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Framework for an environmental safety case for geological disposal in the UK

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ABSTRACT

The implementation of a geological disposal facility requires the demonstration of confidence that such a facility would be safe during both the operational period and in the long-term after the closure of such a facility. The generic environmental safety case described in this paper is the vehicle used to demonstrate an understanding of environmental safety. It will be used to prepare a site-specific environmental safety case in due course. The approach taken will be consistent with a staged development and approval process, as advocated by the environmental regulators.

Keywords: safety case, geological disposal facility, radioactive waste.

Introduction

The Nuclear Decommissioning Authority, Radioactive Waste Management Directorate (NDA RWMD) has developed a generic environmental safety case (ESC) (Nuclear Decommissioning Authority, 2010*a*) for a geological disposal facility (GDF). The ESC is a set of claims concerning the environmental safety of the disposal of radioactive waste in a GDF, substantiated by a structured collection of arguments and evidence. It considers environmental safety at the time of disposal and in the long-term, after wastes have been emplaced and the facility has been closed. The ESC needs to address the more detailed regulatory principles and requirements contained in the environmental regulators' *Guidance on Requirements for Authorisation* (GRA) (Environment Agency and the Northern Ireland Environment Agency, 2009), which encompasses management, radiological and technical aspects of the safety case for a GDF. It is not possible to produce a full ESC until the location of the geological disposal system is known and a detailed design has been produced. Indeed, the assessment strategy and design may play a role in evaluating the suitability of a site. The generic ESC has been developed at this stage in the site selection process to demonstrate our confidence and capability to develop the safety case of a GDF in the future, and to act as a basis for giving waste packaging advice now.

Key aims of the generic ESC are as follows:

(1) Set out the NDA RWMD understanding of the requirements of an ESC, consistent with the GRA, explaining how the ESC will be used at various hold points in the implementation process for a GDF.

(2) Explain the safety strategy for a GDF and the way in which confidence will be built in environmental safety through a range of qualitative and quantitative lines of reasoning.

(3) Provide arguments on the environmental safety of a GDF with reference to the principles and top-level requirements of the GRA; and, consistent with being at a generic stage, show that safety could be provided by a combination of engineered and natural barriers in different geological environments and illustrate how a

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GDF could be implemented in these environments. The safety arguments are based on qualitative discussion and illustrative assessment calculations for a range of illustrative geological disposal concept examples and associated GDF designs as applied to the UK.

(4) Provide a continuing basis for the assessment of waste packaging proposals ('disposability assessments').

(5) Help provide an appropriate basis for undertaking assessments of candidate sites as part of Government policy published in the *Managing Radioactive Waste Safely* (MRWS) White Paper (Department for Environment Fisheries and Rural Affairs *et al.*, 2008).

(6) Identify the research and development (R&D) work needed to provide relevant evidence and develop confidence in the qualitative and quantitative environmental safety arguments presented in future updates of the ESC.

(7) Help demonstrate that the NDA RWMD is developing the capability to perform the functions of a Site Licence Company in due course.

The ESC is just one part of the overall generic disposal system safety case (DSSC) (Nuclear Decommissioning Authority, 2010*b*) that has been produced as part of the preparatory studies in the first phase of the development programme for a GDF. The DSSC is an integrated safety case, encompassing transport of waste to the disposal facility, construction and operation of facility and the long-term safety for people and the environment. The DSSC serves as an integrating tool within the development programme for a GDF. It brings together work in topic areas as diverse as disposal system specification, design, R&D, site characterization, safety assessment, inventory specification, and stakeholder and regulatory dialogue. For each successive update of the DSSC, activities in these topic areas will be integrated as shown in Fig. 1.

Safety strategy

In order to address the specific technical requirements in the GRA, NDA RWMD has

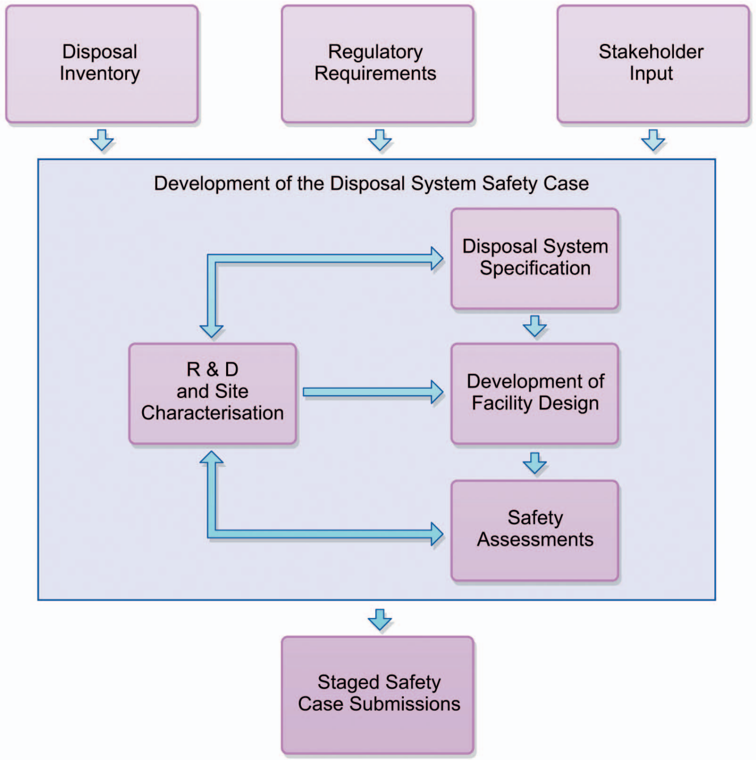

FIG. 1. Interaction between different topic areas that are addressed and integrated in developing the ESC.

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adopted a safety strategy that demonstrates the safety of people and the environment both at the time of disposal and in the future. The approach to developing a safety strategy is derived from national and overseas experience of developing safety assessments, a knowledge of safety cases for GDFs in other countries, working with international (EC, NEA, IAEA) safety case groups, and lessons learned from previous ESCs developed in the UK, e.g. for the national low-level waste repository (LLWR) near the village of Drigg in West Cumbria (Low Level Waste Repository, 2011), and for the proposed Dounreay low-level waste disposal facility (Crawford, 2010). The safety strategy consists of a design and siting strategy, an assessment strategy, and a management strategy:

Design and siting strategy

Within the site offered by a particular host community and for a preferred disposal concept, the ESC would be used to assist in the siting, layout, operation and closure planning of a GDF. Disposal facility design would consider the inventory NDA RWMD is required to manage in a GDF, and would follow international good practice and the GRA in providing for passive safety and using the safety functions of multiple barriers to provide safety. The siting strategy will be developed further once specific candidate sites have been identified by the MRWS site selection process.

Assessment strategy

The assessment strategy follows international good practice and the requirements of the GRA. Some components of the assessment strategy are still under development, and will benefit from dialogue with regulators to better understand their expectations. Many components of the assessment strategy have not been implemented in the generic ESC as it is considered premature to do so until there is sufficiently detailed information from specific candidate sites and a site-specific disposal concept has been developed. However, those parts needed to provide confidence in the ongoing assessment of waste packaging proposals by waste producers have been implemented, to demonstrate GDF viability, and to inform initial desk-based assessments of candidate sites once these sites are available.

Management strategy

An overall management strategy is needed to provide confidence that the disposal system specification and the design and assessment strategies can be delivered in a coherent, integrated way and with appropriate quality and management accountability over the long time-scales of GDF planning and delivery. The NDA RWMD has developed a *Safety and Environmental Management Prospectus* (Nuclear Decommissioning Authority, 2009*a*,*b*) that sets out the management strategy and safety procedures for delivering a GDF. The key elements of the management strategy needed for the near future are already in place, and have, for example, influenced the content of the generic ESC and controlled its production. However, the management strategy will need to develop in the future to meet the needs of the programme as it evolves (e.g. to control site characterization and eventual GDF construction, operation and closure).

Assessment basis

The assessment basis is the information that underpins the qualitative and quantitative safety assessments provided in the environmental safety analysis (described in the following section) of the generic ESC. The assessment basis consists of:

(1) The concept for a GDF, including the waste inventory and uncertainties, waste packaging arrangements, the generic geological environments, and the types of engineered barrier systems (EBS) and GDF layouts that are being considered in the generic ESC.

(2) The scientific and technical information and understanding that underpins the generic ESC, including a summary of expected evolution of a generic GDF.

(3) The models and modelling approaches, including computer codes and databases that have been used to develop and quantify the understanding of generic geological disposal systems.

More detailed information about this underpinning scientific and technical information and understanding is provided in the DSSC Tier 2 safety assessment reports and supporting reports (Nuclear Decommissioning Authority, 2010*b*).

The assessment basis represents a snapshot of the current stage of the GDF programme and will change as the MRWS site selection process moves forward. In particular, when particular

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sites are being considered, the ESC will become increasingly more detailed and the assessment basis will evolve to ensure that it remains 'fit for purpose' (i.e. suitable for the decision required at that stage of the process). Information specific to the sites and geological environments under consideration will be presented, including describing disposal concepts that are appropriate for each geological environment. The assessment basis will be used to explain why particular disposal concepts for each of the sites under consideration have been selected. Whilst there is precedent and UK and overseas understanding to draw on, some issues can only be resolved through detailed, site-specific work, and so the current assessment basis is of necessity more qualitative than future versions will be.

Although there are wide variety of geological environments in the UK that might be suitable to host a GDF, at this stage it is not known in which environment a GDF will be developed. The information about the geological environment and the disposal concepts that might be implemented is therefore generic. The ESC therefore considers a range of GDF concepts in three illustrative geological environments: higher strength rocks, lower strength sedimentary rocks and evaporites. Further information on the UK application of the illustrative geological disposal concept examples is provided in the Tier 2 supporting reports of the DSSC (Nuclear Decommissioning Authority, 2010*b*). The information describing the geological disposal system characteristics illustrates the issues that might need to be addressed once a site has been identified, and is indicative of the type of information that will have to be included in the assessment basis once the disposal concepts relevant for a specific site are being considered.

Different geological disposal systems will require different approaches to the development of the ESC. The generic operational environmental safety assessment (OESA) (Nuclear Decommissioning Authority, 2010*c*) and post-closure safety assessment (PCSA) (Nuclear Decommissioning Authority, 2010*d*) present the results of example calculations of the type that are considered to be appropriate to support the ESC at the current generic stage of the MRWS site selection process. The quantitative environmental safety assessments that will be undertaken in stage 4 of the MRWS site selection process will build on the approaches described in the OESA and the PCSA.

The calculations and illustrative geological disposal concept examples assist in the development of the understanding of the manner in which different types of geological disposal system provide safety through multiple barriers working together, and provide confidence that an appropriate EBS can be designed that will provide the required level of performance to work with the geological environment at the candidate site.

Environmental safety analysis

The purpose of the environmental safety analysis is to show that the GDF would be safe, during both the operational period and in the long term after the closure of such a facility. Different lines of reasoning and environmental safety arguments are developed for the OESA, which is assumed to be largely independent of the geological environment, and post-closure safety, which is considered for a range of generic geological environments and disposal concepts. The safety analysis has three key strands: qualitative safety arguments, quantitative modelling, and the management of uncertainty. Together these strands provide the necessary multiple lines of reasoning.

Operational environmental safety assessment

The purpose of the generic OESA is to provide an illustrative quantitative indication of off site doses to the public and non-human biota associated with the operational phase of a GDF. The potential consequences of accidents and radiological doses to workers are reported outside the OESA as part of the operational safety case (Nuclear Decommissioning Authority, 2010*e*).

Our high level strategy to ensure operational environmental safety is to eliminate hazards during the normal operation of a GDF, and where this is not possible, to provide protection to control any adverse environmental impacts. During the operational period, environmental safety is provided by the safety features inherent in waste packaging specifications, and the safety procedures and management in place during this period. The safety features of the waste packages include the solid form of the wastes; their packaging to reduce the potential for radioactive releases during storage and handling; their disposal in robust containers that provide the necessary degree of radiation shielding and containment, and are capable of normal handling during storage, transport and disposal operations.

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The air underground will be filtered to remove any radioactive particles that might escape from the packages. Illustrative quantitative assessment of possible discharges of radioactive gases from a GDF during the operational period indicates that the regulatory requirements can be met.

The generic OESA (Nuclear Decommissioning Authority, 2010*c*) describes the illustrative calculations to evaluate the off-site consequences of routine radiological discharges during the operational period. As location-specific GDF designs are developed, the potential for non-radiological discharges will be kept under review. The generic OESA uses the methodology for the calculation of dose release ratios (dose per unit release of activity) for such releases presented in the Environment Agency's methodology reports (Allott *et al*., 2006; Lambers and Thorne, 2006). The Environment Agency's methodology used the *PC-CREAM* model (Smith and Simmonds, 2009).

The generic OESA considers the following release pathways:

(1) Aerial discharges from the ventilation system of the underground facilities in gaseous form via a stack with doses to the member of a local resident group who would receive the largest dose from inhalation of activity from the plume, external radiation from the plume, external radiation from deposited activity, and the ingestion of contaminated food.

(2) The assessment of radiological impacts from off-site gaseous radioactive discharge from the underground facilities on non-human biota (fauna and flora) to a range of 'reference organisms' appropriate for a terrestrial biosphere using the *ERICA* tool (www.ceh.ac.uk/protect/ERICAdeliverables.html).

(3) Liquid discharges from a liquid effluent treatment and discharge plant as part of the surface facilities of a GDF.

Impact of the first two pathways are assessed in terms of calculated doses, whilst the impact from the liquid discharges are discussed qualitatively in the OESA.

Post-closure safety assessment

Using both qualitative and quantitative reasoning, the post-closure safety assessment presents an understanding of how a GDF would evolve once it is closed. It shows how environmental safety could be provided by a system of multiple barriers working together to provide safety over timescales of hundreds of thousands of years.

The understanding of post-closure performance and statements on environmental safety will come from various lines of reasoning including:

(1) Description and analysis of the expected evolution of the geological disposal system based on understanding of the environmental safety functions provided by different disposal concepts and sites and by our research, design and site characterization work programmes.

(2) Results of experiments in underground research laboratories in other countries under *in situ* conditions and long-term demonstration experiments.

(3) Studies of archaeological analogues, that is, materials that people have been using for hundreds or thousands of years and that have survived in the environment over long timescales and that are analogous to the materials that could form part of the engineered barrier system of a GDF (e.g. glass, cement and iron).

(4) Studies of natural systems that provide analogues for processes important in containing and retarding radionuclides in the multi-barrier system and which can provide information over timescales comparable to or longer than those considered in our quantitative assessments (e.g. Cigar Lake in Canada, see Fig. 2).

(5) Site-specific natural indicators of safety once we have candidate sites to consider (e.g. indicators of containment and retardation in the geological environment).

(6) Demonstration that the geological disposal system is robust to unexpected events (e.g. climate change), uncertainties (e.g. concerning site-specific understanding) and decisions (e.g. the possible need to dispose of nuclear materials such as separated plutonium or uranium).

The quantitative post-closure safety analysis is provided in the generic PCSA (Nuclear Decommissioning Authority, 2010*d*). This contains illustrative example calculations and/or qualitative discussion for groundwater-mediated, gas-mediated, and human intrusion-mediated releases from a GDF. It considers a range of GDF concepts in three illustrative geological environments: higher strength rocks, lower strength sedimentary rocks and evaporites. It also considers criticality safety in the post-closure period. A range of databases including NDA RWMD databases and international databases have been used to support and parameterize the calculations. The generic PCSA calculations are used to illustrate some aspects of the process of carrying out a performance assessment, but the

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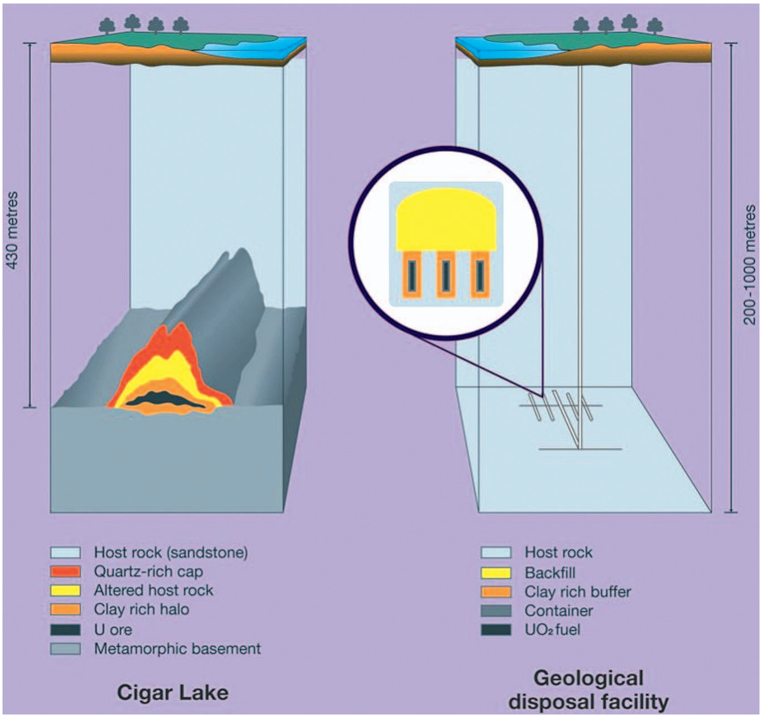

FIG. 2. Illustration of Cigar Lake uranium-ore deposit, showing similarities to a geological disposal system.

main driver for including a quantitative assessment now is to inform the disposability assessments of packaging proposals for waste that is being packaged now, in advance of the identification of a site. It is intended to use the generic PCSA calculations as the benchmark for undertaking future assessments as part of the disposability assessment process. The generic PCSA summarizes the similarities and differences in the current generic assessments with the approaches adopted by Nirex for previous generic assessments used to underpin earlier disposability assessment work (Nirex, 2001, 2003).

Addressing uncertainty

It is recognized that there are inevitable uncertainties associated with processes operating in a geological disposal system on a timescale of hundreds of thousands of years, and that these uncertainties require appropriate treatment in performance assessments in support of a GDF.

In the GRA (Environment Agency and the Northern Ireland Environment Agency, 2009) the environment agencies require that the ESC takes adequate account of uncertainties, including establishing and maintaining a ‘register of significant uncertainties’, and a clear forward strategy for managing each significant uncertainty based on avoidance, mitigation, reduction and/or quantification of the uncertainty.

The uncertainties considered in the ESC include:

(1) There is not, as yet, a candidate site or candidate sites, and therefore the geological environment in which a GDF will be developed or the disposal concept that will be implemented are not known.

(2) Uncertainty in the eventual inventory requiring geological disposal. These include uncertainties in the volumes and radionuclide contents of the currently identified wastes and materials in the baseline inventory (Department for Environment Fisheries and Rural Affairs *et al.*, 2008) and uncertainties in scenarios for the future operation of the nuclear plants that produce these wastes and materials. The possible inclusion of spent fuel, plutonium and uranium owned by the Ministry of Defence that are not currently

within the baseline inventory and a potential programme of new nuclear power stations have also been considered.

(3) Uncertainty over future states of the disposal system as it is not known for certain how a GDF and its environment will evolve over long timescales. Therefore a performance assessment needs to consider a range of different scenarios for future evolution.

(4) Data uncertainty. Data will be incomplete, inaccurate or not available, leading to uncertainty in the parameters required for a performance assessment. In principle uncertainty in these parameters can be reduced by making more measurements (in the case of properties of the rock at a potential site) or carrying out more laboratory experiments (in the case of chemical parameters such as solubility). However, some uncertainty cannot be reduced, for example uncertainty in the range of chemical conditions that might exist in the distant future.

(5) Model uncertainty. Although it is believed that most processes are well understood at an appropriate level, understanding of some of the relevant features, events and processes and how they are inter-related may be inaccurate, causing uncertainty in the selection and formulation of conceptual models.

(6) Uncertainty about human behaviour. Human actions are largely unpredictable and yet can have a significant impact on the performance and impacts of the disposal system. For example, in the future people may drill for water extraction or excavate in the region of a GDF. Human activity may also change the landscape around a GDF and changes in habits may affect the radiological impact of a GDF on future generations.

The ESC is currently at an early stage of development, because the site and design have not yet been chosen. However, its contents builds on more than 30 years of site-specific and generic experience studying geological disposal and undertaking safety assessments in the UK, as well as learning from more than 40 years of such experience in other countries.

Uncertainty can never completely be resolved and it therefore has to be managed. This will include 'designing out' uncertainty as the design of the preferred disposal concept is optimized (Nuclear Decommissioning Authority, 2010*f*). Uncertainty over future states of the disposal system and future human actions can be treated by the development of scenarios. We have developed a structured approach for treating such uncertainty and have a number of methods of treating the other types of uncertainty listed above (Nuclear Decommissioning Authority, 2010*d*). As decisions are made on whether particular nuclear materials are classified as wastes, and on waste conditioning, the key uncertainties in the baseline inventory for the GDF will decrease. There may also be several areas of uncertainty that can only be resolved via discussion with the potential host community(ies) and the environmental regulators.

As the MRWS site selection process moves forwards, key uncertainties will become more focused on site-specific and concept-specific scientific and technical issues. A site-specific register of key technical uncertainties can then be developed at a more detailed level and will be kept under review as the information base increases.

Conclusions and forward programme

The generic ESC illustrates how geological disposal could be implemented safely in different geological environments for the UK's inventory of higher activity radioactive wastes. Confidence in the process is built on an understanding of how multiple barriers can work together to provide the required long-term safety. Once a preferred site and disposal concept have been identified, an optimized design can be developed that meets the environmental safety requirements.

The safety and environmental assessments that have been undertaken by NDA RWMD are sufficient to underpin future disposability assessments of waste packaging proposals. Overall, the knowledge base that has been developed is sufficient to progress from the generic stage to studies of candidate sites when they are identified.

The staged GDF implementation process and progressive updating of the ESC will allow many opportunities for feedback from regulators and other stakeholders, and will provide opportunities to tailor proposals with respect to new findings and comments that are received. The generic ESC summarizes and addresses issues that have been identified by previous regulatory scrutiny. Ongoing dialogue with regulators and other stakeholders will inform the next update to the ESC.

References

Allott, R.W., Lambers, B. and Titley, J.G. (2006) *Initial Radiological Assessment Methodology – Part 1*

https://doi.org/10.1180/minmag.2012.076.8.59 Published online by Cambridge University Press

User Report. Science Report SC030162/SR1. Environment Agency, Bristol, UK.

Crawford, M.B. (2010) *Dounreay New Low Level Waste Facilities*. RSA93 Environmental Safety Case, Galson Sciences Ltd Report to DSRL, NLLWF/3/ESC/GAL/0425/IS/01.

Department for Environment Fisheries and Rural Affairs (DEFRA), Department for Business, Enterprise and Regulatory Reform (BERR) and the Devolved Administration for Wales and Northern Ireland. (2008) *Managing Radioactive Waste Safely: A Framework for Implementing Geological Disposal*. DEFRA, London, 100 pp.

Environment Agency and the Northern Ireland Environment Agency (2009) *Geological Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation*. Environment Agency, Bristol, UK and the Northern Ireland Environment Agency, Belfast, UK.

Lambers, B. and Thorne, M.C. (2006) *Initial Radiological Assessment Methodology – Part 2 Methods and Input Data*. Science Report SC030162/SR2. Environment Agency, Bristol, UK.

Low Level Waste Repository (2011) *The 2011 Environmental Safety Case, Main Report*. LLWR/ESC/R(11)10016. National Low Level Waste Repository, Drigg, Cumbria, UK.

Nirex (2001) *Generic Post-closure Performance Assessment*. Nirex Report N/031/2001.

Nirex (2003) *Generic Repository Studies, Post-closure Performance Assessment*. Nirex Report N/080.

Nuclear Decommissioning Authority (2009*a*) *Safety and Environmental Management Prospectus*. NDA Report NDA/RWMD/RWSP01, Revision 2.0.

Nuclear Decommissioning Authority (2009*b*) *Organisational Baseline Document*. NDA Report RWSP02, Revision 2.0.

Nuclear Decommissioning Authority (2010*a*) *Geological Disposal: Generic Environmental Safety Case main report*. NDA Report NDA/RWMD/021.

Nuclear Decommissioning Authority (2010*b*) *Geological Disposal: An overview of the generic Disposal System Safety Case*. NDA Report NDA/RWMD/010.

Nuclear Decommissioning Authority (2010*c*) *Geological Disposal: Generic Operational Environmental Safety Assessment*. NDA Report NDA/RWMD/029.

Nuclear Decommissioning Authority (2010*d*) *Geological Disposal: Generic Post-closure Safety Assessment*. NDA Report NDA/RWMD/030.

Nuclear Decommissioning Authority (2010*e*) *Geological Disposal: Generic Operational Safety Case Main Report*. NDA Report NDA/RWMD/020.

Nuclear Decommissioning Authority (2010*f*) *Geological Disposal: Proposed approach to optioneering.* NDA Technical Note 12860687, 2010.

Smith, J.G. and Simmonds, J.R. (editors) (2009) *The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment used in PC-CREAM 08*. HPA Report No. HPA-RPD-058, Chilton. Health Protection Agency, Didcot, UK. (www.hpa.org.uk/web/HPAweb&HPAwebStandard/HPAweb_C/1195733792183).

https://doi.org/10.1180/minmag.2012.076.8.59 Published online by Cambridge University Press