer materials in a range of geological settings. Of particular importance in the disposal of high heat generating wastes, such as future spent fuels / MOx, is the thermal stability of buffer materials.

The impact of temperature-induced precipitation of cementing agents (silica, sulphates, carbonates and iron precipitates) on the stress / strain properties of clay buffers may be significant. This is of importance particularly if buffer temperatures higher than 100°C but below the boiling point of water at in situ pressures are considered. Above such temperatures steam can be formed and this has been reported to have deleterious effects on bentonite properties.

This task addresses the need for further research into the mechanisms of bentonite degradation and, given this understanding, whether temperature-resistant clay materials can be synthesised.

Research Need

- To support concept development and the post-closure safety case by determining whether high-heat generating wastes affect the safety functions provided by the bentonite.
- To identify what constraints may need to be imposed on the emplacement of heat-generating wastes.
- To investigate the synthesis of alternative buffer materials with more favourable thermal properties for the disposal of high heat generating wastes.‘

Research Objective

- To understand the thermal limits on bentonites with respect to their chemical / physical alteration of significance to safety functions.
- To investigate whether formulations of bentonite mixtures can increase resilience to alteration when exposed to temperatures >100°C by increasing the thermal conductivity.‘

Scope

Experimental investigation of the possibility of improving the thermal properties of clay-based buffers by mixing bentonite with other materials whilst still delivering the required safety functions.

Further information

Relevant publications include:


### Task Details

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Near-Field Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Evolution of Clay-Based EBS</td>
<td></td>
</tr>
</tbody>
</table>

#### Title
Validation of Bentonite Homogenisation Upon Resaturation in Realistic Conditions

#### Background
Resaturation is a complex process especially in low permeability materials such as those comprising typical clay-based and cement-based engineered barriers. Resaturation will be a heterogeneous process because of variations in the properties of the engineered barrier system (EBS) components and heterogeneity in the host rock. However, the ways in which interactions between disposal system components will affect the rate of resaturation are not yet fully understood. Our planned R&D on EBS resaturation is focused on developing a good understanding of barrier performance to support the development of GDF concepts and the Disposal System Safety Case (D SSC). The rate and manner in which the near-field resaturates controls the evolution of many of the components and affects the long-term performance of the disposal system.

Work is ongoing within several Waste Management Organisations (WMOs) and international collaboration projects to improve the understanding of resaturation for specific sites and to improve modelling capabilities for resaturation.

In the longer term, once site-specific information becomes available, research on understanding and modelling the expected resaturation processes will become central to developing an understanding of near-field evolution in a HLW and spent fuel disposal area (providing a clay-based barrier remains a candidate material). This will be important as resaturation controls the onset of any clay-based backfill swelling process together with gas generation and heat transfer properties. All of these processes will require detailed understanding to inform the development of site-specific designs and the optioneering and, in particular, the planning of installation of EBS materials (e.g. appropriate backfill emplacement procedures). It will therefore be necessary to develop a comprehensive modelling capability to illustrate detailed understanding of the key processes of importance for resaturation and its heterogeneity for a specific site(s). This task comprises an assumed extension to task 466, investigating and modelling the homogeneity of resaturation of bentonite pellets in order to support the achievement of the requisite swelling pressure to deliver the safety functions of a buffer or backfill using data from in-situ or large scale experiments.

#### Research Need
To support DSSC development by demonstrating an understanding of bentonite homogenisation on resaturation and its impact on the safety functions achieved by the buffer.

#### Research Objective
To build confidence in the understanding of the resaturation, swelling and homogenisation of bentonite pellets and the achievement of the required swelling pressures for a buffer or backfill.

#### Scope
To undertake a modelling and experimental programme of work to validate understanding under realistic conditions (e.g. representative groundwaters, Underground Research Laboratory (URL) environment). This task will be informed by the output of Task 466 and output from other participants within the SKB EBS Task Force.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Disposal System Safety Case, Design

#### Further information
Relevant publications include:
D. Holton, S. Baxter and A.R. Hoch, 2012. Modelling Coupled Processes in Bentonite; Recent Results from the UK’s Contribution to the Åspö EBS Task Force, Min Mag 76, 3033-3043.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>474</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Near-Field Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Evolution of Clay-Based EBS</td>
</tr>
</tbody>
</table>

### Title
Further Studies on Novel Clay Formulations (if Required)

### Background
Evolution of clay-based engineered barrier materials in the longer term can impact on the ability of a clay-based barrier to provide containment. Work has been carried out to determine the extent of these processes for several candidate clay buffer materials in a range of geological settings. Of particular importance in the disposal of high heat generating wastes, such as future spent fuels / MOx, is the thermal stability of buffer materials.

The impact of temperature-induced precipitation of cementing agents (silica, sulphates, carbonates and iron precipitates) on the stress / strain properties of clay buffers may be significant. This is of importance particularly if buffer temperatures higher than 100°C but below the boiling point of water at in situ pressures are considered. Above such temperatures steam can be formed and this has been reported to have deleterious effects on bentonite properties.

This task addresses possible future synthesis of temperature-resistant clay materials as a result of the work undertaken in Task 472.

### Research Need
- To support concept development and the post-closure safety case by determining whether high-heat-generating wastes affect the safety functions provided by the bentonite.
- To identify what constraints may need to be imposed on the emplacement of heat-generating wastes.
- To investigate the synthesis of alternative buffer materials with more favourable thermal properties for the disposal of high-heat-generating wastes.'

### Research Objective
To investigate whether formulations of bentonite mixtures can increase resilience to alteration when exposed to temperatures >100°C by increasing its thermal conductivity.

### Scope
- To develop new formulations of bentonite mixtures that could allow temperatures significantly in excess of 100°C to be tolerated.
- The feasibility and scope of this task are dependent on the outcome of Task 472.'

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>5</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Further information
Relevant publications include:
Task Number | 475 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Near-Field Evolution | 4 | PBS level 5 | Thermal Modelling of Heat-generating Processes | 5 | 5

Title
Maintenance and Development of the Thermal Dimensioning Tool (TDT)

Background
The TDT has been developed to explore, for a series of disposal concepts, the impact of a range of key physical parameters and engineering decisions on the temperature in the engineered barrier system. Through its use in: the high-heat-generating wastes project; ongoing work to update the designs for a GDF; and in waste package disposability assessments, a number of possible improvements have been identified that would:
- Increase the range of concepts represented and/or improve the existing representation (e.g. illustrative concept for the disposal of high-heat-generating wastes in lower strength sedimentary rock);
- Extend the functionality to a greater range of calculations (e.g. to find the cooling time that meets a given temperature limit for a given parameter set).
- Improve the outputs such that they include better representation of uncertainties and are better tailored to how the results are commonly presented in reports.

Research Need
To extend the capability of the thermal dimensioning tool and implement potential improvements identified during its initial application such that it can be used to support its ongoing application for design updates, disposability assessments and underpinning concept development work.

Research Objective
To continue to develop the thermal dimensioning tool as necessary for its continued use in RWM.

Scope
To prioritise, implement and test modifications to the thermal dimensioning tool as required by RWM.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
</table>

End point | Maintenance of toolkits |

Further information
Title
Watching Brief on Geosphere Data Acquisition Techniques

Background
In order to inform a decision on the suitability of a site or sites to host a GDF, detailed surface-based investigations will need to be undertaken to acquire and interpret information on the geological, hydrogeological and environmental conditions. The information acquired will be used as an input to the development of the safety case, for engineering design of the disposal facility and to demonstrate confidence to stakeholders that the geosphere of the potential disposal facility site is adequately understood.

Research Need
To maintain and develop understanding of approaches to the design and implementation of information-led investigations (surface-based and underground investigations), input this knowledge and understanding into discussions with key stakeholders, as necessary, and apply it to the design and implementation of site specific investigations in due course.

Research Objective
To ensure that the data acquisition techniques needed to acquire the necessary information are available or can be made available in a timely manner to support site investigation activities.

Scope
- To maintain an understanding of available data acquisition techniques through liaison with overseas sister organisations and attendance at relevant conferences in the site investigation, mining, oil and gas, geothermal and carbon capture and sequestration sectors.
- To maintain an understanding of approaches to underground investigations in Underground Research Facilities (URF) worldwide through attendance at the Annual Technical Meeting of the IAEA’s URF Network.'

SRL at task start 6 SRL at task end 6 Target SRL 6
End point Watching Brief
Customer Site Characterisation

Further information
Further information can be found on the IAEA website found at the location below:
Task Number: 489  
Status: Ongoing

PBS level 4  
Preparations for Site Investigations

PBS level 5  
Preparations for Site Investigations

Title  
Watching Brief on Interpretation and Modelling Techniques for Generation of a Site Descriptive Model

Background  
In order to inform a decision on the suitability of a site or sites to host a GDF, detailed surface-based investigations will need to be undertaken to acquire and interpret information on the geological, hydrogeological and environmental conditions. The information acquired will be used as an input to the development of the safety case, for engineering design of the disposal facility and to demonstrate confidence to stakeholders that the geosphere of the potential disposal facility site is adequately understood.

Research Need  
To maintain and develop understanding of approaches to the design and implementation of information-led investigations (surface-based and underground investigations) and input this knowledge and understanding into discussions with stakeholders, as necessary, and apply it to the design and implementation of site specific investigations in due course.

Research Objective  
To ensure that the techniques needed to interpret and model site characterisation information are available or can be made available in a timely manner to support site investigation activities.

Scope  
- To maintain an understanding of available data interpretation and modelling techniques through liaison with sister organisations overseas and attendance at relevant conferences in the site investigation, mining, oil and gas, geothermal and carbon capture and sequestration sectors.
- To maintain an understanding of approaches to underground investigations in Underground Research Facilities (URF) worldwide through attendance at the Annual Technical Meeting of the IAEA’s URF Network.

SRL at task start: 6  
SRL at task end: 6  
Target SRL: 6

End point: Watching Brief

Customer: Site Characterisation

Further information  
Further information can be found on the IAEA website found at the location below:  
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Preparations for Site Investigations</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Preparations for Site Investigations</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Review of the Impacts of Ongoing Excavation Work on Long-Term Underground Investigations

**Background**

In order to provide assurance of operational and post-closure safety, geoscientific monitoring and underground investigations will be required as part of the development of any GDF in order to validate and optimise the system design and its safety case. As the developer of the GDF, RWM will have to submit specific assessments based upon the data obtained for regulatory review at agreed hold points and the regulators will only permit construction of a GDF to proceed if their requirements are met, as outlined in reference below. This task focuses on the potential impacts of ongoing construction activities upon the integrity of the data obtained.

**Research Need**

To support the disposal system safety case by developing an approach to monitoring and underground investigations which is aligned to the required safety functions.

**Research Objective**

To understand the potential impacts of ongoing excavation work on the ability of long-term underground investigations and monitoring to meet their objectives, and hence to inform the appropriate design of these investigations.

**Scope**

The scope comprises a characterisation of the extent and magnitude of the hydraulic, mechanical, hydrogeochemical and thermal impacts on the surrounding geosphere of all types of construction work which will be undertaken in parallel with long-term investigations and monitoring. The study is expected to draw on experience and data gained in underground excavations, both in the nuclear waste disposal and wider industry, and will include an evaluation of the adequacy of our modelling tools for evaluating the impacts.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>End point</strong></td>
<td>Site Specific Underground Monitoring and Investigation Programme</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Customer</strong></td>
<td>Site Characterisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>492</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

PBS level 4
Preparations for Site Investigations

PBS level 5
Preparations for Site Investigations

Title
Mechanics of Rock Discontinuities Under Elevated Temperatures and Pressures

Background
Current models of stiffness and strength in rock joints (discontinuities) have been derived from laboratory testing and field verification. Previous work has either focussed on ambient temperature conditions or cold climate research. Further research is required regarding how rock discontinuities and rock masses behave at high temperatures in the context of geological disposal due to the need to dispose of high-heat-generating waste. Previous in-situ experiments, using equipment at elevated temperatures, have been unable to replicate a wide range of temperatures for anything other than short (several days) periods of time. UK GDF concepts adopt potential repository zone depths of between 200m – 1000m. The combination of the deep geological conditions and high pressures (c. 20-30 MPa at the deeper depth range), the geothermal gradient (c. 25°C/km) and the decay heat from radioactive waste means that temperatures in such excavations are likely to reach 70-90°C (or significantly higher for high-heat generating wastes) for decades or even many centuries.

Research Need
To support the disposal system safety case by developing an understanding of the influence of heat and pressure on rock mass strength, stiffness and performance.

Research Objective
To investigate the mechanics of rock joints under high temperatures and pressures by identifying the deformational characteristics of rock joints under a wide range of temperature conditions.

Scope
The scope comprises:
- Collection of rock block samples representative of the UK host rock concepts (e.g. granites, shales / mudstones and halite).
- Induction of tensile fractures and characterisation of discontinuities formed at ambient conditions to form a baseline data set (applying standard rock material testing methods, direct shear testing and measurements of normal and shear stiffness).
- Simulation of high pressure conditions using triaxial testing facilities at ambient temperature conditions utilising the seismic wave velocity as an indicator of the degree of closure of the fracture in order to form a baseline data set.

Based on the results of the above, triaxial experiments will evaluate the degree of closure associated with elevated temperature by passing Primary and Secondary waves through the sample. Shearing stresses could subsequently be applied in order to measure shear strength mobilised along discontinuities. Discrete element modelling would be used to scale from single discontinuities to a mass behaviour.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point
Site Specific Application of Understanding

Customer
Site Characterisation, Disposal System Safety Case

Further information
Work to progress this task sheet will begin in the form of a 3.5 year EPSRC iCASE project in September 2015. The University of Leeds, British Geological Survey, ARUP and RWM are partners in this project. Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>494</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Preparations for Site Investigations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Preparations for Site Investigations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Development of an understanding of information requirements for underground monitoring and investigations

**Background**

We envisage that there will have to be considerable confidence in the suitability of a preferred site to host a geological disposal facility based upon surface-based investigations in order to justify the cost and environmental impact of proceeding to underground investigations. However it is recognised that some information requirements needed to support the final environmental safety case and detailed designs will need to be addressed during underground monitoring and investigations. RWM’s current planning assumption is that underground investigation activities and disposal facility construction activities, will be undertaken in an integrated manner both in terms of planning permission and location.

**Research Need**

To understand the information requirements which may need to be addressed by underground monitoring and investigations for potential host rock environments in the UK.

**Research Objective**

To develop sufficient understanding of the information requirements which may need to be addressed by underground monitoring and investigations for potential host rock environments in the UK to a sufficient level to inform the development of the disposal system specification and design at the generic stage.

**Scope**

The scope includes the following activities:

- The likely level of understanding for potential host rock environments which will be achieved at the end of surface-based investigations.
- The gap between this understanding and the likely level of understanding required to develop the Final Environmental Safety Case and detailed designs.
- The information requirements needed to fill this gap in understanding.

At the end of this task, there will be sufficient understanding to allow the specification and design teams to make robust assumptions for planning purposes at the generic stage. Subsequent development of the understanding will be required during the site specific stage to inform the planning for and eventual design of the underground monitoring and investigations.

The outputs of this task will also inform Task 490 which addresses the approach to underground monitoring and investigations.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>5</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>None identified.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Specification, Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

Task Number | 511 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Higher Activity Waste Programme | PBS level 5 | Higher Activity Waste Programme
Title
Development of a Larger Waste Container

Background
The limits placed on the size and mass of waste packages (plus transport container, if required) is expected to be constrained by the required configuration for rail transport to a GDF. However there is significant scope to increase the size of waste containers within the current constraints. Previous work undertaken within Upstream Options identified a range of possible benefits from the use of larger waste containers, including reduced requirement for size reduction, reduced risk to operators and the production of less secondary waste.

Research Need
To develop a business case for a larger waste container.

Research Objective
To develop a business case for a larger waste container, and to develop user requirements, systems requirements and an implementation plan for its design, manufacture and testing.

Scope
- Liaise with Site Licence Companies to determine the demand for a larger waste container and functional requirements.
- Develop user and system requirements.
- Develop implementation plan, including design, manufacture and testing of the larger waste container design.
- Ensure confidence in disposability of the proposed container to allow SLCs to plan for the use of a larger waste container with RWM.

SRL at task start | TRL 2 | SRL at task end | TRL 3 | Target SRL | TRL 3
--- | --- | --- | --- | --- | ---
End point | Proof of Concept | Customer | Higher Activity Waste Programme | Further information

Appendix B - 206
Task Number | 512 | Status | Start date in future
---|---|---|---
PBS level 4 | Higher Activity Waste Programme |  
PBS level 5 | Higher Activity Waste Programme |  
Title
Development of Disposability Manufacturing Specifications

Background
RWM has produced waste package specifications (WPS) for a limited range of standardised waste container designs for the packaging of low heat generating wastes. The purpose of the WPS is to define the standard features and performance requirements which will be compatible with the anticipated systems and safety cases for transport to and disposal in a GDF. RWM also produces guidance on the waste container features that contribute to the performance requirements in the WPS. However, it has been proposed that RWM could build on the current guidance available to waste producers by specifying minimum requirements on waste containers in the form of ‘disposability manufacturing specifications’. This would aid cost-efficient solutions to the packaging of waste.

Research Need
To ensure future designs of waste container meet the WPS requirements and represent a cost-effective solution to the packaging of wastes.

Research Objective
To develop Disposability Manufacturing Specifications for RWM standardised waste containers.

Scope
- Identify industry demand for Disposability Manufacturing Specifications.
- Identify and develop the minimum waste container design features which meet the requirements in the WPS.
- Produce Disposability Manufacturing Specifications for RWM standardised waste containers to be used by waste producers.

SRL at task start | TRL 2 | SRL at task end | TRL 7 | Target SRL | TRL 7
End point | No Further Research Planned
Customer | Higher Activity Waste Programme

Further information
### Background

RWM produces guidance to waste producers as part of the suite of documents in the Waste Package Specification and Guidance Documentation (WPSGD). As new treatments and ways of working are introduced by the nuclear industry, RWM needs to provide guidance on what materials can be disposed of safely without any extra processing. Decontamination is one area where innovative work practices have been developed. The nuclear industry uses a range of materials to decontaminate surfaces, thereby limiting exposure risk to workers and reducing the volumes of waste requiring final disposal in a GDF.

Decontamination agents currently in use in the UK nuclear industry include:
- Cleaning agents.
- Coatings (paints and strippable coatings).
- Coagulants and flocculants.
- Other liquids.

However, these chemicals may in turn require disposal in a GDF and operators need to consider their suitability for disposal.

### Research Need

To provide information to Site Licence Companies on which commonly-used components of decontamination agents are suitable for disposal in a GDF.

### Research Objective

To develop RWM guidance on the disposability of commonly-used components of decontamination agents for use by Site Licence Companies.

### Scope

Familiarisation with existing information on the disposability of decontamination agents, including work completed by RWM and Low Level Waste Repository (LLWR).

Preparation of guidance on the disposability of decontamination agents.

---

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Higher Activity Waste Programme</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Higher Activity Waste Programme</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guidance on the Disposability of Decontamination Agents</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End point</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Further Research Planned</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Activity Waste Programme</td>
</tr>
</tbody>
</table>

---

Appendix B - 208
Task Number | 514 | Status | Start date in future
---|---|---|---
PBS level 4 | Higher Activity Waste Programme | PBS level 5 | Higher Activity Waste Programme

Title
Guidance on the Disposability of Filters

Background
RWM produces guidance to waste producers as part of the suite of documents in the Waste Package Specification and Guidance Documentation. One such guidance document focuses on the disposability of filters, which are widely used in nuclear ventilation and containment systems to remove particulate matter from air and other gas streams. The conditioning of used filters for long-term management presents a challenge for waste packagers because they may:
- Constitute a potentially significant source-term of radioactivity in loose particulate form.
- Incorporate significant voidage in their design that can be difficult to infiltrate using standard techniques and encapsulants.
- Incorporate materials and features that may evolve in a way that potentially weakens the performance of the final waste package (e.g. aluminium spacers).

As the initial version of the guidance was produced in 2006, it was recognised that an update was required to capture new research and techniques used for the conditioning of filters.

Research Need
To ensure an up-to-date and useful guidance document on the conditioning of filters is available to Site Licence Companies.

Research Objective
Update the 2006 'filters' document to capture new research and techniques used for the conditioning of filters. This work will incorporate input from Site Licence Companies who have undertaken practical work on the conditioning of filters.

Scope
Undertake a review and update of the guidance to capture new research and techniques developed by Site Licence Companies for the conditioning of filters.

SRL at task start | 6 | SRL at task end | 6 | Target SRL | 6
End point | No Further Research Planned
Customer | Higher Activity Waste Programme

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>536</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

### PBS level 4
Package Evolution

### PBS level 5
Vitrified HLW

## Title
Scoping Groundwater Dissolution Studies on Simulant Magnox / Blend Glasses

### Background
There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the generic disposal system safety case (GDSSC) to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, in the future, glasses arising from Post-Operational Clean Out.

Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. These studies include the influence of iron-based materials present elsewhere in the disposal system and are aimed at developing underpinning data for use in safety assessments. This task will focus on Magnox and blend HLW glasses, the behaviour of which needs to be evaluated on the basis of dissolution/leaching experiments of suitable simulants and related mechanistic modelling.

### Research Need
To develop a mechanistic understanding of the evolution and dissolution rates (short and long-term) of vitrified HLW glasses in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
- The development of the safety case.

### Research Objective
To determine the effect of a number of variables on the dissolution behaviour of HLW simulants of key waste streams (Magnox/blend glasses up to 18-38% incorporation ratios). In particular, to determine whether:
- Differences in groundwater composition (near-neutral pH) significantly affect the dissolution behaviour of the glass.
- Differences in the chemical composition on the glass (particularly waste incorporation rates and blending ratios) already produced, and expected to be produced at Sellafield, significantly affect the dissolution behaviour of the glass.
- The presence of calcium-rich alkaline plumes that may be generated in the presence of cement-based buffers or due to a co-located, cement-based ILW module affect the long-term dissolution behaviour of the glass in a way which negatively affects the safety case.
- Differences in the dissolution behaviour of UK HLW glass simulants and French HLW glass simulants can be interpreted on the basis of differences in their chemical composition.
- The long-term evolution of the glass in the absence of other engineered barrier system (EBS) components (in particular iron-based materials) is such that any (thermodynamically-stable) phases formed in the long-term are likely to induce dissolution rates faster than those estimated from short-term experiments.
- Results of measurements with low surface area / volume ratio (e.g. monoliths) are consistent with those of high surface area / volume ratio (powder) and can be used to scope the initial and long-term dissolution rate.
- The behaviour of UK glasses can be interpreted on the basis of suitably modified models already available for other glasses (e.g. the Glass Reactivity with Allowance for the Alteration Layer model, GRAAL).

### Scope
The scope comprises the following:
- Sourcing and characterisation of a variety of vitrified HLW products from Sellafield Vitrification Test Rig that are representative of waste arisings from the reprocessing plant (including Magnox and blend glasses).
- Experimental measurements (at 40°C) of the dissolution behaviour of a variety of vitrified HLW product simulants (Magnox / blend glass 18-38 wt.% incorporation) in near-neutral groundwater simulants (deionised water and two near-neutral groundwaters) with high surface area / volume ratio (powders).
- Experimental measurements (at 40°C) of the dissolution behaviour of a variety of vitrified HLW product simulants (Magnox / blend glass 18-38 wt.% incorporation) in alkaline groundwater simulants (three hyperalkaline solutions - NaOH, CaOH₂, and chloride-rich CaOH₂) with high surface/ volume ratio (powders).
- Experimental measurements (at 40°C) of the dissolution behaviour of selected vitrified product simulants in groundwater with low surface area / volume ratio (e.g. monoliths).
- Experimental measurements of the dissolution behaviour of French (SON64) and other simulant glasses (e.g. Ca-common glass) to allow comparison with UK glasses.
- Review of existing mechanistic / parametric models developed internationally (e.g. GRAAL model) to evaluate their applicability to the behaviour of UK glasses.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Customer

Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

Further information

Relevant publications include:


This task is ongoing via procurement through our contractors.
Task Number | 537 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Package Evolution |  |
PBS level 5 | Vitrified HLW |  |
Title | Understanding the Relationship Between the Durability of Simplified and Complex UK HLW Glasses |

**Background**

There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the generic Disposal System Safety Case (gDSSC) to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, in the future, glasses arising from Post-Operational Clean Out.

Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors, including the effects of elevated temperature and groundwater composition, controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. This task will focus on Magnox and blend HLW glasses, and aims to evaluate the applicability of tests carried out to support the development of vitrified products at Sellafield to understand the broad process envelope, as well as the effect of high temperature and cracking, on the dissolution behaviour of suitable glass simulants.

**Research Need**

To develop a mechanistic understanding of the dissolution behaviours of HLW glasses, including the effect of elevated temperature on the evolution and dissolution rates (short and long-term), in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
- The development of the safety case.

**Research Objective**

To further evaluate the use of inactive simplified glass formulations to develop a mechanistic understanding of the behaviour of more complex inactive HLW glass simulants

To correlate the aqueous durability of simplified glass formulations to HLW glass simulants to leverage the existing aqueous durability database produced at Sellafield for disposability assessments.

**Scope**

The scope comprises the following:
- Identify suitable compositional simplification protocols for present (MW25 and blend glasses) and potential future (higher waste loaded) borosilicate glasses in close collaboration with Sellafield Ltd.
- Determine initial, residual rate and any resumption of alteration in both complex and simplified analogue glasses under identical experimental conditions using Product Consistency Test (PCT)-B and initial rate tests.
- Use the results to inform a mechanistic understanding of UK glass durability.
- Compare results in deionised water with simulant groundwaters.
- Compare temperature effects on glass dissolution (40°C vs 90°C).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

**Further information**

Relevant publications include:

J.M. Schofield et al, 2012, Initial Dissolution Rate Measurements for 25 WT% Simulant Waste-loaded
Magnox VTR Product in Simulated Groundwaters, Serco 004844/002 (available from RWM website).
This task is intended for procurement through Academic partners.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>538</td>
<td>Package Evolution</td>
<td>Vitrified HLW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Further Groundwater Dissolution Studies on Simulant Magnox, Blend and Post-Operational Clean Out (POCO) Glasses

**Background**
There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the generic Disposal System Safety Case (gDSSC) to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, in the future, glasses arising from Post-Operational Clean Out (POCO).

Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors, including the effects of elevated temperature and groundwater composition, controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. This task will focus on Magnox, Blend, POCO (and other) glasses, the behaviour of which will be evaluated on the basis of dissolution/leaching experiments of suitable simulants and mechanistic modelling.

**Research Need**
To develop a mechanistic understanding of the evolution and dissolution rates (short- and long-term) of vitrified Magnox, Blend and POCO glasses in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
- The development of the safety case.

**Research Objective**
To determine the effect of a number of variables on the dissolution behaviour of simulants of HLW waste streams expected to arise from future Sellafield operations (e.g. POCO glasses). In particular, to determine whether:
- Differences in groundwater composition (near-neutral pH) significantly affect the dissolution behaviour of the glass.
- The presence of calcium-rich alkaline plumes that may be generated in the presence of cement-based buffers or due to a co-located, cement-based ILW module affect the long-term dissolution behaviour of the glass in a way which negatively affects the safety case.
- Differences in the dissolution behaviour of UK HLW glass simulants of key waste streams (Magnox/Blend glass), other waste streams (e.g. POCO glass) and French HLW glass simulants can be interpreted on the basis of differences in their chemical composition. In particular, if any 'fast' leaching that may be observed in short-term experiments (if any) can be correlated to the formation of soluble (e.g. molybdenum-rich) phases.
- The long-term evolution of the glass in the absence of other engineered barrier system (EBS) components (in particular iron-based materials) is such that thermodynamically-stable phases formed in the long-term are unlikely to induce dissolution rates significantly faster than those estimated from short-term experiments.
- Results from samples with a low surface area / volume ratio (e.g. monoliths) are consistent with those of high surface area / volume ratio (powder) and can be used to scope the initial and long-term dissolution rate.
- The behaviour of POCO-derived glasses can be interpreted on the basis of suitably modified models already available for other glasses (e.g. the Glass Reactivity with Allowance for the Alteration Layer model, GRAAL).

**Scope**
The scope comprises the following:
- Identification, sourcing and archiving of a variety of vitrified HLW products from Sellafield Vitrification Test Rig that are representative of Magnox, Blend and POCO glasses.
- Characterisation of relevant materials.
- Experimental measurements (40°C) of the glass simulants in near-neutral groundwater simulants (deionised water and two near-neutral groundwaters) with high surface area /volume ratio (powders).
- Experimental measurements (40°C) of the dissolution behaviour of glass simulants in alkaline groundwater simulants (three hyperalkaline solutions - NaOH, CaOH₂, and chloride-rich CaOH₂) with high surface area /volume ratio (powders).
- Experimental measurements (40°C) of the dissolution behaviour of glass simulants in groundwater with low surface area / volume ratio (e.g. monoliths).
- Experimental measurements of the dissolution behaviour of French (SON64) and other simulant glasses (e.g. Ca-common glass) to allow comparison.
- Review of existing mechanistic / parametric models developed internationally (e.g. GRAAL model) to evaluate their applicability to the behaviour of glasses.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

End point
- Site Specific Validation
- Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

Further information

Relevant publications include:

This task is ongoing via procurement through our contractors.
Effect of Iron-based Materials and Radiation Damage on the Dissolution Behaviour of Simulant HLW Glasses

Background

There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the generic Disposal System Safety Case (gDSSC) to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, in the future, glasses arising from Post-Operational Clean Out (POCO).

Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. These studies include the influence of iron-based materials present elsewhere in the disposal system and are aimed at developing underpinning data for use in safety assessments. This task will focus on Magnox and blend HLW glasses, the behaviour of which needs to be evaluated on the basis of dissolution / leaching experiments of suitable simulants and mechanistic modelling in groundwater containing iron (arising from container degradation), and including the presence of radiation.

Research Need

To develop a mechanistic understanding of the evolution and dissolution rates (short- and long-term) of vitrified HLW glasses in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
- The development of the safety case.

Research Objective

To determine the effect of a number of variables on the dissolution behaviour of HLW simulants of selected waste streams (Magnox, blend, POCO, etc.). In particular, to determine whether:

- The presence of iron-based materials (e.g. container / structural inserts) in contact with HLW glass affects the evolution and dissolution rates of the glass in a way which is predictable and does not prejudice the safety case (i.e. to determine whether the presence of iron leads to the formation of phases that do not lead to dissolution rates faster than those estimated from short-term experiments).
- The effect of radiation fields has an impact on the dissolution behaviour of the glass and can be interpreted on the basis of available knowledge on radiation chemistry and radiation damage.
- Fracturing and cracking have any significant effect on the dissolution rate of HLW products in relevant conditions and whether any effect is predictable.
- Previously developed models can be successfully refined to take these effects into account.

Scope

The scope comprises the following:

- Sourcing and archiving of samples from large-scale simulants (i.e. from Sellafield Vitrification Test Rig) and / or active samples (e.g. from B13) to support the experimental R&D programme.
- Characterisation of relevant materials.
- Experimental measurements on specific glass compositions in the presence of iron in selected groundwater simulants to investigate the effect of the presence of iron-based materials in contact with the glass under realistic dose-rate conditions.
- Experimental measurements on specific glass compositions in the presence of radiation fields in selected groundwater simulants to investigate the effect of radiation-damage and radiolysis under realistic dose-rate
- Review / refinement of glass dissolution models to consider the effect of radiation-fields and iron-based materials.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

This task is intended for procurement through our contractors with potential input from academic partners. Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Vitrified HLW</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Exposure of Inactive HLW Glass at MACOTE URL Experiment (Phase 2)

**Background**

There is a good general understanding of the long-term evolution of HLW glasses under the expected environmental conditions in a GDF as these have been studied extensively by a number of overseas waste management organisations. However, more detailed understanding and input data are required to support the generic Disposal System Safety Case (gDSSC) to evaluate the behaviour of specific glass compositions used in the UK. RWM plans to study a variety of glass compositions representative of the likely products arising from the Waste Vitrification Plant at Sellafield, including Magnox glass, Magnox-Oxide blend glass and, in the future, glasses arising from Post-Operational Clean Out (POCO).

Initial studies are aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In this context, we will consider recent advances in mechanistic understanding and modelling of glass evolution achieved internationally and its applicability to UK glasses. This task will focus on selected glasses (most likely Magnox / Blend glasses), the behaviour of which will be evaluated on the basis of small-scale field experiments.

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution rates (short- and long-term) of vitrified HLW glasses in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes (in particular to evaluate opportunities to employ less durable container materials than those that may be needed if a fast rate of dissolution was observed).
- The development of the safety case.

**Research Objective**

To determine whether the evolution of simulant glasses in representative disposal environments (i.e. in contact with a host rock) show similar results to those obtained from laboratory-based tests.

**Scope**

Commencement of small-scale demonstration experiments on the durability of glasses in relevant conditions for extended periods, e.g. MACOTE at the Grimsel Test Site under the International Steering Committee (ISCO) programme.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

**Further information**

This task is intended for collaborative funding under the Nagra ISCO programme. Information is available at http://www.grimsel.com/
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Vitrified HLW</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Review of Microstructural Evolution of Glassy and Ceramic Wasteforms and their Impact on Leaching Properties

**Background**
There is a good general understanding of the long-term dissolution/leaching of HLW glasses and spent fuels in a GDF, as these have been studied in other international programmes. There is also information about the dissolution/leaching behaviour of other glassy or ceramic wasteforms (e.g. for the immobilisation of ILW or plutonium residues) from the UK and other programmes. Current work is focusing on testing of UK-specific materials so that they can be compared with that of products tested in other programmes.

Leaching studies, however, do not inherently consider the potential for long-term microstructural evolution processes to affect the behaviour of the wasteform. Relevant long-term evolution processes include the potential for thermal effects (e.g. devitrification), radiation-assisted effects, alpha-decay and mechanical damage to change the surface area and chemical characteristics of the wasteform, affecting its dissolution/leaching behaviour.

This task will focus on HLW glasses, spent fuels (both oxide and metallic) and plutonium residues, but will also consider the potential for relevant effects to occur in any vitrified ILW.

**Research Need**
To develop a mechanistic understanding of the likely long-term dissolution/leaching behaviour of the wasteform. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts for these wastes.
- The development of the safety case.

**Research Objective**
To determine the likely extent of microstructural evolution processes and their impact on the expected dissolution/leaching of relevant wasteforms as well as, in the case of gas-generating processes, the potential of internal pressurisation of the waste container.

**Scope**
A desk-based study reviewing existing information is envisaged. The scope comprises the following:
- Review and discussion in the UK context of likelihood and potential effects of microstructural evolution processes expected in HLW, spent fuels, plutonium residues and, to a lesser extent, vitrified ILW.
- Processes should include thermal effects due to high processing/storage temperatures (e.g. devitrification of HLW), radiation-induced effects (e.g. effect on extent of micro-segregation), gas generation due to alpha-decay and its effect on the amount of cracking (available surface area) - particularly for spent fuel and plutonium residues) - and any cracking introduced by (accidental) mechanical damage.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Validation

**Customer**
Disposal System Safety Case

**Further information**
Relevant publications include:


This task is ongoing via procurement through our contractors.
**Title**
Scoping Dissolution Studies on AGR Fuel in Oxic Conditions

**Background**
Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example Advanced Gas-cooled Reactor (AGR) fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, Pressurised Water Reactor (PWR) fuels).

Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory.

Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ("further") studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task will focus on AGR fuel, the behaviour of which will be evaluated on the basis of scoping experiments in oxic conditions.

**Research Need**
To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**
To scope the Instant Release Fraction (IRF) and long-term dissolution rate of AGR fuels in short-term scoping experiments. In particular:
- To measure the dissolution behaviour of selected fuel samples in groundwater simulants and to determine whether the rates are similar enough to those of LWR fuels to indicate that further measurements are likely to be successful in providing confidence in the behaviour of UK fuels.
- To evaluate whether the observed IRF is consistent with a correlation between the IRF and the fission gas release (FGR) previously observed for LWR fuels.
- To scope whether there are any detrimental effects on the dissolution behaviour of AGR fuel at the levels of burn-up and power history expected in the UK.
- To scope whether the presence of cladding in the proximity of fuel exposed to oxic groundwater results in detrimental effects in the leaching behaviour of the fuel.
- To evaluate whether the results of scoping measurements are consistent with the expected inventory and partitioning / segregation of radionuclides in AGR fuel elements and with the likely oxidation state of the fuel matrix.

**Scope**
The scope comprises the following:
- Macroscopic (i.e. gamma spectroscopy) and microscopic (i.e. Scanning Electron Microscopy /ceramography) characterisation of selected samples of AGR fuel of different burn-up and power histories, including acquisition of inventory and FGR data.
- Dissolution / leaching measurements of selected samples of AGR fuel of different burn-up and power histories in oxic, simplified groundwaters (NaCl + NaHCO3) in the presence of the stainless steel cladding.
- Comparison of results obtained on AGR fuel with those obtained on LWR fuels in other international programmes (e.g. EC First-Nuclides).
- Analysis of any precipitation products that may be formed upon matrix dissolution.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

**Further information**

The IRF is that fraction of fission products associated with grain boundaries and areas of macroscopic accumulation of segregated phases, as opposed to the fuel matrix. Operationally, AGR fuel is exposed to different temperature profiles than LWR fuel, hence a different degree of partitioning of the more volatile fission product may have occurred, potentially leading to different leaching behaviour.

Relevant publications include:


Information is also available at: http://www.firstnuclides.eu/

This task is currently being carried out by contractors that have access to specialist facilities.
EPSRC GEOWASTE: Scoping studies on SimFuel to understand the dissolution behaviour of AGR fuel

Background

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example Advanced Gas-cooled Reactor (AGR) fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, Pressurised Water Reactor (PWR) fuels).

Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory.

Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ('further') studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task will focus on SimFuel, manufactured to replicate AGR fuel; its behaviour will be evaluated on the basis of a variety of scoping experiments and atomistic models. SimFuel is made by doping UO$_2$ with non-radioactive isotopes as surrogates of the fission products expected to form in spent fuels.

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

Research Objective

To evaluate whether it is possible to manufacture inactive simulants of spent fuel (SimFuel) with chemical composition, characteristics and leaching behaviour (with the exception of self-irradiation) which are sufficiently representative of spent AGR fuel to justify their use in AGR spent fuel dissolution studies. In particular, to determine whether:

- The morphology of SimFuel is similar enough to that observed in AGR fuel.
- The partitioning of fission product surrogates in the UO$_2$ microstructure and the resulting oxidation state of the fuel is consistent with experimental observations on AGR fuels.
- The dissolution behaviour of SimFuel is similar to that of AGR fuel, including sensitivity to the groundwater chemistry, temperature, fuel composition (representing the post-discharge 'age' of the fuel) and redox conditions.
- The presence of radiation damage induced ex situ has an effect on the ensuing dissolution behaviour of SimFuel.
- The presence of the stainless steels representative of AGR fuel cladding in leaching experiments affects the dissolution behaviour of the SimFuel.
- Secondary uranium minerals form on SimFuel upon leaching, which are similar to those expected in UO$_2$ spent fuels (which would indicate the retention of uranium and non-radioactive isotopes or surrogates of some important radionuclides).
The scope comprises the following:

- Manufacture and subsequent optical / Scanning Electron Microscopy characterisation of SimFuels doped with non-radioactive isotopes as surrogates of fission products relevant to AGR fuels at different burn-ups and ages (100 - 100,000 years).
- Development of atomistic models of fission products partitioning in UO₂ to evaluate likely thermodynamically stable phases.
- Leach testing, considering effects of groundwater chemistry, redox conditions, radiation damage and the presence of cladding.
- Measurements of the retention of non-radioactive isotopes as fission product surrogates in synthetic uranium minerals.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

- End point: Site Specific Validation
- Customer: Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

Further information

Relevant publications include:


This task is currently being co-funded by the EPSRC as part of the Geowaste programme (with Cambridge University, Imperial College and Lancaster University) under RWM's initiative to support a portfolio of 'curiosity driven' research which complements our 'needs driven' programme.
Title
Scoping Dissolution Studies of Historical Fuels (Windscale AGR: WAGR)

Background
Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example Advanced Gas-cooled Reactor (AGR) fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, Pressurised Water Reactor (PWR) fuels).

Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory.

Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ('further') studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task will focus on AGR fuel, the behaviour of which will be evaluated on the basis of scoping experiments on historic fuels (Windscale AGR (WAGR)) in oxic conditions.

Research Need
To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

Research Objective
To scope whether the characteristics and leaching behaviour of historical fuels being retrieved as part of Sellafield clean-up (in particular WAGR fuel) are sufficiently similar to those of recently discharged AGR fuel to justify their use in AGR fuel dissolution / leaching studies, particularly for fuel elements with cladding that may have degraded during interim storage. In particular, to evaluate whether:
- Sufficiently detailed records of the characteristics (e.g. burn up, chemical composition, initial enrichment) of 'historical' fuels (particularly the prototype WAGR fuel) and of their storage environment(s) exist to indicate that the type of fuel and the environment in which it has been stored is relevant enough to justify experimental studies on these materials as analogues to support the disposal of modern AGR fuel.
- The dissolution behaviour of historical fuel (Instant Release Fraction (IRF) and long-term dissolution rate) for which cladding has retained its integrity over extended periods of pond storage is similar enough to that observed for modern AGR fuels to give confidence in the relevance of any studies carried out on these materials to underpin the disposal of AGR fuel.
- The dissolution rate of water-logged fuels showing significant oxidation is either similar to that estimated in short-term experiments on irradiated AGR fuel (in oxic conditions) or, if higher, shows a correlation with the extent of oxidation observed.
- The cladding of the majority of historical fuel elements shows signs of degradation after prolonged contact with any pond water that may have leached (if any) inside cans employed during interim storage.
- The condition of any water-logged prototype AGR fuel retrieved from Sellafield legacy ponds after storage shows that dissolution processes have led to the formation of phases which impact on the ability to retain radionuclides relevant to the safety case.
- The extent of oxidation in any fuel with cladding that was perforated during storage (as opposed to purposely cut during PIE) is limited to a localised area or to a superficial layer.
- The concentration of radionuclides relevant to the safety case in any water in contact with waterlogged fuel (if any) is compatible with (or lower than) that estimated from the instant release fraction and long-term release rate estimated for AGR / LWR fuels over relevant periods (corrected for radionuclide decay). If significant differences are observed the objective includes determination as to whether these differences can be interpreted on the basis of the likely exchange of solutes with the external environment.

Scope

The scope comprises the following:
- Evaluation of records and Post-Irradiation Examination (PIE) data of relevant materials, samples and storage conditions to establish whether any work carried out on retrieved materials is likely to be sufficiently relevant to the study of commercial AGR fuels.
- Depending on information available (records) and decommissioning constraints, inspection of historical fuels (particularly WAGR) to evaluate the condition of the cladding.
- Depending on information available (records) and decommissioning constraints, undertake characterisation of fuel samples and radiochemical analysis of water in contact with water-logged fuel and dissolution / leaching experiments of intact fuel samples in fresh (oxic) solutions.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Customer

Site Specific Validation

Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

Further information

Relevant publications include:
Information is also available at: http://www.firstnuclides.eu/
This task is currently being carried out by contractors that have access to specialist facilities.
The success of this task, as monitored by a project gate, will determine whether the further work employing historical fuels to study the disposability of spent fuel is funded.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>550</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Spent Fuel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Review of Research Needs for Exotic and High Pu-bearing Spent Fuels

**Background**

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example experimental legacy fuels that are likely to be disposed in smaller quantities. These are known as exotic fuels and include metallic, oxide and carbide materials. These fuels are a legacy from earlier nuclear industry activities such as the development of research, experimental or prototype reactors. Although exotics often share the physical characteristics and properties of Magnox and oxide fuel, their composition and enrichment are varied, with a substantial number containing plutonium (Pu).

Furthermore, by the completion of reprocessing operations, current estimates indicate that there will be approximately 140 tonnes of civil separated plutonium (Pu) in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as mixed oxide (MOX) fuel in light water reactors or in CANDU EC6 reactors, and reuse as metallic fuel in PRISM fast reactors, which would result in the need to dispose of other types of fuels that, although not necessarily unique to the UK, may present specific challenges.

Little work has to date been undertaken on the disposability of exotic fuels and high Pu-bearing fuels (e.g. MOX fuel) as we have focussed our efforts on the large quantities of AGR and Pressurised Water Reactor (PWR) fuel that dominate the UK inventory. This task therefore comprises a desk-based analysis of research needs for exotic fuels and/or high Pu-bearing fuels.

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK exotic fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**

To identify research needs for UK exotic fuels on the basis of available information about their chemical characteristics and previous research studies.

**Scope**

The scope comprises a review of chemical characteristics of exotic fuels and of any Post-Irradiation Examination (PIE) work that has been carried out in the past, together with the identification of research needs to inform the development of a specification for future work.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>1</th>
<th>SRL at task end</th>
<th>2</th>
<th>Target SRL</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development, Strategic Decisions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

This review task may be carried-out by NDA resource with support from the supply chain and academic partners. Opportunities for co-funding from the relevant research council (EPSRC) may be sought. Relevant publications include:

Dissolution studies on Advanced Gas-cooled Reactor Fuels in Anoxic Conditions

Background

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example Advanced Gas-cooled Reactor (AGR) fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, PWR fuels).

Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory.

Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ("further") studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task will focus on AGR fuel, the behaviour of which will be evaluated based on experiments on either freshly discharged fuels or historical fuels in anoxic conditions.

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour of UK spent fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater on the basis of dissolution / leaching experiments of suitable simulants and mechanistic modelling.

Research Objective

To evaluate the Instant Release Fraction (IRF) and long-term dissolution rate of previously tested AGR fuels (either recently discharged or historic fuels) in more realistic disposal conditions. The findings will be used to confirm whether the release rates are low enough to support the development of a safety case for these fuels on the basis of the safety arguments previously developed for these materials. In particular, to determine whether:

- The long-term dissolution rate of spent AGR fuel in anoxic conditions is significantly lower than measured in oxic conditions.
- The presence of iron-based materials (including any carbon steel that is likely to be present in disposal containers) affects the dissolution behaviour of the fuel in a way consistent with the development of low redox conditions or whether other effects need also to be taken into account.

Scope

The scope comprises the following:

- Dissolution / leaching measurements on previously tested fuel samples to evaluate the effect on the long-term dissolution rate of factors not considered in the scoping experiments (in particular, low redox conditions and the presence of iron-based materials).
- Comparison of resulting data with ongoing programmes on LWR fuels to determine similarities and differences.

SRL at task start 3  SRL at task end 4  Target SRL 4

End point Site Specific Validation

Customer Waste Package Disposability Assessments, Concept Development, Disposal System Safety Case

Further information

Relevant publications include:

M. Trummer et al, 2009, H2 Inhibition of Radiation Induced Dissolution of Spent Nuclear Fuel, Journal of
Trygve E. et al, 2012, Radiation-induced Dissolution of UO2 Based Nuclear Fuel – A Critical Review of Predictive Modelling Approaches, Journal of Nuclear Materials, Volume 420, Issues 1–3, Pages 409-423. This task is will be carried out by contractors that have access to specialist facilities.
**Task Number**: 552  
**PBS level 4**: Package Evolution  
**PBS level 5**: Spent Fuel  
**Status**: Start date in future

**Title**  
Further Work on SimFuel to Understand Dissolution Behaviour of Spent Fuel

**Background**

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example Advanced Gas-cooled Reactor (AGR) fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, Pressurised Water Reactor (PWR) fuels).

Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory.

Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ("further") studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. This task comprises further work on SimFuel (following on from task 547), manufactured to replicate relevant spent fuel, whose behaviour will be evaluated on the basis of a variety of scoping experiments and atomistic models. SimFuel is made by doping UO\(_2\) with non-radioactive isotopes as surrogates of the fission products expected to form in spent fuels.

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater.

This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**

To determine whether it is possible to manufacture inactive simulants of spent fuel (SimFuel) with chemical composition, characteristics (with the exception of self-irradiation) and leaching behaviour which are sufficiently representative of UK spent fuels (e.g. AGR, PWR or MOX) to justify their use in leaching experiments aimed at evaluating the leaching behaviour of the fuel. In particular to determine whether:
- The morphology of SimFuel is similar enough to that observed in spent fuel.
- The partitioning of fission product surrogates in the UO\(_2\) microstructure and the resulting oxidation state of the fuel is consistent with experimental observations on spent fuels.
- The dissolution behaviour of SimFuel is similar to that of spent fuels, including sensitivity to the groundwater chemistry, temperature, fuel composition (representing the post-discharge 'age' of the fuel) and redox conditions, including tests to specifically document the effect of alkaline groundwater.
- The presence of radiation damage induced ex-situ has an effect on the ensuing dissolution behaviour of SimFuel.
- The presence of the stainless steel / zircaloy representative of fuel cladding in leaching experiments affects the dissolution behaviour of the SimFuel.
- Secondary uranium minerals form on SimFuel upon leaching, which are similar to those expected in UO\(_2\) spent fuels (which would indicate retention of uranium and non-radioactive isotopes or surrogates of some important radionuclides).

**Scope**
To be developed on the basis of the outcome of task 547.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Specific Validation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Package Disposability Assessments, Concept Development, Disposal System Safety Case</td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:


This task will be carried out through academic partners. The opportunity for co-funding from the relevant research council (EPSRC) may be investigated.
Scoping Studies on Dissolution Behaviour of Exotic and High Pu-bearing Spent Fuels

Background

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example experimental legacy fuels that are likely to be disposed in smaller quantities. These are known as exotic fuels and include metallic, oxide and carbide materials. These fuels are a legacy from earlier nuclear industry activities such as the development of research, experimental or prototype reactors. Although exotics often share the physical characteristics and properties of Magnox and oxide fuel, their composition and enrichment are varied, with a substantial number containing plutonium.

Furthermore, by the completion of reprocessing operations, current estimates indicate that there will be approximately 140 tonnes of civil separated plutonium (Pu) in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as mixed oxide (MOX) fuel in light water reactors or in CANDU EC6 reactors, and reuse as metallic fuel in PRISM fast reactors, which would result in the need of disposing of other types of fuels that, although not necessarily unique to the UK, may present specific challenges.

Little work has to date been undertaken on the disposability of the exotic fuels and high Pu-bearing fuels (e.g. MOX fuel) as we have focussed our efforts on the large quantities of AGR and Pressurised Water Reactor (PWR) fuel that dominate the UK inventory. This task therefore comprises an assumed set of short-term scoping experiments, on real samples of exotic and/or high Pu-bearing fuels or simulants, based on a previous desk-based analysis of research needs for exotic fuels (Task 550).

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

Research Objective

Depending on type of fuel and disposal concept, to scope the dissolution/corrosion behaviour of unirradiated / irradiated exotic fuels as measured in a set of short-term experiments. In particular:

- To measure the dissolution/corrosion behaviour of selected samples in groundwater simulants (including any conditioning/buffering media) to scope expected long-term rate
- Where appropriate, to determine whether the dissolution/corrosion rates are similar enough to those of other fuels (for oxide fuels) or uranium metal (for metallic fuels) to indicate that further measurements are likely to be successful in providing confidence in their behaviour in our standard disposal concepts.
- To scope whether there are any detrimental effects on the dissolution behaviour of the fuel at the levels of burn-up and power history expected.
- To scope whether the presence of cladding in the proximity of exotic fuels exposed to oxic groundwater results in effects which are detrimental to the leaching behaviour of the fuel.
- To evaluate whether the results of scoping measurements are consistent with the expected inventory and partitioning / segregation of radionuclides in fuel elements.
- To evaluate whether, where appropriate (e.g. oxic fuels) the dissolution / leaching of safety-relevant radionuclides can be correlated with any more easily measurable quantities (e.g. the Fission Gas Release (FGR)).

Scope

The scope comprises the following:
- To identify and access relevant fuel samples and underpinning information (e.g. inventory, burn-up, FGR) or suitable simulants (e.g. SimFuel).
- Macroscopic and microscopic characterisation of the fuel samples.
- Dissolution /leaching measurements of relevant fuel samples in controlled chemical conditions.
- Thermodynamic modelling of phase segregation.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End point</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Specific Validation</td>
<td>Waste Package Disposability Assessments, Concept Development, Disposal System Safety Case, Strategic Decisions</td>
</tr>
</tbody>
</table>

Further information

Relevant publications include:

This task will be carried out through contractors and academic partners. Opportunities for co-funding from the relevant research council (EPSRC) may be sought.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>554</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Spent Fuel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Review of Research Needs for Un-Reprocessed Metallic Fuel

**Background**

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique or very specific to the UK, among these metallic fuel produced from Magnox reactors. The NDA's baseline plan is for all Metallic fuel to be reprocessed at Sellafield, however this plan is dependent upon the efficiency of ongoing reprocessing operations and it is therefore possible that RWM may be required to consider the disposal of un-reprocessed metallic fuel.

Research may therefore be required on the disposal of irradiated metallic fuels, depending on the progress of reprocessing operations. This task comprises a possible future review of the research needs associated with these materials, should they require disposal in the GDF.

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution behaviour of UK spent fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**

- To identify research needs for irradiated metallic and high Pu-bearing fuels (and any relevant wasteforms) based on available information about their chemical characteristics.

**Scope**

The scope comprises the following:

- To review the chemical characteristics of metallic fuels and high Pu-bearing fuels (and of any relevant wasteform) and of relevant work that has been carried out in the past.
- Identification of future research needs to inform the development of a specification for future work.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
<th>SRL at task end</th>
<th>3</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development, Strategic Decisions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:


This review task may be carried-out by RWM resource with support from the supply chain.
Further Dissolution Studies on Advanced Gas-cooled Reactor (AGR) Fuel

**Background**

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example Advanced Gas-cooled Reactor (AGR) fuel. RWM plans to study a variety of spent fuels arising from commercial and research reactors that have been operated in the UK, initially focusing on fuels that are likely to require disposal in significant quantities (AGR and, to a lesser extent, Pressurised Water Reactor (PWR) fuels).

Scoping studies will be aimed at developing an initial understanding of the typical leaching rates and identifying the key factors controlling the leaching behaviour. In the case of AGR fuel, which currently makes up the greatest proportion of the disposal inventory, testing methodologies are being developed. The mechanistic understanding gained from these studies is expected to be applicable to a good fraction of the remaining spent fuel inventory.

Initial studies will be more substantial in scope and carried out in two stages (first oxic, then anoxic conditions). These will be followed by additional ('further') studies aimed at proving additional understanding and at underpinning data for use in safety assessments. In this context, RWM will consider recent advances in mechanistic understanding and modelling of spent fuel evolution achieved internationally and its applicability to UK spent fuels. Following on from previous work (Tasks 546, 547, 549, 551, 552), this task will focus on AGR fuel, whose behaviour will be evaluated on the basis of experiments on fuels with differing characteristics.

**Research Need**

To further develop our mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent fuels in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**

To extend the applicability of the results of previous leaching measurements on UK AGR fuels to a broader envelope of spent AGR fuels and to document the effects of alkaline groundwater on the dissolution behaviour. In particular:
- To identify and gain access to specific samples which can be studied to test the applicability of previously estimated instant release fraction (IRF) and long-term dissolution rates to fuels with different power history, burn-up and fission gas release (FGR).
- To carry out leaching studies in controlled chemical conditions to compare with results of previous tests on UK AGR fuels as well as international studies on LWR fuels.
- To rationalise dissolution behaviour of the AGR fuel envelope in the context of the mechanistic understanding being developed in the UK and internationally.

**Scope**

The scope comprises the following:
- Identification and access to relevant fuel samples and underpinning information (e.g. inventory, power history, burn-up, FGR).
- Macroscopic (e.g. optical) and microscopic (e.g. Scanning Electron Microscopy) characterisation of relevant fuel samples.
- Dissolution / leaching measurements of relevant fuel samples in controlled chemical conditions.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
The IRF is that fraction of fission products associated with grain boundaries and areas of macroscopic accumulation of segregated phases, as opposed to the fuel matrix. Operationally, AGR fuel is exposed to different temperature profiles than LWR fuel, hence a different degree of partitioning of the more volatile fission product may have occurred, potentially leading to different leaching behaviour.

Relevant publications include:


Information is also available at: http://www.firstnuclides.eu/

This task is will be carried out by contractors that have access to specialist facilities.
Task Number: 556
Status: Start date in future
PBS level 4: Package Evolution
PBS level 5: Spent Fuel
Title:
Further Dissolution Studies on Pressurised Water Reactor (PWR) Fuel

Background
There is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. RWM plans to build on this international understanding, however it is first necessary to validate the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent Pressurised Water Reactor (PWR) fuel against this understanding. This task will focus on PWR fuel, the behaviour of which will be evaluated based on experiments on fuels with a range of characteristics.

Research Need
To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of UK spent PWR fuel in near-neutral and, to a lesser degree, alkaline groundwater on the basis of dissolution / leaching experiments of suitable samples.

Research Objective
To extend the applicability of the results of previous leaching measurements obtained internationally on LWR fuels (including PWR) to UK PWR fuel. In particular:
- To identify and gain access to specific samples which can be studied to test the applicability of previously estimated Instant Release Fraction (IRF) and long-term dissolution rates to fuels with UK-specific power history, burn-up and Fission Gas Release (FGR).
- To carry out leaching studies in controlled chemical conditions to compare with the results of international studies on LWR fuels.
- To rationalise the dissolution behaviour of the PWR fuel envelope in the context of the mechanistic understanding being developed in the UK and internationally.

Scope
The scope comprises the following:
- To identify and access relevant fuel samples and underpinning information (e.g. inventory, power history, burn-up and FGR).
- To undertake macroscopic and microscopic characterisation.
- To undertake dissolution / leaching measurements in controlled chemical conditions.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation
Customer: Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

Further information
The IRF is that fraction of fission products associated with grain boundaries, as opposed to the fuel matrix. Relevant publications include:
Information is also available at: http://www.firstnuclides.eu/
This task is will be carried out by contractors that have access to specialist facilities and, potentially, in the context of, or in collaboration with, ongoing international studies on LWR fuels.
Further Studies on Dissolution Behaviour of Exotic and High Pu-bearing Fuels

**Background**

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique to the UK, for example experimental legacy fuels that are likely to be disposed in smaller quantities. These are known as exotic fuels and include metallic, oxide and carbide materials. These fuels are a legacy from earlier nuclear industry activities such as the development of research, experimental or prototype reactors. Although exotics often share the physical characteristics and properties of metallic and oxide fuel, their composition and enrichment are varied, with a substantial number containing plutonium (Pu).

Nevertheless, by the completion of reprocessing operations, current estimates indicate that there will be approximately 140 tonnes of civil separated plutonium (Pu) in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as mixed oxide (MOX) fuel in light water reactors or in CANDU EC6 reactors, and reuse as metallic fuel in PRISM fast reactors, which would result in the need of disposing of other types of fuels that, although not necessarily unique to the UK, may present specific challenges.

Little work has to date been undertaken on the disposability of these exotic and high Pu-bearing (e.g. MOX) fuels as we have focussed our efforts on the large quantities of AGR and Pressurised Water Reactor (PWR) fuel that dominate the UK inventory. This task therefore comprises an assumed set of dissolution / leaching experiments, on real samples or simulants, based on a previous desk-based analysis of research needs for exotic fuels and high Pu-bearing (Task 550) and subsequent scoping experiments (Task 553).

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution behaviour of UK exotic fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**

Depending on type of fuel and disposal concept, to determine the dissolution/corrosion behaviour of unirradiated / irradiated exotic fuels as measured in a set of short-term experiments. In particular:

- To measure the dissolution/corrosion behaviour of selected samples in groundwater simulants (including any conditioning from immobilisation/buffering media) to scope the expected long-term rate.
- Where appropriate, to determine whether the dissolution/corrosion rates are similar enough to those of other fuels (for oxide fuels) or uranium metal (for metallic fuels) to indicate that further measurements are likely to be successful in providing confidence in their behaviour in our standard disposal concepts.
- To scope whether there are any detrimental effects on the dissolution behaviour of the fuel at the levels of burn-up and power history expected.
- To scope whether the presence of cladding in the proximity of exotic fuels exposed to oxic groundwater results in effects which are detrimental to the leaching behaviour of the fuel.
- To evaluate whether the results of scoping measurements are consistent with the expected inventory and partitioning / segregation of radionuclides in fuel elements.
- To evaluate whether, where appropriate (e.g. oxic fuels) the dissolution / leaching of safety-relevant radionuclides can be correlated with any more easily measurable quantities (e.g. the Fission Gas Release (FGR)).

**Scope**

To be developed on the basis of the outcome of Task 553.
<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>End point</strong></td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Customer</strong></td>
<td>Disposal System Safety Case, Concept Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:


This task will be carried out through contractors and academic partners. Opportunities for co-funding from the relevant research council (EPSRC) may be sought.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>558</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PBS level 4 Package Evolution
PBS level 5 Spent Fuel

**Title**
Scoping Studies on Dissolution Behaviour of Un-reprocessed Metallic Fuel

**Background**

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique or very specific to the UK, among these metallic fuel produced from Magnox reactors. The NDA's baseline plan is for all metallic fuel to be reprocessed at Sellafield, however this plan is dependent upon the efficiency of ongoing reprocessing operations and it is therefore possible that RWM may be required to consider the disposal of un-reprocessed metallic fuel.

Research may therefore be required on the disposal of irradiated metallic fuel, depending on the progress of reprocessing operations. Following the review undertaken in Task 554, this task comprises a possible scoping study on the behaviour of un-reprocessed Metallic fuel, based on dissolution / leaching experiments of real spent fuel samples or suitable simulants.

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution behaviour of UK spent fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:
- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**

To scope the Instant Release Fraction (IRF) and long-term dissolution rate of metallic fuels and / or high Pu-bearing fuels (and any relevant wasteform). In particular:
- To measure the dissolution behaviour of selected samples in groundwater simulants and to determine whether the rates are similar enough to those of other fuels to provide confidence in their behaviour.
- To evaluate whether there are detrimental effects on the dissolution behaviour at the levels of burn-up and power history expected.
- To evaluate whether the presence of cladding in the proximity of fuel exposed to oxic groundwater results in effects that are detrimental to the leaching behaviour of the fuel.
- To evaluate whether the results of scoping measurements are consistent with the expected inventory and partitioning / segregation of radionuclides in fuel elements and with the likely oxidation state of the fuel matrix.
- To evaluate whether the dissolution / leaching of safety-relevant radionuclides can be correlated with any more easily measurable quantity (e.g. the Fission Gas Release (FGR)).

**Scope**

Following on from the previous review task this scope comprises the:
- Identification and access relevant fuel samples, underpinning information and suitable simulants.
- Macroscopic and microscopic characterisation of relevant fuel samples.
- Dissolution / leaching measurements of relevant fuel samples in controlled chemical conditions.
- Thermodynamic modelling of phase segregation.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

End point Site Specific Validation

Customer Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development, Strategic Decisions

Further information
Relevant publications include:
This task will be carried out by contractors and academic partners. Opportunities for co-funding from the relevant research council (EPSRC) may be sought.
Further Studies on Dissolution Behaviour of Un-Reprocessed Metallic Fuel

**Background**

Based on extensive international research there is good understanding of the behaviour of Light Water Reactor (LWR) spent fuel under conditions relevant to geological disposal. However, the UK inventory contains spent fuels from a number of different reactor types with characteristics that are unique or very specific to the UK, among these, metallic fuel produced from Magnox reactors. The NDA’s baseline plan is for all metallic fuel to be reprocessed at Sellafield, however this plan is dependent upon the efficiency of ongoing reprocessing operations and it is therefore possible that RWM may be required to consider the disposal of un-reprocessed metallic fuel.

Research may therefore be required on the disposal of irradiated metallic fuels, depending on the progress of reprocessing operations. Following the previous work undertaken in Tasks 554 and 558, this task comprises further evaluation of the dissolution / leaching behaviour of real metallic spent fuel samples or suitable simulants.

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution behaviour of UK spent fuels (instant release and long-term dissolution rate) in near-neutral and, to a lesser degree, alkaline groundwater. This is to support:

- The assessment of packaging solutions.
- The development of suitable disposal concepts.
- The development of the safety case and, where appropriate, strategic decisions on suitable waste management strategies for these materials.

**Research Objective**

To be developed on the basis of the outcome of Task 558.

**Scope**

To be developed on the basis of the outcome of task 558.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development, Strategic Decisions

**Further information**

Relevant publications include:

Corrosion Studies of Uranium Hydride in Cement

**Background**

A large body of information, based on over 20 years of R&D in the UK and overseas, shows cement to be an effective encapsulant for many types of ILW and LLW. Based on this experience, the majority of cement-based wasteforms that have been, or would be produced, are expected to perform satisfactorily. However, the long-term reactions of certain wastes may have consequences for wasteform properties and container integrity. For example, grouted reactive metals, particularly Magnox cladding and uranium metal, undergo expansive corrosion. In some cases such processes could have an effect on the physical integrity of the wasteform, or in the extreme the waste container, prior to closure of a GDF. In these cases there is a risk that re-working of waste packages could be required and appropriate provision would need to be made for this future activity.

RWM plans to carry out specific experimental and modelling work to understand the likely evolution of widely available waste-streams (i.e. cross-industry) for which specific technical issues have been identified or observed. This work will be co-ordinated with that of waste producers, who undertake R&D on specific wasteform issues associated with the packaging of individual waste streams (e.g. grout formulation, wasteform stability). This task will focus on the evolution of wasteforms containing uranium, the behaviour of which will be evaluated on the basis of experimental studies with depleted uranium and inactive surrogates.

**Research Need**

To develop a mechanistic understanding of the evolution of cement-based wasteforms for ILW to support the assessment of packaging solutions and the development of the safety case.

**Research Objective**

To determine the rate of development of uranium hydrides in cement-based encapsulants in order to establish whether hydride formation over many decades could prejudice the transport or operational safety case for the GDF.

**Scope**

To conduct experimental studies of uranium (and uranium surrogates) hydride formation and evolution in contact with cement.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

**Further information**

Relevant publications include:


This programme is currently being co-funded by the EPSRC under its Geowaste programme (University of Birmingham, Manchester University and University of Bristol) under RWM's initiative to support a portfolio of 'curiosity driven' research which complements our 'needs driven' programme.
# Task Number

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>572</td>
<td>PBS level 4 Package Evolution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PBS level 5 Cement-Based Wasteforms for ILW</td>
<td></td>
</tr>
</tbody>
</table>

## Title

Studies on the Impact of Reactive Metal Corrosion in Cement

## Background

A large body of information based on over 20 years of R&D in the UK and overseas shows cement to be an effective encapsulant for many types of ILW and LLW. Based on this experience, the majority of cement-based wasteforms that have been, or would be, produced are expected to perform satisfactorily. However, the long-term reactions of certain wastes may have consequences for wasteform properties and container integrity. For example, grouted reactive metals, particularly Magnox cladding and uranium metal, undergo expansive corrosion. In some cases such processes could have an effect on the physical integrity of the wasteform, or in the extreme, the waste container, prior to closure of a GDF. In these cases there is risk that re-working of waste packages could be required and appropriate provision would need to be made for this.

RWM plans to carry out specific experimental and modelling work to understand the likely evolution of cross-industry waste-streams for which specific technical issues have been identified or observed. This work will be co-ordinated with that of waste producers, who undertake R&D on specific wasteform issues associated with the packaging of individual waste streams (e.g. grout formulation, wasteform stability). This task will focus on the evolution of wasteforms containing reactive metals (magnesium, aluminium and uranium), the behaviour of which will be evaluated on the basis of experimental and modelling studies.

## Research Need

To develop a mechanistic understanding of the evolution of cement-based wasteforms for ILW to support the assessment of packaging solutions and the development of the safety case.

## Research Objective

To determine whether significant cracking of the wasteform due to expansive corrosion processes can take place in cement-based wasteforms containing reactive metals, particularly uranium-containing wasteforms. In particular:

- To determine what is a significant / "extensive" degree of cracking in terms of wasteform behaviour.
- To evaluate whether the chronic corrosion rate of uranium in cement is sufficient to induce extensive cracking of the wasteform considering the availability of water and the transport properties of the wasteform and the mechanical properties of the waste container.
- To supplement previous work evaluating whether the chronic corrosion rate of aluminium and Magnox in cement is sufficient to induce extensive cracking of the wasteform if limited quantities of these materials were present in the wasteform, considering the availability of water and the transport properties of the wasteform and the mechanical properties of the waste container.

## Scope

To undertake modelling studies of reactive metal corrosion and expansion in cement.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
<th>End point</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
<td>No Further Research Planned</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development</td>
</tr>
</tbody>
</table>

## Further information

Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Cement-Based Wasteforms for ILW</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Further Research Needs For Expansive Processes

**Background**
A large body of information based on over 20 years of Research & Development (R&D) in the UK and overseas shows cement to be an effective encapsulant for many types of ILW and LLW. Based on this experience, the majority of cement-based wasteforms that have been, or would be, produced are expected to perform satisfactorily. However, the long-term reactions of certain wastes may have consequences for wasteform properties and container integrity. In some cases such processes could have an effect on the physical integrity of the wasteform, or in the extreme, the waste container, prior to closure of a GDF. In these cases there is risk that re-working of waste packages could be required and appropriate provision would need to be made in the future.

RWM plans to carry out specific experimental and modelling work to understand the likely evolution of widely available waste-streams (i.e. cross-industry) for which specific technical issues have been identified or observed. This work will be co-ordinated with that of waste producers, who undertake R&D on specific wasteform issues associated with the packaging of individual waste streams (e.g. grout formulation, wasteform stability).

This task will focus on the evolution of wasteforms which may have been identified as requiring additional research due to the potential occurrence of detrimental evolutionary processes (e.g. formation of expansive, pyrophoric or chemically reactive phases).

**Research Need**
To develop a mechanistic understanding of the evolution of cement-based wasteforms for ILW to support the assessment of packaging solutions and the development of the safety case.

**Research Objective**
To review the use of cements for the immobilisation of ILW to identify any additional research needs.

**Scope**
Review study utilising international Waste Management Organisation (WMO) resources, RWM reports, Letter of Compliance (LoC) submissions, waste owner liaison and the scientific literature, amongst others.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Further Work to be Defined

**Customer**
Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

**Further information**
Relevant publications include:
M. Constable et al, 2010, Review of Wasteform Ageing up to Repository Resaturation (Part Two), WMT 07/P052, (available from the RWM website).
This task will be carried out by RWM contractors and/or internal resources.
### Task Number
574

### Status
Start date in future

### PBS level 4
Package Evolution

### PBS level 5
Cement-Based Wasteforms for ILW

### Title
Studies of the Impact of Uranium Hydride Formation in Cements

### Background
A large body of information based on over 20 years of R&D in the UK and overseas shows cement to be an effective encapsulant for many types of ILW and LLW. Based on this experience, the majority of cement-based wasteforms that have been, or would be produced, are expected to perform satisfactorily. However, the long-term reactions of certain wastes may have consequences for wasteform properties and container integrity. For example, grouted reactive metals, particularly Magnox cladding and uranium metal, undergo expansive corrosion. In some cases such processes could have an effect on the physical integrity of the wasteform, or in the extreme, the waste container, prior to closure of a GDF. In these cases there is risk that re-working of waste packages could be required and appropriate provision would need to be made for this future activity.

RWM plans to carry out specific experimental and modelling work to understand the likely evolution of widely available waste-streams (i.e. cross-industry) for which specific technical issues have been identified or observed. This work will be co-ordinated with that of waste producers, who undertake R&D on specific wasteform issues associated with the packaging of individual waste streams (e.g. grout formulation, wasteform stability).

This task will focus on the evolution of wasteforms containing uranium, the behaviour of which will be evaluated on the basis of a review of existing information on the likelihood of hydride formation and impact on the safety case.

### Research Need
To develop a mechanistic understanding of the evolution of cement-based wasteforms for ILW to support the assessment of packaging solutions and the development of the safety case.

### Research Objective
To evaluate the impact of uranium hydride formation on the chemical properties and evolution of the wasteform.

### Scope
To undertake a review utilising international Waste Management Organisation (WMO) resources, RWM reports, Letter of Compliance (LoC) submissions, waste owner liaison and the scientific literature, amongst other sources of information.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

### End point
No Further Research Planned

### Customer
Waste Package Disposability Assessments, Disposal System Safety Case

### Further information
Relevant publications include:


This task will be carried out by contractors and academic partners. Opportunities for co-funding from the relevant research council (e.g. EPSRC) may be sought.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Polymer Based Wasteforms for ILW</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Review Research Needs for Polymeric Wasteforms

**Background**
In the past, in the UK, Nirex and others have commissioned extensive programmes of R&D to demonstrate the effectiveness of cement in immobilising a variety of ILW / LLW in wasteforms suitable for disposal in a GDF. R&D has also considered some alternative wasteforms. A number of organic polymers have been used as encapsulants for radioactive wastes around the world and have possible advantages over cement-based encapsulants in some applications. Recent work in the UK has shown that, under simulated disposal conditions, some epoxy resin formulations have properties and stability that may make them suitable for encapsulation of ILW and LLW. However, the evolution of organic systems over the very long timescales considered in post-closure performance assessments has not been extensively studied.

At this stage of the programme, depending on the drive to employ this type of encapsulant, RWM may continue to undertake experiments to improve its understanding of the long term stability of possible organic polymeric encapsulants in representative conditions expected in a GDF. We plan to evaluate whether the formation of degradation products from these materials has any potential impact on transport, operational or post-closure safety. We may need to undertake work to examine alternative disposal options for this type of wasteform.

This task will focus on candidate polymeric wasteforms emerging in the industry for which research needs will be identified on the basis of a desk-based study.

**Research Need**
To develop a mechanistic understanding of the evolution of polymeric wasteforms for ILW to support the assessment of packaging solutions, the development of disposal concepts for these wasteforms and the development of the safety case.

**Research Objective**
To review the planned use of polymeric materials for the immobilisation of ILW to identify any additional research needs.

**Scope**
To conduct a review of the research needs for polymeric waste encapsulants utilising international Waste Management Organisation (WMO) resources, RWM reports, LoC submissions, waste owner liaison, the scientific literature, etc.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**
Further Work to be Defined

**Customer**
Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

**Further information**
Relevant publications include:
This task will be carried out by our contractors and/or RWM internal resources.
### Scoping Dissolution Studies of Non-optimised Vitrified ILW Simulants in Oxic, Alkaline Groundwaters

**Background**

There are a number of alternatives to classical cementitious wasteforms (e.g. vitrification, non-Ordinary Portland Cement (OPC) based cements, and silicone polymers) to produce non-OPC based inorganic ILW wasteforms. Some processes (particularly high temperature processes such as vitrification) offer specific advantages of volume reduction and reduction of chemical reactivity. There is experience in the application of some of these technologies in radioactive waste management overseas and some R&D has been undertaken recently by waste producers or under the NDA Direct Research Portfolio in the UK.

Dependent upon the process used to create vitrified ILW wasteforms, their homogeneity and performance envelope may lead to less durable materials than their HLW analogues. We plan to carry out experimental studies to scope the dissolution behaviour of vitrified ILW products in both alkaline and near-neutral environments, which will support the development of suitable disposal concepts for these wasteforms. Initial ('scoping') studies will be aimed at developing understanding of typical leaching rates and identifying key factors controlling the leaching behaviour of 'non-optimised' products (i.e. products for which the chemical composition and processing parameters are still being developed). These studies will be followed by further studies on 'optimised' compositions. In contrast to the case of HLW glass, studies on vitrified ILW will not necessarily aim at providing data to support safety assessments, since a demonstration of qualitative understanding may be sufficient for the purposes of the safety case (i.e. in alkaline conditions).

This task will focus on non-optimised wasteform simulants (wasteforms whose chemical composition may change as a result of ongoing or future development work), in oxic, alkaline groundwaters, in particular sodium alumino-silicate glasses for the potential immobilisation of sand / clinoptilolite and iron-rich soda-lime glasses simulating the vitrification of wastes with high metal content.

**Research Need**

To develop a mechanistic understanding of the evolution of vitrified wasteforms for ILW to support the assessment of packaging solutions, the development of disposal concepts for these wasteforms and the development of the safety case.

**Research Objective**

To scope the dissolution / leaching behaviour of vitrified ILW products in alkaline groundwaters by testing non-optimised glass simulants. In particular, to determine whether:

- The rate of dissolution of vitrified ILW simulants in alkaline groundwaters (which may be generated in the presence of cement-based backfill) is low enough that it does not significantly affect the behaviour of other components of the disposal system.

- The dissolution behaviour of vitrified specific ILW (non-optimised) simulants is sensitive to glass composition.

- The presence of specific glass components (e.g. calcium) leads to the formation of (protective or partially protective) gel layers, which could reduce the initial dissolution rate.

- Reducing the silica content of vitrified ILW glass decreases its susceptibility to dissolution at high pH, increasing the likely compatibility of the wasteform with cement-based backfills.

- Reducing the pH of the environment reduces the dissolution rate.

**Scope**

The scope comprises the following:

- Procurement and characterisation of a variety of vitrified ILW products (in particular soda-lime and iron-rich alumino-silicate glasses) which are potentially representative of waste arising from currently emerging vitrification processes applied to relevant waste streams (e.g. high metal content, sand / clin).

- Experimental measurements of the dissolution / leaching behaviour of ILW glass products (50°C) in alkaline groundwaters - one sample in hyperalkaline conditions (pH ~ 12.5) and one in moderately alkaline (pH ~ 10) liquor.

<table>
<thead>
<tr>
<th>Task Number</th>
<th>PBS level 4</th>
<th>Status</th>
<th>PBS level 5</th>
<th>Alternative Inorganic Wasteforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>601</td>
<td>Package Evolution</td>
<td>Ongoing</td>
<td>Alternative Inorganic Wasteforms</td>
<td></td>
</tr>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Further information

Relevant publications include:


This task is intended for procurement through our contractors with significant input from academic partners.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>602</td>
<td>Ongoing</td>
</tr>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Alternative Inorganic Wasteforms</td>
</tr>
</tbody>
</table>

**Title**

Scoping Dissolution Studies of Non-optimised Vitrified ILW Simulants in Oxic, Near-neutral Groundwaters

**Background**

There are a number of alternatives to classical cementitious wasteforms (e.g. vitrification, non-Ordinary Portland Cement (OPC) based cements, and silicone polymers) to produce non-OPC based inorganic ILW wasteforms. Some processes (particularly high temperature processes such as vitrification) offer specific advantages of volume reduction and reduction of chemical reactivity. There is experience in the application of some of these technologies in radioactive waste management overseas and some R&D has been undertaken recently by waste producers or under the NDA Direct Research Portfolio in the UK.

Dependent upon the process used to create vitrified ILW wasteforms, their homogeneity and performance envelope may lead to less durable materials than their HLW analogues. We plan to carry out experimental studies to scope the dissolution behaviour of vitrified ILW products in both alkaline and near-neutral environments, which will support the development of suitable disposal concepts for these wasteforms. Initial (‘scoping’) studies will be aimed at developing understanding of typical leaching rates and identifying key factors controlling the leaching behaviour of ‘non-optimised’ products (i.e. products for which the chemical composition and processing parameters are still being developed). These studies will be followed by further studies on ‘optimised’ compositions. In contrast to the case of HLW glass, studies on vitrified ILW will not necessarily aim at providing data to support safety assessments, since a demonstration of qualitative understanding may be sufficient for the purposes of the safety case (i.e. in alkaline conditions).

This task will focus on non-optimised wasteform simulants (wasteforms whose chemical composition may change as a result of ongoing or future development work), in oxic, near-neutral groundwaters, in particular sodium alumino-silicate glasses for the potential immobilisation of sand / clinoptilolite and iron-rich soda-lime glasses simulating the vitrification of wastes with high metal content.

**Research Need**

To develop a mechanistic understanding of the evolution of vitrified wasteforms for ILW to support the assessment of packaging solutions, the development of disposal concepts for these wasteforms and the development of the safety case.

**Research Objective**

To scope the dissolution / leaching behaviour of vitrified ILW products in near-neutral groundwaters by testing non-optimised glass simulants in order to determine whether:

- The dissolution behaviour of vitrified ILW specific (non-optimised) simulants is sensitive to (near-neutral) groundwater compositions in a variety of potential geological environments.

- The dissolution behaviour of vitrified specific ILW (non-optimised) simulants is sensitive to glass composition.

- The long-term evolution of the glass in the absence of other Engineered Barrier System (EBS) components (in particular iron-based materials) is such that any (thermodynamically-stable) phases formed in the long term will induce dissolution rates faster than those estimated from short-term experiments.

**Scope**

The scope comprises the following:

- The procurement and characterisation of a variety of vitrified ILW products (in particular soda-lime and iron-rich alumino-silicate glasses) which are potentially representative of waste arising from currently emerging vitrification processes applied to relevant waste streams (e.g. high metal content, sand / clino).

- Experimental measurements (at 50°C) of the dissolution / leaching behaviour of ILW glass products in near neutral groundwater simulants and deionised water.

- Review of existing mechanistic / parametric models developed internationally (e.g. Glass Reactivity with Allowance for the Alteration Layer, GRAAL model) to evaluate their applicability to the behaviour of ILW glass compositions.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

End point

Site Specific Validation
## Customer Contact Information

### Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

### Further information

Relevant publications include:


This task is intended for procurement through our contractors with significant input from academic partners.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>603</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Alternative Inorganic Wasteforms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Dissolution Studies of Realistic Vitrified ILW Simulants in Oxic, Alkaline Groundwaters

**Background**
There are a number of alternatives to classical cementitious wasteforms (e.g. vitrification, non-Ordinary Portland Cement (OPC) based cements, and silicone polymers) to produce non-OPC based inorganic ILW wasteforms. Some processes (particularly high temperature processes such as vitrification) offer specific advantages of volume reduction and reduction of chemical reactivity. There is experience in the application of some of these technologies in radioactive waste management overseas and some R&D has been undertaken recently by waste producers or under the NDA Direct Research Portfolio in the UK.

Dependent upon the process used to create vitrified ILW wasteforms, their homogeneity and performance envelope may lead to less durable materials than their HLW analogues. We plan to carry out experimental studies to scope the dissolution behaviour of vitrified ILW products in both alkaline and near-neutral environments, which will support the development of suitable disposal concepts for these wasteforms. Initial (‘scoping’) studies will be aimed at developing understanding of typical leaching rates and identifying key factors controlling the leaching behaviour of ‘non-optimised’ products (i.e. products for which the chemical composition and processing parameters are still being developed). These studies will be followed by further studies on ‘optimised’ compositions. In contrast to the case of HLW glass, studies on vitrified ILW will not necessarily aim at providing data to support safety assessments, since a demonstration of qualitative understanding may be sufficient for the purposes of the safety case (i.e. in alkaline conditions). This task will focus on realistic vitrified ILW simulants, in oxic, alkaline groundwaters, the composition of which is the subject of ongoing development elsewhere in the industry.

**Research Need**
To develop a mechanistic understanding of the evolution of vitrified wasteforms for ILW to support the assessment of packaging solutions, the development of disposal concepts for these wasteforms and the development of the safety case.

**Research Objective**
To evaluate the dissolution / leaching behaviour of vitrified ILW products in alkaline groundwaters by testing non-optimised glass simulants. In particular, to determine whether the behaviour of simulants representative of a realistic envelope of compositions is consistent with previous observations.

**Scope**
The scope comprises the following:
- The procurement and archiving of samples of vitrified ILW products and inactive analogues.
- Experimental measurements on the dissolution / leaching behaviour of ILW glass products on a broader or more representative range of glass compositions in selected groundwater simulants.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**
Relevant publications include:

This task is intended for procurement through our contractors with significant input from academic partners. Opportunities for co-funding from the relevant research council (EPSRC) may be sought.
Title
Dissolution Studies of Realistic Vitrified ILW Simulants in Oxic, Near-Neutral Groundwaters

Background
There are a number of alternatives to classical cementitious wasteforms (e.g. vitrification, non-Ordinary Portland Cement (OPC) based cements, and silicone polymers) to produce non-OPC based inorganic ILW wasteforms. Some processes (particularly high temperature processes such as vitrification) offer specific advantages of volume reduction and reduction of chemical reactivity. There is experience in the application of some of these technologies in radioactive waste management overseas and some R&D has been undertaken recently by waste producers or under the NDA Direct Research Portfolio in the UK.

Dependent upon the process used to create vitrified ILW wasteforms, their homogeneity and performance envelope may lead to less durable materials than their HLW analogues. We plan to carry out experimental studies to scope the dissolution behaviour of vitrified ILW products in both alkaline and near-neutral environments, which will support the development of suitable disposal concepts for these wasteforms. Initial ("scoping") studies will be aimed at developing understanding of typical leaching rates and identifying key factors controlling the leaching behaviour of 'non-optimised' products (i.e. products for which the chemical composition and processing parameters are still being developed). These studies will be followed by further studies on 'optimised' compositions. In contrast to the case of HLW glass, studies on vitrified ILW will not necessarily aim at providing data to support safety assessments, since a demonstration of qualitative understanding may be sufficient for the purposes of the safety case (i.e. in alkaline conditions). This task will focus on realistic vitrified ILW simulants, in oxic, near-neutral groundwaters, the composition of which is the subject of ongoing development elsewhere in the industry.

Research Need
To develop a mechanistic understanding of the evolution of vitrified wasteforms for ILW to support the assessment of packaging solutions, the development of disposal concepts for these wasteforms and the development of the safety case.

Research Objective
To evaluate the dissolution / leaching behaviour of vitrified ILW products in near-neutral groundwaters by testing non-optimised glass simulants. To determine whether:
- The behaviour of simulants representative of a realistic envelope of compositions is consistent with previous observations.
- The previously developed model (in the UK or internationally) can be applied to describe the evolution of realistic ILW glasses.
- The presence of heterogeneities has an impact on the dissolution rate of ILW products in relevant conditions.

Scope
The scope comprises the following:
- The procurement and archiving of samples to support the RWM R&D programme.
- Experimental measurements on the dissolution / leaching behaviour of ILW glass products on a broader or more representative range of glass compositions in selected groundwater simulants to confirm previous understanding.
- Application of previously developed models to the dissolution/leaching behaviour of these glasses.
- Review of existing knowledge and development of simple process models to evaluate the effect of glass heterogeneity.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
</table>

Customer
Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

Further information

Appendix B - 253
Relevant publications include:
This task is intended for procurement through our contractors with significant input from academic partners. Opportunities for co-funding from the relevant research council (EPSRC) may be sought.
Appendix B - 255

<table>
<thead>
<tr>
<th>Task Number</th>
<th>605</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Alternative Inorganic Wasteforms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Title
Studies of Effect of Iron and Radiation on the Leaching Behaviour of Realistic ILW Product Simulants

### Background
There are a number of alternatives to classical cementitious wasteforms (e.g. vitrification, non-Ordinary Portland Cement (OPC) based cements, and silicone polymers) to produce non-OPC based inorganic ILW wasteforms. Some processes (particularly high temperature processes such as vitrification) offer specific advantages of volume reduction and reduction of chemical reactivity. There is experience in the application of some of these technologies in radioactive waste management overseas and some R&D has been undertaken recently by waste producers or under the NDA Direct Research Portfolio in the UK.

Dependent upon the process used to create vitrified ILW wasteforms, their homogeneity and performance envelope may lead to less durable materials than their HLW analogues. We plan to carry out experimental studies to scope the dissolution behaviour of vitrified ILW products in both alkaline and near-neutral environments, which will support the development of suitable disposal concepts for these wasteforms. Initial ('scoping') studies will be aimed at developing understanding of typical leaching rates and identifying key factors controlling the leaching behaviour of 'non-optimised' products (i.e. products for which chemical compositions and processing parameters are still being developed). These studies will be followed by further studies on 'optimised' compositions. In contrast to the case of HLW glass, studies on vitrified ILW will not necessarily aim at providing data to support safety assessments, since a demonstration of qualitative understanding may be sufficient for the purposes of the safety case (i.e. in alkaline conditions).

This task will focus on the leaching behaviour of realistic vitrified ILW simulants (the composition of which is subject of ongoing development elsewhere in the industry) in the presence of iron and in a radiation field.

### Research Need
To develop a mechanistic understanding of the evolution of vitrified wasteforms for ILW to support the assessment of packaging solutions, the development of disposal concepts for these wasteforms and the development of the safety case.

### Research Objective
To evaluate the dissolution / leaching behaviour of vitrified ILW products in near-neutral groundwaters by testing non-optimised glass simulants. In particular, to determine whether:

- The presence of iron-based materials (e.g. the waste container) in contact with ILW glass affects its evolution and dissolution rates in a way which could prejudice the safety case (i.e. does the presence of iron lead to the formation of phases that lead to dissolution rates faster than those estimated from short-term experiments in the absence of iron?).
- The effect of radiation fields has a significant impact on the dissolution behaviour of the glass and can be interpreted on the basis of available knowledge on radiochemistry and radiation damage.
- There is any possibility that radiation fields could lead to de-vitrification.

### Scope
The scope comprises the following:

- Procurement and archiving of samples to support the RWM R&D programme.
- Experimental measurements on the dissolution / leaching behaviour of ILW glass products on specific glass compositions in selected groundwater simulants to investigate the effect of the presence of iron-based materials in contact with the glass and radiation fields.
- Review / refinement of glass dissolution models to consider the influence of radiation-fields and iron-based materials.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information
This task will be carried out by our contractors and academic partners. Opportunities for co-funding from the relevant research council (EPSRC) may be sought.
Definition of Research Needs for Hot Isostatic Pressed (HIPed) Product

Background

For wastes, and materials which may be declared as wastes, where disposal concept development is at its earlier stages, current and future work is aimed at developing our understanding of the available options to support future decisions. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. This type of work is co-ordinated with any work that may be planned in the NDA’s Direct Research Portfolio.

One such potential waste is plutonium (Pu) resulting from reprocessing, for which disposal concepts are not yet well defined. By the completion of reprocessing there will be approximately 140 tonnes of civil separated Pu in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as MOX in light water reactors, reuse in CANDU EC6 reactors and reuse in PRISM fast reactors. Nevertheless, not all of the Pu stocks may be suitable for reuse. It is therefore necessary to research potential wasteforms for these materials (Pu residues) which will provide long-term integrity and criticality safety. A number of potential immobilisation options are currently being considered, including cementation, vitrification, hot or cold pressing into ceramics or incorporation into mixed oxide (uranium(U) / Pu) fuel not intended for reactor use (e.g. 'low spec'); the last two options are recently receiving greater consideration. Past reviews on the expected dissolution / leaching behaviour of such wasteforms indicated that there is only a limited amount of information available from past experimental programmes and that further work is likely to be required to fully underpin the disposal of these materials.

RWM plans to carry out experimental studies on the leaching behaviour of candidate wasteforms once strategic decisions on the fate of plutonium are more mature. Initial ('scoping') studies will be aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling leaching behaviour. These will be followed by 'further' studies aimed at proving additional understanding and at deriving underpinning data for use in safety assessments.

In preparing this task we are assuming that Pu residues (of the order of 10 tonnes) will require processing by Hot Isostatic Pressing (HIP) or incorporation into low specification fuel (not intended for irradiation in reactor). The remaining inventory for disposal will be irradiated (see 'spent fuel' section). This task will focus on HIPed products and/or low spec fuel, with the aim of identifying the research needs via a desk-based study.

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of Pu wasteforms in near-neutral and, to a lesser degree, alkaline groundwater on the basis of dissolution / leaching experiments of suitable simulants and mechanistic modelling.

Research Objective

To identify specific research needs for Pu HIPed products and / or low spec Pu-bearing fuel based on available information regarding their chemical characteristics.

Scope

The scope comprises the following:
- To review the chemical characteristics of Pu HIPed products and / or low spec Pu-bearing fuel and identify relevant work undertaken previously.
- To identify further research needs and inform the development of a specification for follow-up work.

Further information

Relevant publications include:


Conditioning of Plutonium Residues by Hot Isostatic Pressing and Options for Packaging and Disposal (pre-Conceptual stage) - Summary of Assessment, 2009.

This task may be carried out by RWM internal resources with support from the supply chain.
For wastes, and materials which may be declared as wastes, where disposal concept development is at its earlier stages, current and future work is aimed at developing our understanding of the available options to support future decisions. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. This type of work is co-ordinated with any work that may be planned in the NDA’s Direct Research Portfolio.

One such potential waste is plutonium (Pu) resulting from reprocessing, for which disposal concepts are not yet well defined. By the completion of reprocessing there will be approximately 140 tonnes of civil separated Pu in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as MOX in light water reactors, reuse in CANDU EC6 reactors and reuse in PRISM fast reactors. Nevertheless, not all of the Pu stocks may be suitable for reuse. It is therefore necessary to research potential wasteforms for these materials (Pu residues) which will provide long-term integrity and criticality safety. A number of potential immobilisation options are currently being considered, including cementation, vitrification, hot or cold pressing into ceramics or incorporation into mixed oxide (uranium(U) / Pu) fuel not intended for reactor use (e.g. 'low spec'); the last two options are recently receiving greater consideration. Past reviews on the expected dissolution/leaching behaviour of such wasteforms indicated that there is only a limited amount of information available from past experimental programmes and that further work is likely to be required to fully underpin the disposal of these materials.

RWM plans to carry out experimental studies on the leaching behaviour of candidate wasteforms once strategic decisions on the fate of plutonium are more mature. Initial (‘scoping’) studies will be aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling leaching behaviour. These will be followed by ‘further’ studies aimed at proving additional understanding and at deriving underpinning data for use in safety assessments.

In preparing this task we are assuming that Pu residues (of the order of 10 tonnes) will require processing by Hot Isostatic Pressing (HIP) or incorporation into low specification fuel (not intended for irradiation in reactor). The remaining inventory for disposal will be irradiated (see ‘spent fuel’ section). Following on from Task 616, this task will focus on HIPed products and / or low spec fuel, the behaviour of which will be scoped on the basis of dissolution / leaching experiments of real product samples or suitable simulants.

Research Need
To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of Pu wasteforms in near-neutral and, to a lesser degree, alkaline groundwater on the basis of dissolution / leaching experiments of suitable simulants and mechanistic modelling.

Research Objective
To scope the Instant Release Fraction (IRF) and long-term dissolution rate of Pu HIPed products and/or low spec Pu-bearing fuel from short-term experiments. In particular:
- To measure the dissolution behaviour of selected samples in groundwater simulants and to determine whether the rates are similar enough to those of other wasteforms to provide confidence in their behaviour.
- To evaluate whether there are any detrimental effects associated with preferential leaching of neutron poisons (such as hafnium or gadolinium).
- To evaluate whether the presence of cladding in the proximity of fuel exposed to oxic groundwater results in effects which are detrimental to the leaching behaviour of the wasteform.
- To evaluate whether the dissolution / leaching of safety-relevant radionuclides can be correlated with any more easily measurable quantity.

Scope
The scope comprises the following:
- To identify and archive relevant HIPed product and/or Pu-bearing low spec fuel samples, underpinning information and suitable simulants.
- To perform macroscopic and microscopic characterisation.
- To undertake dissolution / leaching measurements in controlled chemical conditions.
- To undertake thermodynamic modelling of phase segregation.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation


Further information

Relevant publications include:
Conditioning of Plutonium Residues by Hot Isostatic Pressing and Options for Packaging and Disposal (pre-Conceptual stage) - Summary of Assessment, 2009.

This task will be carried out by our contractors and/or RWM internal resources.
Scoping studies on the use of simulants to study the dissolution behaviour of Hot Isostatic Pressed (HIPed) Plutonium and unirradiated MOX Fuel

Background

For wastes, and materials which may be declared as wastes, where disposal concept development is at its earlier stages, current and future work is aimed at developing our understanding of the available options to support future decisions. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. This type of work is co-ordinated with any work that may be planned in the NDA’s Direct Research Portfolio.

One such potential waste is plutonium (Pu) resulting from reprocessing, for which disposal concepts are not yet well defined. By the completion of reprocessing there will be approximately 140 tonnes of civil separated Pu in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as MOX in light water reactors, reuse in CANDU EC6 reactors and reuse in PRISM fast reactors. Nevertheless, not all of the Pu stocks may be suitable for reuse. It is therefore necessary to research potential wasteforms for these materials (Pu residues) which will provide long-term integrity and criticality safety. A number of potential immobilisation options are currently being considered, including cementation, vitrification, hot or cold pressing into ceramics or incorporation into mixed oxide (uranium(U) / Pu) fuel not intended for reactor use (e.g. ‘low spec’); the last two options are recently receiving greater consideration. Past reviews on the expected dissolution/leaching behaviour of such wasteforms indicated that there is only a limited amount of information available from past experimental programmes and that further work is likely to be required to fully underpin the disposal of these materials.

RWM plans to carry out experimental studies on the leaching behaviour of candidate wasteforms once strategic decisions on the fate of plutonium are more mature. Initial (‘scoping’) studies will be aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling leaching behaviour. These will be followed by ‘further’ studies aimed at proving additional understanding and at deriving underpinning data for use in safety assessments.

In preparing this task we are assuming that Pu residues (of the order of 10 tonnes) will require processing by Hot Isostatic Pressing (HIP) or incorporation into low specification fuel (not intended for irradiation in reactor). The remaining inventory for disposal will be irradiated (see ‘spent fuel’ section). This task will focus on HIPed products and/or low spec Pu-bearing fuel, the behaviour of which will be evaluated on the basis of dissolution/leaching experiments with suitable simulants (similar to SimFuel).

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of Pu wasteforms in near-neutral and, to a lower degree, alkaline groundwater on the basis of dissolution / leaching experiments of suitable simulants and mechanistic modelling.

Research Objective

To determine whether it is possible to manufacture inactive simulants of Pu wasteforms with chemical composition, characteristics (with the exception of self-irradiation) and leaching behaviour which are sufficiently representative of HIPed products and / or low spec Pu-bearing fuel to justify their use in leaching experiments aimed at evaluating their leaching behaviour. In particular, to determine whether:

- The morphology of the simulants is similar enough to that observed in the real materials.
- The partitioning of radionuclides in the microstructure is consistent with experimental observations on the real materials.
- The dissolution behaviour of the simulants is similar to that of Pu wasteforms, including sensitivity to the groundwater chemistry, temperature, composition and redox conditions, including tests to specifically document the effect of alkaline groundwater.
- The presence of radiation damage induced ex-situ has an effect on the ensuing dissolution behaviour.
- The presence of the cladding materials in leaching experiments affects the dissolution behaviour.
- Secondary minerals form upon leaching, that are similar to those expected in the wasteform.

Scope
The scope comprises the following:
- To identify and archive relevant samples, underpinning information and suitable simulants (e.g. SimFuel).
- To undertake macroscopic and microscopic characterisation.
- To perform dissolution / leaching measurements in controlled chemical conditions.
- To undertake thermodynamic modelling of phase segregation.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Disposal System Safety Case, Assessment of Packaging Solutions, Concept Development

**Further information**

Relevant publications include:
- Conditioning of Plutonium Residues by Hot Isostatic Pressing and Options for Packaging and Disposal (pre-Conceptual stage) - Summary of Assessment, 2009.

This task will be carried out by our contractors and/or RWM internal resources.
Further Studies on the Dissolution Behaviour of Hot Isostatic Pressed (HIPed) Products

Background

For wastes, and materials which may be declared as wastes, where disposal concept development is at its earlier stages, current and future work is aimed at developing our understanding of the available options to support future decisions. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. This type of work is co-ordinated with any work that may be planned in the NDA’s Direct Research Portfolio.

One such potential waste is plutonium (Pu) resulting from reprocessing, for which disposal concepts are not yet well defined. By the completion of reprocessing there will be approximately 140 tonnes of civil separated Pu in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as MOX in light water reactors, reuse in CANDU EC6 reactors and reuse in PRISM fast reactors. Nevertheless, not all of the Pu stocks may be suitable for reuse. It is therefore necessary to research potential wasteforms for these materials (Pu residues) which will provide long-term integrity and criticality safety. A number of potential immobilisation options are currently being considered, including cementation, vitrification, hot or cold pressing into ceramics or incorporation into mixed oxide (uranium(U) / Pu) fuel not intended for reactor use (e.g. 'low spec'); the last two options are recently receiving greater consideration. Past reviews on the expected dissolution/leaching behaviour of such wasteforms indicated that there is only a limited amount of information available from past experimental programmes and that further work is likely to be required to fully underpin the disposal of these materials.

RWM plans to carry out experimental studies on the leaching behaviour of candidate wasteforms once strategic decisions on the fate of plutonium are more mature. Initial ('scoping') studies will be aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling leaching behaviour. These will be followed by 'further' studies aimed at proving additional understanding and at deriving underpinning data for use in safety assessments.

In preparing this task we are assuming that Pu residues (of the order of 10 tonnes) will require processing by Hot Isostatic Pressing (HIP) or incorporation into low specification fuel (not intended for irradiation in reactor). The remaining inventory for disposal will be irradiated (see 'spent fuel' section). Following on from Tasks 616 and 617, this task will focus on HIPed products and/or low spec fuel, the behaviour of which will be evaluated on the basis of dissolution / leaching experiments of real product samples or suitable simulants.

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of Pu wasteforms in near-neutral and, to a lesser degree, alkaline groundwater on the basis of dissolution / leaching experiments of suitable simulants and mechanistic modelling.

Research Objective

To be developed on the basis of the outcome of task 617.

Scope

To be developed on the basis of the outcome of task 617.

Further information

Relevant publications include:


Conditioning of Plutonium Residues by Hot Isostatic Pressing and Options for Packaging and Disposal (pre-
Conceptual stage - Summary of Assessment, 2009.
This task may be carried out by RWM internal resources with support from the supply chain.
Further Studies on Hot Isostatic Pressed (HIPed) Products and Unirradiated MOX Fuel to Address Outstanding Uncertainties

Background

For wastes, and materials which may be declared as wastes, where disposal concept development is at its earlier stages, current and future work is aimed at developing our understanding of the available options to support future decisions. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. This type of work is co-ordinated with any work that may be planned in the NDA’s Direct Research Portfolio.

One such potential waste is plutonium (Pu) resulting from reprocessing, for which disposal concepts are not yet well defined. By the completion of reprocessing there will be approximately 140 tonnes of civil separated Pu in the UK. The NDA has concluded that reuse remains the preferred option and that there are three credible reuse options: - reuse as MOX in light water reactors, reuse in CANDU EC6 reactors and reuse in PRISM fast reactors. Nevertheless, not all of the Pu stocks may be suitable for reuse. It is therefore necessary to research potential wasteforms for these materials (Pu residues) which will provide long-term integrity and criticality safety. A number of potential immobilisation options are currently being considered, including cementation, vitrification, hot or cold pressing into ceramics or incorporation into mixed oxide (uranium(U) / Pu) fuel not intended for reactor use (e.g. 'low spec'); the last two options are recently receiving greater consideration. Past reviews on the expected dissolution/leaching behaviour of such wasteforms indicated that there is only a limited amount of information available from past experimental programmes and that further work is likely to be required to fully underpin the disposal of these materials.

RWM plans to carry out experimental studies on the leaching behaviour of candidate wasteforms once strategic decisions on the fate of plutonium are more mature. Initial (‘scoping’) studies will be aimed at developing an understanding of the typical leaching rates and identifying the key factors controlling leaching behaviour. These will be followed by ‘further’ studies aimed at proving additional understanding and at deriving underpinning data for use in safety assessments.

In preparing this task we are assuming that Pu residues (of the order of 10 tonnes) will require processing by Hot Isostatic Pressing (HIP) or incorporation into low specification fuel (not intended for irradiation in reactor). The remaining inventory for disposal will be irradiated (see ‘spent fuel’ section). This task will focus on HIPed products and / or low spec Pu-bearing fuel, the behaviour of which will be evaluated on the basis of dissolution / leaching experiments with suitable simulants (similar to SimFuel).

Research Need

To develop a mechanistic understanding of the evolution and dissolution behaviour (instant release and long-term dissolution rate) of Pu wasteforms in near-neutral and, to a lower degree, alkaline groundwater on the basis of dissolution / leaching experiments of suitable simulants and mechanistic modelling.

Research Objective

To be developed on the basis of the outcome of Tasks 618 and 619.

Scope

To be developed on the basis of the outcome of Tasks 618 and 619.

Further information

Relevant publications include:


Conditioning of Plutonium Residues by Hot Isostatic Pressing and Options for Packaging and Disposal (pre-
Conceptual stage) - Summary of Assessment, 2009.
This task will be carried out by our contractors and/or RWM internal resources.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Uranium Wasteforms</td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>Review of Uranium (U) Integrated Project Team (IPT) Output and Identification of Wasteform Research Needs</td>
<td></td>
</tr>
</tbody>
</table>

**Background**

For wastes whose disposal concept is at earlier stages of development, current and future work is aimed at developing understanding of the available options to support future decisions. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. This type of work is co-ordinated with that which may be planned in the Direct Research Portfolio.

This subtopic of the R&D programme covers potential uranium wasteforms, for which disposal concepts are not yet well defined. This work is mainly relevant to Depleted, Natural and Low Enriched Uranium (DNLEU) wasteforms (there is a large volume of DNLEU and uranium (U)-238 and uranium-235 have very long half-lives) and, to a lesser extent, to highly-enriched uranium (HEU). There is a good understanding of the long-term evolution of a range of uranium solids in the literature, obtained to support uranium mining and understanding of nuclear fuels.

We have recently set up an Integrated Project Team (IPT) to consider wider issues associated with the disposability of uranium (specifically DNLEU) and may commission work in this area depending on whether additional information needs are identified through the IPT. This task will focus on these arising research needs.

**Research Need**

To develop a mechanistic understanding of the evolution and dissolution behaviour of uranium wasteforms to support strategic decisions, the disposability assessment process, the development of disposal concepts for these wasteforms and the safety case.

**Research Objective**

To identify research needs to underpin the disposal of uranium (in particular DNLEU) on the basis of the output of the work of the UIPT.

**Scope**

To review documented outputs from the U IPT and to interview key personnel involved with the project.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**End point**

Further Work to be Defined

**Customer**

NDA Strategy, Assessment of Packaging Solutions, Concept Development, Disposal System Safety Case

**Further information**

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>636</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

### PBS level 4
Package Evolution

### PBS level 5
Graphite Wasteforms and Non-Encapsulated Wasteforms

**Title**
CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite

**Background**
For wastes such as graphite arising from the dismantling of the Magnox and Advanced Gas Reactor (AGR) fleets, where the disposal concept is at an early stage of development, current and future work is aimed at developing our understanding of the available options to support future decisions. More extensive work will be carried out in the future pending a strategic decision on the management of such materials. This type of work is co-ordinated with that which may be planned in the NDA’s Direct Research Portfolio.

If disposed of in a GDF, commercial reactor core graphite is likely to be packaged without encapsulation. This material is likely to be stable and unlikely to evolve in a way which affects the performance of a waste package. However, the release of carbon-14 from graphite is an important aspect of RWM’s R&D.

Relevant research is being carried out through a UK-coordinated EC project (CAST WP5, Task 5.4). In that task possible new processes for conditioning or decontaminating irradiated graphite are being studied.

**Research Need**
To understand possible options for processing graphite prior to disposal.

**Research Objective**
To apply knowledge from EU-funded Project CAST (Carbon-14 Source Term) on irradiated graphite in a UK context.

**Scope**
The scope is to review outputs from CAST WP5 Task 5.4 in a UK context.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Validation

**Customer**
Disposal System Safety Case

**Further information**
### Task Number

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>637</td>
<td>PBS level 4</td>
<td>Package Evolution</td>
</tr>
<tr>
<td></td>
<td>PBS level 5</td>
<td>Graphite Wasteforms and Non-Encapsulated Wasteforms</td>
</tr>
</tbody>
</table>

### Title

Review of CAST WP5 in UK context (C-14 Integrated Project Team (IPT))

### Background

For wastes such as graphite arising from the dismantling of the Magnox and Advanced Gas Reactor (AGR) fleets, where the disposal concept is at an early stage of development, current and future work is aimed at developing our understanding of the available options to support future decisions. Nevertheless, we are confident, based on work conducted in programmes such as the EC CARBOWASTE programme that the UK graphite inventory is disposable.

If disposed of in a GDF, commercial reactor core graphite is likely to be packaged without encapsulation. This material is likely to be stable and unlikely to evolve in a way which affects the performance of the waste packages. However, the release of carbon-14 from graphite is an important aspect of RWM’s R&D.

Relevant research is being carried out through a UK-coordinated EC project (CAST (Carbon-14 Source Term) WP5). The disposal behaviour of graphite will be evaluated in this task on the basis of the CAST WP5 experiments with irradiated samples and model development.

### Research Need

To develop a mechanistic understanding of the leaching behaviour of other graphite wasteforms to support strategic decisions, the disposability assessment process, the development of disposal concepts for these wasteforms and the safety case.

### Research Objective

To evaluate the output of the CAST EU project in the UK context.

### Scope

The scope comprises a desk-based review of the output of CAST and discussion in the context of the disposal of the UK graphite inventory and, in particular, the large quantities which will arise during dismantling of the Magnox and AGR reactor fleets.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
<th>End point</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
<td>Site Specific Validation</td>
<td>Disposal System Safety Case</td>
</tr>
</tbody>
</table>

### Further information

This will be used to support strategic decisions on the management of these wasteforms, the assessment of packing solutions, the safety case and the development of disposal concepts for these wasteforms.

Relevant publications include:


Background

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel (SF). However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure periods is generally well understood and underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in-situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including considerations of the potential coupling between chemical and mechanical effects.

Building on previous work (Sanderson et al. 2013), this task considers all candidate container designs identified so far (particularly corrosion-allowance designs), with the aim of evaluating their durability on the basis of models and information available in the technical literature.

Research Need

To develop a mechanistic understanding of the durability of HLW / spent fuel disposal containers in periods preceding and following closure of a GDF (e.g. dry interim storage, buffer underground ‘storage’ at a GDF, and reversible / retrievable disposal periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on HLW / spent fuel management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels) and the development of the safety case.

Research Objective

To further underpin evaluation of the suitability of previously considered candidate container materials and recently considered alternatives (cast iron) on the basis of additional information and taking into account potential coupling between chemical (i.e. corrosion) and mechanical effects. In particular:

- To determine whether the conclusions of previous studies evaluating the durability of candidate materials and the effect of detrimental (‘marginal’ and ‘critical’) factors on their durability are consistent with the latest information arising from international programmes.
- To demonstrate the applicability of available techniques to carry out a quantitative evaluation of the durability of a specific container design in a specific operational and disposal scenario (taking into account coupling between expected chemical and mechanical processes) and generalise the results of the analysis through sensitivity analysis.
- To consider the application of this type of analysis to a broader range of container designs and operational and disposal scenarios.
- To identify requirements on environmental control and buffer quality to ensure adequate performance of container materials during the operational and post-closure period.

Scope

The scope comprises the following:

- To update previous work reviewing the corrosion behaviour of copper and carbon steel, advantages and disadvantages of different materials, operational factors / mitigation strategies and ‘critical’ and ‘marginal’ conditions with new information.
- To review the corrosion behaviour of cast iron in relevant conditions (previously not considered in detail).
- To quantitatively apply Failure Assessment Diagrams to a Variant 2 (carbon steel) design and carry out a
- To qualitatively apply Failure Assessment Diagrams to a broad range of container designs and disposal scenarios, including copper and cast iron.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**  
Site Specific Validation  
**Customer**  
Disposal System Safety Case, Design

### Further information

SRLs for Corrosion Resistant Materials are lower - SRL Start (3), SRL End (3), SRL Target (4).

‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion.

Relevant publications include:

- D. Sanderson et al, 2013, The Use of Failure Assessment Diagrams to Evaluate the Durability of HLW and Spent Fuel Waste Containers, AMEC report 17697/TR/05 (available from RWM website)
- F. King et al., 2010, Review of the Corrosion Performance of Selected Metals as Canister Materials for UK Spent Fuel and/or HLW, Quintessa QRS-1384J-1 Version 2.1 (available from RWM website)

This task will be carried out by our contractors.

This task addresses both corrosion allowance and corrosion resistant materials and appears as two separate lines in the long term graphic (Appendix C).
Appendix B - 272

Title
Protoype Repository Project (Copper)

Background
The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel (SF). However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wastesforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure period is generally well understood and is underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including consideration of the potential coupling between chemical and mechanical effects.

Extensive R&D has been undertaken in Sweden on the development of copper disposal containers which, in the presence of a bentonite clay buffer at sufficient density, is anticipated to maintain its integrity for hundreds of thousands of years. This task will focus on such copper containers, the behaviour of which will be evaluated on the basis of a collaborative, multi-national, in situ, full-scale demonstration experiment at the Åspö Underground Research Laboratory (URL) in Sweden.

Research Need
To develop a mechanistic understanding of the durability of HLW / spent fuel containers in periods following closure of a GDF in a variety of relevant disposal scenarios.
This work will support the assessment of packaging solutions, the development of suitable disposal concepts for these wastes and the development of the safety case.

Research Objective
To determine whether the corrosion behaviour of oxygen-free copper in contact with bentonite in the Åspö facility is consistent with the expected behaviour. In particular, to determine whether:
- The amount of general corrosion observed on the material is consistent with the expected timing of resaturation, the amount of oxygen that was trapped in the near-field at the time of backfilling, and the quantity of sulphide present in the bentonite.
- Corrosion processes in this real environment lead to the formation of copper oxides and sulphides.
- Biofilm formation is inhibited at the container / buffer interface.
- A limited extent of localised corrosion is observed, consistent with current estimates.
- There is any evidence of corrosion mechanisms that may lead to a faster degradation.

Scope
Participation in a full-scale demonstration experiment investigating the durability of oxygen-free copper containers in contact with compacted bentonite, exposed to 'natural' resaturation at relevant temperatures (e.g. 90°C), for about a decade, in simulated early post-closure conditions, followed by retrieval. Specific measurements include:
- Experimental observation of the corrosion behaviour of the containers, including extraction of surface samples, microscopy and chemical characterisation of the bentonite in contact with the container surface and of any corrosion products formed on the extracted samples.
- Electrochemical polarisation measurements (i.e. linear polarisation resistance) on embedded copper coupons, as well as measurement of redox potential by embedded sensors.

SRL at task start 5 SRL at task end 5 Target SRL 5
End point Site Specific Validation
<table>
<thead>
<tr>
<th>Customer</th>
<th>Disposal System Safety Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Further information</td>
<td></td>
</tr>
</tbody>
</table>

‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. Relevant publications include:


Information is also available at www.sbk.se

This contract has been procured through a collaboration with SKB and other international partners.
Materials Corrosion Test (MaCoTe): In-situ Test

Background
The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel (SF). However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure period is generally well understood and is underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in-situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including consideration of the potential coupling between chemical and mechanical effects.

This task will focus on copper and carbon steel, the behaviour of which will be evaluated on the basis of a collaborative multi-national, in situ, small-scale demonstration experiment at Nagra’s Grimsel Test Site in Switzerland.

Research Need
- To develop a mechanistic understanding of the durability of HLW / spent fuel containers in periods following closure of a GDF in a variety of relevant disposal scenarios.
- To support the assessment of packaging solutions, the development of suitable disposal concepts for these wastes and the development of the safety case.'

Research Objective
To determine whether the corrosion behaviour of candidate container materials (carbon steel and copper) in contact with groundwater-saturated (chloride-containing) anoxic bentonite in an in-situ experiment planned at the Grimsel Underground Research Laboratory (URL) is consistent with the expected behaviour. In particular to determine:
- Whether any formation of microbial biofilm on container materials is inhibited if sufficiently compacted (i.e. dense) bentonite is used.
- The (general) corrosion rate of coupons, including whether the effect of microbial activity on container materials can be estimated on the basis of the concentration of any aggressive by-products (e.g. sulphide) produced ‘far’ from the container-buffer interface.
- Whether any localised corrosion is observed and, if so, whether this is consistent with current estimates (e.g. based on the previously evaluated ‘pitting factor’).

Scope
An in-situ experiment focusing on the exposure of coupons of candidate materials (carbon steel and copper) to groundwater-saturated (chloride-containing) anoxic bentonite at different levels of compaction. The experiment will specifically observe the effect of this parameter on the ability of naturally-occurring microbes to affect the behaviour of the engineered barrier system.

Further information
‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion.
This task is intended for collaborative funding under the Nagra ISCO programme.
Information is available at http://www.grimsel.com/
This task will be carried out by our contractors.
Appendix B - 276

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>649</td>
<td>Ongoing</td>
<td>Package Evolution</td>
<td>HLW / SF Corrosion Allowance Container Materials</td>
<td>EPSRC GEOWASTE: Development of Experimental Techniques to Study the Metal-Clay Interface</td>
</tr>
</tbody>
</table>

**Background**

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel (SF). However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure period is generally well understood and underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in-situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including consideration of the potential coupling between chemical and mechanical effects.

Building on previous work using synchrotron-based techniques to study the development of localised corrosion on stainless steel in atmospheric conditions (relevant to the storage and disposal of ILW), this task will pioneer the use of similar techniques to study the evolution of the carbon steel / bentonite interface, to test and develop methodologies that could be used in future studies.

**Research Need**

To support the post-closure safety case by developing a mechanistic understanding of the durability of HLW / SF containers in the post-closure phase in a variety of relevant disposal scenarios.

**Research Objective**

- To develop techniques that could be employed for future studies of the evolution of the waste container / buffer interface (in particular the carbon steel / bentonite and copper / bentonite systems).
- To evaluate the early stages of the evolution of the interface, thus providing a mechanistic understanding of the formation of corrosion products and alteration of the surrounding bentonite.

**Scope**

The scope comprises the x-ray tomographic analysis of carbon steel / bentonite samples’ exposure in-situ or ex-situ to controlled conditions to evaluate the extent and nature of alteration products.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**

‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion.

Relevant publications include:


This programme is currently being co-funded by the EPSRC under its Geowaste programme (University of Birmingham, University of Manchester and University of Bristol) under RWM’s initiative to support a portfolio of 'curiosity driven' research which complements our ‘needs driven’ programme.
### Task Number

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>651</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 4</td>
<td>HLW / SF Corrosion Allowance Container Materials</td>
<td></td>
</tr>
</tbody>
</table>

### Title

Participation in the FEBEX Experiment (Full Scale Engineering Barrier Demonstration Experiment (FEBEX) - Dismantling Project)

### Background

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel (SF). However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure period is generally well understood and is underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in-situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including consideration of the potential coupling between chemical and mechanical effects.

This task will focus on carbon steel, the behaviour of which will be evaluated on the basis of a collaborative multi-national, full-scale demonstration experiment at Nagra’s Grimsel Underground Research Laboratory (URL) in Switzerland. The Full Scale Engineered Barrier Experiment (FEBEX) experiment was commenced in 1997 (construction started in 1995) with the aim of studying and providing confidence in the evolution of a carbon steel / bentonite Engineered Barrier System (EBS). Following previous activities (FEBEX I, FEBEX II and NF-Pro), which included partial dismantling and analysis of the experiment, a final experiment (FEBEX) has been running, with final dismantling planned to commence in 2015. One of the aims of the final experiment, among others (e.g. thermal evolution, gas generation, etc.), is to evaluate the corrosion behaviour of the waste container (carbon steel) and corrosion coupons (made in a variety of materials). Following the planned termination of the experiment, the controlled recovery of the experimental system presents a unique opportunity for the study of the evolution of the disposal system over a period of almost 20 years.

### Research Need

To develop a mechanistic understanding of the durability of HLW / spent fuel containers in periods following closure of a GDF in a variety of relevant disposal scenarios.

This work will support the assessment of packaging solutions, the development of suitable disposal concepts for these wastes and the development of the safety case.

### Research Objective

To determine whether the corrosion behaviour of carbon steel (and other materials) in contact with clay (bentonite) in a real environment is consistent with the expected behaviour. In particular, to determine whether:

- The level of corrosion observed on the material is consistent with the expected timing of resaturation, the amount of oxygen that was trapped in the near field at the time of backfilling and the levels of corrosive species present in the bentonite.
- Corrosion leads to the formation of expected corrosion products (e.g. for carbon steel iron oxides, carbonates).
- Biofilm formation is inhibited at the container / buffer interface.
- A limited amount of localised corrosion is observed, consistent with current estimates.
- There is any evidence of corrosion mechanisms that may lead to a faster degradation of the containers.

### Scope

To undertake a controlled recovery of the FEBEX experimental components, including the full-scale carbon steel container, heating system and instrumentation which have been buffered by groundwater-saturated (chloride-containing), anoxic bentonite for almost 20 years. The scope of relevant tests will include:
- Characterisation of the thermo-mechanical evolution of the bentonite and of the nature of any phases present or developing.
- Chemical analysis of the porewater developed in the system.
- Analysis of corrosion rate and corrosion products developed on coupons of different materials present in the experiment.
Analysis of microbiological activity may also be included.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>5</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. This task is intended for collaborative funding under the Nagra ISCO programme. Information is available at http://www.grimsel.com/

This task will be carried out by our contractors. Note that our involvement in the FEBEX project is also captured by Tasks 461 and 464 in the Engineered Barrier System area.
Development of Component Models for HLW / SF containers

Background
The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel (SF). However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the corrosion performance of corrosion-allowance designs in environmental conditions relevant to the post-closure period is generally well understood and underpinned by a variety of laboratory studies and natural and man-made analogues. Specific outstanding uncertainties are being evaluated through focused experimental programmes and, where appropriate, through ongoing in situ or demonstration experiments. Building on previous work, current R&D is focusing on developing methodologies aimed at refining the treatment of container durability in the safety case, including considerations of the potential coupling between chemical and mechanical effects. This task considers the development of component models for the treatment of radionuclide containment in HLW / SF containers during the post-closure period of a GDF.

Research Need
To support the development of the post-closure safety case by refining the treatment of radionuclide release from waste containers.

Research Objective
To develop component models for the treatment of radionuclide containment in the engineered barrier system in periods following closure of a GDF for specific disposal concepts based on expected corrosion mechanisms.

Scope
The scope comprises the following:
- Based on previously developed information, evaluate degradation mechanisms of selected concepts for which component models could be meaningfully developed (covering a range of geologies) in a variety of thermal, chemical and mechanical conditions.
- If appropriate, develop parametric models yielding expected containment timescales, including uncertainty ranges.

Further information
‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion.

In our modelling hierarchy we define a component model as a collection of process models that use multidisciplinary information to calculate particular parameters that are used in the total system model. It sits in the middle of our modelling hierarchy (the Total System Model being the highest level); elements of both a top-down and bottom-up approach may be used in its development, some representation of uncertainty is usually required.

Previous publications include: Sanderson et al, AMEC 17697/TR/05, 2013.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>HLW / SF Corrosion Allowance Container Materials</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Studies of Container Durability During Prolonged Exposure to High Temperature Atmospheric Conditions

**Background**

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel (SF). However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Although most information produced in waste management programmes has been focused on materials behaviour during the post-closure period, there is also a good understanding of the corrosion performance of candidate container designs in conditions relevant to the periods that may precede closure of a GDF, including potentially long periods of exposure to atmospheric or oxic conditions (e.g. interim storage). A challenge which is relatively specific to the UK, however, is the development of containers (multi-purpose containers, MPCs) able to withstand high thermal outputs for long periods of surface / underground storage, which may affect the durability of container materials before and after closure of a GDF.

This task considers MPC designs based on the use of a carbon steel disposal over pack (recently developed by RWM), and aims at evaluating their durability on the basis of models and information available in the technical literature.

**Research Need**

To develop a mechanistic understanding of the durability of HLW / spent fuel disposal containers in periods preceding closure of a GDF (e.g. dry interim storage, buffer underground 'storage' at a GDF, and reversible / retrievable disposal periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on HLW / spent fuel management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels) and the development of the safety case.

**Research Objective**

To underpin the evaluation of the durability of HLW-SF containers in conditions of prolonged exposure to high-temperature atmospheric conditions. In particular:

- To develop an initial understanding of the deliquescence properties of aerosols and contaminants likely to be present in underground environments.

- To model the likely occurrence of surface wetting based on expected conditions of power output, air relative humidity and surface contaminants.

- To evaluate the corrosion behaviour (both aqueous corrosion and dry oxidation) of candidate materials in the environmental conditions and timescales of interest.

- To consider the potential coupling between mechanical and corrosion effects in representative scenarios, including effects associated with internal pressurisation, hydrogen embrittlement and stress corrosion.

**Scope**

The scope comprises the following:

- To gather additional information on the likely contaminants present in underground excavations based on existing information and field measurements.

- To refine models of the deliquescence behaviour of contaminants being developed to evaluate the durability of container materials for ILW during prolonged operational periods, considering the conditions of temperature and relative humidity present in this case.

- To evaluate expected corrosion mechanisms and relative rates for candidate materials.

- To carry out a coupled chemical-mechanical analysis in specific scenarios using methodologies previously developed (i.e. Failure Assessment Diagrams).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion.

Relevant publications include:

This task will be carried out by our contractors.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>HLW / SF Corrosion Allowance Container Materials</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Further Studies of Internal Corrosion / Pressurisation, Including Considerations of Accident Scenarios

**Background**

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Previous studies indicate a very limited extent of structural damage, but some potential for hydrogen pressurisation, in scenarios of storage and disposal of waterlogged AGR fuel elements. Based on previous studies, this work will consider the potential for internal corrosion and pressurisation in a variety of storage and disposal systems, including packages featuring different designs (particularly multi-purpose containers, MPCs), different wasteforms (e.g. fuels generating higher amounts of heat), and disposal scenarios (including packaging dates and assumed water content of the wasteform). Considerations will be extended to the case of fire accidents.

**Research Need**

To develop an understanding of the potential for significant internal corrosion and pressurisation of a variety of spent fuels and container designs to storage and disposal scenarios.

This work will underpin the safety case, the disposability assessment process, upstream waste management strategies and the development of suitable disposal concepts for spent fuels.

**Research Objective**

To determine:
- Whether the amount of water carried over in spent fuel containers could result in internal corrosion of structural elements (steel / cast iron) to an extent which affects their ability to provide structural strength (i.e. providing containment) and maintaining the designed configuration (criticality safety), if no action (draining /drying) was undertaken.
- The dryness level required to ensure that fuel will produce insufficient internal pressurisation to require the container to be treated as a pressurised vessel and whether this is compatible with the levels that can be achieved with deployable drying technologies and/or waste management strategies (e.g. selective loading of fuel into waste containers to ensure spreading of water-logged fuel).
- Whether the expected levels of pressurisation in the case of water-logged fuel could be reduced through engineering design of the waste container (e.g. by controlling thermal conductivity and free volume).
- The expected level of pressurisation from other sources, particularly helium.

**Scope**

Based on previous studies on AGR fuel, through a combination of new calculations, additional sensitivity analysis and qualitative considerations, this study should form a view of the potential for internal corrosion and pressurisation of a disposal container for a variety of other types of spent fuel, container designs (e.g. MPCs) and storage/disposal scenarios. The scope comprises the following:
- Consideration of the effect of other spent fuels (e.g. PWR and new build fuel), including anticipated higher power output.
- Consideration of the effect of a variety of relevant container designs, including previously considered designs (e.g. the Variant 1 as bounding case) as well as designs not previously considered (e.g. MPC-12), considering differences in heat density, efficiency of heat dissipation, and internal volume.
- Consideration of the likely effect of a variety of relevant packaging, storage and disposal scenarios, including scenarios of good or incomplete dryness, timing of packing and disposal, and thermal properties associated with boundary conditions (e.g. thermal conductivity of buffer materials and host rock after disposal).
- Specific consideration of the expected level of pressurisation in a fire accident scenario of both dry and waterlogged fuel, including consideration of any expected contribution from fissile gases/helium and on the
release of volatile radionuclides in the container.

<table>
<thead>
<tr>
<th>Customer</th>
<th>Disposal System Safety Case</th>
</tr>
</thead>
</table>

Further information

‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion.

Completed deliverables include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>HLW / SF Corrosion Allowance Container Materials</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Collaboration on the Feasibility and Quality of Manufacture of Copper Electrodeposition on Steels

**Background**
The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the manufacture of corrosion-allowance designs envisaging the use of single shell carbon steel containers or dual shell copper/cast iron containers is feasible, as demonstrated by large scale prototypes developed in a variety of national programmes (e.g. in Sweden and Switzerland). Recent developments in Canada, however, indicate that manufacture of copper-based containers may be simplified by developing single-shell designs (carbon steel) with a relatively thin layer (few mm) of electrodeposited or cold-sprayed copper.

In collaboration with NWMO (the Canadian waste management organisation), this task will explore the feasibility of manufacturing small-scale, copper-plated steel samples with an electrodeposition process. The quality of the deposited layer, including its chemical and mechanical characteristics, will be established.

**Research Need**
To support concept development by underpinning the feasibility of manufacture of HLW / spent fuel containers and the quality of the resulting designs.

**Research Objective**
To determine the feasibility of manufacture of small-scale samples of steels electrodeposited with thin layers of copper, as well as the quality of the resulting material.

**Scope**
The scope of work will include:
- Manufacture of tens of copper-electrodeposited samples up to a few mm in thickness.
- Mechanical and chemical characterisation of the deposited copper layer, including visual inspection, micro-hardness, elemental analysis, ductility and adhesion.

**SRL at task start** | **SRL at task end** | **Target SRL** | **TRL 4**
---|---|---|---
TRL 2 | TRL 4 | Target SRL | TRL 4

**End point**
Further Technical Development Required

**Customer**
Concept Development, Design

**Further information**
‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. Relevant publications include:


This work will be carried out in collaboration with the Canadian waste management organisation (NWMO).
Considerations on the Feasibility and Quality of Manufacture of Containers for HLW and Spent Fuel

Background

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel. However, significant work has been carried out in other countries, particularly for materials that would form the basis of a corrosion-allowance concept (copper, carbon steel and, to a lesser degree, cast iron). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK and on taking part in demonstration experiments ongoing internationally.

Existing information indicates that the manufacture of corrosion-allowance container designs based on the use of carbon steel or copper is feasible, as demonstrated by large scale prototypes developed in a variety of national programmes (e.g. in Sweden and Switzerland). Information produced in the past in other programmes (e.g. in the USA), indicates that it may be also feasible to manufacture containers with corrosion-resistant materials (e.g. titanium, stainless steel or nickel alloys), although less work is available to evaluate the feasibility and resulting quality of this type of operations.

Based on existing information (desk-based study), this task will explore the feasibility of manufacturing and the anticipated quality of a variety of container designs, including designs based on the use of corrosion-resistant materials. Information will include available manufacturing techniques, their maturity, anticipated characteristics (e.g. nature, size and frequency of expected defects) and consideration of costs.

Research Need

To support concept development by underpinning the feasibility of manufacture of HLW / spent fuel containers and the quality of the resulting designs.

Research Objective

Based on existing information, to evaluate the feasibility of manufacture and anticipated quality of a variety of container designs, including those based on the use of corrosion-resistant materials.

Scope

The work will present a desk-based study considering all candidate HLW/spent fuel container materials (copper, carbon steel, cast iron, titanium, stainless steel and nickel alloys). The information presented will consider specific design and manufacturing studies previously carried out in the radioactive waste industry, as well as experiences in the manufacture of similar components in other industries. The scope will include:

- A description of the type of designs considered so far for HLW and spent fuel containers (e.g. single shell, dual shell) and of the type of materials considered in different designs.
- A review of manufacturing techniques for the manufacture of large scale, critical components in the materials of interest, including techniques considered in the radioactive waste industry and elsewhere.
- Consideration of the anticipated wall thickness of relevant components, including thick-walled components (e.g. any mechanical inserts for dual shell containers) and thin-walled components (e.g. the external corrosion barrier in dual shell designs).
- Consideration of the manufacturing of components in a non-radioactive environment and final welding in the presence of a radioactive wasteform.
- Consideration of the anticipated quality achieved with different types of design and manufacturing techniques, including nature, frequency and typical size of expected defects and resulting inspection regimes.
- High level consideration of the cost of different options, to inform a comparative analysis.

Further information

‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under
chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. Relevant publications include:
This work will be carried out by our contractors.
Further Experimental Studies on the Corrosion Behaviour of Corrosion Resistant Materials

Background

The UK does not have a long history of research into the evolution of candidate container designs for HLW and spent fuel. However, work relevant to corrosion-resistant designs (based on titanium, stainless steel and nickel alloys) has been carried out in other countries (Canada, Japan and the USA). Current work in the UK focuses on gathering the available information to inform studies that consider wasteforms, waste management and disposal scenarios relevant to the UK. Particular focus is placed on the post-closure behaviour of candidate materials, to evaluate whether the required durability can be obtained.

Existing information indicates that the corrosion performance of corrosion-resistant designs in environmental conditions relevant to the post-closure period of an anoxic disposal facility is only partly understood, mainly based on laboratory work and relatively short-term experience with the use of candidate materials in relevant contexts. Conditions and alloy grades in which specific forms of corrosion (e.g. localised corrosion) do not occur are generally understood. Uncertainty, however, exists regarding the potential kinetics of damage propagation in corrosive conditions (including any ‘stifling’ effects intrinsic to the material, associated with the resistivity of buffer materials and / or generated by changes in temperature and redox conditions), as well as the potential long-term effects of additional, slow degradation mechanisms (i.e. oxide film growth and spalling). Building on previous work (Task 666), this task focuses on a more detailed evaluation of specific uncertainties associated with the crevice corrosion of a titanium alloy (grade-2), a material likely to offer a high resistance to most forms of corrosion, including microbiological mechanisms.

Research Need

To develop a mechanistic understanding of the durability of alternative HLW / spent fuel container materials in support of the development of suitable disposal concepts.

Research Objective

To underpin the suitability of specific grades of titanium alloys and/or other corrosion-resistant grades / materials to provide corrosion protection in representative disposal conditions. In particular, to evaluate whether:

- Any localised corrosion induced by exposure to high temperature, oxic, chloride-rich environments tends to progressively cease naturally with time even at constant levels of oxygen.
- Any localised corrosion induced by exposure to high temperature, oxic, chloride-rich environments tends to progressively cease with time as the environment gradually becomes anoxic.
- The extent of localised corrosion in either or both situation is limited, suggesting that penetration of thin walled components may be unlikely.
- Mechanistic arguments explaining the observed behaviour can be substantiated with further experimental work and modelling development.
- Corrosion is not induced in conditions simulating microbiological colonisation.

Scope

The scope comprises an extensive programme of corrosion experiments of grade-2 titanium alloys (or other grades) in high temperature, chloride-rich environments with either constant or variable levels of oxygenation, including electrochemical measurements and ex-situ characterisation, as well as scoping tests to confirm the resistance of specific materials / grades to microbiological effects.

Relevant publications include:


This task has been procured through our contractors with input from academic partners.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>ILW Corrosion Allowance Container Materials</td>
</tr>
</tbody>
</table>

**Title**
Review of the Durability of Paint Systems in Atmospheric Conditions

**Background**
Previously, Nirex carried out a limited amount of research relating to the use of carbon steel to dispose of ILW in anoxic, alkaline environments. Research evaluating the use of this and other relevant materials (e.g. cast iron) for the management and disposal of ILW or other radioactive wastes (e.g. HLW and spent fuel) has also been carried out internationally.

RWM places a significant emphasis on evaluating the durability of container materials during periods of atmospheric exposure likely to precede the closure of a disposal facility, to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Building on a recently completed desk-based study evaluating the long-term general corrosion rates of cast iron based on the technical literature (including measurements carried out in humid underground environments), this task will develop an understanding of the long-term behaviour of relevant paint systems, expected to be an important control on the durability of the waste containers.

**Research Need**
To develop a mechanistic understanding of the durability of ILW corrosion-allowance (carbon steel, cast iron) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible / retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF, and the development of the safety case.

**Research Objective**
To determine the expected behaviour of relevant paint systems in humid, indoor conditions based on information existing in the literature, and identification of any further testing required to understand their long-term performance.

**Scope**
The scope comprises a desk-based review of the durability of relevant paint systems, key environmental controls affecting their performance, their expected impact in conditions relevant to interim storage and disposal.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
</table>

**End point**
No Further R&D Required

**Customer**
Disposal System Safety Case, Assessment of Packaging Solutions

**Further information**
Relevant publications include:

This task will be procured through our contractors with input from academic partners.
### Title

Studies of Internal Pressurisation and Hydrogen Embrittlement on Carbon Steel / Cast Iron Containers

### Background

Previously, Nirex carried out a limited amount of research relating to the use of carbon steel to dispose of ILW in anoxic, alkaline environments. Research evaluating the use of this and other relevant materials (e.g. cast iron) for the management and disposal of ILW or other radioactive wastes (e.g. HLW and spent fuel) has also been carried out internationally.

RWM places a significant emphasis on evaluating the durability of container materials during periods of atmospheric exposure so as to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (and including a long GDF operational period and possible reversible / retrievable periods) and the design of suitable storage and disposal facilities. Building on the approach employed in similar studies for HLW / spent fuel containers, this task focuses on the potential for corrosion processes to induce a significant degradation of the structural performance of carbon steel and cast iron waste containers (such as ductile cast iron containers (DCICs)), including effects associated with hydrogen embrittlement.

### Research Need

To support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts (in particular, concepts envisaging long underground periods in un-backfilled tunnels), GDF design, and the development of the post-closure safety case by gaining a mechanistic understanding of the durability of ILW corrosion-allowance (carbon steel, cast iron) containers in periods preceding closure of the GDF.

### Research Objective

- To evaluate the expected extent of general corrosion on the basis of realistic assumptions of the amount and distribution of water in the system, the effectiveness of environmental control in interim stores and a GDF, and expected post-closure conditions.

- To evaluate whether localised corrosion, stress corrosion cracking and / or microbially-influenced corrosion can be expected on the inside or on the outside of the waste container.

- To evaluate the extent of internal pressurisation likely to be associated with hydrogen generation inside and outside the container and any resulting embrittlement of the waste container.

- To evaluate the impact of the expected level of embrittlement on the ability of the container to withstand expected loads during periods preceding and following closure.

- To evaluate the overall durability of the container in relevant scenarios.'

### Scope

The scope comprises a desk-based study to determine the degree of internal corrosion, pressurisation and hydrogen embrittlement of carbon steel / cast iron ILW container designs during periods preceding and following closure of a GDF. It includes the calculation of the likely amount of general corrosion and discussion of the potential for localised corrosion, stress corrosion and microbial corrosion on the basis of existing information. It also includes an assessment of the expected pressurisation and associated hydrogen embrittlement, the effect of hydrogen embrittlement on the fracture toughness in relevant loading conditions and the durability of waste containers based on assumed system evolution, including sensitivity analysis.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further R&amp;D Required</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Appendix B - 290**
Title
Testing and Refinement of the ACSIS (Atmospheric Corrosion of Stainless Steel in Stores) Model, Including Extension to Carbon Steel and Cast Iron Components

Background
Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex, but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term. This task focuses on the refinement of a parametric model (developed in Task 698) to evaluate the durability of stainless steel ILW containers based on information produced in Tasks 680 and 681.

Research Need
To support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts (in particular, concepts envisaging long underground periods in un-backfilled tunnels), GDF design, and the development of the post-closure safety case by gaining a mechanistic understanding of the durability of ILW containers in periods preceding closure of a GDF.

Research Objective
To refine a previously developed parametric model (Task 698) to evaluate the likely durability of both stainless steel and (painted) carbon steel / cast iron components in conditions of temperature, relative humidity and surface contamination expected in interim stores and during the operational period of a GDF. In particular, based on existing data and on data produced by Tasks 680 and 681, to:
- Refine the evaluation of the frequency and duration of wetting events based on the deliquescent properties of salt mixtures found in real ILW stores.
- Evaluate the likelihood of initiation of corrosion based on defined criteria for both stainless steel (e.g. critical temperature) and painted carbon steel / cast iron (e.g. incubation periods for water absorption under paint).
- Improve the quantification of the damage likely to be developed in single ‘corrosive’ events, based on their duration and assumed kinetics.
- Improve the quantification of the damage likely to be developed in multiple ‘corrosive’ events, based on assumed probabilities of re-initiation at the same site.

Scope
The scope comprises the further development of a parametric model that includes:
- A refinement of the ‘environmental’ module, able to identify the occurrence of surface-wetting based on the deliquescent properties of specific salt mixtures that may be present in the environment.
- A refinement of the ‘corrosion initiation’ module, introducing aspects relevant to the initiation of corrosion for painted carbon steel and cast iron components.
- A refinement of the ‘corrosion propagation’ module, refining the treatment of stress-corrosion cracking propagation in stainless steel based on refined kinetic information and introducing aspects relevant to the initiation of corrosion for painted carbon steel and cast iron components.
<table>
<thead>
<tr>
<th>Further information</th>
</tr>
</thead>
</table>
| ‘Corrosion allowance’ is a term used to denote waste container materials that corrode actively under chemical conditions relevant to the post-closure phase of a geological disposal facility. Containers constructed from such materials are designed with suitably thick walls to take account of this corrosion. Relevant work has been carried out for carbon steel spent fuel containers, specifically:  
Corrosion Studies of Carbon Steel / Cast Iron in Cyclic Conditions and Salt Mixtures

Background

Previously, Nirex carried out a limited amount of research relating to the use of carbon steel to dispose of ILW in anoxic, alkaline environments. Research evaluating the use of this and other relevant materials (e.g. cast iron) for the management and disposal of ILW or other radioactive wastes (e.g. HLW and spent fuel) has also been carried out internationally.

RWM places a significant emphasis on evaluating the durability of container materials during periods of atmospheric exposure likely to precede the closure of a disposal facility, to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Building on previous reviews of the atmospheric corrosion of cast iron, of the durability of paint systems and work carried out on stainless steel (Atmospheric Corrosion of Stainless Steel in Interim Stores, ACSIS), this task will carrying out a targeted experimental programme on both painted and bare samples of carbon steel and cast iron to provide data needed to extend ACSIS to carbon steel and cast iron containers.

Research Need

To develop a mechanistic understanding of the durability of ILW corrosion-allowance (carbon steel, cast iron) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible / retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

Research Objective

To evaluate whether, on the basis of existing mechanistic understanding and any new data generated in this task, predictive models of degradation of ILW containers manufactured in painted carbon steel or cast iron can be developed. In particular, to determine:

- Whether relevant paint systems are likely to suffer environmental degradation in static conditions of temperature, relative humidity and surface contamination expected in interim stores and during the operational period of a GDF.
- The typical timescales of water transport and subsequent corrosion of the substrate, including the effect of cyclic conditions of temperature and relative humidity and increases in the deposition of surface contaminants, on them.
- The corrosion rate of the substrate under painted areas which have been accessed by moisture, the nature of corrosion products formed and their effect on the kinetics of paint spalling.
- The corrosion rate of the substrate in conditions of paint spalling.

Scope

The scope comprises the following:

- Experimental studies of water absorption and resulting paint degradation in selected conditions of surface contamination and in constant / cyclic conditions of temperature and relative humidity.
- Experimental studies of carbon steel / cast iron corrosion in selected conditions of surface contamination and in constant / cyclic conditions of temperature and relative humidity with, and without paint systems.

Further information

Relevant publications include:
This task will be procured through our contractors with input from academic partners.
Background

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Work carried out by Nirex investigating the corrosion behaviour of stainless steel in conditions simulating disposal of ILW in a cement-based near field indicated that corrosion can only occur if groundwaters containing sufficiently high levels of chloride were to come into contact with waste containers whilst relatively high temperatures (from curing of the backfill) and relatively high redox conditions (e.g. due to any unreacted oxygen) are still present in the near-field. Limited tests on the potential effect of thiosulphate (a known corrosive agent that may be produced in a GDF by microbial activity or by the oxidation of pyrite minerals) were also carried out.

Building on work carried out by Nirex, this task comprises the development of a parametric model able to estimate the likely release of radionuclides from initially vented / sealed stainless steel, carbon steel and cast iron containers following their eventual post-closure degradation. To date, the post-closure safety case takes no credit for the presence of the waste container.

Research Need

To develop an understanding of the ability of ILW containers to retain radionuclides in periods following closure of a GDF.

This work will support the development of the safety case.

Research Objective

To develop a parametric model able to evaluate the evolution of ILW containers in the post-closure period and the subsequent rate of radionuclide release from both stainless steel and carbon steel / cast iron containers (vented or sealed) in relevant hydrogeochemical conditions in order to:

- Underpin any contribution of the waste package in achieving containment of radionuclides.
- Understand to what extent the development of corrosion may impact on the rate of radionuclide release.

Scope

The scope comprises the development of parametric models of the flow of radionuclides from both intact (vented) and corroded ILW containers in assumed geochemical and hydrogeological conditions and considering an assumed size distribution and surface density of corroded areas (i.e. pits), including sensitivity analysis.

Further information

Relevant publications include:

A.V. Chambers et al, 2008, Data for a Representation of Physical Containment in a Repository-scale Model, SA / ENV-0658.

This task will be procured through our contractors.
Task Number  685  Status  Start date in future
PBS level 4  Package Evolution
PBS level 5  ILW Corrosion Allowance Container Materials

Title
Monitoring and Demonstration of Carbon Steel and Cast Iron Components in Atmospheric Conditions

Background
Previously, Nirex carried out a limited amount of research relating to the use of carbon steel to dispose of ILW in anoxic, alkaline environments. Research evaluating the use of carbon steel and other relevant materials (e.g. cast iron) for the management and disposal of ILW or other radioactive wastes (e.g. HLW and spent fuel) has also been carried out internationally. RWM places a significant emphasis on evaluating the durability of container materials during periods of atmospheric exposure likely to precede closure of a disposal facility, to underpin interim storage and disposal strategies that envisage long periods of atmospheric exposure and the design of storage and disposal facilities. A recently completed desk-based study evaluated the long-term general corrosion rates of carbon steel and cast iron, based on the technical literature. This task will focus on the monitoring / demonstration of the corrosion behaviour of such materials in conditions relevant to interim storage and disposal facilities.

Research Need
To develop a mechanistic understanding of the durability of ILW corrosion-allowance (carbon steel, cast iron) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible / retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

Research Objective
To determine:
- Typical environmental conditions (e.g. temperature and relative humidity fluctuations, type and nature of contaminants) relevant to interim stores and the operational period of a GDF.
- Whether practical experience with the use of painted carbon steel / cast iron under prolonged exposure to expected atmospheric conditions indicates levels of paint spalling, general corrosion and surface roughening consistent with predictions based on existing knowledge.
- Whether previously developed parametric models (ACSIS) are able to reproduce the behaviour observed in real conditions.

Scope
The scope comprises observation of corrosion damage developed in relevant circumstances (e.g. in existing underground facilities), as well as the setting up of monitoring programmes for painted carbon steel and cast iron containers in conditions relevant to interim storage and the GDF operational period, including monitoring of environmental conditions and resulting corrosion damage.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

End point  No Further Research Required.

Customer  Disposal System Safety Case, Assessment of Packaging Solutions, Disposal System Specification

Further information
Previous publications include:
Experimental Studies on Stainless Steel in Cyclic Conditions and with Salt Mixtures

Background

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term.

This task focuses on the potential for stress corrosion cracking (SCC) of stainless steel in conditions relevant to interim storage facilities.

Research Need

To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible / retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

Research Objective

To determine whether:
- Cycling of relative humidity in controlled exposure tests has an impact on the initiation of stress corrosion cracking (i.e. incubation time) such that typical variations expected in the natural environment are likely to accelerate or inhibit initiation.
- Controlled tests in salt mixtures representative of contamination in relevant facilities, as opposed to pure chloride salts, affect the likelihood of stress corrosion cracking (by either inhibiting chloride-induced corrosion and / or by affecting the deliquescence properties of contaminated surfaces).
- Parametric models aimed at evaluating the development of corrosion indicate that the development of pitting and stress corrosion is unlikely to lead to substantial damage in the long-term.

Scope

The scope comprises the following:
- A survey of environmental conditions in typical ILW stores across the UK.
- Experimental studies of SCC in realistic atmospheric conditions in the presence of relative humidity cycles (relatively aggressive conditions of temperature and chloride contamination).
- Experimental studies of SCC in atmospheric conditions in the presence of mixed salts of composition relevant to that found in typical ILW stores.
- Development of parametric models of the wetting behaviour of stainless steel surfaces in relevant environmental conditions and of the likely initiation and propagation of corrosion.
<table>
<thead>
<tr>
<th>Further information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous publications include:</td>
</tr>
</tbody>
</table>
### Background

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term.

This task focuses on the initiation of pitting corrosion and stress corrosion cracking of stainless steel in conditions relevant to interim storage facilities.

### Research Need

To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible / retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

### Research Objective

To determine whether sufficient mechanistic understanding of pitting and stress corrosion cracking of relevant stainless steel grades (austenitic grades 304 / 316 and duplex 2101 / 2205) is available, or can be developed, to support the development of mechanistic and parametric models that can be used to evaluate the likely evolution of damage over relatively long timescales (many decades).

### Scope

The scope comprises the following:

- Experimental studies including in situ, real time techniques, able to elucidate / confirm propagation mechanisms and identify kinetic parameters (including the presence of mixed salts).
- Experimental studies to evaluate outstanding uncertainties on re-initiation (i.e. cumulative vs. non-cumulative damage).
- Experimental studies to support identification of corrosive / non-corrosive conditions in the presence of mixed salts.

### End point

Long-Term Experiment

### Customer


### Further information

Relevant publications include:


A.B. Cook, et al, Under-deposit Chloride-induced Stress Corrosion Cracking in Austenitic Stainless Steels:
Aspects Associated with Deposit Type, Size and Composition, ECS Transactions 58 (accepted).
This programme is currently being co-funded by the EPSRC under its Geowaste programme (University of Birmingham, Manchester University and University of Bristol) under RWM's initiative to support a portfolio of 'curiosity driven' research which complements our 'needs driven' programme.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>ILW Corrosion Resistance Container Materials</td>
</tr>
</tbody>
</table>

**Title**

Development of Parametric Model: Atmospheric Corrosion of Stainless Steel in Stores (ACSIS)

**Background**

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long term. This task focuses on the development of a parametric model to evaluate the durability of stainless steel ILW containers during prolonged periods of atmospheric exposure (in an interim store and/or during the operational period of a GDF).

**Research Need**

To support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts (in particular, concepts envisaging long underground periods in un-backfilled tunnels), GDF design, and the development of the post-closure safety case by gaining a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods preceding closure of a GDF.

**Research Objective**

To develop a parametric model to evaluate the likely durability of stainless steel components in conditions of temperature, relative humidity and surface contamination expected in interim stores and during the operational period of a GDF. In particular, based on existing data and on data produced by tasks 696 and 697, to:

- Evaluate the typical frequency and duration of wetting events in specified conditions of temperature (T) and relative humidity (RH) on the basis of the deliquescent properties of contaminants expected to be present in specific facilities.
- Evaluate the likelihood of initiation of pitting corrosion and stress corrosion cracking based on defined criteria (T, RH, chloride contamination and, for stress corrosion cracking, any incubation time).
- Quantify the damage likely to be developed in single ‘corrosive’ events based on their duration and assumed kinetics.
- Quantify the damage likely to be developed in multiple ‘corrosive’ events based on assumed probabilities of re-initiation at the same site.

**Scope**

The scope comprises the development of a parametric model that includes:

- An ‘environmental’ module, able to identify the occurrence of surface wetting conditions based on the assumed deliquescent properties of the surface (dependent on the nature of surface contaminants) and on user-specified input parameters (T / RH).
- A ‘corrosion initiation’ module, able to identify ‘corrosive’ conditions based on specific environmental criteria and, in the case of SCC, specific initiation kinetics (e.g. an incubation period).
- A ‘corrosion propagation’ module, able to estimate the amount of damage likely to be generated by the occurrence of repeated ‘corrosive’ periods based on the duration of such periods, assumed kinetics of propagation and assumed probability of re-initiation at previously corroded sites.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>End point</td>
<td>Long-Term Experiment</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------</td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Disposal System Specification</td>
<td></td>
</tr>
<tr>
<td>Further information</td>
<td>'Corrosion resistance' is a term used to denote waste container materials which, in chemical conditions relevant to geological disposal, corrode at a rate that does not require them to be designed with a corrosion allowance (thin walled design). Relevant publications include: F. King et al, 2013, ACSIS - A Model to Assess the Potential for Atmospheric Corrosion of Stainless Steel ILW Containers During Interim Storage and the Operational Phase of a UK Geological Disposal Facility, Proc. 2013 NACE Corrosion Conf., 2013, Paper 2717. This task is being procured through our contractors with input from academic partners.</td>
<td></td>
</tr>
</tbody>
</table>
Studies of Stress Corrosion Cracking Propagation in Stainless Steel

**Background**

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term. This task will follow on from Task 697 to investigate the kinetics of stress corrosion cracking in both austenitic stainless steel grades (304/316) and duplex grades in conditions relevant to interim storage facilities.

**Research Need**

To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible / retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

**Research Objective**

To determine:

- The kinetics of development of stress corrosion in static conditions, at levels of temperature, relative humidity and surface contamination relevant to interim stores and the GDF operational period.
- The effect of cycling of environmental conditions on the overall kinetics of propagation.

**Scope**

To be developed depending on outcome of existing projects, but likely to include further work on residual stresses and SCC propagation rates.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

Long-Term Experiment

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Disposal System Specification

**Further information**

This task will be procured through our contractors with input from academic partners. Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>ILW Corrosion Resistance Container Materials</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Monitoring and Demonstration Studies of Stainless Steel Components in Atmospheric Conditions

**Background**

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Current research on the durability of stainless steel during prolonged atmospheric exposure is aimed at evaluating remaining uncertainties (mainly associated with the effect of cyclic conditions of temperature and relative humidity and of specific contaminants expected in indoor environments) and at developing mechanistic and parametric models able to evaluate the likely extent of corrosion in the long-term. This task focuses on the monitoring/demonstration of the corrosion behaviour of both austenitic stainless steel grades (304 / 316) and relevant duplex grades (e.g. 2101 / 2205) in conditions relevant to interim storage facilities for which relevant data can be obtained.

**Research Need**

To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible/retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

**Research Objective**

To determine:
- Typical environmental conditions (e.g. temperature and relative humidity fluctuations, type and nature of contaminants) present in interim stores and anticipated in the operational period of a GDF.
- Whether practical experience with the use of stainless steel under prolonged atmospheric exposure in relevant conditions indicates evidence of deep pits and stress corrosion cracks.
- Whether any signs of corrosion, as observed by routine waste package monitoring, can be correlated with environmental conditions expected to yield pitting and stress corrosion on the basis of laboratory experiments and models.
- Whether previously developed parametric models (ACSIS) are able to reproduce the behaviour observed in real conditions.

**Scope**

The scope comprises a continuation of data collection on environmental conditions and the level of corrosion found on relevant materials, in indoor (inland) locations previously used, in more aggressive (i.e. coastal) locations and/or in underground environments.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

Long-Term Experiment

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Disposal System Specification

**Further information**

Demonstration experiments relevant to the evolution of stainless steel containers in contact with an oxic/anoxic cement wasteform/near-field have not been carried out. A substantial body of knowledge, however, is available from laboratory-based experiments. Relevant studies include N.R. Smart et al.
Results of a long-term monitoring programme on the evolution of cement-based wasteform simulants in contact with stainless steel small-scale and full-scale containers are also available from Magnox (reported on a regular basis by P. Fennell et al.).
Studies of Stainless Steel Corrosion in Cement in the Presence of Radiation and Thiosulphate

Background

Previously, Nirex carried out extensive research relating to the use of stainless steel to dispose of ILW in anoxic, alkaline environments. There has also been significant effort evaluating the likely behaviour of stainless steel during any phase preceding disposal and the potential for the wastes and wasteforms to affect the durability of the container materials. R&D carried out by RWM has built on the understanding developed by Nirex but considers in more detail the durability of waste containers during a long period preceding closure of a disposal facility to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Work carried out by Nirex investigating the corrosion behaviour of stainless steel in conditions simulating disposal of ILW in a cement-based near-field indicated that corrosion can only occur if groundwaters containing sufficiently high levels of chloride were to come into contact with waste containers whilst relatively high temperatures (from curing of the backfill) and relatively high redox conditions (e.g. due to any unreacted oxygen) are still present in the near field. Limited tests on the potential effect of thiosulphate (a known corrosive agent that may be produced in a GDF by microbial activity or by the oxidation of pyrite minerals) were also carried out.

Building on work carried out by Nirex, this experimental and modelling task considers outstanding uncertainties associated with the effects on stainless steel of radiation and specific chemical species (thiosulphate) that may be present in the disposal environment.

Research Need

To develop a mechanistic understanding of the durability of ILW corrosion-resistant (stainless steel) containers in periods following closure of a GDF.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels) and safety case development.

Research Objective

To evaluate outstanding uncertainties relative to the corrosion behaviour of stainless steel in contact with a cement backfill. In particular:

- To identify the effect of ionising radiation (if any) on the likelihood of localised corrosion (due to an increase in redox potential) in a cement backfill at the dose rates expected in thin-walled ILW waste containers and, if any effect is observed, to identify any dose rates at which corrosion is not observed.

- To test whether the high alkalinity of cement backfills is able to inhibit the potential for localised corrosion (and SCC) in mixtures of chloride and thiosulphate previously observed to induce corrosion (up to pH 11).

- To evaluate whether the typical resistivity of cement backfills is likely to stifle localised corrosion, resulting in limited depth of propagation.

Scope

The scope comprises the following:

- Experimental studies on the effect of ionising radiation on the corrosion potential and overall susceptibility to localised corrosion at high pH and at relevant dose rates.

- Experimental studies of localised corrosion initiation and propagation in the presence of chloride / thiosulphate at high pH.

- Development of models of localised corrosion propagation in cement considering kinetic parameters relevant to cement systems (i.e. resistivity).
Relevant publications include:


This task will be procured through our contractors with input from academic partners.
### Task Number
711

<table>
<thead>
<tr>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Package Evolution</td>
</tr>
<tr>
<td>PBS level 5</td>
<td>ILW Concrete Containers</td>
</tr>
</tbody>
</table>

### Title
Review of the Durability of Concrete ILW containers

### Background
Previously, in the UK, very limited research has been carried out relating to the use of concrete containers for the storage and disposal of ILW. Research evaluating the use of this type of container, however, has been carried out internationally.

RWM places a significant emphasis on evaluating the durability of container materials during periods of atmospheric exposure likely to precede the closure of a disposal facility, to underpin interim storage and disposal strategies envisaging long periods of atmospheric exposure (e.g. including long GDF operational periods) and the design of storage and disposal facilities.

Building on previous reviews on cement-based wasteforms and on the corrosion of steels in cement, this task will produce a review of the information available from the UK, other waste management programmes (particularly the French programme) and relevant technical literature, to develop a view of the likely durability of concrete containers and elicit any further detailed research needs.

### Research Need
To develop a mechanistic understanding of the durability of ILW concrete containers in periods preceding closure of a GDF (e.g. dry interim storage, GDF emplacement and reversible / retrievable periods), and of the potential for operational factors to affect the durability of containers during the post-closure period.

This work will support strategic decisions on ILW management, the assessment of packaging solutions, the development of suitable disposal concepts for these wastes (in particular disposal concepts envisaging long underground periods in un-backfilled tunnels), the design of a GDF and the development of the safety case.

### Research Objective
To evaluate, on the basis of existing mechanistic understanding and relevant data, the likely durability of concrete containers during long periods or exposure to indoor atmospheric conditions. In particular, to:
- Identify the main degradation processes expected (i.e. steel corrosion, carbonation, chloride ingress, cement hydration and radiolysis), and their expected rate.
- Evaluate their likely impact on the durability of waste containers.
- Identify areas of uncertainty, in which further work would be beneficial.

### Scope
The scope comprises a desk-based review of the information available from:
- Previous studies on the degradation of cement-based wasteforms and on the corrosion of steel wastes in cement, including an evaluation of their relevance to the behaviour of concrete containers, considering differences in cement formulation.
- Previous studies on the degradation of concrete containers from other international programmes, in particular the French programme.
- Previous studies on the degradation of concrete structure technical literature, with particular focus on (relatively) controlled indoor conditions and considering relevant concrete formulations.
- Practical experience relative to the durability of concrete in relevant environments, including experience with concrete structures and existing ILW containers (in the UK and internationally).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Further Work to be Defined</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Further information
Relevant publications include:


This task will be procured through our contractors.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>736</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Radionuclide Behaviour in the EBS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Laboratory Demonstration of Chemical Containment

**Background**

An understanding of radionuclide behaviour in the Engineered Barrier System (EBS) is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWM's programme has been developed to build confidence in the concepts being considered. This is being achieved through commissioning dedicated studies or by contributing to international initiatives.

RWM considers that the mechanisms of radionuclide transport through engineered barriers are well-understood with current datasets and process knowledge, commensurate with the needs of the generic stage of the GDF programme. For cement-based EBS materials an extensive dataset exists regarding radionuclide sorption in grouts / backfills (based on UK studies). Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. However, noting the Nirex public enquiry requirement for chemical containment to be an established technology, radionuclide sorption on potential backfill materials is a topic of continued R&D focus.

**Research Need**

To support safety assessments by determining the extent to which Nirex Reference Vault Backfill (NRVB) will reduce radionuclide mobility in the near field.

**Research Objective**

To determine whether the enhanced retardation and immobilisation of radionuclides by NRVB backfill means that aqueous radionuclide transport out of the EBS will not challenge the post-closure safety case.

**Scope**

This is a multi-year project to demonstrate the principle of chemical containment by a cement conditioned near-field environment of a GDF, on a laboratory scale using a range of radionuclides.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Long-Term Experiment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:


M. Felipe- Sotelo, J. Hinchliff, D. Drury, N.D.M. Evans, S. Williams, D. Read, 2014, Radial Diffusion of Radioceesium and Radiiodide through Cementitious Backfill, Physics and Chemistry of the Earth, 70-71, 60-70
**Task Number:** 737  
**PBS level 4** Radionuclide Behaviour  
**PBS level 5** Radionuclide Behaviour in the EBS  
**Title**  
Mechanisms of Chemical Containment - Scoping Study (U, Ni + TBC)  

**Background**  
An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWM’s programme has been developed to build confidence in the concepts being considered. This is being achieved through commissioning dedicated studies or by contributing to international initiatives. RWM considers that the mechanisms of radionuclide transport through engineered barriers are well-understood with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. For cement-based EBS materials an extensive dataset exists regarding radionuclide sorption in grouts / backfills (based on UK studies). Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. However, noting the Nirex public enquiry requirement for chemical containment to be an established technology, radionuclide sorption on potential backfill materials is a topic of continued R&D focus in the EC BELBaR Study on Bentonite Erosion. Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed ‘linear sorption’, and it is generally argued that it is a valid approximation where the concentration of dissolved contaminant is significantly lower than the concentration of sorption sites. This approach is called the Kd approach, with Kd being the distribution ratio. The current working assumption is that the Kd approach is an adequate simplification for use in performance assessment.  

**Research Need**  
To support safety assessments by demonstrating a mechanistic understanding of the processes by which radionuclides are taken up by cement phases.  

**Research Objective**  
- To determine whether the distribution coefficient (Kd) approach for sorption is an appropriate simplification (and to identify situations where it is inappropriate).  
- To undertake an initial scoping study to determine the methodology and evaluate the benefit of analytical techniques available for the characterisation of cement phases.”  

**Scope**  
An initial exploratory R&D programme to determine micro-scale sorption mechanisms on a range of cement minerals (currently unspecified) using Science & Technology Facilities Council (STFC) facilities. The following sub-objectives have been identified:  
- To determine the mechanisms of metal ion uptake by cement phases, combining experimental and modelling approaches (where beneficial).  
- To gain mechanistic insights into the uptake of radionuclides onto / into surfaces of interest.  
- To develop understanding of the key issues of reversibility of sorption and attainment of chemical equilibrium in radionuclide uptake processes by cement materials.  
- To understand the limitations of the Kd approach when applied to systems relevant to a GDF.’  

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
<th>End point</th>
<th>Long-Term Experiment</th>
<th>Customer</th>
<th>Disposal System Safety Case</th>
</tr>
</thead>
</table>

**Further information**  
Relevant publications include:  
**Background**

An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWMs programme has been developed to build confidence in the illustrative concepts adopted. This is being achieved through commissioning dedicated studies or by contributing to international initiatives.

RWM considers that the mechanisms of radionuclide transport through engineered barriers are well-understood with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme.

Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed ‘linear sorption’, and it is generally argued that it is a valid approximation where the concentration of dissolved contaminant is significantly lower than the concentration of sorption sites. This approach is called the Kd approach with Kd being the distribution ratio. The current working assumption is that the Kd approach is an adequate simplification for use in performance assessment. This task will seek to understand the mechanisms in which radionuclides are sorbed / incorporated into a range of EBS relevant mineral phases.

**Research Need**

To underpin the safety case by demonstrating an understanding of the processes by which radionuclides are taken up by the EBS.

**Research Objective**

To determine whether:
- Key environmental factors can be identified which will determine the evolution of atomic scale surface structure and chemistry in a typical GDF EBS environment (inferred from a model system).
- Key environmental factors can be identified which determine the speciation of key long-lived radionuclides based upon an assessment of their interaction with model EBS systems.
- Radionuclide binding for a range of EBS surfaces and systems relevant to geological disposal can be predicted using an optimised experimental and modelling methodology.

**Scope**

The key objectives of this work are:
- To determine the atomic-scale surface structure and chemistry of model systems relevant to geological disposal and to understand the key environmental factors that determine the evolution of these surfaces in a typical GDF.
- To determine the speciation of key long-lived radionuclides upon their interaction with the model systems and determine the effect of key environmental factors upon radionuclide speciation.
- To couple experiments and modelling approaches in order to gain mechanistic insights into the uptake of radionuclides onto/into model surfaces as a function of environmental conditions.
- To develop a generic experimental and predictive modelling methodology that will allow an optimised approach to predicting radionuclide binding onto model surfaces for a range of systems of relevance to the post-closure GDF groundwater pathway for radionuclide transport.

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>738</td>
<td>Ongoing</td>
<td>Radionuclide Behaviour</td>
<td>Radionuclide Behaviour in the EBS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPSRC GEOWASTE (AMASS): Mechanistic Studies of Engineered Barrier System (EBS) Surface Interactions - Mineral Surface Evolution</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Background</th>
</tr>
</thead>
</table>

This is an integrated experimental and modelling programme (Imperial College, Manchester University).
Loughborough University, DIAMOND) under the EPSRC Geowaste programme and also under RWM's initiative to support a portfolio of 'curiosity driven' research which complements our 'needs driven' programme.
Appendix B - 314

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Radionuclide Behaviour in the EBS</td>
<td></td>
</tr>
</tbody>
</table>

Title
Review and Testing of Sorption Processes in Clay Backfills

Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatment to be incorporated into performance assessments. During the current preparatory studies phase, RWM’s research programme has been developed to build confidence in the concepts adopted. This is being achieved through commissioning dedicated studies or by contributing to international initiatives.

RWM considers that the mechanisms of radionuclide transport through engineered barriers are well-understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. Whilst not studied extensively in the UK, research into the properties of clays, such as bentonite, has been conducted overseas in support of the development of disposal concepts for spent fuel. In the UK however the spent fuel disposal concept has not yet been finalised and further work is required on the sorption properties of possible clay formulations once they have been identified as potentially suitable on the basis of their thermal properties.

This task requires input from concept development and the High Heat Integrated Project in order to narrow down which clay minerals to study.

Research Need
To identify a small range of candidate EBS materials for further evaluation to be used in support of developing the HLW / Spent Fuel (SF) disposal concept.

Research Objective
To determine whether suitable buffer / backfill clay formulations can be identified that provide the necessary safety function of limiting radionuclide mobility in addition to being resistant to long-term thermal degradation.

Scope
Characterisation of a range of clay-based buffer / backfill formulations and selection of a small range of candidate EBS materials to take forward for further evaluation, with results to be used in support of developing the HLW / SF disposal concept.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

End point
Site Specific Validation

Customer
Disposal System Safety Case, Concept Development

Further information
Relevant publications include:
Mechanism of Chemical Containment in Aged Cements for a Range of Key Radionuclides

Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWM's programme has been developed to build confidence in the concepts being considered. This is being achieved through commissioning dedicated studies or by contributing to international initiatives.

RWM considers that the mechanisms of radionuclide transport through engineered barriers are well-understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. For cement-based EBS materials an extensive dataset exists regarding radionuclide sorption in grouts / backfills (based on UK studies). Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. However, noting the Nirex public enquiry requirement for chemical containment to be an established technology, radionuclide sorption on potential backfill materials is a topic of continued R&D focus.

Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed ‘linear sorption’, and it is generally argued that it is a valid approximation where the concentration of dissolved contaminant is significantly lower than the concentration of sorption sites. This approach is called the Kd approach with Kd being the distribution ratio. The current working assumption is that the Kd approach is an adequate simplification for use in performance assessment. This task follows on from earlier scoping studies and will extend this work to more cement mineral phases (including aged systems) and additional radionuclides.

Research Need
To support safety assessments by demonstrating a mechanistic understanding of the processes by which radionuclides are taken up by cement phases.

Research Objective
- To determine whether the distribution coefficient (Kd) approach for sorption is an appropriate simplification (and to identify situations where it is inappropriate).
- To undertake a focussed mechanistic study on aged cement phases and radionuclides of safety case importance.

Scope
To undertake a step-wise research programme (experimental and modelling as appropriate) to extend the knowledge base to aged cements (ageing process to be decided) and a wider range of radionuclides than included in the previous scoping study. Laboratory-scale experiments may include materials from natural and anthropogenic analogues (e.g. naturally occurring CSH or reinforced concrete) utilising state-of-the-art STFC facilities which allow investigation at a nanometer scale.

Relevant publications include:
### Background

An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatments to be incorporated into performance assessments. During the current preparatory studies phase, RWM's programme has been developed to build confidence in the illustrative concepts adopted. This is being achieved through commissioning dedicated studies or by contributing to international initiatives.

RWM considers that the mechanisms of radionuclide transport through engineered barriers are well-understood, with current datasets and process knowledge commensurate with the needs of the generic stage of the GDF programme. Whilst bentonite-based materials have not been studied extensively in the UK, data from overseas programmes are considered by RWM to be sufficient for current requirements. As concept development progresses specific details related to UK clay based backfill materials will be required.

In addition, there will be other materials within the EBS which have the potential to sorb radionuclides (e.g. container corrosion products). This task will consider sorption properties of clay backfill materials and other EBS components such as corrosion products.

### Research Need

To support HLW / Spent Fuel (SF) concept development by demonstrating understanding of the processes by which radionuclides are taken-up by EBS components, e.g. clay, corrosion products, etc.

### Research Objective

- To determine whether the distribution coefficient (Kd) approach for sorption processes is an appropriate simplification and also to identify situations where it is inappropriate, including consideration of the presence of container corrosion products.
- To undertake a focussed mechanistic study on clay mineral phases for a range of radionuclides.'

### Scope

To undertake a step-wise research programme to extend the knowledge base to other EBS components including clay, corrosion products, and a range of radionuclides.

Laboratory-scale experiments may be undertaken at the nanometre scale using the state-of-the-art Science & Technology Facilities Council (STFC) facilities. Experiments may include natural and anthropogenic analogues materials (e.g. naturally occurring bentonite).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

### End point

Site Specific Validation

### Customer

Disposal System Safety Case

### Further information

Study Cellulose Degradation Product (CDP) Metabolism by Micro-organisms and Consequent Impact on Radionuclide Mobility

Background

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and geosphere is important in order for appropriate treatments to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our recent work.

UK and overseas R&D programmes have undertaken investigations on cellulose degradation under cementitious conditions and the consequential effects of cellulose degradation products (CDP) on radionuclide behaviour. Other ongoing work is addressing this topic. It is however thought that microbial populations are likely to be present in the waste packages and the geosphere surrounding the GDF. Additionally, microbial communities may develop within areas of the EBS in spite of the ultra-high pH environment present. The role of microbial processes in the degradation of organic wastes and the composition of resultant small organic molecules is unknown and it is possible that microbially-enhanced degradation could have a beneficial effect by enhancing the rate of decomposition of potential complexants.

Research Need

To support safety assessments by determining the potential impact of cellulose degradation products on radionuclide mobility and establish whether these effects could challenge the safety case.

Research Objective

To determine whether microbes can actively respire on cellulose degradation products within the wasteform, reducing available organic complexants and therefore having a beneficial impact in reducing radionuclide mobility.

Scope

To investigate:
- The utilisation of CDP products formed under repository conditions.
- The direct impact of microbial metabolism on radionuclide speciation.

The project aims to develop a deeper understanding of the potential microbial processes that could impact on the fate of iso-saccharinic acid (ISA) under GDF-relevant conditions. The study will use enrichment and pure cultures to determine the impact of ISA biodegradation on the mobility of key target radionuclides. Comparative data will be collected from enrichment cultures constructed at neutral pH, under conditions analogous to geosphere conditions surrounding ILW and the associated alkali-disturbed zone. The study will aim to predict the rate and extent of ISA degradation under a range of biogeochemical conditions around a GDF in the event that CDPs travel significant distances from the ILW / Alkali-Disturbed Zone (ADZ).

Further information

This study is being undertaken via a doctoral study at the University of Manchester.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>752</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

**PBS level 4**
Radionuclide Behaviour  
**PBS level 5**
Other Influences on Radionuclide Behaviour

**Title**
Assessment of the Impact of PVC Degradation Products on Radionuclide Mobility (using U, Ni & Pu)

**Background**
An understanding of radionuclide behaviour in the engineered barrier system (EBS) and geosphere is important in order for appropriate treatments to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our recent work.

This work area includes R&D on the impact of organic complexants. Recent work by RWM has identified that the baseline inventory of buoyant Non-Aqueous Phase Liquids (NAPLs), derived from the decomposition of plastics and rubbers, will not challenge the disposal system. However, aqueous miscible complexants may be formed from the radiolysis and hydrolysis of materials such as polyvinylchloride (PVC).

**Research Need**
To support safety assessments by determining the potential impact of PVC degradation products on radionuclide mobility and establish whether these effects could challenge the disposal system safety case.

**Research Objective**
To determine whether PVC degradation products have a significant impact on radionuclide mobility in the cementitious near-field of a GDF for ILW.

**Scope**
This is an experimental project investigating the release and degradation behaviour of PVC additives under near-field conditions to ascertain the degradation products arising and to evaluate their impact on the solubility and sorption of U, Ni and Pu.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
No Further Research Planned

**Customer**
Disposal System Safety Case

**Further information**
This project is to be co-funded by the Belgian waste management operator, Niras / Ondraf, under a bilateral international cooperation.

Relevant publications include:
S. Watson, S. Benbow, N. Chittenden, A. Lansdell, M O Rivett and G Towler, 2012, Potential for Buoyant Non-aqueous Phase Liquid to Migrate in the Free Phase from a GDF, RWMD 17698 / TR / 03.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>753</td>
<td>Ongoing</td>
<td>Radionuclide Behaviour</td>
<td>Other Influences on Radionuclide Behaviour</td>
</tr>
</tbody>
</table>

**Title**

Colloids: The Effect of Non-Clay Colloids on Radionuclide Mobility

**Background**

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our own work.

This work area also includes R&D on the impact of colloids on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they would affect the migration of radionuclides. To date, considerable international effort has focussed on understanding the impact of colloids derived from clay-based EBS materials such as bentonite. However, colloids may originate from other materials that might be present in the disposal system (the wasteform, cementitious backfill, crushed rock, sand, iron corrosion products, etc.) or from the geosphere (e.g. humic acids).

**Research Need**

To support safety assessments by developing an improved understanding of whether colloids will significantly affect radionuclide mobility in either the near field or the geosphere.

**Research Objective**

To determine whether:

1. Colloids generated within the EBS (including the wasteform) will significantly increase radionuclide mobility through the EBS for the range of RWM concepts.
2. Colloids generated within the EBS, or carried within natural groundwaters, will significantly increase radionuclide mobility through the geosphere for the range of RWM concepts.

**Scope**

EPSRC CASE award at University of Manchester for a PhD. The key areas of the project are:

- Simple surface complexation computational modelling of systems of interest.
- Literature review of reversibility of sorption of radionuclides to colloids and relevant analysis such as the identification of sorption mechanisms, etc.
- Laboratory-scale experimental work to look at the interaction between colloids and radionuclides, the mechanism of sorption and de-sorption of radionuclides on the colloids and determination of sorption and de-sorption rates. The details of which will be determined as part of the modelling and literature review. The effect of chemical conditions and colloid size will be studied.

The experimental data obtained, along with speciation and surface complexation modelling, will provide information on the mechanism of these processes. The implications of the work for radionuclide mobility will also be covered.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Disposal System Safety Case

**Further information**

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>754</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radionuclide Behaviour</td>
<td>Other Influences on Radionuclide Behaviour</td>
</tr>
</tbody>
</table>

**Title**
Colloids: EC BELBaR - Laboratory Study of the Effect of Bentonite Colloids on Radionuclide Mobility

**Background**
An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our own work.

This work area also includes R&D on the impact of colloids on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they would affect the migration of radionuclides. A key area of international interest and effort is on understanding the impact of colloids derived from clay-based EBS materials such as bentonite due to its importance in applications such as the Swedish KBS 3 spent fuel disposal concept.

**Research Need**
To support safety assessments by developing an improved understanding regarding whether colloids will significantly affect radionuclide mobility in either the near field or the geosphere.

**Research Objective**
To determine:
- If the attachment of radionuclides to clay colloids is readily reversible and whether the clay colloids would subsequently become bound to mineral surfaces within the geosphere thus resulting in a limited impact of colloid associated radionuclide transport.
- Whether the impact of colloids on radionuclide transport can be quantified by model calculations and used as a basis for safety assessments.

**Scope**

This collaborative project will:
- Improve the understanding regarding when bentonite colloid complexes are unstable.
- Improve quantitative models for erosion of the bentonite barrier for the cases where colloids are stable.
- Improve understanding regarding how radionuclides attach to clay colloids.

Information gathered will be used to formulate improved transport models for the assessment of radionuclide transport in the geosphere. Experimental programmes (laboratory-scale and large-scale) and quantitative models will be developed, focussing on issues important to the safety assessment.

**SRL at task start** | **SRL at task end** | **Target SRL**
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Validation

**Customer**
Disposal System Safety Case

**Further information**
For further information:
Appendix B - 321

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>755</td>
<td>Ongoing</td>
<td>Radionuclide Behaviour</td>
<td>Other Influences on Radionuclide Behaviour</td>
</tr>
</tbody>
</table>

**Title**

Colloids: Colloid Formation and Migration (CFM) Experiment – Underground Rock Laboratory (URL) Hot Migration Study on the Effect of Bentonite Colloids on Radionuclide Mobility

**Background**

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments.

This work area includes research on the impact of naturally occurring colloids (microscopic particles with the potential to complex with radionuclides) on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they would affect the migration of radionuclides. A key area of international interest and effort is on understanding the impact of colloids derived from clay-based EBS materials such as bentonite due to its importance in applications such as the Swedish KBS 3 spent fuel disposal concept. This task investigates the formation of bentonite-derived colloids and their binding to a range of radionuclides in a real, fractured host-rock environment, followed by investigation of their migration and their subsequent collection and characterisation. The experiment is underway at the Grimsel Test Site in Switzerland.

**Research Need**

To support safety assessments by developing an improved understanding of whether colloids will significantly affect radionuclide mobility in either the near-field or the geosphere.

**Research Objective**

- To understand whether colloidal processes present a significant challenge to bentonite-based disposal concepts (for example due to the rate of colloid formation and transport from bentonite).
- To investigate whether the stability of complexes formed between repository-relevant radionuclides and bentonite colloids, demonstrated in a realistic geological environment, is sufficient to significantly enhance radionuclide transport through the geosphere.
- To investigate whether reversibility in the binding of radionuclides by colloids lessens concerns over their potential to enhance radionuclide migration through the geosphere (for example whether, over the timescales relevant to radionuclide return to surface via groundwater, the radionuclides will partition with the aqueous phase and sorb onto geological materials, thereby becoming dissociated from the mobile colloidal phase).
- To utilise the Colloid Formation and Migration (CFM) experiment to provide methodology and expertise in the sampling and characterisation of colloids such as to be beneficial during site characterisation.

**Scope**

RWM are participating in the CFM multi-partner experiment at the Grimsel Test Site. The CFM project is dedicated to the study of: colloid formation / bentonite erosion, the groundwater / pore water mixing zone, colloid migration (filtration) and colloid-associated radionuclide transport.

CFM is a well established experiment with a proven track record of success in studying radionuclide behaviour in a well characterised shear zone under repository-relevant boundary conditions.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**

For further information see:

http://www.grimsel.com/gts-phase-vi/cfm-section/cfm-introduction
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>756</td>
<td>Ongoing</td>
<td>Radionuclide Behaviour</td>
<td>Other Influences on Radionuclide Behaviour</td>
</tr>
</tbody>
</table>

**Title**

NERC RATE (Imperial): Development of Coupled Process Models of Tracer and Colloidal Transport at the Grimsel URL

**Background**

The presence of a GDF will affect the surrounding geosphere during construction, operation and the post-closure phase. The extent of the interactions and their significance will depend strongly on the features of the disposal concept and the host rock. An important consideration, both for the natural processes of geosphere evolution and for changes arising from the presence of a GDF, is that many are coupled. These are frequently referred to as ‘THMC coupled processes’ to represent the thermal, hydraulic, mechanical and chemical processes which interact in these complex natural systems. As a consequence, developing an understanding of the expected couplings, and a capability to model those effects, is central to RWM’s geosphere research. In our current phase of the programme we are supporting international collaborations and academic studies in this field.

One such task (under the HydroFrame project) is being undertaken under our collaboration with the Natural Environment Research Council (NERC) and the Environment Agency, with the objective of developing a coupled process numerical model of tracer-bound colloidal transport at the Grimsel Test Site URL utilising data from the Colloid Formation and Migration (CFM) project (see Task 755). The main outcomes will be a set of new and/or improved methodologies, codes and protocols for analysing various processes that occur during the lifetime of a GDF. We are co-funding this project under our initiative to support a portfolio of ‘curiosity-driven’ research which complements our ‘needs-driven’ programme.

**Research Need**

To build up expertise and capability in modelling hydromechanical and biogeochemical processes that occur in fractured rock masses in the vicinity of a GDF.

**Research Objective**

- To develop a new and improved methodology to model the properties of fractured rock masses with regards to the influence of these properties on the colloidal transport of radionuclides.
- To determine whether colloidal processes need explicit inclusion in process-level models or whether they are bounded by existing chemical models.'

**Scope**

To develop new and improved methods of characterising and modelling the properties of fractured rock masses with regards to the influence of these properties on the performance of a GDF.

To investigate whether microbes and natural organic matter lead to increased actinide mobility in fractured rocks, also in the context of a GDF. Subtasks include the development of coupled process numerical models of tracer and colloidal transport in the Grimsel Test Site URL, being undertaken by the University of Birmingham.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Research ('Curiosity Driven'), Disposal System Safety Case

**Further information**

RWM's role in HydroFrame is in supporting the academic cohort by reviewing the technical output of the project and its applicability to RWM.

Relevant further information can be found in the following:

http://www.nerc.ac.uk/research/funded/programmes/rate

Testing and Selection of Candidate Superplasticisers

**Background**

Technical work on this task is complete and the final report in the peer review process.

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex or ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our recent work.

Organic superplasticisers may offer significant benefits to waste producers during packaging of wastes by allowing them to package more waste in each waste container whilst ensuring the material is fully encapsulated in cementitious grout. Superplasticisers already exist in some construction materials at UK nuclear facilities which are likely to require eventual disposal; larger quantities of a yet to be specified superplasticiser may be necessary for construction of the GDF, for example in shotcrete. Potential issues exist regarding organic superplasticisers, or their breakdown products, for enhancing radionuclide solubility in the near-field and potentially in the geosphere. Improved formulations and characterisation of their effect on radionuclide sorption and transport are required and the results from this work may feed into the development of a GDF-compatible superplasticiser.

**Research Need**

To identify a suitable formulation for a superplasticiser which may be used within waste packages, and supported via the Letter of Compliance (LoC) process, and in the construction of the GDF via the provision of suitable underpinning data for use in the post-closure safety case and its performance assessment.

**Research Objective**

To support LoC and safety assessments by determining whether the use of superplasticisers in waste formulations is compatible with the GDF safety cases.

**Scope**

To work with Site Licence Companies and a commercial superplasticiser provider to identify the relevant requirements and to develop a product to meet those requirements whilst not impacting on the safety functions of the EBS.

**Further information**

For further information:
An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatments to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected.

RWM has a good understanding of the processes occurring within the EBS leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our recent work.

This work area also includes R&D on the impact of organic complexants in order for RWM to decide whether there are processes which need to be represented in the performance assessment (and whether to gather additional data). Large UK and overseas R&D programmes have been investigating cellulose degradation under cementitious conditions and the consequential effects of cellulose degradation products (CDPs) on radionuclide behaviour. Previous work by RWM has identified that for representative trivalent and tetravalent species their behaviour is bounded by the CDP iso-saccharinic acid and that at levels likely to be present in the GDF there will be negligible enhancement of radionuclide transport.

This task will identify the need for any further work, such as studies on key radionuclides (such as Pu and U) and will facilitate a more accurate representation of the processes of cellulose degradation, and subsequent migration and interaction behaviour of the CDPs with radionuclides.

**Research Need**

To support safety assessments by determining the potential impact of cellulose degradation products (CDPs) on radionuclide mobility and to accurately represent these effects within the safety case.

**Research Objective**

- To determine whether iso-saccharinic acid is a suitable model compound for cellulose degradation product complexation behaviour with key radionuclides.
- To develop a suitably validated model to represent CDP behaviour in the EBS.
- To identify future research requirements.

**Scope**

This project will:

- Capture knowledge from ongoing projects looking at Cellulosic Degradation Products and previous work programmes.
- Develop a process model to simulate cellulose degradation and subsequent interaction with radionuclides within the near-field. Model uncertainties and sensitive input parameters will be evaluated.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>3</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:

### Background

An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatment to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected.

RWM has a good understanding of the processes occurring within the geosphere regarding containment of radionuclides, which is based upon previous work carried out by Nirex or ongoing works by Waste Management Organisations (WMOs) in other countries. In this area, RWM’s objective is to maintain an up-to-date understanding of relevant issues through exchange with overseas WMOs, contribution to international programmes and literature reviews.

This work area also includes R&D on the impact of organic complexants on radionuclide behaviour. Improved understanding of these aspects is required in order for RWM to decide whether there are processes which need to be represented in performance assessment (and whether to gather additional data); the current state of knowledge is summarised below:

- **Cellulose degradation** – significant UK and overseas R&D programmes have been undertaken regarding cellulose degradation under cementitious conditions and consequential effects of cellulose degradation products on radionuclide behaviour.
- **Organic superplasticisers** – superplasticisers may offer significant benefits to waste producers during packaging of wastes. Potential issues exist regarding organic superplasticisers, or their breakdown products, for enhancing radionuclide solubility in the GDF and near field in the EBS.

### Research Need

To support safety assessments and future Letter of Compliance submissions by determining the potential impact of superplasticisers contained within ILW decommissioning concrete / cement rubble upon radionuclide mobility.

### Research Objective

To determine whether superplasticisers contained within irradiated concrete for disposal within a GDF will have a significant impact on disposal system performance by supplying a source of potential radionuclide complexants to the disposal vaults.

### Scope

To undertake a desk based assessment of the composition of concrete / cement decommissioning rubble to be disposed at the GDF (including concrete reactor pressure vessels).

Based on knowledge of the inventory (composition and quantity) and mobility of superplasticisers and their decomposition products, this task will assess the potential for superplasticisers in the aforementioned rubble to challenge the post-closure performance of the disposal system.

### Further information

Relevant publications include:

- A Clacher et al, Effects of Superplasticiser on Radionuclide Solubility, AMEC 006180.
Appendix B - 326

<table>
<thead>
<tr>
<th>Task Number</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>760</td>
<td>Radionuclide Behaviour</td>
<td>Other Influences on Radionuclide Behaviour</td>
</tr>
<tr>
<td>Title</td>
<td>Application of Knowledge Gained through BIGRAD (Biogeochemical Gradients and Radionuclide Transport)</td>
<td></td>
</tr>
</tbody>
</table>

**Background**

RWM's understanding of radionuclide transport mechanisms in the geosphere is mature. When site-specific geological data become available we plan to measure radionuclide transport properties of the various rocks that would lie along the groundwater pathway from a GDF to the surface. Initial experiments will be carried out in the laboratory, but we may also include in-situ measurements at an appropriate stage.

Alkaline reducing conditions will develop within the engineered barrier systems of the ILW / LLW disposal areas of a GDF after closure. These will result in steep biogeochemical gradients at the interface with the surrounding host geology. This chemically disturbed zone (CDZ) may influence the transport of radionuclides from the near-field to the far-field. Within this CDZ conditions may exist which can support the development of microbial communities which, in turn, have the potential to enhance or retard radionuclide migration. BIGRAD (Biogeochemical Gradients and Radionuclide Transport) is a UK NERC-funded consortium that is developing a better understanding of the geochemical and microbiological evolution of the subsurface environment surrounding the ILW / LLW disposal areas of a GDF.

BIGRAD is organised into three interlinked work packages:

- WP1 concerns geosphere evolution around a GDF.
- WP2 investigates radionuclide form, reaction and transport in an evolving CDZ environment.
- WP3 encompasses the synthesis and application of WP1 and WP2 to performance assessment.

In addition there are two cross cutting themes:

- Theme 1 - Biogeochemical processes in the chemically disturbed zone.
- Theme 2 - Predictive modelling.

**Research Need**

To support the safety case by understanding the effect of biogeochemical processes in a CDZ around cement-based disposal concepts on radionuclide behaviour.

**Research Objective**

To review and synthesise the knowledge developed under BIGRAD in the context of safety case arguments for a UK GDF.

**Scope**

The scope comprises a review of the key results from BIGRAD, their relevance in the context of the disposal of ILW in the UK and implications for radionuclide transport in the post-closure safety case.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Disposal System Safety Case

**Further information**

It is envisaged that this task will comprise a joint report or paper prepared by BIGRAD, RWM and the RWM supply chain.

Relevant publications /sources of information include:


Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatment to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected. RWM has a good understanding of the processes occurring within the geosphere regarding containment of radionuclides based upon previous work carried out by Nirex or ongoing works by Waste Management Organisations (WMOs) in other countries. In this area, RWM’s objective is to maintain an up-to-date understanding of relevant issues through exchange with overseas WMOs, contribution to international programmes and literature reviews.

This work area also includes R&D on the impact of organic complexants on radionuclide behaviour. Improved understanding of these aspects is required in order for RWM to decide whether there are processes which need to be represented in performance assessments (and whether to gather additional data); the current state of knowledge is summarised below:
- Cellulose degradation – significant UK and overseas R&D programmes have been undertaken regarding cellulose degradation under cementitious conditions and consequential effects of cellulose degradation products on radionuclide behaviour.
- Organic superplasticisers – superplasticisers may offer significant benefits to waste producers during packaging of wastes. Potential issues exist regarding organic superplasticisers, or their breakdown products, for enhancing radionuclide solubility in the GDF and near field in the EBS.

Research Need
To identify a suitable formulation for a superplasticiser which may be used within waste packages, and supported via the Letter of Compliance process, and in the construction of the GDF via the provision of suitable underpinning data for use in the post-closure safety case and its performance assessment.

Research Objective
To develop a superplasticiser formulation suitable for use in waste formulations which is compatible with the GDF safety cases.

Scope
The scope will be informed from preceding Task 757, but is likely to include a phased set of laboratory solubility and sorption experiments utilising the superplasticiser developed for the nuclear industry using a combination of batch and pore-water squeezate leaching tests for a range of radionuclides.

A derivation of mechanistic understanding of the release of radionuclides from cured cements and complexation with a range of radionuclides will be required, including a computational model (e.g. PHREEQC).

SRL at task start 2  SRL at task end 5  Target SRL 5
End point No Further Research Planned
Customer Disposal System Safety Case, Disposal System Specification

Further information
Relevant publications include:
A Clacher, G Baston, F Glasser, G Jauffret and S Swanton, 2013, Effects of Superplasticiser on Radionuclide Solubility, AMEC 006180.
### Synthesis Report on Colloidal Understanding

#### Background

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our own work. This work area also includes R&D on the impact of colloids on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they would affect the migration of radionuclides.

#### Research Need

To support safety assessments by developing an improved understanding of whether colloids will significantly affect radionuclide mobility in either the near field or the geosphere.

#### Research Objective

To compile a summary of research to determine:
- A conceptual basis (including tools and techniques) to represent colloids in the generic Disposal System Safety Case (gDSSC).
- Whether or not colloidal processes present a significant challenge to disposal concepts (for example, due to the low rate of colloid formation and slow migration from bentonite).
- If the stability of complexes formed between repository relevant radionuclides and colloids is sufficient to significantly enhance radionuclide transport through the geosphere.
- Whether reversibility in the binding of radionuclides by colloids lessens concerns over their enhanced migration through the geosphere.
- A methodology for the sampling and characterisation of colloids that will be beneficial during the site characterisation phase of the UK geological disposal programme.

#### Scope

To produce a summary report consolidating understanding gained from a variety of projects involving RWM regarding colloids and their potential impact on radionuclide behaviour (including the EC BELBaR project (Task 754), the Grimsel-based Colloid Formation and Migration (CFM) experiment (Task 755) and related studies (Tasks 753 and 756)). Other international work will also be included.

#### Further information

Relevant publications include:


Review of Organic Additives to Cement Powders (e.g. Grinding Agents)

Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our own work.

Considerable effort has focussed on the potential role of organic superplasticisers as additives to grout formulations and their potential role in radionuclide mobilisation in the near-field and the geosphere. However, commercial cement powders contain other proprietary materials for which there is little understanding of their ability to interact with radionuclides. Potential issues exist regarding these materials and this task will investigate whether further work is required.

In addition, other potential complexants may be present in decommissioning wastes deriving from, for example, chemical decontaminants (e.g. citrate) and strippable coatings.

Research Need
To support safety assessments by determining the potential impact of non-cellulosic organic materials and inorganic decontamination agents on radionuclide mobility in the near field and to establish whether these effects could challenge the safety case.

Research Objective
To identify the composition and inventory of small quantities of organic / inorganic components of wastes, which may have a significant impact on radionuclide mobility in a GDF.

Scope
To review previous and ongoing Letter of Compliance (LoC) assessments to determine if any experimental work is required on additional organic components of wasteforms (these are likely to include decontamination agents, cement additives / grinding aids, etc).

SRL at task start 1 SRL at task end 3 Target SRL 4

End point Site Specific Validation
Customer Disposal System Safety Case

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>764</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Other Influences on Radionuclide Behaviour</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Update Process Model - Understanding of Cellulose Degradation Product (CDP) Metabolism**

**Background**

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and geosphere is important in order for appropriate treatments to be incorporated into performance assessments. Once materials for the GDF have been selected, UK-specific data for radionuclide behaviour (conditioned to the candidate site-specific groundwater) will need to be collected.

RWM has a good understanding of the processes occurring within the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our recent work.

UK and overseas R&D programmes have been undertaken investigating cellulose degradation under cementitious conditions and the consequential effects of cellulose degradation products on radionuclide behaviour. RWM has developed a near-field component model which enables us to examine the effects of various parameters within an abstracted representation of the cementitious near-field of the ILW disposal concept. To date however, this model does not include representation cellulose degradation products (CDP).

**Research Need**

To support safety assessments by developing the cementitious near-field component model to include the effects of CDP on radionuclide mobility and establishing whether these effects could challenge the safety case.

**Research Objective**

To determine whether microbes can actively respire utilising CDP within the wasteform, thus having a beneficial impact by reducing radionuclide mobility by rapidly reducing available organic complexants.

**Scope**

Undertake an update to the process model generated in Task 758 utilising the knowledge gained in Task 751.

SRL at task start | 4 | SRL at task end | 4 | Target SRL | 4 | End point | No Further Research Planned | Customer | Disposal System Safety Case | Further information |
Appendix B - 332

<table>
<thead>
<tr>
<th>Task Number</th>
<th>765</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Other Influences on Radionuclide Behaviour</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Review of Superplasticisers for GDF Construction

**Background**

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex or ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our recent work.

A yet to be specified superplasticiser may be necessary for construction of the GDF, for example in shotcrete. Potential issues exist regarding organic superplasticisers, or their breakdown products, by enhancing radionuclide solubility in the near-field and potentially in the geosphere. Improved formulations and characterisation of their effect on radionuclide sorption and transport are required. Based on a previous task (Task 764) it is assumed that successful laboratory-scale trials will have been completed and an experiment in an Underground Research Laboratory will have been started on a newly formulated superplasticiser.

**Research Need**

To support safety assessments by determining the potential impact of superplasticisers in GDF construction upon radionuclide mobility.

**Research Objective**

To identify whether a different superplasticiser will be required during construction than any identified for use in waste encapsulation (through Tasks 757 and 761).

**Scope**

To identify functional requirements for superplasticisers required during construction and to review the results from Tasks 757 and 761 to determine whether any superplasticiser identified during these tasks will meet construction requirements.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Customer**

Disposal System Safety Case, Disposal System Specification

**Further information**

Relevant publications include:


A Clacher, G Baston, F Glasser, G Jauffret and S Swanton, 2013, Effects of Superplasticiser on Radionuclide Solubility, AMEC 006180.
Title
Investigation of Whether the Effect of Organics, Colloids and Microbes on Radionuclide Solubility are Additive

Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our own work.

This work area also includes R&D on the impact of organic complexants, colloids and non-aqueous phase liquids (NAPLs) on radionuclide behaviour. Improved understanding of these aspects is required in order for RWM to decide whether there are processes which need to be represented in performance assessment (and whether to gather additional data); the current state of knowledge is summarised below:
- Cellulose degradation – significant UK and overseas R&D programmes have been undertaken regarding cellulose degradation under cementitious conditions and consequential effects of cellulose degradation products on radionuclide behaviour.
- Organic superplasticisers – superplasticisers may offer significant benefits to waste producers during packaging of wastes. Potential issues exist regarding organic superplasticisers, or their breakdown products, for enhancing radionuclide solubility in the GDF and near-field in the EBS.
- Microbes – RWM recognises that microbes could potentially impact upon radionuclide transport in the EBS.
- NAPLs – the generation and migration of NAPLs has potential to impact radionuclide behaviour. However, recent work by RWM suggests that the yield of NAPLs is unlikely to be significant and that even if released they are unlikely to leave the EBS.

No work has however been undertaken to investigate whether there are any synergistic effects which lead to a greater cumulative impact than might be expected on a simplistic additive basis.

Research Need
To support safety assessments by developing an improved understanding of the cumulative effect of multiple process on radionuclide transport in the near field.

Research Objective
To determine whether the effects of individual factors (such as colloids, complexants and microbes) on radionuclide transport are additive.

Scope
A multi-component experimental programme to understand the cumulative effects upon radionuclide behaviour (to include the presence of colloids, complexants and microbes).
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Other Influences on Radionuclide Behaviour</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Experimental Screening Study of Radionuclide Behaviour in the Presence of Potential Complexants

**Background**

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our own work.

Considerable effort has focused on the potential role of organic superplasticisers as additives to grout formulations and their potential role in radionuclide mobilisation in the near-field and the geosphere. However, commercial cement powders contain other proprietary materials for which there is little understanding of their ability to interact with radionuclides. Potential issues exist regarding these materials and this task will investigate whether further work is required.

In addition, other potential complexants may be present in decommissioning wastes deriving from, for example, chemical decontaminants (e.g. citrate) and strippable coatings. This task follows an initial review of the potential inventory and composition of such materials (Task 763).

**Research Need**

To support safety assessments by determining the potential impact of non-cellulosic organic materials and inorganic decontamination agents on radionuclide mobility in the near field and to establish whether these effects could challenge the post-closure safety case.

**Research Objective**

To determine whether small quantities of organic / inorganic components of wastes have a significant impact on radionuclide mobility under representative near-field conditions of a GDF.

**Scope**

Scope will be determined by the output of Task 763. An experimental research programme to assess the likely impact on radionuclide behaviour is anticipated.

**SRL at task start** | **SRL at task end** | **Target SRL** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**

Further research would be necessary if results indicate that Colloid Degradation Products (CDP) is not a bounding case for organic influence on radionuclide behaviour, in which case an SRL of 5 will be required.
### Task Number: 768

<table>
<thead>
<tr>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Radionuclide Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Other Influences on Radionuclide Behaviour</td>
</tr>
</tbody>
</table>

**Title**

Synthesis Report on Microbial Understanding

**Background**

Ensuring that an engineered barrier system (EBS) will perform its desired functions requires integration – of an iterative nature – of the following: site-specific information; information on the waste properties; understanding of material properties and performance; and in-situ and laboratory testing and modelling relating to key processes that will affect near-field evolution.

As RWM’s programme develops it will be important to build confidence that the individual components within the near field, such as the various waste modules or individual barriers, work together to provide a system that functions correctly. Within this research sub-topic RWM considers additional processes to those already discussed above, which overlap with other key research areas (such as radiation effects, gas generation, waste package longevity, and wasteform degradation) and could impact on near-field evolution. Internationally, considerable work has been carried out to understand and quantify microbial influences on many near-field evolution processes. These influences have been considered in the recently-published review of microbial effects on repository performance.

The overall influences of microbial activity on the performance of an EBS are complex and dependent (amongst other things) on the disposal concept and geological setting; however, there is considerable uncertainty concerning the impact of microbial processes on redox-sensitive radionuclides.

This task comprises a review of recently commissioned microbial research in order to consolidate RWM’s knowledge base in support of the Disposal System Safety Case (DSSC) and will integrate ongoing learning from participation in the EC MIND project. This project has an emphasis on quantifying specific measurable impacts of microbes on safety cases under repository conditions to develop understanding of microbes and their representation in safety case performance assessment models.

**Research Need**

To support safety assessments by determining the extent to which microbes have the potential to alter the chemical and physical form of radionuclides (for example, by utilising some elements as nutrient sources and altering the surrounding environment, e.g. redox processes).

**Research Objective**

To support the DSSC by developing sufficient mechanistic understanding of microbial processes and the controls that these have upon radionuclide behaviour to enable development of predictive models / scientific underpinning.

**Scope**

To review knowledge regarding microbial processes in GDF relevant conditions and the controls that these have upon radionuclide behaviour.

Work conducted as part of Tasks 383, 392, 443, 467, 751 and 760 as well as that by other Waste Management Organisations (WMOs) (amongst others) will be reviewed in support of this task.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**

This work follows on from that completed as part of Tasks 383, 392, 443, 467, 751 and 760.
Task Number | 769 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Radionuclide Behaviour |  |  
PBS level 5 | Other Influences on Radionuclide Behaviour |  |  
Title
Update Synthesis Report on Colloidal Understanding

Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the EBS and the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex and ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our own work.

This work area also includes R&D on the impact of colloids on radionuclide behaviour. Improved understanding is required on how colloids might be produced, how they would interact with radionuclides originating from evolving wasteforms and how they would affect the migration of radionuclides. This task is an update of a previous review, Task 762.

Research Need
To support safety assessments by developing an improved understanding of whether colloids will significantly affect radionuclide mobility in either the near field or the geosphere.

Research Objective
To compile a summary of research to determine:
- A conceptual basis (including tools and techniques) to represent colloids in the generic Disposal System Safety Case (gDSSC).
- Whether or not colloidal processes present a significant challenge to disposal concepts (for example, due to the low rate of colloid formation and slow migration from bentonite).
- If the stability of complexes formed between repository-relevant radionuclides and colloids is sufficient to significantly enhance radionuclide transport through the geosphere.
- Whether reversibility in the binding of radionuclides by colloids lessens concerns over their enhanced migration through the geosphere.
- A methodology for the sampling and characterisation of colloids that will be beneficial during the site characterisation phase of the UK geological disposal programme.

Scope
A revision of the summary report to pull together the understanding gained through a variety of projects focussed on colloids and their potential impact on radionuclide behaviour. This update is to incorporate understanding gained from completion of BELBaR, the current phase of the Colloid Formation and Migration (CFM) experiment and understanding gained from multi-component large-scale experiments.

| SRL at task start | 5 | SRL at task end | 5 | Target SRL | 5 |
|--- | --- | --- | --- | --- |
| End point | Site Specific Validation |  |  |
| Customer | Disposal System Safety Case |  |  |

Further information
Relevant publications include:
http://www.grimsel.com/gts-phase-vi/cfm-section/cfm-introduction

Appendix B - 336
### Background

An understanding of radionuclide behaviour in the engineered barrier system (EBS) and the geosphere is important in order for appropriate treatment to be incorporated into the safety case and its supporting performance assessments. RWM has a good understanding of the processes occurring within the geosphere leading to containment of radionuclides and retardation of their aqueous transport. This understanding is based upon previous work carried out by Nirex or ongoing works by Waste Management Organisations (WMOs) in other countries, as well as by our recent work.

Organic superplasticisers may offer significant benefits to waste producers during packaging of wastes by allowing them to package more waste in each waste container whilst ensuring the material is fully encapsulated in cementitious grout. Superplasticisers already exist in some construction materials at UK nuclear facilities and these are likely to require eventual disposal and larger quantities of a yet to be specified superplasticiser may be necessary for construction of the GDF, for example in shotcrete. Potential issues exist regarding organic superplasticisers, or their breakdown products, for enhancing radionuclide solubility in the near field and potentially in the geosphere. Improved formulations and characterisation of their effect on radionuclide sorption and transport are required. Based on a previous task it is assumed that successful laboratory-scale trials will have been undertaken on a newly formulated superplasticiser. Further validation will however be required in a real geological environment and this task addresses this need.

### Research Need

To identify a suitable formulation for a superplasticiser which may be used within waste packages, and supported via the Letter of Compliance (LoC) process, and in the construction of the GDF via the provision of suitable underpinning data for use in the post-closure safety case and its performance assessment.

### Research Objective

To validate laboratory-scale tests on a superplasticiser, specifically formulated for the UK nuclear industry, in a real geological environment.

### Scope

Large scale test in an overseas Underground Research Laboratory (URL).

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned


### Further information

Relevant publications include:


A Clacher, G Baston, F Glasser, G Jauffret and S Swanton, 2013, Effects of Superplasticiser on Radionuclide Solubility, AMEC 006180.
Background

An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatment to be incorporated into performance assessments. As RWM’s programme progresses, it will be important to build confidence that the individual components of the EBS work together to provide a system that functions correctly. Within this research sub-topic, RWM considers additional processes that overlap with other key research areas (such as gas generation, waste package longevity and wasteform degradation) that impact on near-field evolution. Internationally, considerable work has been carried out to understand microbial influences on many near-field processes. These influences have been considered in a published review of microbial effects on repository performance.

The extent to which microbial activity can proceed in and around a GDF may have an impact on the transport of radionuclides, particularly C-14. The overall influences of microbial activity on the performance of an EBS are complex and dependant on the disposal concept and the geological setting. The expected evolution of the near field and the associated alkaline disturbed zone will have a profound impact on the associated microbial activity. The predicted pH conditions (>12.5 for 100,000s of years) are above that normally associated with even the most extreme alkaliophiles. The upper pH limits for microbial activity is subject to some uncertainty with pH 12 proposed as upper limits, however, evidence exists for microbial activity above this value up to pH 13.

Research Need

To support the disposal system safety case (DSSC) by determining the environmental limits (maximum pH) at which sulphate reduction and methanogenesis can proceed under conditions relevant to the near field of a GDF.

Research Objective

To determine a process level understanding of the environmental limits relevant to methanogens and sulphate-reducing bacteria under GDF-relevant conditions and the subsequent impact on the microbially-induced gas generation rates within the near field.

Scope

This PhD project will investigate the maximum pH at which sulphate reduction and methanogenesis can proceed under conditions consistent with the near field and associated alkaline disturbed zone of a GDF and will investigate:

- Whether biofilm growth increases the effective pH at which methanogenesis and sulphate reduction can proceed.
- Whether methanogens can access precipitated carbonates to drive methane generation.
- Whether methanogenic and sulphate-reducing bacteria biofilms are established on the surface of cementitious materials.
- Whether methanogens have a greater pH tolerance than sulphate reducing bacteria under simulated near-field conditions.

Further information

This study is being undertaken via a doctoral project at the University of Huddersfield.

### Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatment to be incorporated into performance assessments. As RWM's programme progresses, it will be important to build confidence that the individual components of the EBS work together to provide a system that functions correctly. Within this research sub-topic, RWM considers additional processes that overlap with other key research areas (such as gas generation, waste package longevity and wasteform degradation) that impact on near-field evolution. Internationally, considerable work has been carried out to understand microbial influences on many near-field processes. These influences have been considered in a published review of microbial effects on repository performance.

The extent to which microbial activity can proceed in and around a GDF may have an impact on the transport of radionuclides. The overall influences of microbial activity on the performance of an EBS are complex and dependent on the disposal concept and the geological setting.

This project will investigate the influence of microbial sulphate reduction and associated sulfidation processes in controlling the long-term fate of radionuclides under GDF relevant conditions.

### Research Need
To support the disposal system safety case (DSSC) by developing an improved understanding of the impact of microbial sulphate reduction on radionuclide behaviour in the near field.

### Research Objective
- To develop an improved mechanistic and molecular scale understanding of the impact of sulfidation on uranium and technetium fate in relevant metal oxide phases such as ferricyanide, goethite and magnetite under abiotic and biotic conditions.
- To explore the long term fate of radionuclides in model systems relevant to geological disposal.

### Scope
The key areas of this laboratory-based PhD project are:
- To create a range of radionuclide-spiked model mineral phases expected in radioactive wastes – oxic models such as U(VI) sorbed to iron oxides relevant to Enhanced Actinide Removal Plant wastes, reduced models such as U(IV) and Tc(IV) sorbed to phases expected from iron corrosion and/or microbial Fe(III)-reduction.
- To assess the speciation and solubility changes when these model phases are reduced abiotically with sulphide under relevant physico-chemical conditions (ambient to mildly alkaline conditions) using a combination of wet geochemical and direct speciation approaches including EXAFS and electron microscopy.
- To develop model pure culture and relevant consortium culture sulphate-reducing systems to alter the model minerals biotically and to examine the fate of the radionuclides during alteration processes using wet geochemical and direct speciation approaches.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

### End point
Site Specific Validation

### Customer
Disposal System Safety Case

### Further information
This study is being undertaken via a doctoral project at the University of Manchester.
Title
Microbial niches in the ILW near field

Background
An understanding of radionuclide behaviour in the engineered barrier system (EBS) is important in order for appropriate treatment to be incorporated into performance assessments. As RWM’s programme progresses, it will be important to build confidence that the individual components of the EBS work together to provide a system that functions correctly. Within this research sub-topic, RWM considers additional processes that overlap with other key research areas (such as gas generation, waste package longevity and wasteform degradation) that impact on near-field evolution.

Microbes will be present in the GDF environment; some species may be present naturally in the host rock, whilst others may be introduced from the surface during GDF construction and operation. Microbial processes have the potential to alter the near-field chemistry and to promote corrosion and other degradation processes. The microbial community present and its activity will be influenced by the cementitious backfill and its geochemical evolution. In the early post-closure period, the most significant effect on microbial activity is thought to be the effect of the high pH on the microbial community. Other factors introduced by heterogeneities within the near field may lead to the development of microbial niches, such as the development of areas of NRVB which has been carbonated or the effect of areas of lower pH.

Research Need
To support the disposal system safety case (DSSC) by developing an understanding of the effect of heterogeneity within a cementitious ILW vault on the establishment of microbial niches.

Research Objective
To develop an understanding of heterogeneity within a cementitious ILW vault under GDF-relevant conditions and the subsequent impact on the microbial activity within the near field.

Scope
This PhD project will involve a laboratory-based study to:
- Investigate the evolution of the microbial community in response to cementitious backfill material and its geochemical evolution, and characterise the microbial communities and activity in geochemical niches within the cement backfill
- Investigate the interactions of microbes with cementitious backfill materials, and characterise the microscale chemical and physical changes to the cement

SRL at task start 3    SRL at task end 4    Target SRL 4
End point Site Specific Validation
Customer Disposal System Safety Case

Further information
This study is being undertaken via a doctoral project at the University of Strathclyde.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>786</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

### PBS level 4
Radionuclide Behaviour

### PBS level 5
Radionuclide Behaviour in the Geosphere

### Title
NERC RATE Lo-RISE - Physicochemical Speciation and Transport

### Background
Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. Nevertheless, it is possible to study a range of near-surface environments which have been contaminated by natural and anthropogenic radionuclides in order to understand the speciation, transport and mobility of these radionuclides as they enter the food web.

### Research Need
To support safety assessments by developing a mechanistic understanding of the effects of biogeochemical processes upon radionuclide behaviour.

### Research Objective
To determine whether the study of four near-surface UK sites will allow the key environmental and biological processes which control the movement of C-14, U / Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 to be understood and modelled. This will facilitate the:

- Definition of biogeochemical baseline parameters.
- Definition of marine speciation and dispersion of C-14 and I-129.
- Understanding of soil and sediment transport properties.
- Molecular characterisation of naturally occurring organic matter-radionuclide interactions.

### Scope
- To characterise biogeochemical, biological and radiological conditions at four UK ‘natural laboratories’ spanning marine, intertidal and terrestrial settings. The focus is on C-14 and U / Ra, as radiologically important radionuclides, but the study will also collect information, where appropriate on Cs-137, Am-241, Pu, Sr-90 and I-129.
- To carry out controlled laboratory experiments, targeting key environmental variables which control radionuclide transport and biological uptake.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRL at task end</td>
<td>4</td>
</tr>
<tr>
<td>Target SRL</td>
<td>5</td>
</tr>
</tbody>
</table>

End point Site Specific Application of Understanding

Customer Disposal System Safety Case

### Further information
This is an RWM / NERC / EA co-funded project, managed on behalf of NERC under the Radioactivity and the Environment (RATE) programme by the British Geological Survey. In addition to the scientific objectives, the RATE programme has an objective of capacity building in the UK’s academic institutions. This collaboration with NERC and the EA underpins RWM's commitment to a tranche of ‘curiosity-driven’ research to balance our highly focussed needs driven research programme.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>787</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Radionuclide Behaviour in the Geosphere</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

NERC RATE Lo-RISE - Ecological Transfers and Transformations

**Background**

Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised.

Nevertheless, it is possible to study a range of near-surface environments which have been contaminated by natural and anthropogenic radionuclides in order to understand the speciation, transport and mobility of these radionuclides as they enter the food web.

**Research Need**

To support safety assessments by developing a mechanistic understanding of the effects of biogeochemical processes on radionuclide behaviour.

**Research Objective**

To determine whether the study of four near-surface UK sites will allow the key environmental and biological processes which control the movement of C-14, U / Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 to be understood and modelled. This will facilitate the:

- Definition and quantification of soil-plant transfers for U / Ra.
- Determination of the role of typical microbial communities present in the near-surface environment.
- Characterisation of the effects of the microbial population on U / Ra speciation and mobility.
- Determination of the ecosystem transfer factors for C-14 in the marine environment.

**Scope**

- Utilisation of four UK ‘natural laboratories’ to define and quantify soil-plant transfers and the role of microbial communities in these systems.'

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Site Specific Application of Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

This is an RWM / NERC / EA co-funded project, managed on behalf of NERC under the Radioactivity and the Environment (RATE) programme by the British Geological Survey. In addition to the scientific objectives, the RATE programme has an objective of capacity building in the UK’s academic institutions. This collaboration with NERC and the EA underpins RWM’s commitment to a tranche of ‘curiosity-driven’ research to balance our highly focussed needs driven research programme.
### Background

Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised. Nevertheless, it is possible to study a range of near surface environments which have been contaminated by natural and anthropogenic radionuclides in order to understand the speciation, transport and mobility of these radionuclides as they enter the food web.

### Research Need

To support safety assessments by developing a mechanistic understanding of the effects of biogeochemical processes on radionuclide behaviour.

### Research Objective

To determine whether the study of four near-surface UK sites will allow the key environmental and biological processes which control the movement of C-14, U / Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 to be understood and modelled. This will facilitate the:

- Development of reactive transport modelling for soils and sediments.
- Mechanistic modelling of plant uptake.
- Understanding of C-14 transport and food-web modelling in the marine environment.
- To undertake reactive transport modelling in soils and sediments.
- The mechanistic modelling of plant uptake.
- To understand C-14 transport and food web modelling in the marine environment

### Scope

- To develop, test and apply mathematical models of radionuclide transport and biological uptake for relevant ecological processes at the four UK field sites: including marine dispersion, marine food web transfers, biogeochemical transport and soil-plant transfer.¹

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRL at task end</td>
<td>4</td>
</tr>
<tr>
<td>Target SRL</td>
<td>5</td>
</tr>
</tbody>
</table>

### Further information

This is an RWM / NERC / EA co-funded project, managed on behalf of NERC under the Radioactivity and the Environment (RATE) programme by the British Geological Survey. In addition to the scientific objectives, the RATE programme has an objective of capacity building in the UK’s academic institutions. This collaboration with NERC and the EA underpins RWM’s commitment to a tranche of ‘curiosity-driven’ research to balance our highly focussed needs driven research programme.
Task Number: 789
Status: Start date in future

PBS level 4: Radionuclide Behaviour
PBS level 5: Radionuclide Behaviour in the Geosphere

Title
Application of Lo-RISE Outputs in the GDF Context

Background
Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised.

Nevertheless, it is possible to study a range of near surface environments which have been contaminated by natural and anthropogenic radionuclides in order to understand the speciation, transport and mobility of these radionuclides as they enter the food-web. This task is a review of the outputs from the radionuclide behaviour aspects of the RATE Lo-RISE programme (Tasks 786-788), which runs from 2014 – 2019, studying the near-surface environment.

Research Need
To support safety assessments by developing a mechanistic understanding of the effects of biogeochemical processes on radionuclide behaviour.

Research Objective
To determine whether the understanding of the key environmental and biological processes which control the movement of C-14, U / Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 in the near surface are the same as those at depth.

Scope
To assess environmental and biological processes from Lo-RISE and a specify a work programme to validate these in relevant deep environments that are representative of the GDF and to incorporate these into process models.

SRL at task start: 2  SRL at task end: 4  Target SRL: 5

End point: Site Specific Application of Understanding

Customer: Disposal System Safety Case

Further Information
This is an internal review of the outputs of a RWM / NERC / EA co-funded project, managed on behalf of NERC under the Radioactivity and the Environment (RATE) programme by the British Geological Survey. In addition to the scientific objectives, the RATE programme has an objective of capacity building in the UK’s academic institutions. This collaboration with NERC and the EA underpins RWM's commitment to a tranche of ‘curiosity-driven’ research to balance our highly focussed needs driven research programme.
Appendix B - 345

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Radionuclide Behaviour in the Geosphere</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Laboratory / In Situ Studies to Address any Key Radionuclide Behaviour Uncertainties Arising from Lo-RISE

**Background**

Our understanding of radionuclide transport mechanisms is considered to be mature. The uptake of radionuclides on rocks surrounding the GDF is an important safety function in many concepts and is influenced by rock composition and groundwater geochemistry (amongst others). However, until a potential candidate site is identified the deep geological performance cannot be characterised.

Nevertheless, it is possible to study a range of near surface environments which have been contaminated by natural and anthropogenic radionuclides in order to understand the speciation, transport and mobility of these radionuclides as they enter the food-web.

This task has been created in order to build on the outputs from the RATE Lo-RISE programme which runs from 2014 – 2019, studying the near-surface environment.

**Research Need**

To support safety assessments by developing a mechanistic understanding of biogeochemical processes on radionuclide behaviour.

**Research Objective**

To determine whether the understanding of the key environmental and biological processes which control the movement of C-14, U / Ra, Cs-137, Am-241, Pu, Sr-90 and I-129 in the near surface are the same as those at depth.

**Scope**

The scope will depend on the assessment of Lo-RISE outputs (Task 789).

In order to confirm important near-surface processes are the same as those at depth some confirmatory studies may be required. These may be modelling activities or laboratory tests.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Application of Understanding

Customer: Disposal System Safety Case

**Further information**

This is a follow-on task to be undertaken following review of the outputs of a RWM / NERC / EA co-funded project, managed on behalf of NERC under the Radioactivity and the Environment (RATE) programme by the British Geological Survey. In addition to the scientific objectives, the RATE programme has an objective of capacity building in the UK's academic institutions. This collaboration with NERC and the EA underpins RWM's commitment to a tranche of 'curiosity-driven' research to balance our highly focussed needs driven research programme.
Background

The 2010 generic Disposal System Safety Case (DSSC) was the first holistic consideration of the potential implications of managing depleted, natural and low-enriched uranium (DNLEU) through geological disposal. The same concept as used for ILW / LLW was extended to cover DNLEU as a first-pass approach to the consideration of these materials in a geological disposal system.

As part of the generic DSSC, the 2010 generic Post-closure Safety Assessment (PCSA) illustrative calculations for the ILW / LLW and DNLEU disposal concepts were therefore based on the radionuclide dataset that was used previously by Nirex in 2003 in the Generic Performance Assessment. Whilst some information was published explaining the rationale behind the chosen parameter values a need exists to improve the underpinning of this work. The output from this task (conducted under RWM's Uranium Integrated Project) will increase confidence in the thermodynamic data for U and its daughter elements used in assessment calculations and in the representation of uncertainties in performance assessment studies.

Research Need

To support the Safety Assessment and Concept Development Teams by developing an appropriate set of parameter distributions for uranium to reflect the associated uncertainty. These distributions will be used in scoping assessment calculations and in the representation of uncertainties for these data.

Research Objective

- To develop an improved set of thermodynamic data for U and its daughter elements.
- To afford a more appropriate understanding of the long-term behaviour of DNLEU in a geological disposal facility.

Scope

This task comprises a new elicitation of U solubility in the near-field of a GDF under a number of potential future conditions. The task may be extended to include the sorption coefficient for U in the near field, and near-field solubility / sorption parameters for U daughters, as required. This material will be included in the task report to provide confidence in the appropriateness of the derived parameter distributions.

Further information

Relevant publications include:
J Wilson, S Watson, G Towler, and L Limer, 2012, An Assessment of Key Controls for the Disposal of Uranium Wastes, Quintessa Report QRS-1384P-R1, v2.2 for NDA RWMD.
Uranium Integrated Project Team (IPT): Improved Data Set for Depleted Natural Low-Enriched Uranium (U) and Daughter Elements in the Far-Field

Background

The 2010 generic Disposal System Safety Case (DSSC) was the first holistic consideration of the potential implications of managing depleted, natural and low-enriched uranium (DNLEU) through geological disposal. The same concept as used for ILW / LLW was extended to cover DNLEU as a first-pass approach to the consideration of these materials in a geological disposal system. As part of the generic DSSC, the 2010 generic Post-closure Safety Assessment (PCSA) illustrative calculations for the ILW / LLW and DNLEU disposal concepts were therefore based on the radionuclide dataset that was used previously by Nirex in 2003 in the Generic Performance Assessment. Whilst some information was published explaining the rationale behind the chosen parameter values a need exists to improve the underpinning of this work. The output from this task (conducted under RWM’s Uranium Integrated Project) will increase confidence in the thermodynamic data for U and its daughter elements used in assessment calculations and in the representation of uncertainties in performance assessment studies.

Research Need

To support the Safety Assessment and Concept Development Teams by developing an appropriate set of parameter distributions for uranium to reflect the associated uncertainty. These distributions will be used in scoping assessment calculations and in the representation of uncertainties for these data.

Research Objective

- To afford a more appropriate understanding of the long-term behaviour of DNLEU in a GDF by developing a conceptual model of the transport of U and its daughters from a GDF, taking account of interactions with naturally occurring U and daughters in the far-field. The aim is to identify those processes that could significantly affect the overall rates of transport of uranium and daughters through the disposal system.
- To support wider understanding of the potential for uranium and daughter migration from a GDF, in order to underpin future PCSA calculations and long-term safety arguments.

Scope

Development of this conceptual model will include identification of the processes and mechanisms that determine U transport in the presence of naturally occurring uranium and the factors that determine where these processes would take place and the rates at which they occur. If further development of the approach is considered necessary, this task would consider potential approaches to implementation. At this stage, it is considered that a reactive transport model would be appropriate for implementing the revised conceptual model at a detailed level in order to inform parameterisation of future generic post-closure performance assessment studies.

SRL at task start 4  SRL at task end 4  Target SRL 5

End point Site Specific Elicitation

Customer Disposal System Safety Case, Concept Development

Further information

Relevant publications include:


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Complete, pending publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Representation of Radionuclide Behaviour in Assessment Models</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Uranium Integrated Project Team (IPT): Review UK Solubility and Sorption Parameters for Uranium (U) and its Daughter Elements

**Background**

The 2010 generic Disposal Systems Safety Case (DSSC) was the first holistic consideration of the potential implications of managing depleted, natural and low-enriched uranium (DNLEU) through geological disposal. The same concept as used for ILW / LLW was extended to cover DNLEU as a first-pass approach of considering these materials in a geological disposal system.

As part of the generic DSSC, the 2010 generic Post-closure Safety Assessment (PCSA) illustrative calculations for the ILW / LLW and DNLEU disposal concepts were therefore based on the radionuclide dataset that was used previously by Nirex in 2003 in the Generic Performance Assessment. Whilst some information was published explaining the rationale behind the chosen parameter values a need exists to improve the underpinning of this work. The output from this task (conducted under RWM's Uranium Integrated Project) will increase confidence in the thermodynamic data for U and its daughter elements used in assessment calculations and in the representation of uncertainties in performance assessment studies.

**Research Need**

To support safety assessments and concept development by developing an appropriate set of parameter distributions for uranium to reflect the associated uncertainty. These distributions will be used in scoping assessment calculations and in the representation of uncertainties for these data.

**Research Objective**

- To afford a more appropriate understanding of the long-term behaviour of DNLEU in a geological disposal facility.
- To increase confidence in the thermodynamic data for uranium and its daughter elements used in assessment calculations and in the representation of uncertainties in these data.'

**Scope**

To re-examine the information underpinning parameter value distribution functions used in performance assessment studies in order to determine whether it is feasible to separate out the different uncertainties from the results of the previous elicitation sessions. A critical review of the information resulting from this exercise will identify where the description of disaggregated uncertainties is appropriate, and make recommendations for any additional elicitation exercises that might be required.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRL at task end</td>
<td>4</td>
</tr>
<tr>
<td>Target SRL</td>
<td>5</td>
</tr>
<tr>
<td>End point</td>
<td>Site Specific Elicitation</td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
</tr>
</tbody>
</table>

**Further information**

Relevant publications include:

Task Number 800

Status Start date in future

PBS level 4 Radionuclide Behaviour

PBS level 5 Representation of Radionuclide Behaviour in Assessment Models

Title

Data Elicitation for High Priority Radionuclide Sorption Parameters (e.g. Tc, U other long-lived HLW radionuclides)

Background

Where international consensus does not exist for data required in the safety case we use a structured process of data elicitation, whereby a trained team of international experts use a controlled process to derive probability density functions (PDFs) for the parameters.

A previous task (Task 898) will have developed an accepted and validated methodology for data elicitation and there is a subsequent need (covered by this task) to apply the methodology to certain key parameters.

Research Need

To support safety assessments by conducting expert data elicitation for high priority sorption parameters (e.g. Tc, U other long-lived HLW radionuclides).

Research Objective

- To use data elicitation to support the quantification and treatment of uncertainty for sorption parameters in a manner that feeds effectively into the safety case throughout the siting process.

Scope

To elicit from a suitably qualified expert panel and utilising approved methodology, sorption parameters (e.g. Tc, U other long-lived HLW radionuclides) to feed into the safety case.

SRL at task start 4
SRL at task end 5
Target SRL 5

End point Site Specific Elicitation

Customer Disposal System Safety Case

Further information

Relevant Publications Include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>801</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PBS level 4**
Radionuclide Behaviour

**PBS level 5**
Representation of Radionuclide Behaviour in Assessment Models

**Title**
Data Elicitation for Other Radionuclide Sorption Parameters

**Background**
Where international consensus does not exist for data required in the safety case we use a structured process of data elicitation, whereby a trained team of international experts use a controlled process to derive probability density functions (PDFs) for the parameters.

A previous task (Task 898) will have developed an accepted and validated methodology for data elicitation and there is a subsequent need (covered by this task) to apply the methodology to certain parameters.

**Research Need**
To support safety assessments by conducting expert data elicitation for lower priority sorption parameters.

**Research Objective**
Continuation of Task 800, with the objective to use data elicitation to support the quantification and treatment of uncertainty in a manner that feeds effectively into the safety case throughout the siting process.

**Scope**
To elicit from a suitably qualified expert panel and utilising approved methodology, sorption parameters for a range of lower priority radionuclides to feed into the safety case.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Application of Understanding

**Customer**
Disposal System Safety Case

**Further information**
Relevant Publications Include:
Review of the Use of Beta Values

Background

Data parameters for the sorption to the geosphere bulk rock are determined largely from laboratory experiments on crushed rock samples equilibrated with various radionuclides in appropriate groundwater or near field simulant solutions. Laboratory measurements made on crushed rock are likely to have different surface areas to intact rock samples. In order to derive values of sorption distribution coefficients that are appropriate for sorption to intact rock from values obtained in batch laboratory experiments the crushed rock Kd values are multiplied by a factor called the 'beta factor'. The beta parameters reflect an understanding of the relative surface areas of crushed and intact rock samples and have been derived by comparison of the results of batch and intact rock sorption experiments through the application of this correction factor.

The beta values were elicited as part of the Nirex programme using experimental sorption measurements on crushed and intact rock for a selection of radionuclides. The beta values are used for species in addition to these; therefore, a review of the applicability of the beta values is advised.

Research Need

To support the integrity of the post-closure safety case by reviewing the validity of our use of beta values to correct batch-derived sorption data for a realistic scenario of contacting intact rock.

Research Objective

To substantiate the use of beta values.

Scope

The scope comprises the following elements:
- To review the use of beta values for scaling crushed rock experiments to bulk intact rock values required as part of the total system model.
- To specify the appropriateness of the values (e.g. for which rock / mineral types, radionuclides, etc).
- To consider whether one beta value set is required for all radionuclides or whether they should be radionuclide-specific.
- A review of how other organisations deal with scaling will also be undertaken to ensure RWM are using best practice.

SRL at task start 4 SRL at task end 4 Target SRL 4

End point No Further Generic Research Planned

Customer Disposal System Safety Case

Further information

Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>806</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Development of Thermodynamic Database</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

NEA Thermodynamic Database (TDB): Development of Internationally Recommended High Quality Thermodynamic Data Parameters (Actinide Update, Cement Phases, High Ionic Strength Media and High Temperature Corrections)

**Background**

Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed 'linear sorption', and it is generally argued that the approach is an adequate simplification for use in performance assessment. Thermodynamic modelling is used to build understanding of sorption processes and to confirm the adequacy of the linear sorption approach; the output from such modelling is strongly dependent on the quality of thermodynamic data used to calculate chemical speciation.

RWM are involved in a number of projects to develop and maintain thermodynamic databases (TDB). This includes development and maintenance of the current RWM TDB HATCHES, which was developed by Nirex in the late 1980s, and more recently collaboration with Andra on the development of their thermodynamic database ThermoChimie.

This task relates to the Nuclear Energy Agency (NEA) TDB. The first phase of the NEA TDB project was initiated in 1984 to fulfil the need for a high quality, internationally recognised and quality assured database for modelling purposes. NDA partially fund this project in collaboration with other international organisations under the auspices of the NEA to produce high quality, peer reviewed and internally consistent datasets for elements of interest in the geological disposal of radioactive waste. Now in Phase 5, the project continues with an aim to provide continued improvements and additional thermodynamic data, updating the database and addressing methodological developments.

**Research Need**

To develop and maintain a consistent set of thermodynamic data to support safety assessments.

**Research Objective**

To identify internationally recommended high-quality thermodynamic data parameters for key elements and minerals. By gaining international consensus, consistency will be improved between other programmes and a robust data-trail created.

**Scope**

This is Phase 5 of the NEA TDB project and will include an actinide update, cement review, high ionic strength review and non-standard temperature correction methods.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>Application of Understanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

For further information:

NEA TDB project website [https://www.oecd-nea.org/dbtdb/](https://www.oecd-nea.org/dbtdb/)
<table>
<thead>
<tr>
<th>Task Number</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>807</td>
<td>Radionuclide Behaviour</td>
<td>Development of Thermodynamic Database</td>
</tr>
</tbody>
</table>

**Title**

Database Maintenance Including Updates From Reviews and Experiments on Elements of Importance Within Near Field and Geosphere

**Background**

A database with enhanced user interface and up-to-date thermodynamic properties is required for key radionuclides and chemotoxic elements in the presence of cement and a variety of rock and mineral surfaces relevant to GDF scenarios (e.g. sorption coefficients, binding constants). The current thermodynamic database (TDB), HATCHES, was developed by Nirex in the late 1980s as a referenced TDB that contained information on the aqueous chemistry of key radionuclides. A key objective of HATCHES is to provide a fully referenced source of thermodynamic data, which has a transparent audit trail of database updates, for use by RWM.

Whilst HATCHES is the current TDB it has gone through a period of limited maintenance. As a result of this, a review was held to identify the way forward in developing a TDB. This review identified collaboration with Andra on their TDB, ThermoChimie, as the preferred option. An exploratory collaboration with Andra is ongoing to jointly develop ThermoChimie to ensure consistency and validation of the thermodynamic data within the database and provide robust traceability during database development. In the meantime HATCHES will remain as RWM's TDB.

In addition to funding the development of our thermodynamic dataset, NDA also part-fund a multi-national effort under the auspices of the NEA to produce high-quality, peer-reviewed, internally consistent datasets for elements of interest in the geological disposal of radioactive waste. The existence of internationally-agreed, high quality thermodynamic data is of benefit to RWM as it provides access to internationally-recognised, world-class data for the radionuclides which are critical for determining the safety of a GDF.

**Research Need**

To develop and maintain a consistent set of thermodynamic data to support safety assessments.

**Research Objective**

To identify a consistent set of thermodynamic data to support the RWM programme.

**Scope**

- To develop and maintain a thermodynamic database.
- To conduct research to close data gaps using data from a variety of sources.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Application of Understanding

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:


https://www.thermochimie-tdb.com
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Radionuclide Behaviour</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Development of Thermodynamic Database</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

NEA Thermodynamic Database (TDB): Further Development of Internationally Recommended High Quality Thermodynamic Data Parameters (Actinide Update, Cement Phases, High Ionic Strength Media and High Temperature Corrections)

**Background**

Sorption is currently represented in post-closure assessments by an approach that assumes that the ratio of adsorbed to dissolved contaminant is constant and independent of the concentration of contaminants in the system. This concept is termed 'linear sorption', and it is generally argued that the approach is an adequate simplification for use in performance assessment. Thermodynamic modelling is used to build understanding of sorption processes and to confirm the adequacy of the linear sorption approach; the output from such modelling is strongly dependent on the quality of thermodynamic data used to calculate chemical speciation.

RWM are involved in a number of projects to develop and maintain thermodynamic databases (TDB). This includes development and maintenance of the current RWM TDB HATCHES, which was developed by Nirex in the late 1980s, and more recently collaboration with Andra on the development of their thermodynamic database ThermoChimie.

This task relates to the Nuclear Energy Agency (NEA) TDB. The first phase of the NEA TDB project was initiated in 1984 to fulfil the need for a high quality, internationally recognised and quality assured database for modelling purposes. NDA partially fund this project in collaboration with other international organisations under the auspices of the NEA to produce high quality, peer reviewed and internally consistent datasets for elements of interest in the geological disposal of radioactive waste. Now in Phase 5, the project continues with an aim to provide continued improvements and additional thermodynamic data, updating the database and addressing methodological developments.

**Research Need**

To develop and maintain a consistent set of thermodynamic data to support safety assessments.

**Research Objective**

Continuation of Task 806 with the objective of identifying internationally recommended high quality thermodynamic data parameters for key elements and minerals and providing consistency with other programmes and a robust data trail by gaining international consensus.

**Scope**

This task is based on the assumption that the NEA Thermodynamic Database project will continue after Phase 5 (as outlined in Task 806). The scope is yet to be determined.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Application of Understanding

**Customer**

Disposal System Safety Case

**Further information**
Task Number | Status | Start date in future
--- | --- | ---
809 |  | 

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Radionuclide Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Development of Thermodynamic Database</td>
</tr>
</tbody>
</table>

**Title**
Further Database Maintenance Including Updates From Reviews and Experiments on Elements of Importance Within the Near Field and Geosphere

**Background**
A database with enhanced user interface and up-to-date thermodynamic properties is required for key radionuclides and chemotoxic elements in the presence of cement and a variety of rock and mineral surfaces relevant to GDF scenarios (i.e. sorption coefficients, binding constants). The current thermodynamic database (TDB), HATCHES, was developed by Nirex in the late 1980s as a referenced TDB that contained information on the aqueous chemistry of key radionuclides. A key objective of HATCHES is to provide a fully referenced source of thermodynamic data, which has a transparent audit trail of database updates, for use by RWM.

Whilst HATCHES is the current TDB it has gone through a period of limited maintenance. As a result of this, a review was held to identify the way forward in developing a TDB. This review identified collaboration with Andra on their TDB, ThermoChimie, as the preferred option. An exploratory collaboration with Andra is ongoing to jointly develop ThermoChimie to ensure consistency and validation of the thermodynamic data within the database and provide robust traceability during database development. In the meantime HATCHES will remain as RWM's TDB.

In addition to funding the development of our thermodynamic dataset, NDA also part-fund a multi-national effort under the auspices of the NEA to produce high-quality, peer-reviewed, internally consistent datasets for elements of interest in the geological disposal of radioactive waste. The existence of internationally-agreed, high quality thermodynamic data is of benefit to RWM as it provides access to internationally-recognised, world-class data for the radionuclides which are critical for determining the safety of a GDF.

**Research Need**
To develop and maintain a consistent set of thermodynamic data to support safety assessments.

**Research Objective**
To identify a consistent set of thermodynamic data to support the RWM programme.

**Scope**
To ensure that the thermodynamic database remains up-to-date and fit for purpose by having a supporting experimental programme.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point | Application of Understanding
--- | ---
Customer | Disposal System Safety Case

**Further information**
Relevant publications include:
https://www.thermochimie-tdb.com
Task Number | 816 | Status | Start date in future
PBS level 4 | Radionuclide Behaviour
PBS level 5 | Development and Maintenance of Thermodynamic Models

Title
Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour

Background
The development of models to interpret experimental data is important to provide understanding of the processes which control radionuclide behaviour in the various barriers of a GDF and to support the GDF post-closure safety assessment. Thermodynamic models are important for the interpretation of experimental observations of radionuclide behaviour and prediction of behaviour over the long timescales relevant to a GDF (e.g. ~1 million years).

Research Need
To support the safety case by developing a suite of detailed mechanistic models for the processes that control sorption and solubility.

Research Objective
- To represent radionuclide sorption to a range of surfaces, and partitioning between phases, using detailed mechanistic models.
- To develop modelling tools to appropriately represent the processes of sorption and solubility of radionuclides in the near and far-fields of a GDF.

Scope
To develop detailed mechanistic models for the processes controlling sorption and solubility using outputs and knowledge gained from experimental programmes of work, e.g. tasks 736, 737, 740 and 741.

SRL at task start | 3 | SRL at task end | 4 | Target SRL | 5
End point | Site Specific Application of Understanding
Customer | Disposal System Safety Case

Further information
For further information:
'http://hatches-database.com/
http://www.thermochimie-tdb.com/
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>817</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PBS level 4 | Radionuclide Behaviour

PBS level 5 | Development and Maintenance of Thermodynamic Models

**Title**

Update to Process Model for Colloidal / Microbial Processes

**Background**

The development of models to interpret experimental data is important to provide understanding of the processes which control radionuclide behaviour in the various barriers of a GDF and to support the GDF post closure safety assessment. Thermodynamic models are important for the interpretation of experimental observations of radionuclide behaviour and prediction of behaviour over the long timescales relevant to a GDF (e.g. ~1 million years).

**Research Need**

To support the safety case by developing a suite of detailed mechanistic models for the processes that control sorption and solubility.

**Research Objective**

To represent radionuclide uptake and partitioning in models to take account of colloidal and microbial affects.

**Scope**

Update to the mechanistic models of sorption and solubility controlling processes, developed in Task 816, to incorporate microbial- and colloidal-mediated processes using knowledge gained from experimental programmes of work e.g. Tasks 383, 754, 755, 756.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Application of Understanding

**Customer**

Disposal System Safety Case

**Further information**

This work follows on from that completed as part of Tasks 383, 754, 756.
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>826</td>
<td>Ongoing</td>
<td>Safety Assessments</td>
<td>Transport Safety Case</td>
</tr>
</tbody>
</table>

**Title**

Development of a Suite of Contents Specification Documentation for all Package Types

**Background**

RWM develops and maintains a range of transport container designs and an associated suite of contents specification documentation. This is to demonstrate that radioactive wastes can be transported safely to a geological disposal facility and to inform the disposability assessment of the transport safety or waste producer waste packaging proposals. The contents specification documentation sets out the contents requirements in order to ensure:

- Containment of the radioactive contents during handling and transport (Containment System).
- Control of external radiation levels (e.g. by shielding).
- Prevention of nuclear criticality in the case of fissile material.
- Prevention of the damage caused by heat (e.g. by heat dissipation).

Prior to commencing radioactive waste transport to a geological disposal facility a range of transport container designs will require approval. It is envisaged that the contents specification documentation will be used as a basis for producing the package design safety reports for the transport container designs for which RWM is the design authority.

RWM's contents specification documentation is currently structured into two subsets of documents: contents specification documents, which set out the limits to ensure containment, control external radiation levels and prevent damage caused by heat; and criticality safety assessments, which set out limits to ensure sub-criticality for package designs anticipated to be qualified to contain fissile material.

**Research Need**

To demonstrate that radioactive wastes can be transported safely to a geological disposal facility, and to inform disposability assessments of the transport safety or waste producer waste packaging proposals.

**Research Objective**

To develop and maintain a suite of contents specification documentation.

**Scope**

The scope of this task includes: development of the contents specification documentation (i.e. the suite of contents specification documents and criticality safety assessments), their underpinning methodologies and some supporting data or information. Thus the task scope for mature designs is a watching brief. Other scope includes:

- Accounting for improvements in the knowledge base, e.g. changes in good practice in the wider radioactive material transport community.
- Addressing new or innovative waste packaging proposals or changes to generic transport system design.
- Responding to changes in regulatory requirements for the transport of radioactive material.
- Produce the methodology and contents specification for the SWTC-150.
- Development of criticality safety assessments for the SWTC family of transport package designs.
- Consider the effect of packaging materials that contain other classes of dangerous goods as well as class 7 (radioactive materials).

SRL at task start | SRL at task end | Target SRL |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

Watching Brief

**Customer**

Disposal System Safety Case

**Further information**

Relevant publications include:

Task Number | Status
--- | ---
828 | Ongoing

PBS level 4 | Safety Assessments
PBS level 5 | Transport Safety Case

Title

Maintenance of Transport Safety Assessment Toolkits

Background

To inform the disposability assessment of transport safety or waste producer waste packaging proposals, RWM develops and maintains a range of transport container designs and an associated suite of contents' specification documentation. The contents specification documentation sets out the contents requirements in order to ensure:

- Containment of the radioactive contents during handling and transport (containment system).
- Control of external radiation levels (e.g. by shielding).
- Prevention of nuclear criticality in the case of fissile material.
- Prevention of the damage caused by heat (e.g. by heat dissipation).

To provide a robust means of checking a waste packaging proposal against the constraints set out in the contents specification documentation, RWM produces toolkits that automate the comparison of a waste package inventory against the numerical contents limits.

RWM currently maintain three transport safety assessment toolkits:

- Transport Contents Assessment Toolkit (TOpCAT), which considers limits to ensure containment safety, control external radiation levels and prevent damage caused by heat;
- Criticality Contents Assessment Toolkit (CritiCAT), which considers limits to ensure sub-criticality;
- Transport and Operations Dose Assessment toolkit (TODA), providing dose uptake information.

Research Need

To provide a means to check waste producer waste packaging proposals against the transport package contents limits to ensure transport safety.

Research Objective

The scope of this task is maintenance of existing transport safety assessment toolkits. Thus the task scope is responsive to changes in the underlying contents limits and other needs. Specific development needs are:

- Update of the toolkits to take account of revisions in the transport regulations.
- Update of the toolkits to the contents limits for a new package design.
- Update of the toolkits to provide compatibility with a new software operating environment.
- Update of the toolkits facilitate the new fissile exception.

Scope

This task is a watching brief to maintain the transport safety assessment toolkits in response to changes in the underlying contents limits.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
<th>End point</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td>6</td>
<td>Maintenance of Toolkit</td>
<td>Disposal System Safety Case</td>
</tr>
</tbody>
</table>

Further information

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>830</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Safety Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Transport Safety Case</td>
</tr>
</tbody>
</table>

**Title**

Review and Update the Transport Safety Manual (TSM) to Take Account of Peer Review by INS and Lessons Learned in TSM 2016

**Background**

The transport safety manual (TSM), taken to include the associated procedures and work instructions, was adopted as part of the RWM management system in 2015. This will be used to support and control production of the 2016 transport safety case.

**Research Need**

Review and update the TSM based on learning from using the manual in the 2016 transport safety case update and to address feedback provided as a result of INS peer review.

**Research Objective**

Provide confidence that the TSM remains fit for purpose.

**Scope**

- Commission peer review of TSM from INS, agree peer review comments and consequential required changes.
- Following completion of the 2016 transport safety case update, undertake review of the TSM and supporting procedures and work instructions, identify lessons learned and identify appropriate changes.

Note: This should be the first of an on-going review cycle.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>End point</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reissued Transport Safety Manual</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposal System Safety Case</td>
<td></td>
</tr>
</tbody>
</table>

**Further information**

Disposal System Safety Case
Task Number | 847 | Status | Ongoing
--- | --- | --- | ---
PBS level 4 | Safety Assessments
PBS level 5 | Operational Safety Case
Title | Develop and Maintain Operational Safety Assessments Toolkit(s)

Background
At this early stage of design, it is not possible to carry out a fully comprehensive fault analysis to provide an Operational Safety Case (OSC). However, in order to progress in establishing our methodology an example accident assessment on the sub-set of quantifiable faults has been carried out and was published in the 2010 Disposal System Safety Case (DSSC). This will continue to be developed into an OSC that meets the requirements of Office of Nuclear Regulation (ONR). Following its publication in 2010, regulatory review of the DSSC resulted in a recommendation for RWM to align the safety case with the ONR Safety Assessment Principles (SAPs) (recommendation R22).

An Operational Safety Assessment Toolkit (known as ROSA) was developed to support the Design Basis Accident (DBA) analysis and reported in the 2010 OSC. To support the update to the 2016 DSSC, there are separate programmes of work to develop toolkits that underpin different parts of the safety case. The current status is as follows:

- OSC Vol.1: Conventional and construction safety. No toolkits are planned to support this safety case.
- OSC Vol.2: Normal operational safety case. To support the normal operational safety case, a Transport and Routine Dose Assessment Toolkit (known as TODA) will jointly developed with RWM’s transport experts to provide estimated direct external radiation doses to workers and the public;
- OSC Vol.3: Accident safety assessment. No toolkits are planned to support this update to the safety case. A replacement toolkit for ROSA was planned to support the Disposability Assessment process;
- OSC Vol.4: Criticality safety assessment. A toolkit RADSORT has been developed which employs a screening methodology based on previously determined safe fissile masses for various waste categories and package types to identify those waste streams that could present a criticality concern during the operational phase of a GDF.

Research Need
To support the development of the Operational Safety Case by developing appropriate methodologies and toolkits in line with the ONR’s Safety Assessment Principles.

Research Objective
To develop the methodologies and toolkit(s) that support the Operational Safety Case in line with regulatory guidance and expectations.

Scope
The scope comprises the following activities:
- To develop and publish RWM’s Nuclear Operational Safety Manual. This will establish the methodologies for each of the different parts of the OSC.
- To develop the toolkits to apply the methodologies and assess the operational safety of a GDF.
- To establish the performance data (in terms of radionuclide release and dose rates) for input into the toolkits; e.g. waste package impact accident, criticality performance, etc.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>3</th>
<th>SRL at task end</th>
<th>4</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
</table>
End point | Site Specific Validation
Customer | Disposal System Safety Case

Further information
Relevant publications include:
Nuclear Decommissioning Authority, Geological Disposal: Generic Operational Safety Assessment -
| ONRs SAPs: http://www.onr.org.uk/saps/ The current version is 2006 edition (Revision 1, 2008). |
**Task Number** | **848**  
---|---  
**Status** | Start date in future  
**PBS level 4** | Safety Assessments  
**PBS level 5** | Operational Safety Case

**Title**
Develop and Maintain Operational Safety Assessments Toolkit(s) to Assess Specific Sites

**Background**
Moving towards a specific site or sites with a detailed design for a GDF, sufficient data will be available to carry out a fully comprehensive fault analysis to provide a Preliminary Safety Report (PSR). A PSR for each site will be submitted to the Office of Nuclear Regulation (ONR). To support the site-specific PSR(s), the current toolkits will need to be developed to provide estimated dose consequence data for use in the operational safety case arguments.

**Research Need**
To support the development of the Operational Safety Case through appropriate methodologies and toolkits in line with the ONR’s Safety Assessment Principles.

**Research Objective**
To develop the methodologies and toolkit(s) that support the Operational Safety Case in line with regulatory guidance and expectations.

**Scope**
The scope for this task is dependent upon the results and findings of preceding Task 849 (in which the initial toolkits were developed) and is currently undefined, however the following activities may be required:
- Normal operational safety – the range of calculations in TODA (see Task 849) may need to be expanded to include other facilities at a GDF not in the emplacement route, such as the Active Effluent Treatment Plant;
- A toolkit to support the Design Basis Accident analysis may be required (see Task 849);
- The RADSORT toolkit to support the operational criticality safety case may require further development (see task number 849).

Other toolkits will be required to extend our safety case to include understanding of:
- Probabilistic Safety Assessment, which requires details of facility items such as crane failure probabilities;
- Maintenance schedules, which are schedules of all work needed on the facility and plant (including periodic review) and its periodicity. The safety analysis could be supported by a toolkit.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>5</th>
</tr>
</thead>
</table>

**End point**
Maintenance of Toolkit

**Customer**
Disposal System Safety Case

**Further information**
For further information:
Appendix B - 364

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Safety Assessments</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Operational Safety Case</td>
<td></td>
</tr>
</tbody>
</table>

### Title

Development of Methodologies and Safety Assessment for 2016 Operational Safety Case

### Background

The operational safety case (OSC) was published in 2010 as a component of the generic disposal system safety case (DSSC). The generic DSSC is maintained under change control and will be updated periodically to reflect changes in the knowledge base or to meet other external drivers. The DSSC suite is being updated in the period 2015-16 in order to reflect changes brought about by the 2013 UK Radioactive Waste Inventory and the 2014 White Paper so that it can provide a suitable basis to support the revised GDF siting process. The OSC is a major component of the generic DSSC and will be updated, peer reviewed and published as part of this process.

### Research Need

To present a modern standards operational safety case.

### Research Objective

To demonstrate feasibility of geological disposal from perspective of operational safety.

### Scope

- Develop basis of assessment
- Undertake updated assessments
- Peer review
- Publication.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Disposal System Safety Case

### Further information


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>850</td>
<td>PBS level 4</td>
<td>Safety Assessments</td>
</tr>
<tr>
<td></td>
<td>PBS level 5</td>
<td>Operational Safety Case</td>
</tr>
</tbody>
</table>

**Title**
Extension of the Operational Safety Case to Cover Backfilling, Sealing and Closure

**Background**
Generic disposal facility design and operational safety case reports do not address backfilling, sealing and closure in sufficient detail to demonstrate that these operations can be accomplished safely and with minimal risk to operators. In order to bring our understanding up to the same level as for the rest of the operational period we need to define the operations required and identify potential faults and hazards. This will address regulator Recommendation R16 from the joint review of the 2010 generic disposal system safety case.

**Research Need**
To demonstrate that we understand the activities and hazards associated with backfilling, sealing and closure of a GDF.

**Research Objective**
To extend the scope of the operational safety case to cover backfilling sealing and closure.

**Scope**
This work requires collaboration between Engineering Design and Assessments teams:
- Define operations/activities involved in backfilling, sealing and closure of a GDF
- Extend functional Process Flow Diagram to cover these additional activities
- Undertake HAZID/HAZOP and extend Fault and Hazard Schedule
- Undertake safety assessment
- Update design and operational safety case documentation

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point: Site Specific Validation

Customer: Disposal System Safety Case

Further information
Task Number 851 | Status | Start date in future
---|---|---
PBS level 4 | Safety Assessments |
PBS level 5 | Operational Safety Case |

**Title**
Review and Update the Nuclear Operational Safety Manual (NOSM) to Take Account of Lessons Learned in 2016 Operational Safety Case

**Background**
The Nuclear Operational Safety Manual (NOSM) (taken to include the associated procedures and Work Instructions) was adopted as part of the RWM Management System in 2015. This will be used to support and control production of the 2016 operational safety case.

**Research Need**
Review and update the NOSM based on learning from using the manual in the 2016 operational safety case update.

**Research Objective**
Provide confidence that the NOSM remains fit for purpose.

**Scope**
Following completion of the 2016 operational safety case update, undertake review of the NOSM and supporting procedures and WIs, identify lessons learned and incorporate changes.

*Note: This should be the first of an on-going review cycle.*

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
Site Specific Validation

**Customer**
Disposal System Safety Case

**Further information**
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Safety Assessments</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Operational Safety Case</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Respond to Regulator Recommendation R21

**Background**

Following publication of the 2010 disposal system safety case regulators reviewed the documentation and issued a scrutiny report providing their views and a number of recommendations. Recommendation R21 states:

Consider regulatory expectations, as described in the HSE Safety Assessment Principles (SAPs), with respect to examination, inspection, maintenance and testing (EIMT), asset management, longevity and ageing/degradation.

**Research Need**

Demonstrate that we are aware of the impact of ageing on GDF plant and equipment and have a structured process, in line with Office of Nuclear Regulation (ONR) expectations, to identify maintenance requirements and record these in a fit for purpose engineering schedule.

**Research Objective**

Revisit and update the engineering schedule.

**Scope**

This work requires collaboration between Engineering Design and Assessments teams.

- Identify requirements to meet ONR expectations regarding examination, inspection, maintenance and testing (EIMT), asset management, longevity and ageing/degradation
- Update the engineering schedule
- Update generic disposal facility design report and operational safety case

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Site Specific Validation

**Customer**

Disposal System Safety Case

**Further information**
Task Number | 853 | Status | Start date in future
--- | --- | --- | ---
PBS level 4 | Safety Assessments | PBS level 5 | Operational Safety Case

Title
Undertake Evaluation of GDF Design and Safety Case Against the Western European Nuclear Regulators Association (WENRA) Safety Reference Levels for Radioactive Waste Disposal

Background
The Western European Nuclear Regulators Association (WENRA) has compiled a series of Safety Reference Levels for radioactive waste disposal facilities. These Safety Reference Levels are intended as a basis for future harmonisation at a European Level, although at this stage appear to be directed for use within individual member states. The WENRA report states that it is each country’s responsibility to implement actions to ensure that these levels are reached.

Research Need
Undertake a preliminary review of WENRA Safety Reference Levels to determine where we are compatible and where gaps may exist.

Research Objective
Undertake a gap analysis to inform future development of the Science & Technology Plan.

Scope
This work requires collaboration between Engineering Design and Assessments teams. The proposed approach is to review RWM processes, design and safety case against the Safety Reference Levels and come to a conclusion for each:

- RWM compliant
- RWM partially compliant – gap to be filled
- RWM not compliant – gap to be filled
- RWM not compliant – not expected to be compliant at this stage, gap to be filled in future
- RWM not compliant – not relevant

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point
Site Specific Validation

Customer
Disposal System Safety Case

Further information
### Task Number 854

**Status** Start date in future

**PBS level 4** Safety Assessments

**PBS level 5** Operational Safety Case

**Title**

Develop Licence Condition Arrangements Pertaining to Safety Case Development

**Background**

Before RWM applies for an environmental permit or nuclear site licence it will need to develop and submit to regulators “arrangements” for the production of safety and environmental documentation. These arrangements (often called Licence Condition Arrangements or LC Arrangements) will need to be submitted to the regulators for approval, as will any changes to the Arrangements.

These arrangements apply specifically to Licence Conditions (e.g. LC13, LC14, LC17, LC36) and the Environment Agency’s Guidance on Requirements for Authorisation (GRA) (e.g. R3, R4, R11). The arrangements will need to cover a wide range of RWM activities (including more than just Science & Technology). However, for the purposes of the Science & Technology Plan, we concentrate on those Arrangements particularly relevant to safety case development (e.g. LC14 Safety Documentation).

**Research Need**

Develop an understanding of the scope and requirements of safety-related Arrangements

**Research Objective**

Produce an overall Arrangements structure and specifications for safety related Arrangements.

**Scope**

- Develop LC Arrangements in skeleton form
- Develop document specifications for safety related documents
- Agree with internal stakeholders
- Adopt in Management System

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point** Site Specific Validation

**Customer** Disposal System Safety Case

**Further information**
**Task Number**: 855  
**Status**: Start date in future  

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Assessments</td>
<td>Operational Safety Case</td>
</tr>
</tbody>
</table>

**Title**  
Update of Disposability Assessment Work Instructions Based on 2016 Disposal System Safety Case

**Background**  
RWPR60-WI01 describes the evaluations and assessments required to support the Disposability Assessment process. Following publication of the 2016 generic disposal system safety case, the three work instructions controlling safety case evaluations will be required to be updated to reflect the revised safety case. The Work Instructions involved are:  
- RWPR60-WI13 Transport Safety Assessment  
- RWPR60-WI14 Operational Safety Assessment  
- RWPR60-WI15 Post-closure Safety Assessment

**Research Need**  
Review and update the Work Instructions controlling safety evaluations for the disposability assessment process

**Research Objective**  
Work Instructions that reflect the published generic safety cases

**Scope**  
Review and update as necessary:  
- RWPR60-WI13 Transport Safety Assessment  
- RWPR60-WI14 Operational Safety Assessment  
- RWPR60-WI15 Post-closure Safety Assessment

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**  
Site Specific Validation

**Customer**  
Waste Package Disposability Assessments

**Further information**  
This task interfaces with the task sheet related to operational safety toolkit update (Task 847)
Understanding the Implications of Voidage to the Post-closure Safety Case

Background

The disposal concept for ILW in higher strength rock requires the backfilling of disposal vaults with an ultra-high pH cement, such as the Nirex Reference Vault Backfill (NRVB), so as to provide conditions which minimise the mobility of radionuclides; this is termed the chemical barrier. RWM recognises that some degree of voidage within a GDF is inevitable and could be present, for example, through the inclusion of waste packages containing voidage, decisions regarding the disposal concept design and the practicalities of backfilling.

Recent waste packaging proposals for non-encapsulated wastes have highlighted the potential for the introduction for larger amounts of in-package voidage in a GDF than previously considered. This has led to the need to develop and substantiate appropriate post-closure safety arguments in order to ascertain the implications of introducing such voidage within a GDF. The aim of this task is to provide guidance to waste producers regarding the maximum allowable voidage within waste packages.

Research Need

To support the Letter of Compliance process by determining whether it is possible, or not, to provide guidance on acceptable levels of voidage within waste packages and within the GDF near-field with respect to post-closure safety in the absence of site-specific information.

Research Objective

To consider and develop post-closure safety arguments in relation to voidage to inform RWM decision making related to concept option selection, waste packaging guidance and safety case development.

Scope

To produce a clear summary of RWM’s position on voidage by:

- Undertaking a focussed literature review of the conceptualised mechanical, hydrogeological, and possibly, chemical evolution of a GDF.
- Further developing, and subsequently assessing, RWM’s conceptual models of the mechanical evolution of a GDF (also considering other coupled thermal, hydrogeological and chemical processes), for the illustrative host rocks and concepts considered by RWM.
- Developing safety arguments for relevant evolution scenarios and determining the limitations of what can be meaningfully inferred on the topic of voidage at a generic stage.
- If necessary, undertaking a simple analysis to determine the practicalities and implications (safety and indicative costs) of void-filling packages prior to disposal in a GDF but after they have been packaged.

Relevant publications include:

- Nuclear Decommissioning Authority, 2012, Geological Disposal: Overview of RWMD Approach to Definition of Safety Functions, [Section 2.3].
Title
Development of Total System Models to Assess the Post-closure Performance of Disposal Concepts for the 2016 Generic Disposal System Safety Case Update

Background
RWM uses a suite of total system models to evaluate the post-closure performance of concepts for the disposal of radioactive waste. These models represent the key physical and chemical processes which might influence post-closure performance. At a generic stage of siting it is the qualitative insight obtained from such models, rather than the absolute numerical outputs, which is significant.

Development of total system models is an ongoing task. In particular, for the 2016 generic DSSC update there is a requirement to address a wider range of geological environments within Total System Models. In addition, the high-heat, concept development and C-14 projects have identified benefits associated with the development of enhanced total system modelling capability to support concept and design development.

Research Need
- To support concept and design development and waste disposability assessments by developing understanding of the key factors that may influence the post-closure impact of the GDF.

Research Objective
- To incorporate understanding of chemotoxicity and recent advances in the C-14 gas-pathway in the post-closure models.
- To extend our existing suite of models of the evolution of a GDF in crystalline rock to also include a GDF in lower strength sedimentary rock for application in the 2016 Generic Disposal System Safety Case.

Scope
The scope comprises the following activities:
- Inclusion of chemotoxic, as well as radioactive, contaminants in GoldSim models.
- Development of a total system model to evaluate the risks associated with gaseous release of C-14.
- Development of models which more explicitly represent different types of geological environment.

Models will incorporate the results of research in assessments as they become available, e.g. C-14 biosphere modelling and experiments, experiments on glass and spent fuel dissolution, uranium IPT outputs.

SRL at task start 3 SRL at task end 4 Target SRL 5

End point Maintenance of Generic Model
Customer Disposal System Safety Case, Concept Development

Further information
Preparation of Total System Models for Future Application in the Siting Process

**Background**

The 2010 generic Disposal System Safety Case was the first holistic consideration of the potential implications of managing depleted, natural and low-enriched uranium (DNLEU) through geological disposal. The same concept as used for ILW / LLW was extended to cover depleted, natural and low-enriched uranium (DNLEU) as a first-pass approach to the consideration of these materials in a geological disposal system.

This task builds on Task 868, to further develop the models built to support the 2016 generic Disposal System Safety Case, to more explicitly represent different types of geological environment for application in the siting process.

Development of total system models was also identified as a requirement following external reviews of the 2010 generic Disposal System Safety Case. In addition, the high-heat, concept development and C-14 integrated projects have identified benefits associated with the development of enhanced total system modelling capability.

**Research Need**

- To support concept and design development and waste disposability assessments by developing understanding of the key factors that may influence the post-closure impact of the GDF.

**Research Objective**

- To update and/or extend our existing suite of models.
- To support their future application in the siting process.

**Scope**

The scope comprises the following activities:

- Further development of the models, developed in support of the 2016 generic Disposal System Safety Case, to more explicitly represent different types of geological environment for application in the siting process.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**Customer**

Disposal System Safety Case

Further information


Task Number | 869 | Status | Start date in future  
--- | --- | --- | ---  
PBS level 4 | Safety Assessments |  
PBS level 5 | Environmental Safety Case  
Title  
Uranium IPT: Preferred Options for DNLEU Disposal  
Background  
The 2010 generic Disposal System Safety Case was the first holistic consideration of the potential implications of managing depleted, natural and low-enriched uranium (DNLEU) through geological disposal. The same concept as used for ILW / LLW was extended to cover DNLEU as a first-pass approach to the consideration of these materials in a geological disposal system.  
Building on the work carried out in previous tasks comprising the Uranium IPT (Tasks 796-798), this task involves identifying the preferred approaches by which geological disposal of DNLEU could be implemented, including the preferred wasteforms, waste packages and disposal concepts. Identification and evaluation of the full lifecycle implications for the NDA and other DNLEU owners of the preferred DNLEU management scenarios identified by the IPT will also be carried out.  
Research Need  
- To support concept and design development and waste disposability assessments for DNLEU.  
Research Objective  
To develop an improved understanding of: (i) the DNLEU inventory, (ii) conditioning, packaging and disposal concepts, and (iii) lifecycle implications of concepts.  
Scope  
The scope comprises the following activities:  
- The synthesis and final write-up of the project conclusions on the disposability and full lifecycle implications of managing DNLEU as version 2 of the DNLEU Status Report.  
- The identification of preferred conditioning, packaging and disposal concept options for DNLEU and evaluation of lifecycle issues, based mainly on assessment work performed in previous stages.  
| SRL at task start | 3 | SRL at task end | 5 | Target SRL | 5  
End point | Site Specific Validation  
Customer | Disposal System Safety Case  
Further information  
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Safety Assessments</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Environmental Safety Case</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Review and update the Environmental Safety Manual to Take Account of Peer Review by LLWR and Lessons Learned in Environmental Safety Case 2016

**Background**

The environmental safety manual (ESM), taken to include the associated procedures and work instructions, was adopted as part of the RWM management system in 2015. This will be used to support and control production of the 2016 environmental safety case.

**Research Need**

Review and update the ESM based on learning from using the manual in the 2016 environmental safety case update and to address feedback provided as a result of LLWR peer review.

**Research Objective**

Provide confidence that the ESM remains fit for purpose.

**Scope**

- Commission peer review of ESM from LLWR, agree peer review comments and consequential required changes.
- Following completion of the 2016 environmental safety case update, undertake review of the ESM and supporting procedures and work instructions, identify lessons learned and identify appropriate changes.

Note: This should be the first of an on-going review cycle.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Reissued Environmental Safety Manual

**Customer**

Disposal System Safety Case

**Further information**

Reissued Environmental Safety Manual
Title
Environmental Baseline Monitoring

Background
RWM is participating in a Technical and Scientific Working Group, set up under the European Technology Platform for Implementing Geological Disposal (IGD-TP), to develop a generic reference framework for long-term environmental monitoring and testing.

Establishing how best to characterise the environment at a proposed geological disposal site, before implementation, has been identified as a priority topic for IGD-TP. The focus of the work is on establishing an environmental “reference state” so that a robust baseline can be defined for Environmental Impact Assessment (EIA). However, it is recognised that the outputs from the working group will also be of relevance to safety assessments and detailed design development.

The working group was established in 2014 and is scheduled to run until 2018.

Research Need
To support RWM’s preparatory work for Environmental Impact Assessment and site characterisation.

Research Objective
To define, at a generic level, the environmental parameters to be monitored and to identify appropriate techniques for data acquisition, interpretation and dissemination to provide the information required for EIA and associated consultation and stakeholder engagement activities.

Scope
- To document current good practice in environmental monitoring and testing across Europe’s radioactive waste management organisations.
- To identify innovative technical approaches to: hydrogeology and sub-surface studies; monitoring biodiversity; characterising a socio-economic reference state; characterising a radiochemical reference state.
- To review the role of stakeholder involvement in the design of monitoring and testing programmes and to consider the implications of recent developments in information technology and the use of social media for disseminating monitoring and testing data.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point
Site Specific Validation

Customer
Site Selection

Further information
http://www.igdtp.eu
Task Number | Status
---|---
896 | Ongoing

PBS level 4 | Socio-Economic
PBS level 5 | Socio-Economic

**Title**

Participation in the Forum for Stakeholder Confidence (FSC) of the Nuclear Energy Agency (NEA).

**Background**

The Forum for Stakeholder Confidence (FSC) facilitates the sharing of experience in addressing the societal dimension of radioactive waste management. It has been in existence since 2000, with more than seventeen countries participating in the forum as well as number of international organisations. The participating countries include: Finland, Sweden, Switzerland, Japan, France, Canada, USA, UK, Spain, Germany, Hungary, Belgium, Czech Republic and Slovenia and the recent additions of South Korea and Russia.

RWM attends the meetings of the FSC and is on the Steering Group, directing the work of the programme.

**Research Need**

- To strengthen public confidence in decision making-processes
- To identify how to facilitate effective dialogue between organisations (such as RWM) and the public.

**Research Objective**

To actively participate in the FSC in order to share RWM experiences, and understand experiences / different perspectives of other organisations regarding the societal dimension of radioactive waste management. This research is undertaken with a view to furthering knowledge and understanding of engaging and communicating with communities and the wider public audience.

**Scope**

- Participation in FSC meetings held approximately three times per year and subsequent support and contribution to the development of publications arising in topics relevant to RWM.
- Participation in bi-annual workshops to learn about processes in the host country, meeting a wide range of local stakeholders in order to share experiences across all the countries taking part and to understand the different perspectives of the organisations involved.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

Ongoing Engagement

**Customer**

Site Selection

**Further information**

RWM sponsored the attendance of three 'Cumbria Partnership' members at the country workshop in Bure, France in 2009. In 2011 RWM sponsored the involvement of two members of the partnership in the country workshop in Gimo, Sweden. In 2012 the FSC Country Workshop was held in the Czech Republic.

Further information regarding NEA FSC project is available at the following website:

http://www.oecd-nea.org/rwm/fsc
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>897</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Safety Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 5</td>
<td>Environmental Assessment</td>
</tr>
</tbody>
</table>

**Title**
Developing the approach to Generic Environmental, Socio-economic and Health Impact Assessments

**Background**
RWM periodically undertakes (non-statutory) generic environmental, socio-economic and health impact assessments to support the siting process for geological disposal and to inform generic design work for the disposal system - in line with RWM’s iterative development process.

These generic assessments are currently being updated to support the launch of the siting process in 2017. They will be published as part of RWM’s generic Disposal System Safety Case update planned for 2016.

**Research Need**
Developing the scope of / approach to the generic assessment work is an on-going process, informed by stakeholder feedback and the evolution of good practice.

**Research Objective**
To ensure that the generic assessment work is consistent with current good practice and reflects the information needs of RWM's stakeholders.

**Scope**
As part of the current update, the scope of / approach to the generic assessment work is being reviewed in light of stakeholder feedback and developing good practice. This includes reviewing similar work undertaken by other Waste Management Organisations through participation in appropriate information exchange fora.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**
No further generic assessment work.

**Customer**
Disposal System Safety Case, Design

**Further information**
Development of a Consistent Methodology for Data Elicitation and Quantification of Uncertainty

Background

A methodology for the quantification of uncertainty is necessary in many technical areas of the programme to develop a GDF. In particular, the need to demonstrate safety over very long timescales post-closure requires an appropriate treatment of considerable uncertainties. Data elicitation in this context is defined as no more and no less than a structured approach to the quantification of various experts’ uncertainty in any defined parameter in the form of a probability density function (PDF), or on some occasions a simple probability, and the suitable recording of this exercise.

Parameters in this context are varied. For example, they could include: solubility of elements under a range of possible conditions; permeabilities of various types of rock on different length scales; corrosion rates; dissolution rates. The resulting PDFs produced during an elicitation are typically used in probabilistic models – in which calculations are run many times, each time sampling different values from the PDFs representing uncertainty. We have many years’ experience of carrying out data elicitation but now wish to develop and document a methodology that can be used consistently across RWM and through all stages of our programme to develop a GDF. This will have specific benefits in communicating our treatment of uncertainty to stakeholders. In the past we have usually followed a formal facilitated workshop approach to data elicitation from a group of experts, requiring a consensus to be reached. This method is time and resource-intensive and this task seeks to develop an approach to uncertainty quantification and elicitation that uses resources commensurate with the importance and available information about a parameter.

Research Need

To support the development of the post-closure safety case and to enhance our communication of uncertainty by developing a formal methodology for data elicitation.

Research Objective

- To develop a multi-level methodology for data elicitation, that can be used consistently across RWM, that ranges from using relatively quick automated tools to full formal facilitated elicitation sessions, depending on the nature of the uncertainty and the importance of the parameter in question.
- To document this methodology in a clearly written report, supported by software toolkits.
- To design a research project to test the effectiveness and accuracy of quick automated elicitation tools to quantify uncertainty.

Scope

The scope comprises production of a storyboard for a report on data elicitation and uncertainty quantification; detailed development of a multi-level methodology for data elicitation that can be used consistently across RWM, and production of a clearly written and illustrated report on data elicitation and uncertainty quantification more generally.

As appropriate, software solutions should be developed in order to facilitate various aspects of the methodology. A research project should be developed to test and document the effectiveness and accuracy of quick automated elicitation tools to quantify uncertainty.

Feedback on aspects of the methodology will be obtained at an international workshop on uncertainty planned for September 2015, which will aim to build confidence in the methodology.

Further information

Relevant publications include:

The intent is to use this methodology iteratively, using the most resource-intensive method only for...
important parameters where sufficient information is available, probably at later stages of our programme.
### Task Number 899

<table>
<thead>
<tr>
<th>PBS level 4</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS Level 4</td>
<td>Socio-Economic</td>
<td> </td>
</tr>
<tr>
<td>PBS Level 5</td>
<td>Socio-Economic</td>
<td> </td>
</tr>
</tbody>
</table>

#### Title

Effect of Individual Differences in Psychology on Approach to Mathematical Modelling

#### Background

RWM makes extensive use of mathematical and computer modelling in a wide range of technical areas. RWM invests significant resource in modelling and on occasions modelling projects fail to provide the understanding for which they were developed, or provide it in an inefficient way.

Many of the models are developed to aid understanding of the post-closure evolution of a GDF, and are used to support evaluation of performance in the post-closure safety case. There are often large uncertainties that need to be managed when developing such models.

When developing a model of a complex system to provide understanding, the extent to which a deterministic, detailed, bottom-up approach or an iterative, abstracted, probabilistic top-down approach is the most appropriate depends on the nature and significance of the uncertainties. Experience has suggested, however, that when developing conceptual and mathematical models researchers make this choice of approach based not on a consideration of the nature of the uncertainty, but instead based on their own preferred way of thinking, i.e. based on individual differences in psychology. This may lead to models which are not fit-for-purpose.

#### Research Need

To help improve the quality of modelling as an input to the post-closure safety case by understanding how psychological preferences can influence a modeller’s choice of modelling approach.

#### Research Objective

- To design an experiment to measure the extent to which individual differences in the psychology of a modeller determine the approach taken to developing a conceptual and mathematical model in order to solve problems for systems with different levels of uncertainty.
- To consider the implications for optimising modelling projects and communicating results.
- To document the findings in a paper in a peer-reviewed journal.

#### Scope

The scope comprises designing an appropriate experiment, including: defining the problems to be solved by developing and applying a conceptual and mathematical model, developing a methodology for scoring the methods used by different modellers, use of a psychometric test to identify individual differences in psychology, and an analysis to identify any correlations. Further scope includes consideration of the implications of the results of the experiments, deciding on an appropriate peer reviewed journal and writing up the findings in a paper.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Disposal System Safety Case, Design, Site Characterisation

#### Further information

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PBS level 4  Environmental and Socio-economic Assessment
PBS level 5  Socio-economic assessment

Title
Development and Implementation of Community Benefit Agreements

Background
Implementing geological disposal will involve direct, project-related investment in the local host community. The UK Government is also committed to providing additional investment to the community that hosts a GDF. The Government’s Community Representation Working Group (CRWG) is considering options for disbursement of such additional community investment, including when payments should be made, management of the investment, criteria for assessment of any funding applications and the ability of communities to influence investment within their geographic areas.

“Community benefit agreements” are increasingly being used as a vehicle for integrating and managing both project-related and additional community investment, and for supporting effective community engagement. In particular, they can:
- Ensure that the local ‘costs’ of projects are balanced with desired improvements.
- Incorporate local knowledge and concerns.
- Feedback and respond to information about on-going effects.
- Define a local community’s economic participation in the development and secure the continuing involvement of communities in determining their futures relative to the development process.

There are various models and approaches to developing and implementing such agreements. There is also general recognition that agreements must be tailored to a specific socio-economic and cultural context. But, in all cases, agreements are designed to facilitate open and honest community discussions about desired futures (“visioning”) and the acceptability of likely impacts and potential benefits - so that there can be a negotiated and enduring agreement between the project promoter and affected communities.

Research Need
To support RWM’s preparatory work for the siting process and formal community engagement.

Research Objective
To provide a robust evidence base for the possible development of an appropriate community benefits model during formal community engagement.

Scope
To review the different models and approaches that have been used to develop and implement community benefit agreements. To evaluate their relative success in supporting project implementation, effective community engagement and maintaining a social licence to operate. To consider the applicability of these models and approaches in a UK context.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point  Site Specific Validation
Customer   Site Selection

Further information

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Environmental and Socio-economic Assessment</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Socio-economic assessment</td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Web-based and Social Media Tools for Community Engagement

**Background**
Traditionally, tracking public opinion on a new development and managing community engagement has relied on a combination of hearsay and static snapshots of opinion from polls, interviews, public meetings and formal consultations. However, such feedback may not always be representative of wider community opinion and such opinion can be quite volatile.

Software and social media tools are now available to (anonymously) analyse developing public opinion and stakeholder concerns in real time – so that trends (positive and negative) can be identified and addressed quickly. Sentiment analysis / opinion mining can also be used to provide a breakdown of positive and negative trends so that communication and engagement strategies can be adjusted accordingly. Some tools also extend the analysis to map published project information and stated objectives against stakeholder expectations – to see where the gaps are. Originally used in the on-line retail sector this type of software and associated applications are now proving useful in development projects to increase public participation in project development and to increase the developer’s awareness of emerging issues.

Some of these tools are passive - in other words they just track and analyse opinion, and don’t seek to encourage debate or feedback on proposals. Some are more active and are used to manage interaction between the developer and the local community - for example, they might be used to ensure consistent messages are delivered to the local community, to track when and how commitments are honoured and to encourage stakeholders to raise issues and concerns with the developer.

**Research Need**
To support RWM’s preparatory work for the siting process and formal community engagement.

**Research Objective**
To evaluate the usefulness and applicability of web-based and social media tools during formal community engagement.

**Scope**
To review the different web-based and social media tools that are being used to support community engagement for major infrastructure projects in the UK and internationally. To evaluate their relative success in supporting project implementation, effective community engagement and maintaining a social licence to operate. To consider the applicability of these tools in the siting process for a Geological Disposal Facility.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>Target SRL</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>Site Selection</td>
</tr>
</tbody>
</table>

**End point**
No Further Research Planned

**Further information**
## Appendix B - 384

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Socio-Economic</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Socio-Economic</td>
<td></td>
</tr>
</tbody>
</table>

### Title
EPSRC: Series of Seminars on the Societal Aspects of Geological Disposal

### Background
The implementation of geological disposal prompts numerous questions of a social, technical, political and ethical nature. Experts at the University of Sheffield have won funding from the Economic and Social Research Council (ESRC) for a series of seven seminars over two years, looking at the societal aspects of geological disposal. Funding is also being provided by RWM and RWM staff will attend and present at the seminars.

### Research Need
This research is undertaken with a view to furthering knowledge and understanding of the societal aspects of geological disposal among a range of stakeholders. The seminars will actively engage and develop understanding of the different perspectives of organisations regarding the societal dimension of radioactive waste management.

### Research Objective
This research is undertaken with a view to furthering knowledge and understanding of the societal aspects of geological disposal among a range of stakeholders. The seminars will actively engage and develop understanding of the different perspectives of organisations regarding the societal dimension of radioactive waste management.

### Scope
The scope comprises seven seminars on:
1. Looking back, looking forward: understanding the socio-technical dimensions of nuclear
2. ‘Sociotechnical dimensions of the geological’
3. Publics and the practices of participation
4. Making waste knowledge: building trust
5. Disposal cultures
6. Planning & siting infrastructure
7. Nuclear imaginations and entanglements

The output will include academic talks and papers and briefing papers.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

### End point
Further work to be defined

### Customer

### Further information
Further information regarding the seminars is available at the following website:
http://www.sheffield.ac.uk/socstudies/research/research-seminars/esrc-nuclear-futures
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ongoing</td>
<td>Waste Package Accident Performance</td>
<td>Impact Accident Methodologies and Criteria</td>
</tr>
<tr>
<td>Title</td>
<td></td>
<td>Performance of Aged Packages - Effect of Ageing</td>
<td></td>
</tr>
<tr>
<td>Background</td>
<td></td>
<td>RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. One area of uncertainty pertains to the impact performance of waste packages many decades after their manufacture and this task further develops research, initiated in 2001, into this aspect. The current state of knowledge is that there are no known factors likely to lead to detrimental ageing of cementitious materials over the timescales considered, but no work has been undertaken on alternative encapsulants.</td>
<td></td>
</tr>
<tr>
<td>Research Need</td>
<td>To support the operational and transport safety cases and waste package disposability assessments by addressing our knowledge gap in the impact performance of aged cementitious waste packages.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research Objective</td>
<td>To quantify the variation of break-up properties of wasteforms due to ageing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scope</td>
<td>The scope includes the following activities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- To undertake a desk study to develop the ageing study carried out in 2001, in order to consider the likely effect of ageing on stress-strain properties and breakup properties of wasteforms other than cement encapsulated wasteforms.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- To develop a long-term test strategy and test programme to allow the effects of ageing to be studied and to procure test samples (as defined above) and put them into storage.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- To carry out break-up and compression tests to assess the ageing of a simulated wasteform that was prepared in 1985, and subsequently tested in 1992. Following which, a comparison will be undertaken between the two sets of test results.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRL at task start</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRL at task end</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target SRL</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Further information</td>
<td>Relevant publications include:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Number</td>
<td>Status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Impact Accident Methodologies and Criteria</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Develop Methodologies for Scaling Release Fraction Data for Varying Drop Heights

**Background**

RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. In reality, the impact release fraction (RF) will differ for each combination of, for example, container, waste inventory, wasteform, drop height, drop orientation, target type and package age. The Waste Package Accident Performance (WPAP) status report adopts standard impact RFs for ten generic waste package types and a range of specified drops identifying the respirable fraction to be utilised in accident scenario studies. Research is required in order to develop methodologies for scaling release fraction data in order for RWM to provide appropriate performance data for each current scenario and any future requirements. This task comprises the development of methodologies for scaling impact release fraction data appropriate to the updated impact scenarios described in the GDF fault and hazard schedule. Influences on impact performance include drop heights, orientations, target types, break-up of the wasteform and the particulate size(s) of concern for the inhalation dose pathway.

**Research Need**

To support the operational and transport safety cases and waste package disposability assessments by developing methodologies for the scaling of impact release fraction data to alternative drop heights and the particulate size(s) of concern for the inhalation dose pathway.

**Research Objective**

To extend existing RWM work that investigated the scaling of RFs from 25 m to 15 m for particulates smaller than 100 μm to 40 and 10 μm, to evaluate other drop heights and particulate sizes; the results will lead to less pessimistic dose estimates to workers and the public.

**Scope**

The scope is to apply the methodology established in the scoping report to derive the scaling factor for alternative drop heights and particle sizes. Two approaches for scaling test data are needed:

- A method to scale drop test data at 25 m down to 15 m needs to be extended to other drop heights.
- A method to scale the predicted airborne particle size released (100 μm) from a waste package to the inhalation particle size that could be inhaled and retained in the lungs (~10 μm) may need to be extended to smaller particle sizes; possibly 1 μm for some public dose calculations.

**SRL at task start** | **SRL at task end** | **Target SRL** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

**Further information**

Relevant publications include:

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>913</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

**PBS level 4** Waste Package Accident Performance  
**PBS level 5** Impact Accident Methodologies and Criteria  

**Title**  
Develop, Refine and Document Holistic Impact Methodology

**Background**  
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target. In reality, the impact release fraction (RF) will differ for each combination of, for example, container, waste inventory, wasteform, drop height, drop orientation, target type and package age. The Waste Package Accident Performance (WPAP) status report adopts standard impact RFs for ten generic waste package types and a range of specified drops identifying the respirable fraction to be utilised in accident scenario studies. The Letter of Compliance (LoC) disposability assessment process applied by RWM evaluates the disposability of a waste package by adopting a holistic methodology to estimate the amount of particulate that could be generated based on data on the total amount of energy absorbed from the wasteform and results of computational modelling combined with small-scale wasteform break-up tests. However, this holistic methodology requires refinement since it is believed that the current approach over-predicts (by approximately 10 times) levels of particulate generated and released, compared to full-scale test data.

**Research Need**  
To support the operational and transport safety cases and waste package disposability assessments by addressing the potential over-estimate in the impact RF from cementitious waste packages.

**Research Objective**  
- To determine whether an accurate, systematic and transparent methodology can be developed (based on existing partially-developed approaches and currently available data) to estimate impact RFs for a variety of packaging approaches and drop scenarios.
- To quantify any possible reduction in the quantity of particulate generated from impact accidents because the wasteform will be 'confined' within the container and may 'flow' rather than become airborne.

**Scope**  
This task comprises the following scope:
- Undertaking a test programme to understand the mechanics of grout flow versus grout break-up during a package impact accident and revising and validating the holistic impact methodology such that flow behaviour can be taken into account.
- Arranging and facilitating independent expert peer review of the proposed revised holistic impact methodology.
- Publishing the revised holistic impact methodology in peer-reviewed journals and at conferences.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point** No Further Research Planned  
**Customer** Disposal System Safety Case

**Further information**  
Relevant publications include:  
Develop Improved ILW Package Models (Finite Element Analysis, FEA)

Background
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. Based on consideration of the likely design and layout of a GDF, we wish to transform the safety case from the current bounding criteria towards a range of more realistic accident scenarios. In some cases it may be possible to eliminate or reduce the assessed effect of an impact accident. RWM will then be better placed by focusing on addressing impact scenarios important to the safety of the facility.

Research Need
To support the operational and transport safety cases, waste package disposability assessments and upstream waste processing at decommissioning sites by eliminating potential over-conservatisms which have led to onerous constraints.

Research Objective
To extend the understanding of the impact performance of the 2 metre and 4 metre boxes.

Scope
The scope comprises the following elements:
- To analyse an existing finite element model of the generic 3 cubic metre box for a 9 metre drop in lid-edge, lid-corner, lid-down and side-drop orientations onto a flat unyielding target. This task may include creation of a new box model if required.

- To develop a detailed model of the 2 and 4 metre boxes with shielding thicknesses of 0 mm, 100 mm and 200 mm. The model results will be analysed for a 10 metre drop in the worst orientation onto a flat target and its behaviour evaluated to derive release fraction (RF) values; following which comparison will be made with the RF from the designs with different shielding thickness.

Appendix B - 389
Appendix B - 390

<table>
<thead>
<tr>
<th>Task Number</th>
<th>915</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Impact Accident Methodologies and Criteria</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Title
Impact Accident - Behaviour and Properties of Containers and Wasteforms

Background
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. Finite element (FE) modelling is used extensively in order to evaluate the performance of waste packages in accident scenarios in the most efficient and safe, yet robust, manner. Such modelling requires data parameters gained in laboratory stress-strain experiments and drop-test experiments on real packages. There is a need to compile a reference data set of agreed and consistent data of stress-strain and break-up properties to support these modelling studies. Currently such data are disseminated over a range of data sources and reports. This task comprises the collation of this data set in order to improve the efficiency and consistency of FE evaluations.

Research Need
To support the operational and transport safety cases and waste package disposability assessments by improving the efficiency and consistency of FE input parameters.

Research Objective
To compile an agreed and consistent reference stress-strain and break-up data set to support the modelling of packages in impact accident scenarios.

Scope
The scope of work includes the collation of data and relevant underpinning from existing work carried out by RWM and its predecessor companies, regarding stress-strain and break-up behaviour of wasteforms and encapsulants.

End point
No Further Research Planned

Customer
Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Impact Accident Methodologies and Criteria</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Validation and update of the impact performance methodology for the 500 litre robust shielded drum and the 3 cubic metre robust shielded drum.

**Background**

A methodology for evaluating Release Fractions (RFs) from Robust Shielded Containers (RSCs) following an impact fault and subsequent seal failure was developed by RWM for a recent packaging proposal. This methodology was adopted by the waste producers and has yet to assessed for continued suitability for the final LoC stage where a higher level of scrutiny is appropriate.

**Research Need**

To support the disposability assessment of RSCs, a validated methodology for predicting any possible release fraction from pressurised RSCs following an impact fault which results in lid seal failure is required.

**Research Objective**

To evaluate the current methodology for provision of RFs for RSCs resulting from a sudden seal failure from a maximally pressurised RSC following a GDF fault which leads to an impact accident and subsequent seal failure within the RSC.

This evaluation is to assess the suitability of the methodology for use in the final stage Letter of Compliance (LoC) process.

**Scope**

The scope comprises consideration of the 500 litre robust shielded drum and the 3 cubic metre robust shielded drum containers under maximum pressurisation with fault conditions as appropriate for the RSC vault. The output is to be a reasoned recommendation, with evidence wherever possible, as to whether the current methodology is suitable or not. The evaluation shall contain at least (but not be limited to) consideration of:

- The relevance of breakup data used.
- The RSC cavity airborne release fraction used.
- The current methodology as defined in the RWM technical note;
- The height scaling factor.

In addition:

- Consideration of the likely effect of the vent orifice size on the result (this is not considered at all in the current methodology).

Should the evaluation recommend that the current methodology is suitable, this should be presented in a report.

Or:

Should the evaluation recommend that the current methodology is unsuitable then outline suggestions for further work (both desk-based and/or experimental) to improve or replace the current methodology and the data it relies on are to be made to ensure it is suitable for use in final stage LoC assessments.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Waste Package Disposability Assessments, Operational Safety Case

**Further information**

Appendix B - 392

### Task Number 917

#### Status
Start date in future

| PBS level 4 | Waste Package Accident Performance |
| PBS level 5 | Impact Accident Methodologies and Criteria |

#### Title
Develop Improved ILW Package Models - Including Credit for Design Features (e.g. Capping Grout)

#### Background
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted, providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. Based on consideration of the likely design and layout of a GDF, we wish to transform the safety case from the current bounding criteria towards a range of more realistic accident scenarios. In some cases it may be possible to eliminate or reduce the assessed effect of an impact accident. RWM will then be better placed by focusing on addressing impact scenarios important to the safety of the facility.

#### Research Need
To support the operational and transport safety cases, waste package disposability assessments and upstream waste processing at decommissioning sites by eliminating potential over-conservatisms which have led to onerous constraints.

#### Research Objective
- To define the benefits to impact performance of having an annulus and capping grout in unshielded intermediate-level waste (UILW) and shielded intermediate-level waste (SILW) waste package designs. In addition, to give guidance on the design of the annulus, including material type, strength and thickness for the 500 litre drum, 3 cubic metre box, 2 metre box and 4 metre box packages.
- To give an indicative understanding of the performance of waste packages in a standard waste transport container (SWTC) in order to reduce over-conservatism in the RF.
- To estimate the RF from four drums in a SWTC in an International Atomic Energy Authority (IAEA) transport accident scenario, taking into account the realistic boundary conditions, as defined for the SWTC.
- To extend the understanding of the impact performance of the 2 metre and 4 metre boxes.

#### Scope
The scope comprises the following elements:
- To carry out finite element (FE) analysis on models of a 3 cubic metre box design, a 500 litre drum design, a 2 metre box design and a 4 metre box design in order to quantify the benefits of an annulus; and to define the benefits of the annulus and capping grout in impact performance
- To give guidance to disposability assessments and waste producers on the recommended design of annulus and capping grout.
- To give guidance to disposability assessments regarding whether the annulus or capping grout can be considered uncontaminated and under what conditions they can be considered uncontaminated.

### Task Start and End SRLs

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>5</th>
<th>SRL at task end</th>
<th>6</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Further information
Relevant publications include:
Background
Within the Letter of Compliance process there is a long history of the use of analogues to support package accident performance submissions; see example reports given under ‘Further Information’. The basis is that the understanding of the performance of a package that has been extensively analysed, either by physical testing or by Finite Element analysis, can be applied to other packages that have similar design, construction and materials properties. The comparison needs to be made by an appropriately qualified and experienced person and that expected divergence in performance due to differences in the packages being compared should be explored.

RWM is receiving an increased number of Letter of Compliance submissions attributing performance benefits for specific package features which reduce predicted releases by a specified fraction (called a Decontamination Factor). Submissions may be supported by offering performance data from an analogous package.

Research Need
To develop the principles of what constitutes an appropriately analogous package or container feature when used to support a performance submission for another package or container feature.

Research Objective
Provision of a document clearly defining the principles to be followed to identify appropriate analogues used to support assessments of package or container feature performance. This document should allow consistent selection of appropriate analogues by well-informed technical persons. If possible, some guidance should be provided on how to identify if a proposed analogue has diverged too far from the package or container feature being considered to be valid.

Scope
A desk-based study of previous accepted analogues and an analysis of what divergences in packaging and container features have been accepted between proposed package and analogue. This will be coupled with elicitation from a variety of experts on the guidelines for what should be considered when choosing an analogue.

Further information
Title
Package Decontamination Factors - Part 2 – Accounting for Multiple Barriers

Background
Within the Safety Assessment process there are some examples of the use of multiple barriers to improve accident performance: see example reports given under ‘Further Information’.
RWM is receiving some Letter of Compliance submissions which attribute performance benefits for multiple barriers, some sealed and some unsealed, which reduce predicted releases by a specified fraction (called a Decontamination Factor).

Research Need
To support waste package disposability assessments by the quantification of the likely benefits of a range of multiple barriers of containment within waste packages.

Research Objective
To quantify, to orders of magnitude, the likely benefits of multiple layers of containment within a package. Specifically, the predicted benefit of a steel liner grouted within a 3 cubic metre box both with a sealed lid and without a lid. Also a paint tin containing waste encapsulated in cementitious grout with a sealed lid and with a loosely fitting lid. The wastes to be considered are: powders, grouted solids, ungrouted solids and liquids.

Scope
This is a desk-based study that will review previous work on packages with multiple containment barriers, the available literature on this topic and the Sellafield Release Fraction Database. The task may include an element of Finite Element modelling with recently developed package models to assess the benefit of the various extra barriers.

SRL at task start 4  SRL at task end 5  Target SRL 5

End point No Further Research Planned

Customer
Waste Package Disposability Assessments, Disposal System Safety Case, Waste Producers

Further information
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Impact Accident Methodologies and Criteria</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Effect of Cracked Wasteform on Impact Performance

**Background**

It is understood that as cementitious wasteforms cure and age, they may undergo some cracking. It is also known that some wastes which undergo expansive corrosion such as Magnox metal can contribute to any cracking of the wasteform.

The RWM position, arrived at via elicitation, is that moderate cracking of a wasteform which leaves largely monolithic pieces of wasteform is unlikely to be detrimental to the impact performance of the package. Uncertainty arises when cracking of the wasteform is extensive.

**Research Need**

An understanding as to whether cracking of the wasteform leads to reduced package impact performance. Should cracking reduce impact performance, is there a point at which this cracking becomes an issue? Are there any ‘cliff edge’ effects? How might the level of cracking be quantified?

**Research Objective**

Quantification of what level of cracking, if any, reduces the impact performance of a package to a degree where its presence must be taken into consideration for transport or operational safety. Guidance is to be provided as to the effect on package release fraction of various levels of wasteform cracking. Information will be required for standard wasteform types in standard packages.

Additional: if required by the operational safety case at the time of commencement, information on any increase in particulate present in a cracked cementitious wasteform over an un-cracked wasteform prior to any impact fault.

**Scope**

This task will begin with a literature survey of waste producers’ research, and also that of general industry (specifically construction), to determine what information is already available. Following this, small-scale experimental trials may be conducted to determine the effect of a cracked wasteform on impact performance.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Customer**

Disposal System Safety Case, Waste Package Disposability Assessments

**Further information**

Nuclear Decommissioning Authority, 2008, Calculations of Times to Wasteform Cracking and Container Rupture for Packages Containing Metal Waste, SERCO/TAS/000755/001.


Update to the Holistic Impact Methodology Following Breakup Versus Flow Tests

Background
The holistic impact methodology (see Arup references in ‘Further Information’ below) is being updated to incorporate the effect of breakup versus flow on impact (Task 913), the effect of wasteform ageing on impact performance (Task 911) and the effect of wasteform cracking on impact performance (Task 920). There will be a need to update the impact methodology to incorporate the output from these tasks.

Research Need
To support the wasteform disposability assessments process, the operational safety case and the transport safety case, a methodology for assessing the impact performance of waste packages that reduces conservatisms and areas of uncertainty is required.

Research Objective
To provide a single methodology synthesising the work that has been performed in this area.

Scope
This desk-based task will review the research tasks performed since the last update to the holistic impact methodology and detail an approach to incorporate any advancements to reduce pessimisms and uncertainty into an updated methodology.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

End point
No Further Research Planned

Customer
Waste Package Disposability Assessments, Disposal System Safety Case

Further information
## Background

In support of fire and impact accident performance evaluation, RWM have defined a set of generic package type groupings (encompassing minor design modifications such as bolting arrangements and closure types) to enable extrapolation from well characterised packages to those which are similarly configured, but which have not been subject to extensive experimental or modelling studies.

For each waste package type, small-scale test data have been grouped according to what is considered to be representative of the likely simulated wasteforms or plain grout formulations that could be present.

Generic release fraction (RF) values for each waste package type are given in the Waste Package Accident Performance (WPAP) Status Report and the derivations are discussed in detail in the Arup report “Waste Package Impact Release Fraction Data Report”. This grouping is based on expert judgement, and has been done in order to narrow the range of values where possible.

This task considers the revision of the ten current waste package type groups:
- Expanding the waste package type groups to account for variations in waste package design.
- Differentiating between packages of the same design but with different annulus / shielding thickness.
- Expanding the groups to account for different wasteform types.

## Research Need

To support the operational and transport safety cases and waste package disposability assessments by reviewing whether less pessimistic generic RFs can be assigned to a particular package in the absence of a specific RF based on experiment or computational analysis.

## Research Objective

To re-define the waste package type groups in the WPAP Status Report to account for: variations in waste package design within each waste package type; new bounding waste stream definitions; and new package types.

## Scope

The waste package type groups will consider sub-types; to include, but not be limited to: wasteform types (e.g., heterogeneous, homogeneous); encapsulant types (e.g., polymer, cement); and, package design elements (e.g., engineered annulus, grouted annulus, double lid with anti-floatation plate) - essentially, the features that provide a distinct step-change in RF.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

End point | No Further Research Planned

Customer | Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

## Further information

Relevant publications include:

Impact Thresholds Below Which Releases Will Not Occur

Background

RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. In reality, the impact release fraction (RF) will differ for each combination of, for example, container, waste inventory, waste form, drop height, drop orientation, target type and package age. Currently, the Generic Waste Package Specification (GWPS), identifies impact accident performance requirements for a 0.3m drop without ‘loss or dispersal of the radioactive contents’ for Shielded ILW (SILW) waste packages. There is clearly benefit to the Transport and Operational safety case if drop heights can be identified below which no release could occur, since this may allow consideration of the small drop height impact accidents to be eliminated.

Research Need

To support the operational and transport safety cases and waste package disposability assessments by identifying whether threshold drop heights can be derived for waste packages, below which consideration of radionuclide release can be neglected.

Research Objective

To establish a threshold drop height below which there is no release of contents, for representative Unshielded Intermediate Level Waste (UILW) and SILW packages.

Scope

The scope for this task is to model one design of each UILW and SILW package type (i.e. the 2 metre box, 4 metre cubed box, 500 litre drum, corner stacking 3 cubic metre box, mid-side stacking 3 cubic metre box, 3 cubic metre drum, Miscellaneous Beta Gamma Waste Store box and 6 cubic metre box) in the orientation most vulnerable to release in an impact, from a drop height of 0.3 m and increasing the height at 1 m intervals until there is release of radioactive particulates or until the drop height reaches 10 m.

SRL at task start 5
SRL at task end 6
Target SRL 6
End point No Further Research Planned

Further information

Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>929</th>
<th>Status</th>
<th>Ongoing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Impact Accident Release Fraction Data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Title**
Derivation of ab initio Release Fraction Values for the 6 cubic metre box; revised 3 cubic metre drum; MBGWS Box and Corner Lifting 3 cubic metre Box

**Background**
RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. The current approach for assessing impact performance assumes a bounding drop onto an unyielding target, based on an analysis of historical GDF designs. In reality, the impact release fraction (RF) will differ for each combination of, for example, container, waste inventory, wasteform, drop height, drop orientation, target type and package age. The Waste Package Accident Performance (WPAP) status report adopts standard impact RFs for ten generic waste package types and a range of specified drops, identifying the respirable fraction to be utilised in accident scenario studies. The RFs for the revised 3 cubic metre drum, the corner-lifting 3 cubic metre box, the Miscellaneous Beta Gamma Waste Store (MBGWS) box and the 6 cubic metre box (previously known as the WAGR box) were based on analogy to other waste packages for which an RF based upon experiment or modelling already exists. To improve the robustness of the RF data and for consistency with other package types, this task comprises the ab initio finite element analysis (FEA) calculation of these data.

**Research Need**
To support the operational and transport safety cases and waste package disposability assessments by deriving more robust RF data (ab initio, rather than by analogy) for use in impact accident assessments.

**Research Objective**
To derive new RF values to replace the existing values for the following package types: 6 cubic metre box; revised 3 cubic metre drum; MBGWS box; and corner-lifting 3 cubic metre box.

**Scope**
The scope comprises the following activities:
- Undertaking a review of the RF values from the RWM commissioned detailed Finite Element (FE) analyses recently completed for the 6 cubic metre box.
- Detailed FEA to derive RF values for the revised 3 cubic metre drum and the MBGWS box.
- Review of Sellafield Ltd drop test and FEA data for the corner-lifting 3 cubic metre box.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>6</th>
<th>SRL at task end</th>
<th>6</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>End point</td>
<td>No Further Research Planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further information**
Relevant publications include:
Appendix B - 400

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>930</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PBS level 4**

Waste Package Accident Performance

**PBS level 5**

Impact Accident Release Fraction Data

**Title**

Prepare Impact Performance Data Set

**Background**

RWM has developed a good understanding of the performance of waste packages in bounding impact accidents. Based on this understanding, RWM has developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages extensive testing and modelling have been conducted providing a good knowledge base from which to assess package performance. Methodologies have been developed to understand the size distribution and quantity of particulate generated within the wasteforms and hence released from these waste packages. Following completion of a number of impact accident work activities in previous tasks, the impact accident standard release fractions (RFs) will need to be revised. The revisions, in particular, need to reflect a change to more realistic accident scenarios currently being introduced by RWM, revised scaling factors (Task 912) impact threshold work (Task 928) and improved models (Tasks 914, 929 and 913).

**Research Need**

To support the operational and transport safety cases and waste package disposability assessments by collating the state of knowledge on impact accident RFs.

**Research Objective**

To collate impact RF data from existing work currently used in support of packaging assessments and from the output of tasks in the Waste Package Accident Performance (WPAP) research programme, to identify additional tests and analyses which may need to be carried out and to prepare a new impact RF report (replacing the existing “Waste Package Impact Release Fraction Data Report”) as a key input to a future WPAP Status Report.

**Scope**

The scope of work for this task includes:
- Collating impact RF data from existing work and from other tasks in the WPAP research programme.
- Identifying additional tests and analyses which may need to be carried out.
- Preparing a new impact RF report to replace the existing Waste Package Impact Release Fraction Data Report.

The RFs will be based on the package type groups defined in Task 926.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

**Further information**

Relevant publications include:
Data Requirements for Updated Operational Safety Case Approach

Background
The operational safety case is updating the methodology used for both identification of bounding waste streams and for fault analysis. This updated methodology proposes additional factors for use in calculating potential releases for fire and impact faults. At the time of writing the updated methodology is being refined. This task sheet therefore provides only an outline of the work that may be required.

Research Need
To support the operational safety case by supplying suitable data to allow assessment of predicted radiation doses to worker and public in the event of fire or impact faults using the updated methodology.

Research Objective
Exact requirements are to be confirmed by the operational safety case. The outline objectives comprise a review of available data for the following new input requirements:
- Inherent wasteform factors. What fraction of activity is already in a form available for release from a package prior to any accident, for radionuclides of interest when the following in physical forms:
  - Activated object
  - Gross contamination
  - Surface contamination
  - Liquid
  - Gas
- Containment factors (also known as decontamination factors). What fraction of the releasable material which becomes available following a fire or impact accident is withheld by the various container layers?

Scope
This is a desk-based study comprising literature review and data evaluation. Data will be required for radionuclides of radiological dose consequence significance and for packages identified using the new bounding waste stream methodology. Data for all bounding waste streams will be located from suitable sources, evaluated for validity and confidence. Where data is not available, data elicitation supported by analogous data where possible is to be used.
Appendix B - 402

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Complete, pending publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Fire Accident Methodologies and Criteria</td>
<td></td>
</tr>
</tbody>
</table>

Title
Development of Fire Release Fractions

Background
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

The safety case currently uses highly conservative bounding assumptions of radionuclide release from a fire accident. However, by considering more realistic accident scenarios, in some cases it will be possible to eliminate or reduce the effect of a fire accident; the current bounding approach for assessing fire performance assumes a fully engulfing fire of one hour duration. We are improving our understanding of the underlying mechanisms for the release of radioactivity in fire accidents and have developed a dedicated furnace rig to test small-scale active samples of simulant wasteforms under controlled conditions. This facility is able to test a range of radionuclides, including volatile species such as compounds containing radioactive hydrogen-3 (tritium) and carbon-14, for which RWM currently makes pessimistic assumptions about their release. This task comprises a review of previous work in order to determine the likely level of pessimism in the currently recommended release fractions.

Research Need
To support the operational and transport safety cases and waste package disposability assessments by reviewing the findings of release fraction experiments in order to identify potential over-conservatisms and, where possible, derive more appropriate RF data.

Research Objective
- To understand data reliability by reviewing the findings of current and previous Activity Release in Fire Accident Conditions (ARFAC) and ILW RF measurement tests carried out on samples of encapsulated floc, Magnox sludges and encapsulated fuel hulls.
- To compare older and more recent results to show the effect of sample composition / preparation and / or the effect of the inert gas flow-rate on the release fraction results obtained, thus highlighting any pessimisms in the data.
- To provide input to the proposed new ARFAC work within the current Waste Package Accident Performance research programme (Tasks 1010 and 1011).'

Scope
The scope comprises:
- Reviewing the ARFAC and more recent ILW test results and comparing these measured release fractions against those in the contractor report “Release Fractions from Waste Packages Exposed to Fire” to determine the likely level of pessimism in the currently recommended release fractions.
- Identifying and obtaining reports on relevant ARFAC and ILW tests carried out by NIREX and more recent test data.
- Developing an analysis and interpretation strategy that fulfils the research objectives.
- Evaluating test results to determine, based on these data, if it is possible to assess the effect of differing sample composition / preparation and / or the radionuclide transfer enhancement arising from the inert gas flow-rate used to move volatilised material from the sample to the measurement apparatus.

SRL at task start 4  
SRL at task end 5  
Target SRL 5  
End point No Further Research Planned  
Customer Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites  

Further information
This task is related to task 946.
Relevant publications include:
Methodology for Use of Analogy to Other Waste Package Types

Background

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

The Waste Package Accident Performance (WPAP) status report adopts standard fire RFs for radionuclides grouped by volatility. The RFs for the revised 3 cubic metre drum, the corner-lifting 3 cubic metre box, all variants of the 500 litre drum (with both homogeneous and heterogeneous wastes) and the 6 cubic metre box (previously known as the WAGR box) were based on analogy to other waste packages for which a release fraction (RF), based upon experiment or modelling, already exists. To improve the robustness of the RF data, and for consistency with other package types, this task comprises production of a justification for this practice and the delivery of any further finite element analysis that is required.

Research Need

To support the operational and transport safety cases and waste package disposability assessments by producing a justification for the practice of determining the RF for some waste packages by analogy to others which have been subject to experimental or modelling studies. Where this is not possible further Finite Element Analysis (FEA) analysis is needed.

Research Objective

- To produce a justification on a package by package basis, for the practice of determining the RF by analogy to other package types which have been subject to experimental or modelling studies.
- To conduct any further FE modelling shown to be required to validate the fire accident RFs employed by RWM in its safety cases and waste package disposability assessments.

Scope

The scope comprises:

- Confirmation of the list of package types for which RFs are derived by analogy with similar designs of package. The differences between each of these packages and the package with which it is assumed to be analogous will be considered and the significance of each difference to the overall package RF judged on the basis of experience (supported by calculations where necessary).
- Production of a report considering the extent to which the analogy approach can be applied to different wasteforms in the same package type. The report will also include advice on when the analogy cannot be used and delivery of any further FE modelling.

SRL at task start  4  SRL at task end  6  Target SRL  6

End point Input to Waste Package Disposability Assessments

Customer Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

Further information

Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>948</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

**PBS level 4**
- Waste Package Accident Performance

**PBS level 5**
- Fire Accident Methodologies and Criteria

**Title**
Development of Improved ILW Package Models for Fire Analysis

**Background**
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

The current bounding approach for assessing fire performance assumes a fully engulfing fire of one hour duration. Finite Element (FE) modelling is used extensively in order to evaluate the performance of waste packages in accident scenarios in the most efficient and safe, yet robust, manner. Modelling of the 6 cubic metre box (previously known as the WAGR box), the 2 metre box with 0, 100mm or 200mm shielding and the 4 metre box with 0 and 100mm shielding is yet to be carried out.

**Research Need**
To support the operational and transport safety cases, waste package disposability assessments and upstream waste processing at decommissioning sites by undertaking FE modelling on those waste packages which have not yet been modelled for fire accident RF.

**Research Objective**
To undertake 3-dimensional fire modelling of the 6 cubic metre box and the 2 metre and 4 metre boxes (with requisite shielding) to provide supporting data for the DSSC and waste package disposability assessments. This includes ungrouted / unshielded packages.

**Scope**
The scope comprises:
- Agreement between RWM and the contractor of a standardised group of a ‘typical’ 6 cubic metre box, 2 metre box and 4 metre box waste package representative of those in the derived inventory and development of models of the 2 and 4 metre box with different thicknesses of concrete (0 mm, 100 mm and 200 mm).
- Development of ABAQUS thermal models of these waste packages to simulate the effect of fires with temperatures and durations suitable for use in support of the Disposal System Safety Case.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
<th>End point</th>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
<td>No Further Research Planned</td>
<td>Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites</td>
</tr>
</tbody>
</table>

**Further information**
Relevant publications include:
## Task Number 1006 Status Ongoing

| PBS level 4 | Waste Package Accident Performance |
| PBS level 5 | Fire Accident Release Fraction Data |

### Title
Derivations of Temperature Thresholds Below Which Release Will Not Occur

### Background
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

The current bounding approach for assessing fire performance assumes a fully engulfing fire of duration one hour. The Disposal System Safety Case (DSSC) suite of documents includes illustrative generic designs for a GDF in three generic geological settings. We are now able to analyse these designs to develop a more realistic set of fire accident scenarios. For example, it may be possible to reduce the duration of the reference fire, and hence the maximum temperature reached by much of the package, in the identified accident scenario.

We are improving our understanding of the underlying mechanisms for release of radioactivity in fire accidents and have developed a dedicated furnace rig to test small-scale active samples of simulant wasteforms under controlled conditions. This facility is able to test a range of radionuclides, including volatile species such as radioactive hydrogen-3 (tritium) and carbon-14 (C-14), for which RWM currently makes pessimistic release fraction (RF) assumptions.

In order to reduce conservatisms in the transport and operational safety cases there a need to define, by package and waste type, a minimum temperature below which there is no predicted release during a fire. It is currently assumed for all packages that there is no release below 50°C; this value is however considered to be conservative for many wastes and package types. A large proportion of the wasteform in a fire is at a relatively low temperature, i.e. <100°C. Below approximately 80°C there would be less release of radionuclides through entrainment in rapidly evaporating pore water. Due to the limited test data currently available the same RFs are applied to waste between 50°C and either 300°C or 700°C, depending on the wasteform type.

### Research Need
To support the operational safety case by reducing the pessimisms associated with a lack of data on temperatures below which there is no release of volatile radionuclides.

### Research Objective
- To determine whether the current assumptions regarding thermal release fractions are over-conservative.
- To determine whether the threshold temperatures for releases can be raised for many wastes and packages and whether large proportions of the wasteform in a fire may not exceed these thresholds.

### Scope
The scope comprises:
- Planning a test programme, specifying test conditions, sample types and numbers, the type of test and the isotopes to be tested. The objective for the testing programme will be to maximise learning and data from a minimum number of samples and analyses.
- Definition of procedures for work involving the ‘hot rig’ - an existing piece of experimental equipment designed and built for investigating radionuclide release from heated wasteform materials. The following waste types will be considered: mild steel, graphite, floc, sludge.
- Undertaking the experimental programme utilising the ‘hot rig’.
- Additional samples may also be produced for storage and later testing to allow them to age significantly.

<p>| SRL at task start | 4 | SRL at task end | 6 | Target SRL | 6 |
| SRL at task start | 4 | SRL at task end | 6 | Target SRL | 6 |
| End point | No Further Research Planned |
| Customer | Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites |</p>
<table>
<thead>
<tr>
<th>Further information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant further information can be found in the following:</td>
</tr>
</tbody>
</table>
**Task Number** | 1007 | **Status** | Complete, pending publication
--- | --- | --- | ---
**PBS level 4** | Waste Package Accident Performance | **PBS level 5** | Fire Accident Release Fraction Data

**Title**
Revise Volatility Groups

**Background**
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

For simplicity, fire accident scenarios consider radionuclides in six ‘volatility groups’ and wasteforms in a small number of generic waste package types. All the elements are currently categorised into six groups based on the volatility of the chemical form of the element when in equilibrium with steam and air up to 1000°C. Volatility Group I has the highest volatility, where all the elements have one or more chemical forms that are gases. It is assumed that the more volatile the chemical, the greater the fire RF of the associated radionuclide. In fact, Group I volatiles are always given an RF of 1 (i.e. a 100% release). Volatility Group I nuclides can be in different chemical forms, rather than those which are readily mobile as gases, but this is not currently considered and is a likely over-conservatism.

**Research Need**
To support the operational and transport safety cases and waste package disposability assessments by reviewing whether less pessimistic fire RFs can be assigned to a particular package by the use of volatility assignments that more accurately reflect the true release of radionuclides.

**Research Objective**
To review the six volatility groups, possibly recommending sub-division of the groups or individual RFs for key nuclides (or a reduction in the number of groups), although the focus should be on those radionuclides and groups that are challenging the safety case, e.g. the Group I radionuclides (i.e. H 3, C-14, Cl-36, Se-79, I-129) and key Group II to VI radionuclides (i.e. Sr-90 and isotopes of Am, U and Pu). This assessment will be based on whether the activity is fixed or mobile, and a consideration of the chemical form of the elements.

**Scope**
The work scope is broken down by grouping, as follows:
- Obtain data for radionuclides that are most challenging to the Operational Safety Case (OSC) and Transport Safety Case (TSC) regarding package type and chemical form (e.g. based on the bounding waste streams).
- Consider the volatility of each radionuclide (along with modification of the volatility groups to account for the different releases from different elements and chemical forms).
- Review the availability of suitable test data to support volatility-specific RFs for a range of chemical forms.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>4</th>
<th>SRL at task end</th>
<th>5</th>
<th>Target SRL</th>
<th>6</th>
</tr>
</thead>
</table>
**End point** | No Further Research Planned | **Customer** | Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

**Further information**
Relevant publications include:

Appendix B - 408
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>PBS level 4</th>
<th>PBS level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1008</td>
<td>Ongoing</td>
<td>Waste Package Accident Performance</td>
<td>Fire Accident Release Fraction Data</td>
</tr>
</tbody>
</table>

**Title**

Revision of Release Fractions for Volatility Group 1 Radionuclides

**Background**

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

For simplicity, fire accident scenarios consider radionuclides in six ‘volatility groups’. All the elements are currently categorised into these six groups based on the volatility of the chemical form of the element when in equilibrium with steam and air up to 1000°C. We have developed a dedicated furnace rig to test small-scale active samples of simulant wasteforms under controlled conditions. This facility is able to test a range of radionuclides, including the Volatility Group I species such as radioactive hydrogen-3 (tritium) and carbon-14 (C-14), for which we currently make pessimistic release fraction (RF) assumptions. The package Release Fractions (RFs) calculated in the disposability assessment process and used in the operational safety case and transport safety case use the 2001 Bush and Harris report on recommended release fractions as a key reference. However, this report has not been updated to reflect more recent experimental data such as were obtained from the fire test-rig commissioning tests. This is particularly relevant to radionuclides in Volatility Group I, which are currently all assumed to be fully liberated at temperatures above 50°C.

**Research Need**

To support the operational and transport safety cases and waste package disposability assessments by eliminating over-conservatisms in the fire accident RFs for the Volatility Group I radionuclides.

**Research Objective**

To update RF data for Volatility Group I radionuclides as a function of temperature in light of recent fire test-rig data.

**Scope**

The scope comprises:
- Comparing RFs for Volatility Group I as reported in the Bush & Harris report and the results of the fire rig commissioning tests.
- Development of RFs for Volatility Group I, as a function of temperature, with these values presented in a peer reviewed report.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

**Further information**

Relevant further information can be found in the following:


Task Number | Status | Complete, pending publication
--- | --- | ---
PBS level 4 | Waste Package Accident Performance
PBS level 5 | Fire Accident Release Fraction Data
Title
Derivation of a Reference Data Set for Fire Accident Scenarios

Background
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

RWM also needs to assess the performance of waste container materials and different simulant wasteforms for which there are gaps in understanding, such as C50 shield concrete and graphite.

Finite Element Analysis is a key tool for determining the fire accident performance of waste packages, however this relies on consistent and robust data. This task comprises the compilation of an agreed, consistent reference data set of thermal properties for polymers and concretes at temperatures up to 1000°C. Relevant data are either not currently recognised by RWM (currently we treat polymerised wastes as unconditioned wastes due to insufficient supporting data), or are dispersed over a range of data sources and reports.

Research Need
To support the operational and transport safety cases and waste package disposability assessments by improving the efficiency and consistency of fire impact modelling via production of a reference data set of thermal properties.

Research Objective
To document and collate thermal property data for polymers and concretes at temperatures up to 1000°C. Thermal properties of an encapsulation polymer, concrete (including C50) and graphite, within each waste package type, are to be determined.

Scope
The scope comprises the:
- Identification and review of the thermal performance data currently utilised in the Letter of Compliance process for polymers and concrete at temperatures up to 1000°C.
- Identification of data from other assessments and research programmes (including historical Central Electricity Generating Board research), polymer trials with fuel element debris (FED) and the RWM fire rig commissioning tests.
- Preparation of a report in which a consistent set of materials properties data are reported and their source appropriately referenced.
- Identification of data gaps for concrete and polymer material types.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

End point
No Further Research Planned

Customer
Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

Further information
Relevant publications include:
Task Number: 1010
Status: Ongoing

PBS level 4: Waste Package Accident Performance
PBS level 5: Fire Accident Release Fraction Data

Title: Fire Performance of Aged Packages

Background:
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, RWM have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

One area of uncertainty pertains to the fire performance of waste packages many decades after their manufacture. Currently RFs are calculated based on “as-made” materials. The assumption that the RF evaluated for ‘pristine’ packages can be safely assumed for ‘aged’ packages depends both on the evolution of the wasteform and the waste container.

The current understanding of the mechanisms of ageing is that the waste containers are unlikely to be affected significantly during interim storage at waste packaging sites or during GDF operations, with very low general corrosion rates of 0.01-0.1 μm per year. The effect of ageing becomes more of an issue as the wasteform ages.

This task comprises research to confirm the activity releases from aged wasteforms compared to tested simulant wasteforms by testing historical samples, accelerated aged samples and / or coupons.

Understanding of the properties of evolved packages is also needed in order to assess waste retrievability.

Research Need:
To support the transport and operational safety cases and consideration of retrievability in support of concept development by determining fire accident release fractions (RFs) for aged waste packages.

Research Objective:
To develop a strategy for obtaining an understanding of the effect of ageing upon the thermal performance of different wasteforms and the release of radionuclides in a fire.

Scope:
The scope comprises:
- A desk study to review possible mechanisms and properties that might be affected by ageing.
- The development of a long-term test strategy and programme that could be performed on aged samples, the findings of which will inform what current samples need to be collected and laid down for future testing.

SRL at task start: 3  SRL at task end: 3  Target SRL: 6
End point: No Further Research Planned

Customer: Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

Further information:
Relevant further information can be found in the following:
WMT 2010, Review of Wasteform Ageing up to Repository Resaturation (Part One), WMT(06)P118.
Title
Evaluation of RFs from Aged Samples

Background
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, RWM have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wastefoms and hence released from these waste packages.

One area of uncertainty pertains to the fire performance of waste packages many decades after their manufacture. Currently RFs are calculated based on “as-made” materials. The assumption that the RF evaluated for ‘pristine’ packages can be safely assumed for ‘aged’ packages depends both on the evolution of the wasteform and the waste container.

The current understanding of the mechanisms of ageing is that the waste containers are unlikely to be affected significantly during interim storage at waste packaging sites or during GDF operations, with very low general corrosion rates of 0.01-0.1 μm per year. The effect of ageing becomes more of an issue as the wasteform ages.

This task, following on from task 1010, comprises research to confirm the activity releases from aged wastefoms compared to tested simulant wastefoms by testing historical samples, accelerated aged samples and / or coupons. Understanding of the properties of evolved packages is also needed in order to assess waste retrievability.

Research Need
To support the transport and operational safety cases and consideration of retrievability in support of concept development by determining fire accident release fractions (RFs) for aged waste packages.

Research Objective
To obtain an understanding of the effect of ageing upon the thermal performance of different wastefoms and the release of radionuclides in a fire through: experimental testing of historical samples, artificially aged samples, or through future testing of samples to be laid down as part of this task.

Scope
The scope comprises:
Performing the testing programme developed in task 1010:
- Testing of historic or artificially aged samples as identified during task 1010.
- Laying down of samples for future testing as outlined in the programme.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

End point
No Further Research Planned

Customer
Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

Further information
Relevant further information can be found in the following:
WMT, 2010, Review of Wasteform Ageing up to Repository Resaturation (Part One), WMT(06)P118.
Scaling Release Fraction Data for Different Fire Scenarios

Background
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of 'release fractions' (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

The current bounding approach for assessing fire performance assumes a fully-engulfing fire of duration one hour. The recent Disposal System Safety Case (DSSC) suite of documents includes illustrative generic designs for a GDF in three generic geological settings. We are now able to analyse these designs to develop a more realistic set of fire accident scenarios. The influences on fire performance that need to be considered include the location of the fire, any protection provided by the transport container, availability of combustible material, degradation of the wasteform and associated release of activity.

Work has been undertaken by the Operational Safety Case team in justifying a reduction in the duration of the reference fires, and hence the maximum temperatures reached by much of the package in these identified scenarios. The heat loading into waste packages is dependent on the temperature difference between the flame temperature and the surface temperature of the waste package. Hence, release fractions (RFs) for package fire assessment do not simply scale with flame temperature or duration; therefore the RFs previously determined for a one hour, 1000°C fire cannot simply be scaled to represent those relating to the more realistic fire accident scenarios. Hence, modelling needs to be performed to derive the RFs appropriate to the new, shorter, fire scenarios. The intention is to provide an improved dataset that can be interpolated and applied to different scenarios. In the future, the fire accident performance data will then be flexible and remain appropriate even if there are further changes to some of the scenarios as the design develops.

Research Need
To support the operational safety case by deriving an improved dataset that, based on more a realistic (shorter duration) reference fire(s), reduces conservatisms in the fire fault release fractions.

Research Objective
To obtain a set of RFs relevant to the set of realistic fire accident scenarios which are currently being developed by RWM. The dataset can then be interpolated and applied to different scenarios.

Scope
The scope comprises the development of thermal models and RFs for each of the 'standard' types of waste package (as listed below) with revised boundary conditions corresponding to the appropriate 'realistic fire accident scenarios'. The standard packages are:
- Unshielded ILW packages - 500 litre drum (homogeneous, heterogeneous and annular grouted), 3 cubic metre box, 3 cubic metre drum and Miscellaneous Beta-Gamma Waste Store (MBGWS) box.
- Shielded ILW packages - 2 metre box (with both 100mm and 200mm of concrete), 4 metre box (with both 100mm and 200mm of concrete) and 6 cubic metre box.

Further information
Relevant publications include:
Appendix B - 414

Title
Effect of Re-Heating on Vitrified Waste

Background
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

For simplicity, fire accident scenarios consider radionuclides in 6 ‘volatility groups’ and wasteforms in a small number of generic waste package types. The ‘vitrification’ of ILW has been proposed by some waste producers, whereby a glass wasteform is formed at temperatures of over 1000°C; there is however currently no information on radionuclide release fractions (RFs) for this material when re-heated. This task will underpin the assumption that the RF for this material is expected to be low.

Research Need
To support the transport and operational safety cases by demonstrating that thermally treated ILW (vitrified ILW) poses no challenge to a fire accident scenario (since it has already been heated to over 1000°C).

Research Objective
To underpin the assumption that the RF for vitrified ILW is expected to be low; this consideration should include consideration of aged or re-wetted wasteforms.

Scope
The scope comprises the thermal modelling of ‘vitrified’ ILW in a fire scenario so as to derive RFs. This study will include an understanding of the manufacture of the wasteform in order to:
- Identify and evaluate the appropriateness of currently available data.
- Prepare a report which identifies any research needs in order for this wasteform to be acceptable to RWM.

SRL at task start 4 | SRL at task end 6 | Target SRL 6
End point No Further Research Planned
Customer Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Fire Accident Release Fraction Data</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Derivation of Fire Release Fractions for Packages Within the Standard Waste Transport Container (SWTC)

**Background**

RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

The current bounding approach for assessing fire performance assumes a fully-engulfing fire of duration one hour. The presence of the Standard Waste Transport Container (SWTC) around the waste package will result, in the event of a fire, in the waste package experiencing lower temperatures, but over a longer period of time. Even under normal conditions of transport some waste packages may experience temperatures above the 50°C limit at which radionuclide releases are currently assumed by RWM to occur.

To support transport assessments information is needed on the impact of longer heating and cooling times for packages inside a Standard Waste Transport Container (SWTC), taking consideration of:
- The effect of the SWTC in reducing the temperature to which wasteforms may be exposed in a fire accident.

**Research Need**

To support the transport safety case by understanding the impact of the presence of the SWTC on the fire performance of waste packages.

**Research Objective**

To provide radionuclide RF data for different types of waste package inside a Standardised Waste Transport Container (SWTC).

**Scope**

The scope comprises:
- Determination of temperatures which waste packages inside the SWTC might experience - both under fire accident conditions as a function of time and under normal conditions of transport. These temperatures will be based on calculations, and will be compared against those which a ‘bare’ waste package might experience in a fire accident.
- Undertaking a review of findings/results of previous experimental research regarding radionuclide RFs (both small-scale and full-scale) to evaluate the effects of duration upon release fractions.
- Consideration on the need to include some longer duration tests in the fire-rig test programme.

**SRL at task start** | **SRL at task end** | **Target SRL**
|-------------------|--------------------|----------------
| 4                 | 6                  | 6              |

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

**Further information**

Relevant publications include:

Appendix B - 416

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Fire Accident Release Fraction Data</td>
<td></td>
</tr>
</tbody>
</table>

Title
Update to Standard Reference Report for Fire Release Fractions

Background
RWM has developed a good understanding of the performance of waste packages in bounding fire accidents. Based on this understanding, we have developed a set of ‘release fractions’ (RFs) for use in safety assessments. For ILW packages, extensive modelling has been conducted, which provides a good knowledge of the expected heat energy absorbed by the waste container. Most of the energy will be absorbed by the immobilised waste and methodologies have been developed to understand the mobile species generated within the wasteforms and hence released from these waste packages.

Following RWM and international research in the Waste Package Accident Performance work area (Tasks 926, 946, 948, 1010 and 1012) a revised version of the AEAT (2001) fire accident release fraction (RF) report (known as the ‘Bush and Harris’ report) is required, including the following updates:
- New fire rig commissioning data.
- International package release data.
- Better substantiation.
- More package types and waste forms.

There may also be a need to revise the solubility data that underpins the Bush and Harris report. It is expected that the new data will enable the recommended RFs at low temperatures (50°C to 150°C) to be significantly reduced, which will have a notable impact upon the predicted releases from many waste packages under fire accident scenarios.

Research Need
To support the operational and transport safety cases and waste package disposability assessments by consolidating recent RWM and international improvements in fire accident RF data in a new standard RWM reference.

Research Objective
To update the ‘Bush and Harris’ recommended fire accident radionuclide RF report using data from the fire-rig commissioning tests, data generated as part of the Waste package Accident Performance work programme and any available international RF data.

Scope
The scope comprises a review of international data on fire accident radionuclide RFs and data from the fire-rig commissioning tests and any further tests. The deliverable for this task is an update of the ‘Bush and Harris’ recommended RF report.

Further information
Relevant publications include:
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Fire Accident Release Fraction Data</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Mixed Oxide Spent Fuel (MOX SF) - Thermal Properties for Use in Fire Fault Modelling

**Background**

Safety assessments require thermal modelling for fire accident performance. These models require relevant and accurate input data in order to produce confident results.

**Research Need**

MOX SF has been identified as requiring identification of its thermal properties in order for thermal fault assessments to be carried out.

**Research Objective**

A set of agreed thermal properties data for MOX SF suitable as input to the finite element modelling codes in use at the time of the task.

**Scope**

A review of the available thermal properties data for MOX SF and selection of a representative dataset for performing safety evaluations.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Waste Package Disposability Assessments, Disposal System Safety Case

**Further information**


<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
<td></td>
</tr>
<tr>
<td>PBS level 5</td>
<td>Combined Fault Accident Methodologies and Criteria</td>
<td></td>
</tr>
</tbody>
</table>

**Title**

Methodology for Determining Release Fractions in Combined Fault Accidents and Identification of Modifying Mechanisms

**Background**

The current approach for assessing combined impact and fire performance is to assume that the two events are independent and can be assessed separately. Further work is required to understand the fire performance following an impact and whether there are any new mechanisms that could give rise to an enhanced release of radioactivity.

The current approach may be appropriate if the waste container is intact following the initial impact. However, if a waste container is breached in the initial impact, there will no longer be a complete barrier to prevent free air ingress. Chemical reactions can proceed faster when there is a supply of oxygen. Hence, compared to the pyrolysis mechanisms considered for an unbreached waste package in a fire-only accident (as considered in Task 946), there could be stronger degradation mechanisms acting on the wasteform. This task considers such mechanisms and evaluates whether there are further research needs in this area.

**Research Need**

To support the transport and operational safety cases by providing the required technical arguments and underpinning data for combined impact and fire accidents.

**Research Objective**

For each of the combined impact and fire accident scenarios and / or for each of the associated package types:

- To document the rationale for considering the impact and fire components of a fault separately and additively (if possible).
- To evaluate whether our current practice of considering impact followed by fire, rather than the reverse scenario, is justified.
- To evaluate whether there are any combined fault mechanisms, that could give rise to additional release of radioactivity.
- To identify further work required to understand the fire performance following an impact.

**Scope**

The scope comprises consideration of each of the combined accident scenarios identified by RWM and each package type which may be involved in such an accident. The effect of the impact damage upon the fire performance (or vice-versa) will be considered and, for each case, the argument as to why it is acceptable to simply add the separate impact and fire RFs will be documented. Cases where the addition of the separate RFs cannot be justified will be identified.

In the event that findings of activities above suggest an accident scenario in which the simple addition approach cannot be justified, the mechanisms that may enhance the combined RFs will be identified and considered, together with any further research requirements.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

End point: No Further Research Planned

Customer: Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

**Further information**

Relevant publications include:


Appendix B - 418
<table>
<thead>
<tr>
<th>Task Number</th>
<th>Status</th>
<th>Start date in future</th>
</tr>
</thead>
<tbody>
<tr>
<td>1031</td>
<td>PBS level 4</td>
<td>Waste Package Accident Performance</td>
</tr>
<tr>
<td></td>
<td>PBS level 5</td>
<td>Combined Fault Accident Release Data</td>
</tr>
</tbody>
</table>

**Title**

Review and Revision of Release Fraction (RF) Data in Combined Fault Accident Scenarios

**Background**

The current approach for assessing combined impact and fire performance is to assume that the two events are independent and can be assessed separately. Further work is required to understand the fire performance following an impact and whether there are any new mechanisms that could give rise to an enhanced release of radioactivity.

Further work, conducted in Task 1026 will consider the fire performance following an impact and whether there are any new mechanisms that could give rise to additional release of radioactivity. The current approach may be appropriate if the waste container is intact following the initial impact. If a waste container is however breached in the initial impact, there will no longer be a complete barrier to prevent free air ingress. Chemical reactions can proceed faster when there is a supply of oxygen. Hence, compared to the pyrolysis mechanisms considered for an unbreached waste package in a fire-only accident, there could be stronger degradation mechanisms acting on the wasteform. This task comprises the collation of a dataset for realistic scenarios of impact followed by fire, for both transport and operations. A release fraction (RF) range, which accounts for uncertainty in material property and test data for each of the combined accident scenarios, is required.

**Research Need**

To support the transport and operational safety cases by providing the a dataset of combined impact and fire Release Fractions for ILW / LLW packages that can be interpolated and applied to different scenarios, retaining flexibility as the design develops.

**Research Objective**

To consider, assess and collate the combined impact and fire accident radionuclide RFs for any scenarios identified previously (task 1026) for which justification cannot be provided for obtaining an overall RF by simply adding the separate fire and impact RFs.

**Scope**

The scope comprises the provision of a dataset of combined impact and fire RFs for ILW / LLW packages which can be interpolated and applied to different realistic scenarios for impact followed by fire, retaining flexibility as the design develops.

<table>
<thead>
<tr>
<th>SRL at task start</th>
<th>SRL at task end</th>
<th>Target SRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**End point**

No Further Research Planned

**Customer**

Disposal System Safety Case, Assessment of Packaging Solutions, Upstream Waste Processing at Decommissioning Sites

**Further information**

Relevant publications include:

Appendix C – Long-range Graphic
Key

- **3** Existing task
- **4** Task end point
- **4** Planned task start
- **-** Task duration
- **-----** Task link
- **Internal / External link**
- **Cross reference**
- **End points**
- **BLUE** Research Council UK collaborative programme ('curiosity driven')
- **RED** Comment
- **4** Continuing task
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
</tbody>
</table>

**BIOSPHERE & CHEMO-TOXICITY**

### BIOSPHERE

- **BIOSPHERE ASSESSMENT APPROACH**
  - Framework and Methodology

### BIOSPHERE - BIOSPHERE UPTAKE OF RADIONUCLIDES

- **(011)** MODARIA: Review and Update of Radiological Data
- **(012)** MODARIA: Biosphere Modelling and Parameter Update
- **(013)** MODARIA: Effects of Acute and Chronic Exposure on Wildlife
- **(014)** NERC TREE: Development of a Mechanistic Understanding of Acute and Chronic Low-dose Exposure and Transgenerational Effects on Non-human Biota
- **(015)** NERC TREE: Spatial Behaviour of Non-human Biota Reference Species
- **(017)** NERC Lo-RISE: Studies of Species Transport and Transfer of Key Radionuclides (U-234, U & Ra) in Naturally Contaminated Environments and Laboratory Studies

### BIOSPHERE - CATCHMENT MODELLING

- **(012)** MODARIA: Review and Update of Radiological Data
- **(013)** MODARIA: Effects of Acute and Chronic Exposure on Wildlife
- **(014)** NERC TREE: Development of a Mechanistic Understanding of Acute and Chronic Low-dose Exposure and Transgenerational Effects on Non-human Biota
- **(015)** NERC TREE: Spatial Behaviour of Non-human Biota Reference Species
- **(017)** NERC Lo-RISE: Studies of Species Transport and Transfer of Key Radionuclides (U-234, U & Ra) in Naturally Contaminated Environments and Laboratory Studies

### BIOSPHERE - UNDERSTANDING THE BEHAVIOUR OF C-14

- **(046)** BIOPROTA: Behaviour of C-14 in Terrestrial & Aquatic Systems – Follow-up International Model Comparison and Validation Study

### CHEMO-TOXICITY

- **(051)** Development of Supporting Information for Post-closure Non-radiological Assessment
- **(052)** Consideration of Non-radiological Post-Closure Safety

### BIOPROTA - GeoSphere / Biosphere Interface Modelling

- **(001)** BIOPROTA: GeoSphere / Biosphere Interface Modelling

### BIOSPHERE - CHEMO-TOXICITY

- **(051)** Development of Supporting Information for Post-closure Non-radiological Assessment
- **(052)** Consideration of Non-radiological Post-Closure Safety

### Further Work to be Defined

- **(003)** Update of BIOMASS Methodology
- **(004)** Interface Biosphere / SEA

### Site Specific Application of Modelling Capability

- **(001) BIOPROTA: Geosphere / Biosphere Interface Modelling**
- **(002) Updated Marine Model for Climate Status Posing a Potential Challenge to the Risk Guidance Level**
- **(003) Update of BIOASS Methodology**
- **(004) Interface Biosphere / SEA**
- **(005) Synthesis of NERC TREE**
- **(006) Further International Collaboration on Effects of Radiation on Non-human Biota**
- **(007) Periodic Review of the Potential Impact of Natural Processes on a GDF**
- **(008) Further Work to be Defined**

**Final Dec '23**

Appendix C - 2
### ALTERNATIVES & CONCEPTS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
<td>Q1 Q2 Q3 Q4</td>
</tr>
</tbody>
</table>

#### REVIEW OF OPTIONS (056)
- **(056) Review of Alternative Waste Management Options**
  - (As this task does not address a specific technology it is not appropriate to present SRLs)

#### CONCEPT DEVELOPMENT (057 – 065)
  - Watch Brief on Alternatives

  - No Further Research Planned

- **(059) Concepts IPT: Development of the Concept Selection Process**
  - (As this task comprises the development of a methodology it is not appropriate to present SRLs or TRLs)
## CRITICALITY SAFETY

### CRITICALITY SAFETY ASSESSMENT FOR SPENT FUEL DISPOSAL (066 – 090)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Control Options Study</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
</tr>
</tbody>
</table>

### CRITICALITY SAFETY ASSESSMENT FOR ILW DISPOSAL (091 – 100)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Criticality Control Options Study</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
</tr>
</tbody>
</table>

### CRITICALITY SAFETY ASSESSMENT FOR PLUTONIUM AND URANIUM DISPOSAL (101 – 115)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Development of Separated Plutonium Disposal Concepts</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
</tr>
</tbody>
</table>

### CRITICALITY SAFETY – LIKELIHOOD OF CRITICALITY POST-CLOSURE (116 – 122)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Application of Models to Revised Inventories / Concepts</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
</tr>
</tbody>
</table>

### CRITICALITY SAFETY – MODELS OF CONSEQUENCES OF HYPOTHETICAL CRITICALITY (130 – 135)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Types of Critical Systems and the Credibility of Rapid Transient Criticality during Post-closure</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
</tr>
</tbody>
</table>

### CRITICALITY SAFETY – ASSESSMENT OF CONSEQUENCES OF HYPOTHETICAL CRITICALITY (136 – 138)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Update to the Post-closure Criticality Consequence Assessment (FCCA)</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
<td>No Further Research Planned</td>
</tr>
</tbody>
</table>
DESIGNS (TRLs)\textsuperscript{4}

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
</tbody>
</table>

### DISPOSAL FACILITY SYSTEM DESIGNS (150 – 180)

- **(152) MPC Vault Design**
- **(154) Development of a 500 Litre Drum Disposal Stillage**
- **(158) Construction Materials**
- **(162) Watching Brief on Technology & Techniques for Safeguards Verification**
- **(163) Disposal Container Design**
- **(164) GDF Investigations and Construction**
- **(165) Package Handling and Transfer**
- **(166) Vault / Tunnel Design and Emplacement**
- **(167) GDF Utilities and Services**
- **(168) Sealing and Closure**
- **(169) Technology and Techniques for Nuclear Security**

### TRANSPORT SYSTEM DESIGNS (181 – 195)

- **(153) Development of SWTC-150 for increased payload**
- **(181) Transport Container Design**
- **(182) UK Transport Infrastructure Constraints in the Geological Disposal System**

### DISPOSAL SYSTEM COST ESTIMATES (196 – 200)

- **(196) Maintaining Up-to-date Cost Estimates for the GDF Programme**

\textsuperscript{4}For engineering design tasks the concept of Technology Readiness Levels (TRLs) is more appropriate than Scientific Readiness Levels (SRLs) as this research and development concerns the planning and provision of engineering solutions rather than developing scientific underpinning. Hence, unless stated otherwise, TRLs are used on this sheet.
### GAS PATHWAY

#### GAS: C-14 RELEASE FROM IRRADIATED METALS (201 – 225)

1. **FY2014/15**
   - 

2. **FY2015/16**
   - (201) EC CAST: WP2 Measurement of the C-14 Release Rate and Speciation from Irradiated Stainless Steels
   - (202) Manufacture and Commission Experimental Rig for CAST Stainless Steel Experiments
   - (203) C-14 IPT: Update of Model of C-14 Release from Irradiated Stainless Steel
   - (204) C-14 IPT: Measurement of C-14 Release from Irradiated Reactive Metals (Magnesium and Aluminium) to the Gas Phase
   - (205) C-14 IPT: Capture Understanding of C-14 Release from Reactive Metals and Apply to Disposal Systems Concept Optimisation
   - (206) EC CAST: WP3 Measurement of the C-14 Release Rate and Speciation from Irradiated Zircaloy in a Range of Aqueous Conditions

3. **FY2016/17**
   - (207) EC CAST WP2 (UK Component): C-14 Release and Speciation from Irradiated Stainless Steel Under pH12 Conditions
   - (209) Update Task with New Understanding of C-14 Release from Reactive Metals (Magnesium, Aluminium)
   - (210) Synthesis of Recent EPSRC and EC CAST Outputs in UK Context

4. **FY2017/18**
   - (211) Further Update of Model of C-14 Release from Irradiated Stainless Steel
   - (212) Mechanistic Study on C-14 Release and Speciation from Zircaloy

5. **FY2018/19**
   - (213) Further Update of Model of C-14 Release from Irradiated Stainless Steel
   - (214) C-14 Release from AGR Steels

6. **FY2019/20**
   - (215) Update Task with New Understanding of C-14 Release from Reactive Metals (Magnox, Aluminium)
   - (216) C-14 Release from AGR Steels

7. **FY2020/21**
   - (217) Further Update of Model of C-14 Release from Irradiated Stainless Steel
   - (218) C-14 Release from AGR Steels

8. **FY2021/22**
   - (219) Further Update of Model of C-14 Release from Irradiated Stainless Steel
   - (220) C-14 Release from AGR Steels

9. **FY2022/23**
   - (221) Further Update of Model of C-14 Release from Irradiated Stainless Steel
   - (222) C-14 Release from AGR Steels

#### GAS: C-14 RELEASE FROM IRRADIATED GRAPHITE (226 – 240)

1. **FY2014/15**
   - (223) EPSCR Geowaste: C14 - Micro-distribution
   - (224) EPSCR Geowaste: C14 - D1G - Micro-Transport
   - (225) EC CAST: WP4 Measurement of the C-14 Release Rate and Speciation from Irradiated Graphite

2. **FY2015/16**
   - (226) C-14 IPT: Update of Model of C-14 Release from Irradiated Graphite
   - (227) C-14 IPT: Measurement of C-14 Release from Irradiated Graphite
   - (228) C-14 IPT: Further Measurements on Release of C-14
   - (229) C-14 IPT: Benefits of Graphite Segregation

3. **FY2016/17**
   - (230) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (231) Update to Data and Model of C-14 Release from Irradiated Graphite
   - (232) Studies of C-14 Release from Graphite from Reactors Other Than Oldbury

4. **FY2017/18**
   - (233) C-14 IPT: Further Measurements on Release of C-14
   - (234) C-14 IPT: Benefits of Graphite Segregation
   - (235) C-14 IPT: Further Measurements on Release of C-14
   - (236) Update to Data and Model of C-14 Release from Irradiated Graphite

5. **FY2018/19**
   - (237) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (238) Study of C-14 Release from Irradiated Graphite
   - (239) C-14 IPT: Further Measurements on Release of C-14

6. **FY2019/20**
   - (240) C-14 IPT: Further Measurements on Release of C-14
   - (241) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite

7. **FY2020/21**
   - (242) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (243) C-14 IPT: Further Measurements on Release of C-14

8. **FY2021/22**
   - (244) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (245) C-14 IPT: Further Measurements on Release of C-14

9. **FY2022/23**
   - (246) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (247) C-14 IPT: Further Measurements on Release of C-14

#### GAS: SYSTEM MODELLING FOR C-14 (251 – 260)

1. **FY2014/15**
   - (252) EC CAST: WP5 International Evaluation of Safety Case Approaches to C-14 Release
   - (253) C-14 IPT: Synthesis of Knowledge Gained from C-14 IPT

2. **FY2015/16**
   - (254) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (255) C-14 IPT: Further Measurements on Release of C-14

3. **FY2016/17**
   - (256) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (257) C-14 IPT: Further Measurements on Release of C-14

4. **FY2017/18**
   - (258) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (259) C-14 IPT: Further Measurements on Release of C-14

5. **FY2018/19**
   - (260) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (261) C-14 IPT: Further Measurements on Release of C-14

6. **FY2019/20**
   - (262) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (263) C-14 IPT: Further Measurements on Release of C-14

7. **FY2020/21**
   - (264) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (265) C-14 IPT: Further Measurements on Release of C-14

8. **FY2021/22**
   - (266) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (267) C-14 IPT: Further Measurements on Release of C-14

9. **FY2022/23**
   - (268) C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite
   - (269) C-14 IPT: Further Measurements on Release of C-14

#### Further Work

- Gas-Pathway
- No Further Research Planned
## GAS PATHWAY (Continued)

### GAS: OTHER RADIOACTIVE GASES
- **FY2014/15**: AM MJ AJ AS ON DJ F M
- **FY2015/16**: AM MJ AJ AS ON DJ F M
- **FY2016/17**: AM MJ AJ AS ON DJ F M
- **FY2017/18**: AM MJ AJ AS ON DJ F M
- **FY2018/19**: AM MJ AJ AS ON DJ F M
- **FY2019/20**: AM MJ AJ AS ON DJ F M
- **FY2020/21**: AM MJ AJ AS ON DJ F M
- **FY2021/22**: AM MJ AJ AS ON DJ F M
- **FY2022/23**: AM MJ AJ AS ON DJ F M

### GAS: BULK GAS GENERATION
- **FY2014/15**: AM MJ AJ AS ON DJ F M
- **FY2015/16**: AM MJ AJ AS ON DJ F M
- **FY2016/17**: AM MJ AJ AS ON DJ F M
- **FY2017/18**: AM MJ AJ AS ON DJ F M
- **FY2018/19**: AM MJ AJ AS ON DJ F M
- **FY2019/20**: AM MJ AJ AS ON DJ F M
- **FY2020/21**: AM MJ AJ AS ON DJ F M
- **FY2021/22**: AM MJ AJ AS ON DJ F M
- **FY2022/23**: AM MJ AJ AS ON DJ F M

### GAS: GAS MIGRATION THROUGH CEMENT-BASED EBS MATERIALS
- **FY2014/15**: AM MJ AJ AS ON DJ F M
- **FY2015/16**: AM MJ AJ AS ON DJ F M
- **FY2016/17**: AM MJ AJ AS ON DJ F M
- **FY2017/18**: AM MJ AJ AS ON DJ F M
- **FY2018/19**: AM MJ AJ AS ON DJ F M
- **FY2019/20**: AM MJ AJ AS ON DJ F M
- **FY2020/21**: AM MJ AJ AS ON DJ F M
- **FY2021/22**: AM MJ AJ AS ON DJ F M
- **FY2022/23**: AM MJ AJ AS ON DJ F M

### GAS: GAS MIGRATION THROUGH THE GEOSPHERE
- **FY2014/15**: AM MJ AJ AS ON DJ F M
- **FY2015/16**: AM MJ AJ AS ON DJ F M
- **FY2016/17**: AM MJ AJ AS ON DJ F M
- **FY2017/18**: AM MJ AJ AS ON DJ F M
- **FY2018/19**: AM MJ AJ AS ON DJ F M
- **FY2019/20**: AM MJ AJ AS ON DJ F M
- **FY2020/21**: AM MJ AJ AS ON DJ F M
- **FY2021/22**: AM MJ AJ AS ON DJ F M
- **FY2022/23**: AM MJ AJ AS ON DJ F M

### GAS: GAS MIGRATION THROUGH CLAY-BASED EBS MATERIALS
- **FY2014/15**: AM MJ AJ AS ON DJ F M
- **FY2015/16**: AM MJ AJ AS ON DJ F M
- **FY2016/17**: AM MJ AJ AS ON DJ F M
- **FY2017/18**: AM MJ AJ AS ON DJ F M
- **FY2018/19**: AM MJ AJ AS ON DJ F M
- **FY2019/20**: AM MJ AJ AS ON DJ F M
- **FY2020/21**: AM MJ AJ AS ON DJ F M
- **FY2021/22**: AM MJ AJ AS ON DJ F M
- **FY2022/23**: AM MJ AJ AS ON DJ F M

---

**For Cement Backfill Carbonation Refer to: Nearfield (189) Experimental Demonstration of NRVB Carbonation at the 500 Litre Drum Scale**

---

**Watching Brief on International RD&D on Bentonite-Gas Interactions**

---

**Input from C-14**: EPSRC GEOWASTE SAFE Barriers: Gas Flow in Saturated Bentonite at Elevated Temperature

---

**Watching Brief on International RD&D on Clay-Gas Interactions**

---

**Input from C-14 Integrated Project**

---

**Site Specific Validation**

---

**Further Work to be Defined**

---

**End-date to be Defined**

---

**Watching Brief on International RD&D on Bentonite-Gas Interactions**

---

**Site Specific Application of Understanding**

---

**Watching Brief on International RD&D on Clay-Gas Interactions**

---

**Site Specific Application of Understanding**

---

**Input: Workshop in Mid-2014**

---

**Input: (443) Study of Hydrogen Utilisation by Microbes in Cement-based EBS**

---

**Input: Conceptual Model of Gas-NRVB Interactions**

---

**Site Specific Application of Understanding**

---

**Watching Brief on International RD&D on Bentonite-Gas Interactions**

---

**Site Specific Application of Understanding**

---

**Input: Conceptual Model of Gas-NRVB Interactions**

---

**Site Specific Application of Understanding**

---

---

Appendix C - 7
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
</tbody>
</table>

**INVENTORY**

INVENTORY (306 - 330)

(306) Further Development of the Derived Inventory

This task does not address a specific technology; it is not appropriate to present SRLs.
## GEOSPHERE - COUPLED PROCESSES (381 – 415)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FY2014/15
FY2022/23
FY2021/22
FY2020/21
FY2019/20
FY2018/19
FY2017/18
FY2016/17
FY2015/16
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
AMJJASONDJFM AMJJASONDJFM AMJJASONDJFM AMJJASONDJFM AMJJASONDJFM AMJJASONDJFM AMJJASONDJFM AMJJASONDJFM AMJJASONDJFM

NEARFIELD
- EVOLUTION OF CEMENT
BASED EBS
(416 – 440)

4

(416) Hydrothermal Ageing of NRVB

5

2
(422) Characterisation and
Leaching of Aged Waste
4
Encapsulation Cements

3

(423) Ageing of NRVB and Impact on Safety Functions

(418) Impact of DCICs and Vitrified ILW on Cement
Backfill Performance

5
4 (431) Rate and Extent of Reactions Between NRVB and Robust Shielded Containers or Vitrified ILW

4

(419) Effect of Groundwater Solutes on Physical Properties of Cementitious Backfill

3

(424) Pilot Backfill Leaching and Migration Experiment
in Overseas URL

5
4 (425) Demonstration Backfill and

Leaching Experiment in Overseas URL

4

(420) Experimental Demonstration
of NRVB Carbonation at the 500
Litre Drum Scale

4

(426) Further Experimental / Modelling Study to be Defined from Task (446)
(427) Effect of Crack Armouring on Groundwater Conditioning for Backfill Under
Advective Flow Conditions

4
-

3

(441) Acceptance Test and Further
Development of Near-field
Component Model

4

4

(429) Application of Novel Experimental Approaches to Understanding Long-term Evolution of Watersaturated Cement

(430) Participation in EC Project CEBAMA

-

3

5

(432) Support to the Development and
Implementation of Strategy for Management of
NDA-owned Materials and Samples
(As this task does not address a specific
technology it is not appropriate to present SRLs)

3

3

(444) Further Development of Near-field
Component Model

(442) Effect of Ionising
Radiation on EBS
Performance

4

4

5

5

Finish
Jan ‘26

Site Specific
Validation

Site Specific
Validation

(446) Application of
4
Near-field
Component Model Using Updated
Understanding of Backfill Evolution

Input to Design Development &
Disposability Assessments

(445) Further Investigation of the Effects of Ionising Radiation on EBS Performance in Cement and Clay Systems
(e.g. Effects on Redox, Organic Degradation Products, Microbial Processes, etc.)

Appendix C - 11

5

5

5

(428) Novel Experimental
Approaches to
Understanding Long-term
4
Evolution of Watersaturated Cement

NEARFIELD
- CEMENT BASED EBS
MODEL & SYSTEM
INTERACTIONS
(441 – 455)

5

4

Input: (758) Devel. of a Process
Model for CDP Behaviour in the
Near Field
(736) Laboratory Demonstration of
Chemical Containment

4

4

4

4
3

(421) Effect of High Temperatures (>100°C) on Cement Backfill for SF / MPC

(417) Expt’l Design:
2
High Temperature
Backfill Functional Reqs

Site Specific Validation

NEARFIELD EVOLUTION

No Further
Research Planned

5


SITE CHARACTERISATION

(486 – 510)

4


3

(492) Mechanics of Rock Discontinuities Under Elevated Temperatures and Pressures

5

(494) Development of an Understanding of Information Requirements for Underground Monitoring and Investigations

Site Specific Application of Understanding

Site Specific Validation

 Appendix C - 13
### HIGHER ACTIVITY WASTE PROGRAMME

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>AM</td>
<td>JJ</td>
<td>AS</td>
<td>ON</td>
<td>DJ</td>
<td>FM</td>
<td>AM</td>
<td>JJ</td>
<td>AS</td>
</tr>
</tbody>
</table>

#### UPSTREAM OPTIONS (511 – 535)

- **(511) Development of a Larger Waste Package** 3 Proof of Concept 7 No Further Generics; Work Required
- **(512) Development of Disposability Manufacturing Standards**
- **(513) Guidance on the Disposability of Decontamination Agents**
- **(514) Guidance on the Disposability of Filters**
- Work Programme Still Under Development Further Work to be Defined

### FY2014/15

- Development of a Larger Waste Package: TRL 3 Proof of Concept
- Development of Disposability Manufacturing Standards: TRL
- Guidance on the Disposability of Decontamination Agents: TRL
- Guidance on the Disposability of Filters: TRL
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WASTEFORM EVOLUTION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- ALTERNATIVE INORGANIC WASTEFORMS (601 – 615)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- URANIUM WASTEFORMS (631 – 635)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>- CAST WP5.4 Evaluation of Waste Treatment Options for Irradiated Graphite (636)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

# Appendix C - 16
## Appendix C - 17

### Previous Work on Atmospheric Corrosion

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>HLW/SF Corrosion Resistance Container Materials (666 – 679)</td>
<td>(666) Scoping Studies on Durability of Grade 2 Ti Alloys</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(667) Full Scale Demonstration Experiment (Titanium and Stainless Steel)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(668) Corrosion Study with Coupled Mechanical and Chemical Analysis</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(670) Studies of Internal Pressure Hydrogen Embrittlement of Carbon Steel / Cast Iron Containers</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(671) Scoping Studies on Durability of ILW Concretes</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(672) Further Studies on the Corrosion Behaviour of Corrosion Resistant Materials</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(673) Development of Component Models for Durability after Closure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(674) Further Studies on the Corrosion Behaviour of Corrosion Resistant Materials</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(675) Development of Component Models for Durability after Closure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>ILW Corrosion Resistance Container Materials (686 – 710)</td>
<td>(676) Experimental Studies on Stainless Steel in Cyclic Conditions and with Salt Mixtures</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(677) EPSRC GEOWASTE: Mechanistic Studies of Pitting and Stress Corrosion of Stainless Steel</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(678) Development of Parametric Model: Atmospheric Corrosion of Stainless Steel in Stores (ACSIS)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(679) Monitoring and Demonstration Studies of Carbon Steel / Cast Iron Components in Atmosphere</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(680) Testing and Refinement of the ACSIS model, including Extension to Carbon Steel and Cast Iron Components</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(681) Corrosion Studies of Carbon Steel / Cast Iron in Cyclic Conditions and Salt Mixtures</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>ILW Concrete Containers (711 – 715)</td>
<td>(711) Review of the Durability of ILW Container</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Further Work to be Defined</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

### Application of Understanding to Concept / Design Development

- Finish Dec '24

### Long-term Experiment

- Duration: 5 years

---

**Notes:**
- **FY:** Fiscal Year
- **Q:** Quarter
- **HLW:** High-Level Waste
- **ILW:** Intermediate-Level Waste
- **ACSIS:** Atmospheric Corrosion of Stainless Steel in Stores
- **Scoping:** Preliminary investigations
- **Site Specific Validation:** Demonstrations in real-world conditions
- **Component Durability:** Evaluation of materials across various conditions
- **Long-term Experiment:** Continuous monitoring over extended periods
- **Finish Date:** Tentative end date for certain activities

---

**References:**
- Various technical reports and studies on corrosion resistance and durability of materials under different conditions.
### Radionuclide Behaviour

**Radionuclide Behaviour**

**From Wasteforms for HLW / Spent Fuel**

- **FY2014/15**
  - Q1: Study of CDP metallisation by micro-organisms and Consequent impact on radionuclide mobility
  - Q2: Assessment of the impact of PVC degradation products on radionuclide mobility (using U, Ni & Pu)
  - Q3: Colloids: EC BELBAN - Laboratory study of the Effect of Bentonite Colloids on Radionuclide Mobility
  - Q4: NERC RATE (Imperial): Development of coupled process models of tracer and colloidal transport at the Grimsel URL

- **FY2015/16**
  - Q1: Study of organic additises to cement (e.g. grinding agents)
  - Q2: Review of superplasticizer chemistry and performance
  - Q3: Review of syntheses relevant to radionuclide mobility and the effects of organic additives on radionuclide mobility
  - Q4: Investigation of whether biodegradable colloids and biopolymer colloids are additive

- **FY2016/17**
  - Q1: Colloids: 1C – URL study on the effect of bentonite colloids on radionuclide mobility
  - Q2: MRC RATE (Imperial): Development of coupled process models of tracer and colloidal transport at the Grimsel URL
  - Q3: Review of potential superplasticizer systems for GDF construction
  - Q4: Development of CDP process model - impact on radionuclide mobility

- **FY2017/18**
  - Q1: Development of a CDP process model - impact on radionuclide mobility
  - Q2: Study on CDP metabolism by micro-organisms and consequent impact on radionuclide mobility
  - Q3: Study on the Impact of PVC Degradation Products on Radionuclide Mobility (using U, Ni & Pu)
  - Q4: Review of organic additives to cement (e.g. grinding agents)

- **FY2018/19**
  - Q1: Review of organic additives to cement (e.g. grinding agents)
  - Q2: Review of potential superplasticizer systems for GDF construction
  - Q3: Development of coupled process models of tracer and colloidal transport at the Grimsel URL
  - Q4: Development of a CDP process model - impact on radionuclide mobility

- **FY2019/20**
  - Q1: Review of potential superplasticizer systems for GDF construction
  - Q2: Review of superplasticizer performance
  - Q3: Site specific validation
  - Q4: Site specific validation

- **FY2020/21**
  - Q1: Review of potential superplasticizer systems for GDF construction
  - Q2: Site specific validation
  - Q3: Site specific validation
  - Q4: Site specific validation

- **FY2021/22**
  - Q1: Review of potential superplasticizer systems for GDF construction
  - Q2: Site specific validation
  - Q3: Site specific validation
  - Q4: Site specific validation

- **FY2022/23**
  - Q1: Review of potential superplasticizer systems for GDF construction
  - Q2: Site specific validation
  - Q3: Site specific validation
  - Q4: Site specific validation

---

### Other Influences on Radionuclide Behaviour

**Other Influences on Radionuclide Behaviour**

- **Nearfield Evolution (422):** Characterisation and Leaching of Aged Waste Encapsulation Cements
- **Nearfield Evolution (420):** Demonstration Batch Kill and Leaching Experiment in Overseas URL
- **Nearfield Evolution (425):** Demonstration Batch Kill and Leaching Experiment in Overseas URL
- **Nearfield Evolution (424):** Pilot Batch Kill Leaching and Migration Experiment in Overseas URL
- **Nearfield Evolution (423):** Pilot Batch Kill Leaching and Migration Experiment in Overseas URL

**Wasteform Evolution Work Programme for Extensive Generic Research Programme Incorporating Radionuclide Release from HLW / SF**

- **Wasteform Evolution (601):** Scoping Dissolution Studies of Non-optimised Vitrified ILW Simulants in Oxic, Near-neutral Groundwaters
- **Wasteform Evolution (602):** Scoping Dissolution Studies of Non-optimised Vitrified ILW Simulants in Oxic, Near-neutral Groundwaters
- **Wasteform Evolution (603):** Effect of iron based materials and radiation damage on the dissolution behaviour of simulants HLW Glasses
- **Wasteform Evolution (584):** Review Research Needs for Polymeric Wasteforms

---

### Geosphere (383):

- Study on the Hydrogeochemical Evolution of the GDF using a UK-Based Industrial Analog Site
- Review of Superplasticisers for GDF Construction

### Nearfield (425):

- Demonstration Batch Kill and Leaching Experiment in Overseas URL

---

### Appendix C - 18
### RADIONUCLEIDE BEHAVIOUR (Continued)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>A</td>
<td>M</td>
<td>J</td>
<td>J</td>
<td>A</td>
<td>S</td>
<td>O</td>
<td>N</td>
<td>D</td>
</tr>
</tbody>
</table>

**Appendix C - 19**

RADIONUCLEIDE BEHAVIOUR - RADIONUCLEIDE BEHAVIOIR IN THE GEOSPHERE

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Near Field.</td>
</tr>
<tr>
<td>2015</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Far Field.</td>
</tr>
<tr>
<td>2017</td>
<td>Database Maintenance, Including Reviews and Experiments on Elements of Importance in Near Field and Geosphere.</td>
</tr>
<tr>
<td>2018</td>
<td>Application of Lo-RISE Outputs in the GDF Context.</td>
</tr>
<tr>
<td>2019</td>
<td>Laboratory / in situ Studies to Address Key Radionuclide Behaviour Uncertainties Arising from Lo-RISE.</td>
</tr>
<tr>
<td>2020</td>
<td>Further Database Maintenance, Including Reviews and Experiments on Elements of Importance in Near Field and Geosphere.</td>
</tr>
<tr>
<td>2021</td>
<td>Review of the Use of Beta Values.</td>
</tr>
<tr>
<td>2022</td>
<td>Development and Integration of Infopath Data Management Tool.</td>
</tr>
<tr>
<td>2023</td>
<td>Finalised.</td>
</tr>
</tbody>
</table>

RADIONUCLEIDE BEHAVIOUR - REPRESENTATION OF RADIONUCLEIDE BEHAVIOIR IN ASSESSMENT MODELS

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Near Field.</td>
</tr>
<tr>
<td>2015</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Far Field.</td>
</tr>
<tr>
<td>2017</td>
<td>Database Maintenance, Including Reviews and Experiments on Elements of Importance in Near Field and Geosphere.</td>
</tr>
<tr>
<td>2018</td>
<td>Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour.</td>
</tr>
<tr>
<td>2019</td>
<td>Update to Process Model for Colloidal / Microbial Processes.</td>
</tr>
<tr>
<td>2020</td>
<td>Application of Understanding.</td>
</tr>
</tbody>
</table>

RADIONUCLEIDE BEHAVIOUR - DEVELOPMENT AND MAINTENANCE OF THERMODYNAMIC MODELS

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Near Field.</td>
</tr>
<tr>
<td>2015</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Far Field.</td>
</tr>
<tr>
<td>2017</td>
<td>Database Maintenance, Including Reviews and Experiments on Elements of Importance in Near Field and Geosphere.</td>
</tr>
<tr>
<td>2018</td>
<td>Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour.</td>
</tr>
<tr>
<td>2019</td>
<td>Update to Process Model for Colloidal / Microbial Processes.</td>
</tr>
<tr>
<td>2020</td>
<td>Application of Understanding.</td>
</tr>
</tbody>
</table>

### RADIONUCLEIDE BEHAVIOUR (Continued)

RADIONUCLEIDE BEHAVIOIR IN THE GEOSPHERE

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Near Field.</td>
</tr>
<tr>
<td>2015</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Far Field.</td>
</tr>
<tr>
<td>2017</td>
<td>Database Maintenance, Including Reviews and Experiments on Elements of Importance in Near Field and Geosphere.</td>
</tr>
<tr>
<td>2018</td>
<td>Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour.</td>
</tr>
<tr>
<td>2019</td>
<td>Update to Process Model for Colloidal / Microbial Processes.</td>
</tr>
<tr>
<td>2020</td>
<td>Application of Understanding.</td>
</tr>
</tbody>
</table>

RADIONUCLEIDE BEHAVIOIR IN THE GEOSPHERE

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Near Field.</td>
</tr>
<tr>
<td>2015</td>
<td>Uranium IPT: Improved Data Set for DNLEU and Daughter Elements in the Far Field.</td>
</tr>
<tr>
<td>2017</td>
<td>Database Maintenance, Including Reviews and Experiments on Elements of Importance in Near Field and Geosphere.</td>
</tr>
<tr>
<td>2018</td>
<td>Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour.</td>
</tr>
<tr>
<td>2019</td>
<td>Update to Process Model for Colloidal / Microbial Processes.</td>
</tr>
<tr>
<td>2020</td>
<td>Application of Understanding.</td>
</tr>
</tbody>
</table>

### Appendix C - 19
## SAFETY ASSESSMENTS

### TRANSPORT SAFETY CASE (826 – 845)

- Development of a Suite of Contents Specification Documentation for All Package Types
- Maintenance of Transport Safety Assessment Toolkits
- Development of Operational Safety Assessment Toolkit
- Maintenance of Toolkit
- Site Specific Validation

### OPERATIONAL SAFETY CASE (846 – 855)

- Development of Off-site Risk Assessment Methodology
- Development of Operational Safety Assessment Toolkit
- Development of Methodologies and Safety Argument for 2016 Operational Safety Case
- Extension of Operational Safety Case to Cover Backfilling, Sealing and Closure
- Respond to Regulator Recommendation R21
- Undertake Evaluation of GDF Design and Safety Case against the WENRA Safety Reference Levels for Radioactive Waste Disposal Facilities
- Develop Licence Condition Arrangements Pertaining to Safety Case Development
- Site Specific Validation

### ENVIRONMENTAL SAFETY CASE (866 – 880)

- Understanding the Implications of Voidage to the Post-closure Safety Case
- Development of Total System Model to Assess the Post-closure Performance of Disposal System Safety Case
- Preparation of Total System Models for Application in the Siting Process
- Review and Update the Environmental Safety Manual to Take Account of Peer Lessons Learned in Environmental Safety Case 2016
- Development of Methodologies and Safety Arguments for 2016 Operational Safety Case
- Site Specific Validation

### INTERNAL INPUT FROM RESEARCH AREAS (846)

- Development of Off-site Risk Assessment Methodology
- Development of Operational Safety Assessment Toolkit
- Development of Methodologies and Safety Argument for 2016 Operational Safety Case
- Review and Update the Transport Safety Manual (TSM) to Take Account of Peer Lessons Learned in TSM 2016
- Development of Total System Model to Assess the Post-closure Performance of Disposal System Safety Case
- Review and Update the Environmental Safety Manual to Take Account of Peer Lessons Learned in Environmental Safety Case 2016
- Site Specific Validation
Appendix C - 21

ENVIRONMENTAL & SOCIO-ECONOMIC ASSESSMENT

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
</tbody>
</table>

**ENVIRONMENTAL ASSESSMENT (881 – 895)**

- (881) Develop a Methodology for Environmental Baseline Monitoring
- (882) Watching Brief
- (883) Development of a Consistent Methodology for Data Elicitation and Quantification of Uncertainty
- (884) Participating in the Forum for Stakeholder Confidence (NEA FSC): ID of Good Practices in Engagement and How Confidence in Geological Disposal can be Increased
- (885) No Further Research Planned

**SOCIO-ECONOMIC ASSESSMENT (896 – 910)**

- (896) Development and Implementation of Community Benefit Agreements
- (897) Web-based and Social Media Tools for Community Engagement
- (898) Effect of Individual Differences in Psychology on Approach to Mathematical Modeling
- (899) Site Specific Application

**Site Specific Validation**

- (900) Development and Implementation of Community Benefit Agreements
- (901) Web-based and Social Media Tools for Community Engagement

- No Further Research Planned

**Site Specific Application**

- (902) ESRC: Series of Seminars on the Societal Aspects of Geological Disposal

Further Work to be Defined
## Waste Package Accident Performance (WPAP)

### Appendix C - 22

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
<td>AMJASONDJFM</td>
</tr>
</tbody>
</table>

### WPAP - Impact Accident Methodologies & Criteria (911 – 925)

1. **(911) Performance of Aged Packages**
2. **(912) Develop Methodologies for Scaling Release Fraction Data for Varying Drop Heights**
3. **(913) Develop, Refine & Document Holistic Impact Methodology**
4. **(914) Develop Improved ILW Package Models (FEM)**
5. **(915) Impact Accident - Behaviour and Properties of Containers and Wasteforms**
6. **(916) Impact Performance of Pressurised Type II and/or IV GSSC Containers**
7. **(917) Develop Improved ILW Package Models - Including Credit for Design Features (e.g. Capping Group)**
8. **(918) Use of Package Decontamination Factors Part 1: Appropriate Analogues**
9. **(919) Use of Package Decontamination Factors Part 2: Multiple Barriers**
10. **(920) Wasteform Cracking**
11. **(921) Updating Holistic Impact Methodology Following Breakup vs Flow Tests**
12. **(922) Derivation of ab initio Release Fraction Values for 3m³ Drum, MBGW Box and Corner-Lifting 3m³ Box**
13. **(923) Package Type Groups**
14. **(924) Prepare Impact Performance Data Set**
15. **(925) Data Requirements for Updated Operational Safety Case Approach**

### WPAP - Impact Accident Release Fraction Data (926 – 945)

1. **(926) Impact Thresholds Below Which Release Will Not Occur**
2. **(927) Use of Package Decontamination Factors Part 1: Appropriate Analogues**
3. **(928) Develop Improved ILW Package Models - Including Credit for Design Features (e.g. Capping Group)**
4. **(929) Use of Package Decontamination Factors Part 2: Multiple Barriers**
5. **(930) Wasteform Cracking**
6. **(931) Data Requirements for Updated Operational Safety Case Approach**

### Research Status
- **No Further Research Planned**

---

**Appendix C - 22**
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Q4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**WASTE PACKAGE ACCIDENT PERFORMANCE (WPAP) Continued**

<table>
<thead>
<tr>
<th>WPAP - FIRE ACCIDENT METHODOLOGIES &amp; CRITERIA (946 – 1005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(947) Methodology for Use of Analogy to Other Waste Package Types</td>
</tr>
<tr>
<td>(948) Development of Improved LW Package Models for Fire Analysis</td>
</tr>
<tr>
<td>(946) Development of Fire Release Fractions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WPAP - FIRE ACCIDENT RELEASE FRACTION DATA (1006 – 1025)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1009) Derivation of a Reference Data Set for Fire Accident Scenarios</td>
</tr>
<tr>
<td>(1007) Revise Volatility Groups</td>
</tr>
<tr>
<td>(1008) Revision of Release Fractions for Volatility Group 1 Radionuclides</td>
</tr>
<tr>
<td>(1012) Scaling Release Fraction Data for Different Fire Scenarios</td>
</tr>
<tr>
<td>(1006) Derivation of Temperature Limits Below Which Release Will Not Occur</td>
</tr>
<tr>
<td>(1010) Fire Performance of Aged Packages</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WPAP - COMBINED FAULT ACCIDENT METHODOLOGIES &amp; CRITERIA (1026 – 1030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1028) Methodology for Determining Release Fractions in Combined Fault Accidents and Identification of Modifying Mechanisms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WPAP - COMBINED FAULT ACCIDENT RELEASE FRACTION DATA (1031 – 1035)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1031) Review and Revision of RF Data in Combined Fault Accident Scenarios</td>
</tr>
</tbody>
</table>

No Further Research Planned

Appendix C - 23
Appendix D – Change Control Record
<table>
<thead>
<tr>
<th>Task No.</th>
<th>Title</th>
<th>Status</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>BIOPROTA: Geosphere / Biosphere Interface Modelling</td>
<td>Ongoing (more than one year delay to completion relative to V1 Plan)</td>
<td>Programme extended because of potential for continuing involvement in a possible successor project within BIOPROTA</td>
</tr>
<tr>
<td>002</td>
<td>Updated Marine Model for Climate States Posing a Potential Challenge to the Risk Guidance Level</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>003</td>
<td>BIOPROTA: Update of BIOMASS (BIosphere Modelling and ASSeessment) methodology</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>004</td>
<td>Interface of Biosphere Programme with Environmental Impact Assessment (EIA)</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>032</td>
<td>Impact of Climate State Transitions</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>046</td>
<td>BIOPROTA: Behaviour of C-14 in Terrestrial and Aquatic Systems – Follow-up International Model Comparison and Validation Study</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Incorrectly shown as ongoing project in Version 1 Science and Technology Plan. This project scheduled to start in Q1 FY16/17</td>
</tr>
<tr>
<td>060</td>
<td>Perform a validation of the 1D thermal model by developing both a 2D and 3D thermal model based on the same starting conditions</td>
<td>Deleted</td>
<td>Task deleted as duplicates other thermal modelling tasks in the V1 S&amp;T Plan</td>
</tr>
<tr>
<td>066</td>
<td>MPC - Criticality Control Options Study</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work is complete and final report is in the review process</td>
</tr>
<tr>
<td>067</td>
<td>MPC - Criticality Safety Assessment for Legacy Fuels</td>
<td>Deleted</td>
<td>Task 67 originally planned to follow on from Task 66. No longer planned as MPC concept shown to be largely unfeasible primarily due to thermal considerations.</td>
</tr>
<tr>
<td>068</td>
<td>Spent Fuel - Criticality Control Options</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed, due to budgetary constraints and following a prioritisation exercise by RWM. Now due to start Q1 FY2016/17.</td>
</tr>
<tr>
<td>069</td>
<td>Disposal Container - Criticality Control Options Study</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed, due to budgetary constraints and following a prioritisation exercise by RWM. Now due to start Q1 FY2016/17.</td>
</tr>
<tr>
<td>070</td>
<td>Concepts (IPT): Feasibility of Disposal Concepts for Exotics</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed, due prioritisation exercise within the Concepts Integrated Project. Now due to start mid FY15/16.</td>
</tr>
<tr>
<td>071</td>
<td>Concepts IPT: Feasibility of Disposal Concepts for Metallic Fuel</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed, due prioritisation exercise within the Concepts Integrated Project. Now due to start mid FY15/16.</td>
</tr>
<tr>
<td>072</td>
<td>MPC - Criticality Safety Assessment for Future Highly Enriched / Low Burn-up Fuels</td>
<td>Deleted</td>
<td>Task 72 originally planned to follow on from Task 66 and 67. No longer planned as MPC concept shown to be largely unfeasible primarily due to thermal considerations.</td>
</tr>
<tr>
<td>080</td>
<td>Develop the Transport Criticality Safety Assessment for the Disposal Container Transport Container</td>
<td>New task</td>
<td>This was originally Task 829 in the Operational Safety area. Following RWM review, transferred to Criticality Safety area</td>
</tr>
<tr>
<td>081</td>
<td>Develop the Disposal Container Transport Container Criticality Safety Assessment for New Fuels in the 2013 Derived Inventory</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>091</td>
<td>Generic Low Likelihood, Low Consequence Package Envelope</td>
<td>Complete and fully reported</td>
<td>Complete and fully reported. Final reports are: T.W. Hicks and T.D. Baldwin, The Likelihood of Criticality: Synthesis Report, AMEC Report 17293-</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>092</td>
<td>Fissile Limits for ILW Transported in an SWTC</td>
<td>Ongoing (more than one year delay to completion relative to V1 Plan)</td>
<td>Draft fissile limits have been derived for 500L drums. Further work is required to finalise these limits, likely including engagement with ONR transport regulators. Work scope will then expand to cover 3m³ boxes and drums.</td>
</tr>
<tr>
<td>093</td>
<td>Transport Fissile Exception Test Case</td>
<td>Ongoing (more than one year delay to completion relative to V1 Plan)</td>
<td>Draft fissile exception has been successfully produced. RWM will now engage further with ONR transport regulators.</td>
</tr>
<tr>
<td>101</td>
<td>Concepts IPT: Feasibility of Separated Pu Disposal</td>
<td>Complete and fully reported</td>
<td>This work was conducted as part of RWM's ongoing Concepts Integrated Project Team (IPT). Relevant publications include: [1] T.W. Hicks and T.D. Baldwin, 2014, The Likelihood of Criticality: Synthesis Report, AMEC Report 17293-TR-023 for the Nuclear Decom</td>
</tr>
<tr>
<td>102</td>
<td>Criticality Safety Considerations for Hot Isostatic Pressed (HiPed) Pu Wasteforms</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>104</td>
<td>Criticality Safety Assessment for HiPed HEU Wasteforms</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>116</td>
<td>Applying the Likelihood of Criticality Models to Future Concepts, Facility Designs and Inventories</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed, due to budgetary constraints and following a prioritisation exercise by RWM. Start deferred to end Q3 FY15/16.</td>
</tr>
<tr>
<td>130</td>
<td>Applying the Consequences of Criticality Models to Future Concepts, Facility Designs and Inventories</td>
<td>Deleted</td>
<td>Deleted due to budget constraints</td>
</tr>
<tr>
<td>131</td>
<td>Types of Critical Systems and the Credibility of Rapid Transient Criticality During Post-closure</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>132</td>
<td>Further Understanding of Types of Critical Systems and the Credibility of Rapid Transient Criticality During Post-closure.</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>136</td>
<td>Update To The Post-Closure Criticality Consequence Assessment (PCCCA)</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work is complete and the final contractor-approved report is in the peer review process.</td>
</tr>
<tr>
<td>153</td>
<td>Development of SWTC-150 for Increased Payload</td>
<td>Complete and fully reported</td>
<td>Impact analysis of the SWTC-150 design identified that significant development of the concept design would be necessary in order to underpin an increase in the payload mass. Work to progress the design has been halted pending clarification of the user re</td>
</tr>
<tr>
<td>154</td>
<td>Development of a 500 litre drum disposal stillage</td>
<td>Technical work complete; final report in review process</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>Development of MPC Designs</td>
<td>Technical work complete; final report in review process</td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>Development of Inlet Cell</td>
<td>Deleted</td>
<td>Task removed and rationalised into a new combined “Package Handling and Transfer” task (Task 165)</td>
</tr>
<tr>
<td>157</td>
<td>Development of Monitoring Programme Requirements</td>
<td>Deleted</td>
<td>Task removed. No requirement for R&amp;D under Design. R&amp;D associated with sub-surface monitoring around a GDF is contained in tasks under Geosphere (Task 404) and Site Characterisation (Task 494) areas</td>
</tr>
</tbody>
</table>

Appendix D - 2
<table>
<thead>
<tr>
<th>Task No.</th>
<th>Title</th>
<th>Status</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>158</td>
<td>Development of Inlet Cell</td>
<td>Deleted</td>
<td>Task removed and rationalised into a new combined “Package Handling and Transfer” task (Task 165)</td>
</tr>
<tr>
<td>159</td>
<td>Develop Inspection and Re-working Cell</td>
<td>Deleted</td>
<td>Task removed and rationalised into a new combined “Package Handling and Transfer” task (Task 165)</td>
</tr>
<tr>
<td>160</td>
<td>Develop Inspection and Re-Working Cell</td>
<td>Deleted</td>
<td>Task removed and rationalised into a new combined “Package Handling and Transfer” task (Task 165)</td>
</tr>
<tr>
<td>163</td>
<td>Develop and Maintain the Disposal Container Designs</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>164</td>
<td>Geological Disposal Facility (GDF) investigations and construction</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>165</td>
<td>Geological Disposal Facility (GDF) Package Handling and Transfer</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>166</td>
<td>Geological Disposal Facility (GDF) Disposal Vault and Tunnel Design</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>167</td>
<td>Geological Disposal Facility (GDF) utilities and services</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>168</td>
<td>Geological Disposal Facility (GDF) Sealing and Closure</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>169</td>
<td>Technology and Techniques for Nuclear Security</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>181</td>
<td>Develop and Maintain Transport Container Designs</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>182</td>
<td>Transport Infrastructure Constraints on the Geological Disposal System</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>196</td>
<td>Maintain Up-to-date Cost Estimates for the Geological Disposal Facility Programme</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>203</td>
<td>C-14 IPT: Update model of C-14 Release from Irradiated Stainless Steel</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete. final project report currently undergoing peer review</td>
</tr>
<tr>
<td>207</td>
<td>EC CAST WP2 (UK Component): C-14 Release and Speciation from 316N (High Nitrogen) Stainless Steel Under pH12 Conditions</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Design, installation and commissioning of experimental equipment in Task 202 is taking longer than expected.</td>
</tr>
<tr>
<td>209</td>
<td>C-14 IPT: Experimental Study on Rate and Speciation of C-14 Release to the Gas Phase from Irradiated Uranium</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred because of current lack of suitable facilities in the UK to undertake this work.</td>
</tr>
<tr>
<td>211</td>
<td>Update Task with New Understanding of C-14 Release from Irradiated Uranium</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Consequence of deferring Task 209</td>
</tr>
<tr>
<td>214</td>
<td>Carbon-14 release from AGR steels</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>228</td>
<td>C-14 IPT: Improved Data and Model of C-14 Release from Irradiated Graphite</td>
<td>Technical work complete; final report in review process</td>
<td>Experimental work is described in: G Baston, S Preston, R Ollett, J Walker, A Clacher, M Kirkham and B Swift, Carbon-14 Release from Oldbury Graphite, AMEC report AMEC/5352/002 Issue 3, 2014. Final project report is still in peer review process, so not ye</td>
</tr>
<tr>
<td>230</td>
<td>C-14 IPT: Benefits of Graphite Segregation</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete. final project report currently undergoing peer review</td>
</tr>
<tr>
<td>232</td>
<td>Studies of C-14 Release from Irradiated Graphite from Reactors Other Than Oldbury</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>252</td>
<td>C-14 IPT: Integrate Revised Data &amp; Understanding &amp; Determine Impact on</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete. final project report currently undergoing peer review</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Operational &amp; Post-Closure Safety Cases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>261</td>
<td>Radon Emanation from Polymer Encapsulated Wastes</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Refer to <a href="http://www.nda.gov.uk/publication/emanation-coefficients-relating-to-in-package-behaviour-of-radon-rwm03026/">http://www.nda.gov.uk/publication/emanation-coefficients-relating-to-in-package-behaviour-of-radon-rwm03026/</a> as published in June 2014. Task 261 is intended to be a follow-on Task from this earlier work, but it is not clear when it will be appro</td>
</tr>
<tr>
<td>266</td>
<td>Gas Generation from Microbial Degradation of Organic Wastes Including Cellulose</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Task 266 is a review task, and it is not essential that it is commenced immediately. A later start date will allow additional non-RWM funded research to progress in the interim.</td>
</tr>
<tr>
<td>268</td>
<td>Progress Understanding of G-values in Relation to Gas Generation from Radiolysis.</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>276</td>
<td>C-14 IPT: C-14 Migration Through the Cementitious EBS</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete. final project report currently undergoing peer review</td>
</tr>
<tr>
<td>278</td>
<td>Review of Benefits of EC FORGE Project to Gas Migration in Cementitious EBS Knowledge Base</td>
<td>Deleted</td>
<td>Not considered necessary at this time</td>
</tr>
<tr>
<td>279</td>
<td>Experimental and Modelling Study to Determine the Rate of Resaturation of Potentially High Gas Generating Packages and Consequent Hydrogen Generation Rates</td>
<td>Deleted</td>
<td>Deleted due to budget constraints</td>
</tr>
<tr>
<td>282</td>
<td>Implications of Understanding from Task 277 for Conceptual Model of Gas Interactions with the Package Vent and Curing Backfill</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>286</td>
<td>Review of Benefits of EC FORGE Project to Gas Migration in Clay EBS Knowledge Base</td>
<td>Deleted</td>
<td>Not considered necessary at this time</td>
</tr>
<tr>
<td>290</td>
<td>Review of Gas-Migration in Bentonite Knowledge Base</td>
<td>Deleted</td>
<td>Deleted due to budget constraints</td>
</tr>
<tr>
<td>296</td>
<td>Review of Benefits of EC FORGE Project, and Other National and International Projects as Relevant, to Gas Migration in Clay Geosphere Knowledge Base</td>
<td>Deleted</td>
<td>Now felt sensible to include knowledge gains from projects additional to EC FORGE project as well, resulting in a delay but a more thorough final deliverable</td>
</tr>
<tr>
<td>297</td>
<td>C-14 IPT: Understanding of the Envelope of Geological Environments in which C-14 Bearing Wastes can be Managed Safely</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete. final project report currently undergoing peer review</td>
</tr>
<tr>
<td>306</td>
<td>Further Development of the Derived Inventory</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>343</td>
<td>PhD to Investigate Signatures of Past Permafrost in Rocks</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>351</td>
<td>Impacts of Thermal Uplift Associated with an Evolving GDF</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>357</td>
<td>Review of Complexants in the Geosphere</td>
<td>Deleted</td>
<td>Deleted due to budget constraints</td>
</tr>
<tr>
<td>359</td>
<td>Using Isotopes for Groundwater Ageing and Development of a Site Descriptive Model</td>
<td>Ongoing (more than one year delay to completion relative to V1 Plan)</td>
<td>Delayed start pending identification of suitable student and discussion regarding the scope of works amongst the partnership team.</td>
</tr>
<tr>
<td>361</td>
<td>Field-scale Borehole Sealing Experiment: Demonstration of Practicability of Approaches</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>362</td>
<td>Follow-on from Review of Complexants in the Geosphere</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>363</td>
<td>Status of Knowledge Review of Groundwater and Groundwater Chemistry Research</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>366</td>
<td>Stress-induced anisotropy in crustal rocks and its influence on underground excavations</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>371</td>
<td>UK Hydrogeochemistry at Depth: Collation of Knowledge Base and Generation of a 'Map'</td>
<td>Deleted</td>
<td>This Task has been deleted because it is superseded by work that is being undertaken as part of the National Geological Screening exercise</td>
</tr>
<tr>
<td>372</td>
<td>Review of Understanding and Approach to Modelling Rock Matrix Diffusion (RMD)</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>373</td>
<td>Knowledge Capture - Summary Paper Collating Learning and Experience from EC PADAMOT Project (Palaeohydrogeology-basis)</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>382</td>
<td>Impacts of Microbes on Hydrogeological Properties</td>
<td>Complete and fully reported</td>
<td>This task is related to a PhD (The impact of hyper-alkaline fluids from a geological radioactive waste repository on the biological and physical characteristics of the host rock environment). The student has had the viva, and is just doing corrections.</td>
</tr>
<tr>
<td>383</td>
<td>Study of the Hydrobiogeochemical Evolution of a UK-based Industrial Site and Consideration of Potential Analogies in Relation to a UK GDF Concept with a High pH Cementitious Material-based EBS</td>
<td>Deleted</td>
<td>RWM has decided that the second phase of the Harpur Hill project is not to be undertaken. The work RWM undertook at Harpur Hill (see <a href="http://www.nda.gov.uk/publication/the-harpur-hill-site-an-assessment-as-an-analogue-to-a-cementitious-gdf/">http://www.nda.gov.uk/publication/the-harpur-hill-site-an-assessment-as-an-analogue-to-a-cementitious-gdf/</a> and <a href="http://www">http://www</a></td>
</tr>
<tr>
<td>393</td>
<td>Review of Implications of Extended GDF Operations on Geosphere Properties</td>
<td>Ongoing (more than one year delay to completion relative to V1 Plan)</td>
<td>Contractor delay in finalising report because resources diverted to other RWM tasks</td>
</tr>
<tr>
<td>394</td>
<td>Co-locating Disposal Modules of a GDF – Derivation of Approach to Determine Separation Distances</td>
<td>Technical work complete; final report in review process</td>
<td>An internal study was developed identifying sufficient understanding exists to justify 500m separation distance. The scope of work was therefore modified and the task is complete. RWM's position is recorded in the 2016 Status Report</td>
</tr>
<tr>
<td>396</td>
<td>Natural Analogue and Modelling Study of the Implications of GDF Operations on Geosphere Host Rock Properties</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>397</td>
<td>Consolidation of Knowledge Gained from Natural Analogue Studies, based on our Natural Analogue Catalogue</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>398</td>
<td>Evolution of the GDF Disturbed Zone</td>
<td>Deleted</td>
<td>This task duplicates Task 396</td>
</tr>
<tr>
<td>403</td>
<td>EPSRC Geowaste Project: SAFE Barriers (Systems Approach For Engineered Barriers) Consortium Outreach Task - Complementary Approaches to Demonstrating Key Coupled Processes in GDF Context</td>
<td>Deleted</td>
<td></td>
</tr>
<tr>
<td>404</td>
<td>EC Modern 2020 Project: Approaches to Monitoring Relevant to GDF Operational Period</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>417</td>
<td>Experimental Design: High Temperature Backfill Functional Requirements</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed, due to budgetary constraints and following a prioritisation exercise by RWM. Start deferred to end Q4 FY15/16.</td>
</tr>
<tr>
<td>420</td>
<td>Experimental Demonstration of</td>
<td>Complete and fully reported</td>
<td>Final report (D.W. Heyes, E.J. Butcher, J. Borwick,</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>421</td>
<td>Effect of High Temperatures (&gt;100°C) on Cement Backfill for Spent Fuel (SF) / Multi-Purpose Containers (MPC)</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Consequence of deferring Task 417</td>
</tr>
<tr>
<td>422</td>
<td>Characterisation and Leaching of Aged Waste Encapsulation Cements</td>
<td>Complete and fully reported</td>
<td>Student has completed and been awarded PhD. Awaiting draft paper(s) for submission to journal.</td>
</tr>
<tr>
<td>424</td>
<td>Pilot Backfill Leaching and Migration Experiment in Overseas Underground Research Laboratories (URL)</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>425</td>
<td>Demonstration Backfill and Leaching Experiment in Overseas URL</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Consequence of deferring Task 424</td>
</tr>
<tr>
<td>428</td>
<td>Novel experimental approaches to understanding long-term evolution of water-saturated cement</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>429</td>
<td>Application of Novel Experimental Approaches to Understanding Long-term Evolution of Water-Saturated Cements</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>430</td>
<td>Participation in EC project CEBAMA</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>431</td>
<td>Rate and Extent of Reactions between NRVB and Robust Shielded Containers or Vitrified ILW.</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>432</td>
<td>Support to the Development and Implementation of Strategy for Management of NDA-owned Materials and Samples</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>442</td>
<td>Effect of Ionising Radiation on Engineered Barrier System (EBS) Performance</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>443</td>
<td>Study on Hydrogen Utilisation by Microbes in Cement-based Engineered Barrier Systems (EBS)</td>
<td>Deleted</td>
<td>This task is no longer being undertaken as the PhD student has resigned</td>
</tr>
<tr>
<td>444</td>
<td>Further Development of Near-field Component Model</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>445</td>
<td>Further Investigation of the Effects of Ionising Radiation on Engineered Barrier System (EBS) Performance in Cement and Clay Systems (e.g. Effects on Redox, Organic Degradation Products, Microbial Processes, etc.)</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>456</td>
<td>High Heat IPT: Data Collation for the Thermal Analysis of UK Design Concepts</td>
<td>Technical work complete; final report in review process</td>
<td></td>
</tr>
<tr>
<td>457</td>
<td>High Heat IPT: 3D-Thermal Analysis Verification of Analytical Model</td>
<td>Technical work complete; final report in review process</td>
<td></td>
</tr>
<tr>
<td>459</td>
<td>Thermal Modelling of Low-heat-generating Waste (LHGW) Disposal Areas</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed, due to budgetary constraints and following a prioritisation exercise by RWM. Start deferred to end Q1 FY16/17.</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>460</td>
<td>Thermal Modelling of High-heat-generating Waste - Scoping Analysis for Various Scenarios</td>
<td>Technical work complete; final report in review process</td>
<td></td>
</tr>
<tr>
<td>461</td>
<td>Modelling of Bentonite Resaturation using Data Provided from Aspo Underground Research Laboratory Under SKB Engineered Barrier System (EBS) Task Force and the FEBEX Dismantling Project</td>
<td>Ongoing (more than one year delay to completion relative to V1 Plan)</td>
<td>Later start than planned due to lack of internal resources to specify work and budgetary constraints</td>
</tr>
<tr>
<td>464</td>
<td>Study of Bentonite Thermal Alteration, Including Participation in SKB ABM (Alternative Buffer Materials) Project</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed start due to lack of internal resources to specify work and budgetary constraints. Now scheduled to start end Q2 FY15/16</td>
</tr>
<tr>
<td>466</td>
<td>Modelling and Laboratory Studies on Bentonite Homogenisation Upon Resaturation</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed start due to lack of internal resources to specify work and budgetary constraints. Now scheduled to start end Q2 FY15/16</td>
</tr>
<tr>
<td>468</td>
<td>Review of International Work on Bentonite Erosion to Identify Future Research Needs</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>469</td>
<td>Further Validation of Bentonite Resaturation</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Consequence of late start of Task 461. Now scheduled to start November 2018</td>
</tr>
<tr>
<td>471</td>
<td>Experimental and Modelling Studies on Bentonite Piping and Erosion</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>472</td>
<td>Experimental and Modelling Study on Alteration of Bentonite at Temperatures &gt;100°C, Including the Possibility of Novel Formulations</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>473</td>
<td>Validation of Bentonite Homogenisation Upon Resaturation in Realistic Conditions</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Consequence of late start of Task 466. Now scheduled to start end Q2 FY17/18</td>
</tr>
<tr>
<td>474</td>
<td>Further Studies on Novel Clay Formulations (if Required)</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>475</td>
<td>Maintenance and Development of the Thermal Dimensioning Tool (TDT)</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>486</td>
<td>Development of a Approach to the Safe Sealing of Boreholes</td>
<td>Deleted</td>
<td>This task has been deleted because it duplicates Task 356</td>
</tr>
<tr>
<td>487</td>
<td>UK Hydrogeochemistry at Depth: Collation of Knowledge Base</td>
<td>Deleted</td>
<td>This task has been deleted because it is superseded by work that is being undertaken as part of the National Geological Screening exercise</td>
</tr>
<tr>
<td>490</td>
<td>Development of an Approach for Monitoring and Underground Investigations During the Excavation Phase</td>
<td>Deleted</td>
<td>This task has been deleted because it overlaps with Task 404 in the Geosphere area</td>
</tr>
<tr>
<td>491</td>
<td>Review of the Impacts of Ongoing Excavation Work on Long-term Underground Investigations</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>493</td>
<td>Evaluation of the Occurrence of Low Strength and Evaporite Rocks at Depth in the Context of a UK Geological Setting (to Support Generic Design)</td>
<td>Deleted</td>
<td>This task has been deleted because it is superseded by work that is being undertaken as part of the National Geological Screening exercise</td>
</tr>
</tbody>
</table>

Appendix D - 7
<table>
<thead>
<tr>
<th>Task No.</th>
<th>Title</th>
<th>Status</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>494</td>
<td>Development of an understanding of information requirements for underground monitoring and investigations</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>511</td>
<td>Development of a Larger Waste Container</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>512</td>
<td>Development of Disposability Manufacturing Specifications</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>513</td>
<td>Guidance on the Disposability of Decontamination Agents</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>514</td>
<td>Guidance on the Disposability of Filters</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>537</td>
<td>Understanding the Relationship Between the Durability of Simplified and Complex UK HLW Glasses</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Delayed start because of difficulties with appointing PhD student</td>
</tr>
<tr>
<td>538</td>
<td>Further Groundwater Dissolution Studies on Simulant Magnox, Blend and Post-Operational Clean Out (POCO) Glasses</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Start delayed because of need to realign with delayed Task 536</td>
</tr>
<tr>
<td>541</td>
<td>Review of Microstructural Evolution of Glassy and Ceramic Wasteforms and their Impact on Leaching Properties</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>548</td>
<td>Understanding the Evolution of the Carbon Component of Dragon Reactor Fuel During the Post-closure Phase</td>
<td>Complete and fully reported</td>
<td>Final report published on the RWM bibliography</td>
</tr>
<tr>
<td>549</td>
<td>Scoping Dissolution Studies of Historical Fuels (Windscale AGR: WAGR)</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>552</td>
<td>Further Work on SimFuel to Understand Dissolution Behaviour of Spent Fuel</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>572</td>
<td>Studies on the Impact of Reactive Metal Corrosion in Cement</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Task deferred due to budget constraints following RWM review of research priorities</td>
</tr>
<tr>
<td>573</td>
<td>Further Research Needs For Expansive Processes</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Start delayed because of need to realign with delayed Task 572</td>
</tr>
<tr>
<td>574</td>
<td>Studies of the Impact of Uranium Hydride Formation in Cements</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>586</td>
<td>Review Research Needs for Polymeric Wasteforms</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Start delayed because of need to realign with delayed Task 586</td>
</tr>
<tr>
<td>603</td>
<td>Dissolution Studies of Realistic Vitrified ILW Simulants in Oxic, Alkaline Groundwaters</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>604</td>
<td>Dissolution Studies of Realistic Vitrified ILW Simulants in Oxic, Near-Neutral Groundwaters</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>605</td>
<td>Studies of Effect of Iron and Radiation on the Leaching Behaviour of Realistic ILW Product Simulants</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>616</td>
<td>Definition of Research Needs for Hot Isostatic Pressed (HIPed) Product</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>617</td>
<td>Scoping Studies on the Dissolution Behaviour of Hot Isostatic Pressed (HIPed) Product</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>618</td>
<td>Scoping studies on the use of simulants to study the dissolution behaviour of Hot Isostatic Pressed (HIPed) Plutonium and unirradiated MOX Fuel</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Start delayed because of need to realign with delayed Task 616</td>
</tr>
<tr>
<td>619</td>
<td>Further Studies on the Dissolution Behaviour of Hot Isostatic Pressed (HIPed) Products</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>620</td>
<td>Further Studies on Hot Isostatic Pressed (HIPed) Products and Unirradiated MOX Fuel to Address Outstanding Uncertainties</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>647</td>
<td>Prototype Repository Project (Copper)</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete. Final report is in the peer review process</td>
</tr>
<tr>
<td>650</td>
<td>Studies of Internal Corrosion / Pressurisation</td>
<td>Complete and fully reported</td>
<td>The final reports from this task are:</td>
</tr>
<tr>
<td>651</td>
<td>Participation in the FEBEX Experiment (Full Scale Engineering Barrier Demonstration Experiment (FEBEX) - Dismantling Project)</td>
<td>New task</td>
<td>D. Burt, S. Massey, A. Horvat, F. King, Impact of water carry over on the extent of structural damage and pressurisation on a Variant 1 AGR spent fuel disposal container, AMEC 17697/TR/04, issue 1, 2014.</td>
</tr>
<tr>
<td>660</td>
<td>Collaboration on the Feasibility and Quality of Manufacture of Copper Electrodeposition on Steels</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>661</td>
<td>Considerations on the Feasibility and Quality of Manufacture of Containers for HLW and Spent Fuel</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>666</td>
<td>Scoping Studies on Durability of Grade-2 Ti Alloys</td>
<td>Complete and fully reported</td>
<td>The final report from this task is:</td>
</tr>
<tr>
<td>667</td>
<td>Further Experimental Studies on the Corrosion Behaviour of Corrosion Resistant Materials</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>684</td>
<td>Development of Component Models for ILW Containers</td>
<td>Start date brought forward by more than one year relative to V1 plan</td>
<td>Start date brought forward as a result of reprioritisation exercise undertaken by RWM</td>
</tr>
<tr>
<td>711</td>
<td>Review of the Durability of Concrete ILW containers</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>739</td>
<td>Review and Testing of Sorption Processes in Clay Backfills</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>740</td>
<td>Mechanism of Chemical Containment in Aged Cements</td>
<td>Deferred start. Either planned to start but not yet started or a</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>757</td>
<td>Testing and Selection of Candidate Superplasticisers</td>
<td>Technical work complete; final report in review process</td>
<td>Work completed in March 2015 and final deliverables in peer review.</td>
</tr>
<tr>
<td>758</td>
<td>Development of Process Model for Cellulose Degradation Product (CDP) Behaviour in the Near Field</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>759</td>
<td>Review of Potential Superplasticiser Inventory in Decommissioned Building Materials</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Although preceding task (Task 757) is complete, RWM is waiting for review comments on an RWM Position Paper on super-plasticisers, which would inform future work. Successor task further deferred due to budget constraints.</td>
</tr>
<tr>
<td>761</td>
<td>Detailed Evaluation of the Performance of a Candidate Superplasticiser for Waste Encapsulation</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Although preceding task (Task 757) is complete, RWM is waiting for review comments on an RWM Position Paper on super-plasticisers, which would inform future work. This means that RWM will not start successor task until end Q3 FY15/16</td>
</tr>
<tr>
<td>762</td>
<td>Synthesis Report on Colloidal Understanding</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>763</td>
<td>Review of Organic Additives to Cement Powders (e.g. Grinding Agents)</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>764</td>
<td>Update Process Model - Understanding of Cellulose Degradation Product (CDP) Metabolism</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>766</td>
<td>Investigation of Whether the Effect of Organics, Colloids and Microbes on Radionuclide Solubility are Additive</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>769</td>
<td>Update Synthesis Report on Colloidal Understanding</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>770</td>
<td>Underground Research Laboratory (URL)-based Hot Migration Test to Validate Superplasticiser Performance</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>771</td>
<td>Environmental Limits of Methanogenesis and Sulphate Reduction</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>772</td>
<td>Long-term Fate of Radionuclides During Sulfidation.</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>773</td>
<td>Microbial niches in the ILW near field</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>796</td>
<td>Uranium Integrated Project Team (IPT): Improved Data Set for Depleted Natural and Low Enriched Uranium (DNLEU) and Daughter Elements in the Nearfield</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete; final report in review process</td>
</tr>
<tr>
<td>797</td>
<td>Uranium Integrated Project Team (IPT): Improved Data Set for Depleted Natural Low-Enriched Uranium (U) and Daughter Elements in the Far-Field</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete; final report in review process</td>
</tr>
<tr>
<td>798</td>
<td>Uranium Integrated Project Team (IPT): Review UK Solubility and Sorption Parameters for Uranium (U) and its Daughter Elements</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work complete; final report in review process</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>799</td>
<td>Strategy for Data Elicitation during the Focussing Phase</td>
<td>Deleted</td>
<td>Task deleted as it duplicates Task 898: Development of a Consistent Methodology for Data Elicitation and Quantification of Uncertainty</td>
</tr>
<tr>
<td>800</td>
<td>Data Elicitation for High Priority Radionuclide Sorption Parameters (e.g. Tc, U other long-lived HLW radionuclides)</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>801</td>
<td>Data Elicitation for Other Radionuclide Sorption Parameters</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>802</td>
<td>Review of the Use of Beta Values</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>816</td>
<td>Development of a Process Model for Colloidal and Microbial Influences on Radionuclide Behaviour</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>817</td>
<td>Update to Process Model for Colloidal / Microbial Processes</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>827</td>
<td>Develop a Fissile Exception Application for Waste Materials Bearing a Low Concentration of Fissile Radionuclides</td>
<td>Deleted</td>
<td>Deleted because this task duplicated Task 093 in the Criticality Safety area</td>
</tr>
<tr>
<td>829</td>
<td>Develop the Transport Criticality Safety Assessment for the Disposal Container Transport Container</td>
<td>Deleted</td>
<td>This task has been re-numbered Task 080: Criticality Safety area</td>
</tr>
<tr>
<td>830</td>
<td>Review and Update the Transport Safety Manual (TSM) to Take Account of Peer Review by INS and Lessons Learned in TSM 2016</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>846</td>
<td>Develop Off-Site Risk Assessment Methodology</td>
<td>Complete and fully reported</td>
<td></td>
</tr>
<tr>
<td>849</td>
<td>Development of Methodologies and Safety Assessment for 2016 Operational Safety Case</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>850</td>
<td>Extension of the Operational Safety Case to Cover Backfilling, Sealing and Closure</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>851</td>
<td>Review and Update the Nuclear Operational Safety Manual (NOSM) to Take Account of Lessons Learned in 2016 Operational Safety Case</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>852</td>
<td>Respond to Regulator Recommendation R21</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>853</td>
<td>Undertake Evaluation of GDF Design and Safety Case Against the Western European Nuclear Regulators Association (WENRA) Safety Reference Levels for Radioactive Waste Disposal</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>854</td>
<td>Develop Licence Condition Arrangements Pertaining to Safety Case Development</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>855</td>
<td>Update of Disposability Assessment Work Instructions Based on 2016 Disposal System Safety Case</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>866</td>
<td>Understanding the Implications</td>
<td>Ongoing (more than one year)</td>
<td>Extended scope to address uncertainties in long-term</td>
</tr>
</tbody>
</table>

Appendix D - 11
<table>
<thead>
<tr>
<th>Task No.</th>
<th>Title</th>
<th>Status</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>867</td>
<td>Development of Total System Models to Assess the Post-closure Performance of Disposal Concepts for the 2016 Generic Disposal System Safety Case Update</td>
<td>New task</td>
<td>void evolution</td>
</tr>
<tr>
<td>868</td>
<td>Preparation of Total System Models for Future Application in the Siting Process</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>869</td>
<td>Uranium IPT: Preferred Options for DNLEU Disposal</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>870</td>
<td>Review and update the Environmental Safety Manual to Take Account of Peer Review by LLWR and Lessons Learned in Environmental Safety Case 2016</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>881</td>
<td>Environmental Baseline Monitoring</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>899</td>
<td>Effect of Individual Differences in Psychology on Approach to Mathematical Modelling</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>This is a lower priority task and has been deferred because of budget constraints</td>
</tr>
<tr>
<td>900</td>
<td>Development and Implementation of Community Benefit Agreements</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>901</td>
<td>Web-based and Social Media Tools for Community Engagement</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>902</td>
<td>EPSRC: Series of Seminars on the Societal Aspects of Geological Disposal</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>917</td>
<td>Develop Improved ILW Package Models - Including Credit for Design Features (e.g. Capping Grout)</td>
<td>New task</td>
<td>The work was originally defined under Task 914 in the Version 1 Science and Technology Plan. (Task 714 is retained for part of the original work scope.) This new task has been defined to reflect the two distinct strands of work in the original task</td>
</tr>
<tr>
<td>918</td>
<td>Package Decontamination Factors - Part 1 – Selecting Appropriate Analogues</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>919</td>
<td>Package Decontamination Factors - Part 2 – Accounting for Multiple Barriers</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>920</td>
<td>Effect of Cracked Wasteform on Impact Performance</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>921</td>
<td>Update to the Holistic Impact Methodology Following Breakup Versus Flow Tests</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>927</td>
<td>Consideration of the Effect on Impact Performance of Voidage / Shrinkage in Waste Packages</td>
<td>Deleted</td>
<td>Task 927 will be scheduled pending the outcome of Task 866</td>
</tr>
<tr>
<td>929</td>
<td>Derivation of ab initio Release Fraction Values for the 6 cubic metre box; revised 3 cubic metre drum; MBGWS Box and Corner Lifting 3 cubic metre Box</td>
<td>Start date brought forward by more than one year relative to V1 plan</td>
<td>Following a review of research priorities in RWM, it was decided to provide a complete and consistent suite of package models to support the operational safety case sooner than originally planned. This is for two reasons: (i) a more consistent modelling a</td>
</tr>
<tr>
<td>931</td>
<td>Data Requirements for Updated Operational Safety Case Approach</td>
<td>New task</td>
<td></td>
</tr>
<tr>
<td>946</td>
<td>Development of Fire Release Fractions</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work is complete; the final report is in the peer review process</td>
</tr>
<tr>
<td>948</td>
<td>Development of Improved ILW Package Models for Fire Analysis</td>
<td>Start date brought forward by more than one year relative to V1 plan</td>
<td>This work is now in progress. Following a review of research priorities in RWM, it was decided to provide a complete and consistent suite of package models to</td>
</tr>
<tr>
<td>Task No.</td>
<td>Title</td>
<td>Status</td>
<td>Justification</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------------------------------------------</td>
<td>---------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1007</td>
<td>Revise Volatility Groups</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work is complete; the final report is in the peer review process</td>
</tr>
<tr>
<td>1009</td>
<td>Derivation of a Reference Data Set for Fire Accident Scenarios</td>
<td>Technical work complete; final report in review process</td>
<td>Technical work is complete; the final report is in the peer review process</td>
</tr>
<tr>
<td>1011</td>
<td>Evaluation of RFs from Aged Samples</td>
<td>Deferred start. Either planned to start but not yet started or a future task deferred by more than one year</td>
<td>Deferred due to budget constraints</td>
</tr>
<tr>
<td>1012</td>
<td>Scaling Release Fraction Data for Different Fire Scenarios</td>
<td>Start date brought forward by more than one year relative to V1 plan</td>
<td></td>
</tr>
<tr>
<td>1016</td>
<td>Mixed Oxide Spent Fuel (MOX SF) - Thermal Properties for Use in Fire Fault Modelling</td>
<td>New task</td>
<td></td>
</tr>
</tbody>
</table>