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An overview of near-field evolution research in support of the UK geological disposal programme

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ABSTRACT

The near field, together with the containment and isolation provided by the geosphere, contributes to the long-term safety provided by a geological disposal facility (GDF) after closure. The different engineered barriers can prevent or limit the release of radionuclides and their migration to the undisturbed host rock or geosphere and are expected to fulfil their post-closure safety functions for many thousands to hundreds of thousands of years. They will continue to contribute to containment after their eventual degradation when there would no longer be confidence that they would continue to fulfil all of their safety functions in their totality. By that time, significant radioactive decay will have occurred, substantially reducing the hazard associated with the wastes. Therefore, demonstration of long-term safety requires an understanding of the evolution of the engineered barriers and the consequences for the generic safety functions that the different barriers provide. This paper provides an overview of the research of the Nuclear Decommissioning Authority Radioactive Waste Management Directorate into the evolution of the near field of a GDF.

KEYWORDS: engineered barriers, geological disposal facility, near-field evolution.

Introduction

THE near field is defined in the UK as the engineered barrier system (EBS) (including the wasteform, waste containers, buffer materials, backfill and seals), and the immediate host rock whose characteristics have been or could be altered by the geological disposal facility (GDF) or its contents. The near field of a geological disposal system will contain two main disposal areas: one for high-level waste (HLW) and spent fuel, and a second for intermediate-level waste (ILW), including a small fraction of some low-level waste (LLW) that is not suitable for disposal in the UK's Low Level Radioactive Waste Repository (LLWR). At this stage in the geological disposal programme, three generic geological environments are considered: a higher strength rock, a lower strength sedimentary rock and an evaporite. When combined with the two disposal areas, this leads to consideration of six illustrative concepts, based on those developed internationally and employing clay-based, cement-based or salt-based backfills or buffers (Baldwin *et al.*, 2008; Hicks *et al.*, 2008).

The near field provides long-term containment of radionuclides after the closure of a GDF as the different engineered barriers prevent or limit the release of radionuclides and their migration to the host rock or geosphere. A variety of EBSs can be envisaged, which complement the protection provided by the natural barriers of a geological disposal system. Together the generic safety functions that the different barriers provide form an integrated multi-barrier disposal concept.

The engineered barriers in the near field are expected to fulfil their post-closure safety functions for many thousands to hundreds of thousands of years but will evolve as they interact

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with each other and with their surroundings. They will eventually degrade to the extent where there is no longer confidence in their ability to fulfil all of their intended safety functions (Fig. 1 illustrates the possible evolution of a cement-based EBS). However, they will continue to contribute to retention, even when significantly degraded. In addition, in such a long time period, significant radioactive decay will have occurred, substantially reducing the hazard associated with the wastes. Together with the retention and isolation provided by the geosphere, the near field contributes to the long-term safety provided by a GDF. Therefore, demonstration of this long-term safety requires an understanding of the evolution of the engineered barriers and the consequences for the generic safety functions that the different barriers provide. Some of these barriers (for example, those forming the waste package) are the subject of other papers in this proceedings.

The aims of the Nuclear Decommissioning Authority Radioactive Waste Management Directorate (NDA RWMD) research on near-field evolution are to:

(1) provide data and understanding to support the post closure safety case and assessments;

(2) improve the component system models for key ILW/LLW near-field evolution processes;

(3) build on the understanding of the evolution of overseas HLW and spent fuel concepts and, allied with skills development, apply this understanding in a UK context; and

(4) gather information that may be needed to inform future engineering and optioneering decisions.

Near-field evolution processes

The NDA RWMD's current understanding of near-field evolution is described in the near-field evolution status report (Nuclear Decommissioning Authority, 2010). This draws on a number of sources, including work undertaken by the NDA RWMD (and previously that carried out by United Kingdom Nirex Ltd), in addition to information available from other organizations that are investigating the possibility of developing a GDF for disposal of radioactive wastes (such as regulators, other waste management organizations and research institutions worldwide).

Processes occurring during the construction and operational period include: (1) creation and partial or complete recovery of an excavation disturbed zone (EDZ); and (2) desaturation and oxidation of part of the host rock immediately surrounding the GDF.

Once wastes and the buffer and/or backfill materials have been emplaced and disposal areas sealed, a series of processes will begin in the initial post-closure period that may continue throughout the later post-closure period. These include:

(1) heat generation from the emplaced waste and, to a lesser extent, from exothermic reactions such as the hydration of cementitious materials, and subsequent thermal effects;

(2) irradiation of engineered barrier materials (particularly of waste package components);

(3) resaturation; this early evolution of the engineered barriers may include swelling of clay buffer and backfills, and hydration of cement buffers and backfills;

(4) host rock creep and compaction of crushed salt buffers;

(5) gradual degradation of engineered barriers, including buffers, backfills and seals, by various processes under lower temperature conditions and in less intense radiation fields, leading to long-term evolution of barrier properties and porewater chemistry;

(6) consolidation and evolution of disposal tunnel and shaft seals and plugs;

(7) gas generation due to corrosion, microbial degradation of some organic materials and radiolysis of water and organic materials;

(8) microbial effects;

(9) waste container corrosion.

The extent and chronology of these processes will vary between different concepts. However, in all cases, they are likely to overlap to an extent, and some are coupled to varying degrees. The specific processes occurring within the evolving near field of a GDF, and their relative importance to safety, will depend upon a number of factors, including:

(1) the nature of the waste inventory, in particular: (i) whether it will generate significant heat through radioactive decay; (ii) how the waste is conditioned to produce a passive wasteform, and how this wasteform is likely to behave over the long term; and (iii) whether waste degradation (and canister corrosion) is likely to cause significant gas generation;

(2) the choice of engineered materials used in components of the near field, and how these interact with each other, with the waste and with the surrounding host rock;

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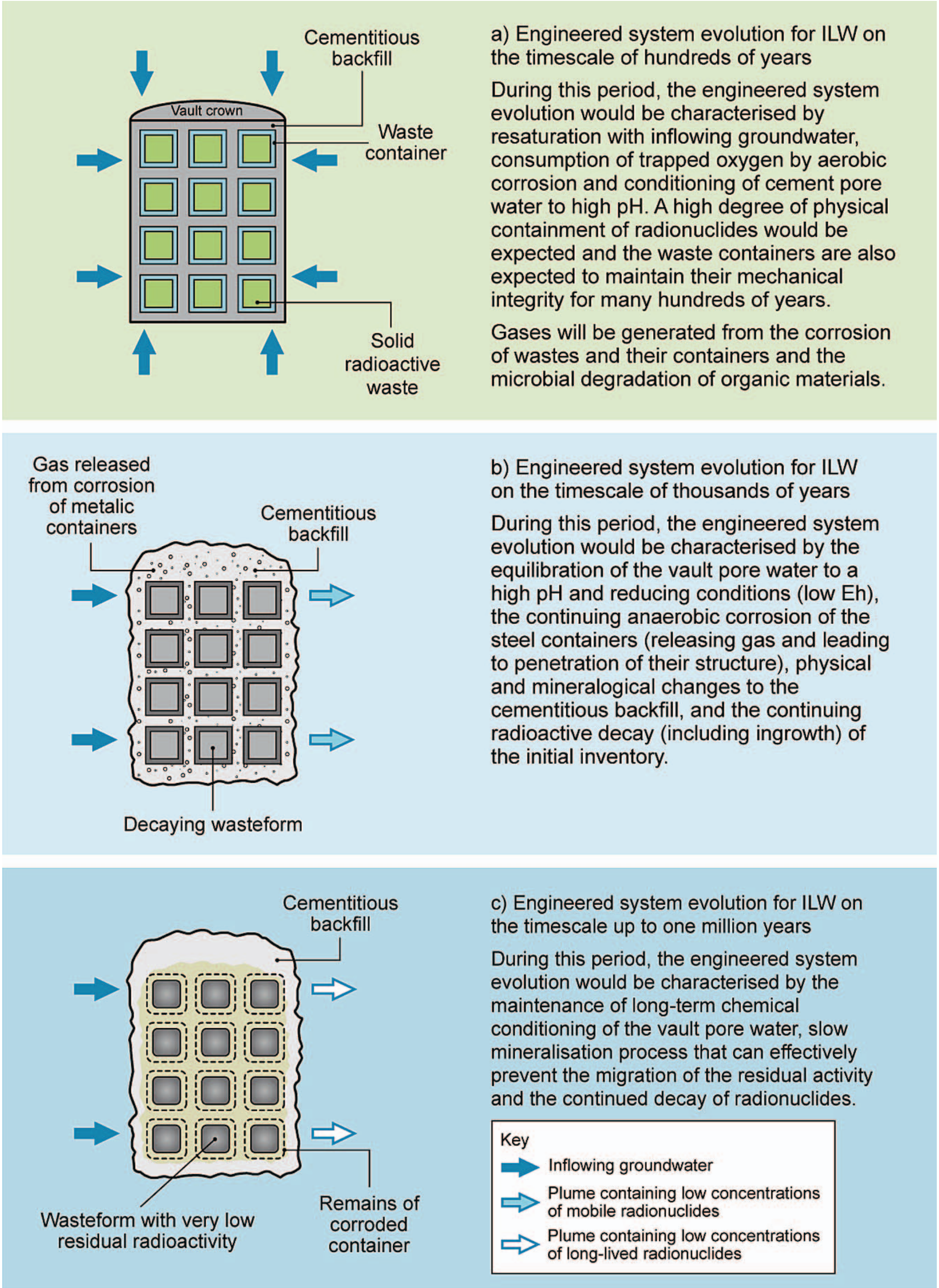

FIG. 1. Evolution of a cement-based engineered barrier system, published with permission of the NDA.

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(3) the nature of the geological environment and the hydrogeology (the nature of the host rock and the groundwater infiltrating the near field will have a significant influence on how the near field evolves);

(4) whether an EDZ is present, and how this evolves.

The main types of processes currently being considered are: (1) heat generation from the emplaced waste and associated thermal effects; (2) resaturation and long-term buffer and backfill alteration processes; and (3) porewater evolution. To link all these, there is a need to develop the understanding of system interactions and coupled process modelling (including the influence of processes occurring outside the EBS).

Significant heat-generation processes in the near field include heat produced due to radioactive decay and heat produced due to cement hydration. Although models exist for heat generation and transfer for HLW/spent fuel (SKB, 1999) and ILW/LLW disposal concepts (Worth and Faulkner, 2009), and these could be developed and applied to a range of EBS design and material options, there is less understanding of thermal effects on the resaturation of clay-based barriers (Nuclear Decommissioning Authority, 2010). Resaturation is a complex heterogeneous process, especially in low permeability materials, whose influence on the performance of the near-field barriers once fully saturated is not fully understood. This, and the long-term evolution of clay-based barriers, is the subject of international work (Nagra, 2009).

Modelling of the resaturation of cement-based engineered barrier systems is fairly well developed but there is a need to understand better how the near field of a cement-based ILW/LLW disposal area evolves. The cement-based components of the EBS will evolve through long-term ageing, leaching and reaction with groundwater solutes and with other components of the near field. The resulting changes may impact on the long-term maintenance of high pH, the physical properties and the uptake of radionuclides. They are likely to vary spatially at particular times and would need to be taken into account in an appropriate manner in models of the evolution of these systems.

The chemistry of the porewater in the near field will influence many key evolutionary processes. Experimental characterization of bentonite porewater parameters has proved difficult because of the small quantities of fluid present in individual pores (Fernández *et al*., 2004) but understanding continues to develop (Arcos *et al*., 2005). In contrast, the rapid development of alkaline conditions in the porewater of cement-based systems is well known and the porewater analyses are more straightforward.

Ensuring that an EBS will perform its desired functions requires integration, often iterative, 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 the programme develops the NDA RWMD will need 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.

There are some areas of near-field evolution where the details of certain processes occurring are uncertain. These would require further consideration once there was a specific site to evaluate.

Research needs for the current phase

The NDA RWMD's near-field evolution research programme can be divided into four broad subtopics as follows: thermal modelling of heat generation processes; investigation of EBS resaturation and long-term buffer/backfill alteration processes; studies of porewater evolution; and consideration of system interactions. Figure 2 shows the structure of the planned research and development programme to address gaps in current knowledge. The main areas of work in the near term are discussed below.

Thermal modelling

Work on heat generation due to radioactive decay from HLW/Spent fuel disposal will continue to build on overseas experience. A HLW/spent fuel disposal area thermal modelling project has recently begun and will develop our heat generation and transfer modelling capability. In the longer term this has the aim of coupling heat, resaturation and solute transport modelling capability.

Thermal modelling capabilities for ILW/LLW disposal areas, including heat generation due to cement hydration, are well developed (Worth and Faulkner, 2009) and will continue to be main-

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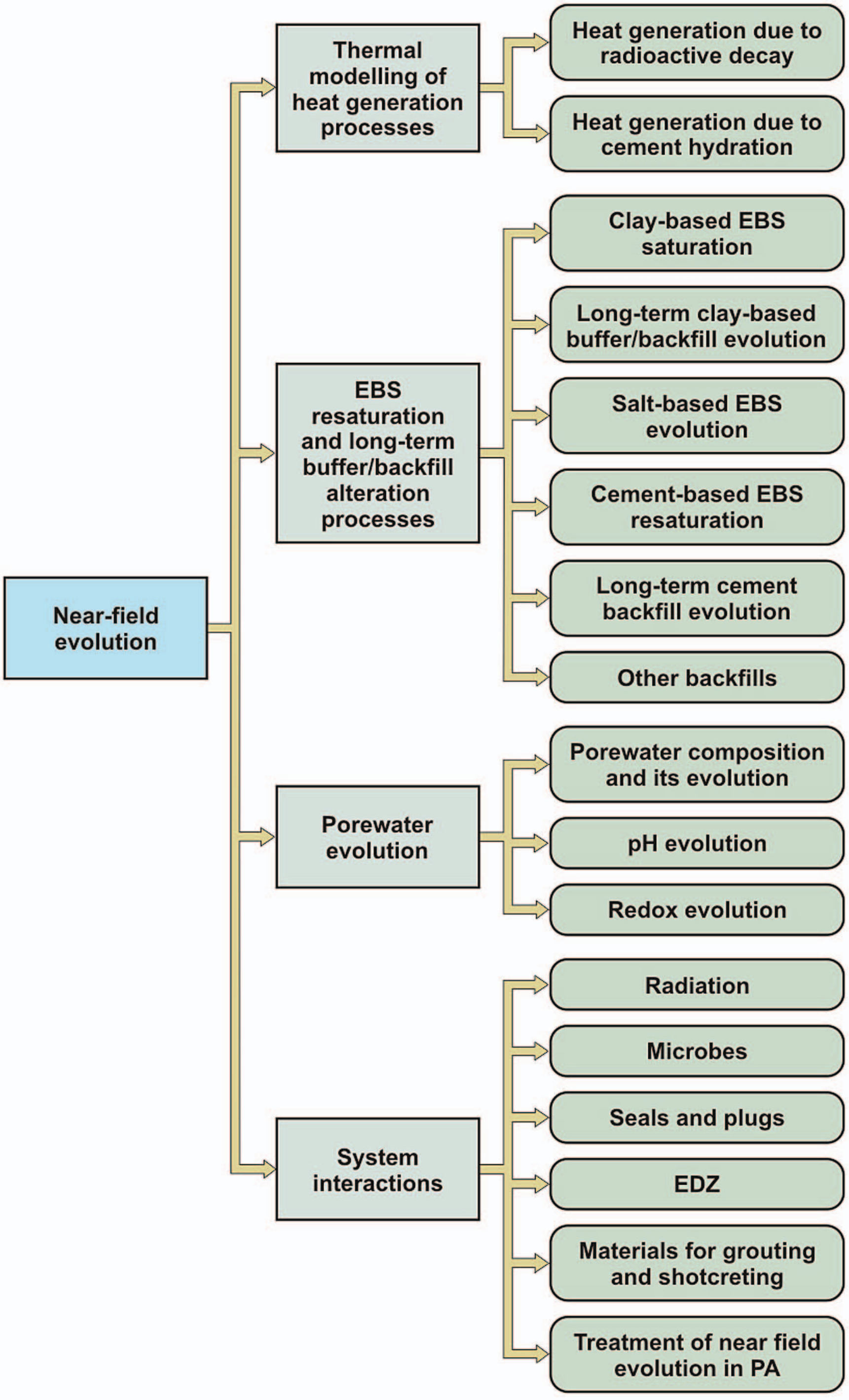

FIG. 2. Structure of the near-field evolution research and development programme, published with permission of the NDA.

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tained with a view to supporting ongoing design activities.

EBS resaturation and long-term buffer/backfill alteration processes

Participation in studies on clay-based EBS resaturation, where work is ongoing within several waste management organizations (WMOs) (Nagra, 2009 and Posiva Oy, 2010), through international collaboration projects, will improve our understanding of resaturation at specific sites and develop modelling capabilities. Theoretical understanding of the implications of major resaturation processes for the UK context will be developed and in the current phase will begin to develop models of thermal effects on resaturation for UK wastes and the generic GDF designs.

A review of UK-specific factors influencing bentonite barrier performance (Wilson *et al.*, 2011) has recently been completed in order to develop the research programme on long-term clay-based buffer and backfill evolution. This has included consideration of cement–bentonite, iron–clay, and waste–clay interactions, in addition to thermal alteration and erosion and piping of clays. The NDA RWMD will continue to keep up to date with research from other WMOs' programmes and participate in international collaboration projects.

Models of cement-based EBS systems are fairly well developed (Nirex, 2005; Nagra, 2008). In the current phase of the programme there will continue to be a focus on understanding the spatial heterogeneity in the near-field of a cement-based ILW/LLW disposal area as part of the development of a near-field component model.

Studies of cement leaching and hydrothermal ageing are ongoing and further work is required to build confidence in the understanding of the long-term evolution of cement-based components of the near field, including 'lower pH' cements. As much of the historic work in the UK has focussed on Nirex reference vault backfill (NRVB), a review of the current status of the wider knowledge relating to the performance of cements as engineered barriers is being undertaken.

In contrast to work on clay-based and cement-based near fields there are no plans to begin a significant programme of work in relation to modelling or experimental studies specific to evaporite EBS near-field evolution processes. Significant work has been undertaken internationally, particularly in Germany (Stührenberg and Heusermann, 2007) and our current awareness of such work carried out by other WMOs will be maintained. Other backfills such as crushed rock may be considered for use in disposal areas of a GDF; these may be investigated as part of a future programme as appropriate.

Porewater evolution

In the current phase of the programme a series of generic groundwater compositions are used to input into work where necessary (e.g. Swift *et al.*, 2010). The NDA RWMD will maintain a watching brief on international work, which continues to be an active area of research and development, and develop the UK understanding for the near-field of a cement-based ILW/LLW disposal area as part of the development of a near-field component model.

Several WMOs and the NDA have published modelling studies that describe pH evolution of typical near-field porewaters for a range of disposal concepts (Atkinson *et al.*, 1988; Small and Thompson, 2010). In the current phase of the programme the pH evolution modelling capability for the near-field of a cement-based ILW/LLW disposal area will be continued as part of the development of a near-field component model.

System interactions

Recent international work has investigated expected near-field redox conditions (e.g. Carlsson and Muurinen, 2008). In the current phase of the programme redox modelling will be developed to support a near-field evolution component model and also to provide a generic redox model applicable to a HLW/spent fuel disposal area. Such work would take into account the findings of the EC ReCOSY project,(www.recosy.eu) which is developing an understanding of redox phenomena controlling the long-term release and retention of radionuclides.

Considerable work has been undertaken internationally to investigate the influences of microbes (Humphreys *et al.*, 2009). As the overall influences of microbial activity on EBS performance are complex, and dependent on the disposal concept and geological setting, there is no intention to carry out significant NDA RWMD work in the current generic phase of the programme, however the NDA RWMD are members of the advisory panel for the NERC

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BIGRAD project (www.bigradnerc.com) and will consider generic PhD studies to develop the UK skills base.

Until site-specific information becomes available and concept development has progressed the NDA RWMD will maintain knowledge capability with respect to grouting and shotcreting, sealing materials, plugs and sealing strategies under development internationally. Where appropriate participation in overseas international programmes will be considered. The different types of sealing materials suitable for fracture sealing (and other sealing applications) will be reviewed in order to inform research required once sites have been selected.

Once site information becomes available and concept development progresses, information relating to the nature of the EDZ surrounding an EBS will become available from underground explorations and desk studies.

A component model of the ILW/LLW near field is being developed to link into the post-closure performance assessment. As part of this work it will be important to understand the key controls on barrier performance. In doing this the information and tools that will be required for the time when site information becomes available will be considered.

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