AN OVERVIEW OF RESPONSES TO THE AMIGO QUESTIONNAIRE ON THE USE OF GEOSCIENCE DATA IN SAFETY CASES

M. Jensen[1], B Goodwin[2]

[1]Ontario Power Generation and [2]Goodwin Environmental Assessment Consulting, Canada

Abstract

AMIGO is the acronym for the OECD/NEA project on the topic of “Approaches and Methods for Integrating Geological Information into the Safety Case”. A key objective of the AMIGO project is to foster awareness of geoscience and its continuing role in the development of a repository safety case. As part of this effort, AMIGO undertook to document current international experience with respect to the practical usage, communication and management of geoscientific data and information that underpin an explanation of the geosphere and its evolution as relevant to assessing repository performance and safety. This paper summarises the responses and collective experiences of many AMIGO participants captured in a questionnaire that provides a snapshot of the evolving role of geoscience in the preparation and communication of a deep geological repository (DGR) safety case for long-lived radioactive waste.

Introduction

AMIGO is the OECD/NEA project on the topic of “Approaches and Methods for Integrating Geological Information in the Safety Case”. The project was undertaken, in part, to advance the understanding of geoscientific methods and approaches as they are applied to support a safety case for a Deep Geologic Repository (DGR). Within the DGR concept, the long-term isolation of radioactive waste form(s) is provided by a system of multiple, independent barriers, including the waste form, engineered repository barriers and the geosphere. During the last decade, considerable experience has been gained internationally in understanding approaches for geosphere characterisation and communicating confidence in geosphere barrier performance at time scales relevant to repository safety (10^5-10^6 a). The knowledge acquired is applicable to the implementation of the DGR concept in sedimentary and crystalline geologic settings, and involves methods for the management and synthesis of geoscientific information to complement a case for repository safety.

In this regard AMIGO undertook to document the current experience in international programmes related to the practical usage and application of geoscience information that complements analyses of repository safety and that helps convey those notions. The starting point was a questionnaire circulated to AMIGO participants that examined various aspects of geoscience related to approaches to integrate results from different geoscience disciplines and to constrain the understanding of far-field evolution. The key goals of the questionnaire were to:

i) Collect examples of geoscientific lines-of-evidence that directly support or convey confidence in the performance of the repository in varied geologic settings.

ii) Consider techniques used for effective communication of geoscientific reasoning and perspectives that support the safety case for a deep geological repository.

iii) Identify methods and procedures that provide the geoscientific basis for the safety case, notably the geosynthesis or integration of multi-disciplinary geoscientific information and approaches that can constrain non-uniqueness and uncertainty in the description of the geosphere.

iv) Explore methods related to planning and organising, to improve the manner in which geoscience information is collected and communicated.

In total, 17 participating groups responded to the questionnaire, representing implementing organisations and regulatory agencies from 12 countries. The responses also reflect a broad cross section of national programmes with a variety of repository concepts in different host rocks and at different stages of development, from conceptual studies to repository siting and licensing.

A main component of the questionnaire surrounded geoscience reasoning and use of multiple lines of evidence underlying quantitative and qualitative arguments related to the long-term behaviour of the geosphere and how it might influence repository performance. The responses included over 30 examples outlining experience and practice in sedimentary and crystalline settings. While the majority of the examples were provided by implementing bodies, others represent regulatory experience, remarks or observations on the use and value of geoscientific arguments.

These examples of geoscience usage covered a broad range of topics relevant to understanding and communicating the role of the geosphere in the repository safety concept. Such work, typically inter-disciplinary in nature, covered topics such as groundwater age and residence times, long-term climate perturbations, sorption and matrix diffusion, diffusion dominant transport regimes, preferential groundwater pathways, depth of penetration by meteoric recharge, geomechanical stability, self-sealing properties of clay, seismicity, erosion and uplift. Taken together, these examples reveal a commonality in international programmes toward the combination of multi-disciplinary evidence to constrain or bound interpretation of geosphere behaviour and to better explain concepts of repository isolation and safety. The examples often serve the safety case directly, for example, by providing information or data for models used in quantitative evaluation of safety, and indirectly, for example by providing evidence to support model assumptions concerning issues such as site stability and response to perturbations.

An area of constant improvement relates to how geoscientists express confidence in their Geosynthesis and conceptual model(s). With this is mind, the questionnaire examines successes and challenges facing geoscientists in enhancing the role of Geoscience in terms of the science itself, in managing and overcoming emerging issues, and in providing clear messages to communicate key results.

The report presents a snapshot in time on how geoscience has been applied to explore and bound an understanding of the geosphere, including past evolution and expected future evolution, to better demonstrate confidence in predictions of geosphere performance and long-term safety. The report also examines the successes and challenges facing Geoscience in its continuing role of supporting the repository safety case.

The responses to the questionnaire have been assembled in a draft NEA-AMIGO report entitled *The Evolving Role of Geoscience in the Safety Case for a Deep Geologic Repository*. This report makes a strong case that Geoscience provides essential contributions to understanding and communicating the role of the far-field in a multi-barrier repository concept and to the development of technically defensible estimates of repository environmental performance.

The role of geoscience in the safety case

In developing the AMIGO questionnaire an emphasis was placed on soliciting illustrative examples that would highlight the emerging role of geoscience in the development of a repository safety case. A fundamental assertion is that understanding the past and future evolution of the geosphere (far-field) assumes an integral role in presenting the safety case of a long-term deep geologic radioactive waste management facility. The advance of international radioactive waste management programmes provides a unique opportunity and practical insight into how geoscience has or may contribute to the preparation of an effective safety case.

Application of geoscience information

The usage of geoscientific information in a safety case is influenced by a number of factors, among them, the site-specific characteristics of the geologic setting and the philosophy applied in design of the multi-barrier repository concept. One of the perhaps most difficult issues associated with geoscience is non-uniqueness in interpretation. Non-uniqueness in geoscience stems in part from the complexity and time scale of the sites' geologic/hydrogeologic evolution and practical limitations imposed on field and laboratory investigation to characterise precisely rock mass volumes of km^3 in dimension. A goal, therefore, might be that investigative geoscience activities emphasize or focus upon the characterisation of site-specific attributes for which uncertainty can be adequately bound for the temporal and spatial scales relevant to repository safety and that best contribute to the explanation and confidence in predicted long-term geosphere barrier performance (i.e. capacity to retard and retain radionuclides; geosphere constancy-predictability).

Geosynthesis

The considered method to resolve the above challenges involves geosynthesis, the assembly and integration of multi-disciplinary geoscience data. Geosynthesis yields several important products (see Box 1). It is used to construct a site-specific conceptual description of the geosphere, also called the geosphere model that is consistent with and justified by the available information. It does so by combining qualitative and quantitative data and reasoned arguments. The coincidence or constancy in interpretation of independent multidisciplinary data provides a rationale to constrain uncertainty, or to place limitations on the geosphere model.

Box 1. Main outcomes of geoscience and geosynthesis

- Provide the required understanding to develop a coherent, logical and defensible geosphere model that describes how the geosphere acts today and how it will evolve over time scales relevant to repository safety.
- Constrain uncertainties in that understanding based on different lines of reasoning that eliminate some possibilities and reinforce others.
- Supply the specialised information and data sets pertaining to the geosphere that are needed for the safety assessment and for the design of the engineered barriers.
- Contribute complementary evidence to support the safety case, notably on the potential significance of key processes and mechanisms.

It is important to recognise that geosynthesis does not lead immediately to a unique, definitive geosphere model. Instead, geosynthesis and the geosphere model advance iteratively throughout the various stages of a repository site investigation. At each stage, geosynthesis has access to more data and information that can be used to extend the model, to eliminate ambiguities and uncertainties, and to confirm the model veracity. Thus geoscience and geosynthesis ultimately underpins the geosphere model, and the model provides summary descriptions of geosphere evolution over time scales germane to safety. The model can then be used to supply information and data needed to perform safety assessments and to design the engineered components of the DGR. For example, the traditional needs for safety assessment includes data for rock porosity, permeability and groundwater velocities to help predict radionuclide movement and discharge locations, while facility design engineers need information on rock strength, location of faults and composition of infiltrating groundwaters to map out emplacement areas and devise suitable containment materials. Other geoscience information, such as an understanding of the current and predicted geochemical environment, can be vital to both safety assessment and engineering design.

Geoscience safety related attributes

For a deep geologic repository, a host geosphere may contribute to the safety case in a variety of ways. The following two attributes are amongst the most common and both are inherently significant. These safety-related attributes provide a convenient grouping scheme for the 30 examples of potential geoscience contributions to a safety case.

- **Stability:** provides a physical and chemical environment that is expected to endure, more or less unchanged, for very long time frames. This environment is expected to be resilient to internal and external perturbations at time frames relevant to repository safety. Examples in this group would be geoscience evidence that deep groundwater has been unaffected by climate change for long time frames and evidence that the proposed repository is completely surrounded by very old, saline groundwater.
- **Barrier function:** contributes to mechanisms and processes that prevent, delay or attenuate radionuclide release and migration. Examples include evidence that fluid flow to and from a repository area is limited or restricted, that radionuclide transport is dominated by diffusion, and that radionuclides tend to sorb strongly onto available mineral surfaces or have solubility.

With respect to stability, more than 20 examples were sorted into the nine headings shown in Box 2. The first three headings pertain to the properties of the deep geosphere and consider the significance of the age of brine groundwaters, the implications of widespread homogeneous low permeabilities and the distinctive geology of a salt dome. The fourth example pertains more to the 'near field' geosphere immediately surrounding a potential DGR and specifically to the swelling and plastic properties of clay. Examples 5 through 8 deal with the potential effects of specific external perturbations: climate change, geochemical transformations, groundwater penetration and seismicity. The last example provided is an advisory concerned with bedrock stability and, with some consideration of the previous examples, points to generic guidance available from geoscience to help with repository siting constraints.

Box 2. Examples of geosphere stability

1. Age of deep brine groundwaters.
2. Low permeability over a large region.
3. Integrity of a salt dome.
4. Self-sealing properties of clay.
5. Climate change including glaciations.
6. Deep geochemical transformations.
7. Depth of groundwater penetration.
8. Seismicity, uplift, erosion, and related processes.
9. Mechanical stability of the host rock.

The concept for deep geological disposal of radioactive waste envisions a set of multiple safety functions that act independently, as much as possible, to provide safety over long time scales. The geosphere can provide an effective barrier function to delay and attenuate the release and migration of radionuclides that eventually escape from the disposal vault. The barriers can be based on processes that include diffusion-limited transport and very slow groundwater rates of movement (or the absence of flow and transport processes), small porosities or permeabilities, sorption processes, the presence of geochemical fronts or gradients and groundwater geochemistry that promotes sorption and precipitation. The geosphere can also contribute to the effectiveness of the engineered barriers to prevent the release of radionuclides. Examples include prolonged performance of copper containers in low-sulphide groundwaters, longer lasting iron containers in electrochemically reducing groundwaters and the slow alteration of bentonite to illite in low-potassium groundwaters. More than 10 examples have been placed in this category under the headings listed in Box 3.

Box 3. Examples of the geosphere barrier function

10. Preferential groundwater flow pathways.
11. Advective or diffusion-dominated transport.
12. Sorption and matrix diffusion.

Enhancing the role of geoscience

This aspect of the report examines issues related to the geosynthesis in the safety case as it relates to the science itself and approaches to communicate results and manage diverse inter-disciplinary information. With regard to the former, specific areas on which respondents commented included: i) inclusion of paleohydrogeologic knowledge to reinforce statements of future site stability; ii) methods for the management of inherent geoscience uncertainties in spatial and temporal geoscience data sets and conceptual descriptive models; and iii) the effect of regulatory guidance and regulations.

Communication

With respect to communication, it is clear that the majority of respondents recognise the unique challenges. For example, the safety case must deal with the uncertainties inherent in the long-term performance of the DGR, which involve the successful integration of multi-disciplinary data sets and the construction of a comprehensive conceptual model(s) of the geosphere. Communication plays a pivotal role in describing to others how the uncertainties have been resolved and why this leads to confidence in the legitimacy of the safety case.

Communication goes beyond the preparation of reports and the presentation of site-specific data. A credible safety case must be transparent and easy to follow, and so must the foundation provided by the underlying geoscience. Practical approaches that enable broader audience awareness and understanding have become essential. The audience includes all stakeholders, including not just peers and colleagues but also academia, decision makers and the public.

Finally, experience with geoscience can be tempered with experience in communicating to highlight what science is needed and how it is best imparted. For example, the application of scientific visualisation technology is a relatively new approach that promotes sharing geometrically complex geoscientific data and realisations in time and space. It is of value to experts in the various geoscience disciplines to ensure that their independently developed data sets are complete and free of unexplained inconsistencies, especially when integrated with other data sets. That is, scientific visualisation can serve as a convincing data quality assurance tool to geoscience experts. For the non-technical stakeholders, scientific visualisation holds promise as a compelling communication aid.

Specific areas related to communication focus on respondents views to: i) the role of peer review; ii) experience related to the presentation and interest in geoscience information to broad stakeholder audiences; iii) integration of geoscience information in the repository barrier design and safety case; and iv) the importance of site characterisation studies to support understanding of safety functions.

Geoscience management issues

It is clear that geoscience contributions to the safety case involve many specialist disciplines. This is particularly true for a site characterisation programme which may include paleohydrogeologic studies of fracture infill mineralogy and paragenesis to assess redox front movement; apatite Fission Track Thermochronology and other methods to estimate formation depth of burial and uplift; derivation of parameters in the laboratory and field to predict radionuclide transport in the scales needed by safety assessment; hydraulic well testing in deep boreholes to derive permeability field distributions for fracture and matrix continua; characterisation of matrix pore fluid elemental and isotopic compositions to assess groundwater origin and residence time; assembly of geologic models of sedimentary basin formation and tectonic evolution to determine effects on clay properties and geologic structure; measurement of deep stress-strain relationships needed for repository construction and to establish criteria for designing mechanically stabile engineered barriers; predictive estimates of how climate change during the Quaternary has affected surface thermal, mechanical and hydraulic boundary condition; and development of numerical flow systems simulations to understand groundwater flow dynamics at regional and local scales in media such as heterogeneous rock with variable salinity. Many of these examples also possess an inherent and valuable predictive element; for example, conclusions regarding past movement of redox fronts can be very constructive if they offer insight into future behaviour.

The AMIGO questionnaire sought experience with methods to improve planning and organising of geoscience information for a safety case. The questions were concerned with current methods of managing geoscience information and potential improvements in its collection and distribution. In particular, the intent of the questions was to examine ways to integrate results more effectively and to provide those results to other stakeholders in a timely fashion.

On issues associated with management tasks, the questionnaire sought experience from respondents on methods to improve planning and organisation of geoscience information for a safety case. Specific responses dealt with i) approaches to manage and integrate multi-disciplinary geoscience databases; ii) establishing geoscience research priorities and iii) the engagement of outside specialists.

Summary

The NEA-AMIGO project conducted an international review of the practical experience with geoscience information used to convey an understanding of geosphere performance as it relates to a multiple barrier repository concept for disposal of long-lived radioactive waste. The review was based on responses to a questionnaire from 17 AMIGO participating organisations in 12 countries. A primary emphasis of the questionnaire was to solicit examples of geoscience support for site-specific repository concepts in sedimentary and crystalline settings. More than 30 examples were described that provide supporting evidence to underpin notions of long-term geosphere stability and, barrier performance and safety functions. The questionnaire also sought out experience related to the communication and management of multi-disciplinary geoscience work programmes that support the repository safety case. The results of the questionnaire provide a broad cross section of experience and provide a snapshot of current practice and future challenges in enhancing the role of geoscience in safety case development. This experience coupled with lessons learnt demonstrates the utility of multi-disciplinary geoscience studies and reasoning in developing convincing and complementary arguments for conveying an understanding of long-term geosphere barrier performance.