History, evolution and current status of geological disposal facility safety cases

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1 Foreword

Development of geological disposal facilities (GDFs) for radioactive wastes is strongly focussed on safety issues. A key element is the production of safety cases that demonstrate to the regulator and the public that the required levels of long-term safety can be achieved. Safety cases are usually produced iteratively as a disposal programme progresses through its different phases. As examples, companion documents to this note outline safety cases prepared for GDF projects in Switzerland and Belgium. This overview reviews the development of safety case methodology and its current status in a generic fashion. The information is largely based on the international literature (in particular from the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), complemented by the direct experience of the authors. The text is aimed more at specialists than the general public; a further accompanying document produced in this project attempt to explain the safety of geological disposal to a more general audience.

2 Origins of the safety case

Safety Cases in other technical areas

In numerous industries the management of operational safety has been based on simply satisfying rigidly formulated prescriptive safety standards. However, a number of serious accidents, including two major incidents in the UK – the fire at the Windscale nuclear plant in the late 1950s and the Piper Alpha Offshore Platform Disaster in the 1990s – initiated new approaches. More emphasis was placed on a systematic, holistic consideration of safety, and on communication of this to the regulator and the public. This led to development of the safety case concept. One early definition was “a documented body of evidence that provides a convincing and valid argument that a system is adequately safe for a given application in a given environment”. More recent definitions make explicit the concept of structured argumentation “A structured argument, supported by a body of evidence that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment”. Today, a safety case is a requirement in many industries. For example, the UK Health and Safety Executive details safety case requirements for the offshore oil industry, rail transport and the nuclear industry. There are specialised companies focussed on developing safety cases for clients from all industries where safety cases are important to minimise both safety risks and commercial risks. For example, clients of the one major European specialist company include Airbus Industries, the European Space Agency, British Energy, UK Network Rail, the European Commission, the Civil Aviation Authority and the Swedish Nuclear Power Inspectorate.

The Safety Case in Radioactive Waste Disposal

The NEA synthesis of a 2013 symposium begins with the words “The concept of a “safety case” for a deep geological repository for radioactive waste was introduced by the NEA Expert Group on Integrated Performance Assessment (IPAG) and further developed in an NEA report on Confidence in the Long-Term Safety of Deep Geological Repositories (1999)”. In practice, as indicated above, the concept of a Safety Case has been in use in many technologies for some decades and the earliest uses of the term in the waste disposal field may have been by US scientists in the early 1990s - although it took the US Nuclear Regulatory Commission many years to adopt the formal terminology. Work on safety cases in waste disposal intensified with the start-up meeting of the Integration Group for the Safety Case of the OECD/NEA in Paris in mid-2000. The meeting included a topical session intended to develop a shared

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2 http://www.hse.gov.uk/offshore/safetycases.htm

3 www.adeland.com


view on the distinctive characteristics and requirements of a safety case, and to start to identify key issues and development needs”.

Before, examining the specific discussions on safety case definition in the waste management area, it is useful to give a definition in plain English, published by experts from outside the field:

“A safety case is a collection of documents that presents the arguments for believing that a proposed potentially-dangerous system is acceptably safe. ... The safety case is thus a collection of data drawn from multiple sources, representing diverse disciplines, and it must be assessed by a range of both technical and non-technical experts, who exhibit a range of differing interests. Accurate and effective communication between the various groups involved in producing and assessing safety cases is therefore an issue of primary importance.”

A useful representation (below) of the safety case system was produced by Cole et al for the Canadian radioactive waste disposal programme.

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3 International guidance

Since the turn of the century, the safety case concept for GDFs has been developed in NEA documents describing the nature and purpose of safety cases and in project work. It has also been introduced into international safety standards and guides and there have been major symposia devoted to the topic.

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6 Stenning, Inder and Gurr of the Human Communication Research Centre (HCRC) in Edinburgh produced this definition

7 Cole K. et al NWMO background paper 3-4 www.nwmp.ca
The currently most widely accepted description of a safety case for geological disposal is that formulated by the IAEA in 2011 and reproduced in the 2013 NEA update. The most important elements defining the contents of a safety case are extracted below.

The safety case … has to provide the basis for understanding the disposal system and how it will behave over time. It has to address site aspects and engineering aspects, providing the logic and rationale for the design, and has to be supported by safety assessment. It also has to address the management system put in place to ensure quality for all aspects important to safety. At any step in the development of a disposal facility, the safety case also has to identify and acknowledge the unresolved uncertainties that exist at that stage and their safety significance, and approaches for their management.

The safety case has to include the output of the safety assessment together with additional information, including supporting evidence and reasoning on the robustness and reliability of the facility, its design, the logic of the design, and the quality of safety assessment and underlying assumptions. The safety case may also include more general arguments relating to the disposal of radioactive waste and information to put the results of safety assessment into perspective.

The structure of a safety case and the components of the safety assessment that it contains are portrayed graphically by the IAEA as follows.

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In the 2013 report of the NEA, a list of reasons for updating the earlier 2004 NEA Safety Case report is given. These are claimed to be that there has been progress in three areas:

1. Scientific understanding - particularly advances in understanding and modelling coupled processes.

2. Advances in computer and hence modelling capability.

3. Experience in writing safety cases for the safety of specific proposed repositories. In these:
   - The role of modelling in support of the safety assessment has generally become more balanced with other lines of evidence
   - There has been some evolution concerning the definition of safety functions and the means for using them to more transparently describe system evolution over time
   - Uncertainties are being addressed more effectively
   - There have also been some developments concerning the use of alternative safety indicators.

In practice, the third point has been most important, since various national programmes have submitted formal safety cases at milestones in their repository project development, often to meet regulatory requirements. Key features of the most important examples are highlighted in the Section 4.

The 2013 NEA Report includes the diagram below, illustrating safety case structure, noting that it has been modified from the earlier 2004 NEA version.
The only significant change is that the block on safety assessment, evidence and arguments now explicitly includes a safety assessment with impacts of uncertainties. Earlier there had been some confusion as to whether the quantitative safety assessment was an integral part of the safety case or an accompanying study.

On comparing the above IAEA and NEA graphics, it is apparent that most elements are common, but there are differences of some emphasis. For example, iterative optimization, operational safety and non-radiological aspects are explicit only in the IAEA representation, while alternative lines of argument such as analogues appear only in the NEA graphic. In practice, developers of a new safety case would be well advised to integrate the two guiding documents.

4 Some examples of current safety case work

The examples chosen are from safety cases that have been or are being developed by national agencies or organisations. The brief comments are intended to point out that they are at different stages in their geological disposal programmes and also to highlight any specific characteristics of the safety case approach used by each that mark them off from other national examples. The diagram below illustrates how different types and amounts of information are available at different stages in a GDF development programme, which affects the style of safety case that is prepared at different programme milestones.
In the examples selected and outlined below, some are at the generic stage, with no chosen GDF concept or site; some are using a generic safety case to guide their R&D programmes; one is in the site selection phase; a few are preparing for or have submitted construction licenses requiring submission of a safety case. Much of the information in this section is extracted from the report on the 2013 NEA safety case symposium.

**Finland – safety case approved for GDF construction**

Being at the forefront of GDF development for one of the most hazardous wastes, spent fuel, the Finnish programme is arguably the most advanced deep geological disposal programme in the world. Apart from spent fuel, the GDF will also contain ILW. The national agency, POSIVA, submitted an application for a license to construct the disposal facility at Olkiluoto in 2012, includes an associated encapsulation facility for the spent fuel. The application included a Preliminary Safety Analysis Report (PSAR) and a long-term...
safety case, TURVA-2012. The safety case was reviewed by the regulatory authority (STUK), which made a positive recommendation to government and Posiva was granted a construction license in 2015. The next step will be the Final Safety Analysis Report (FSAR) called TURVA-2020, in support of an operational licence application around 2020.

TURVA-2012 considered an assessment time frame up to one million years into the future. The structure of the reporting prepared for the long-term safety case is illustrated below. As construction begins, the regulatory authority will ensure it has oversight during the detailed design, construction, fabrication and pre-operational testing, leading up to an operational license application.

**Figure 5: The TURVA-2012 safety case portfolio**

The portfolio consists of safety case reports (green boxes) and supporting reports (blue boxes); brief descriptions of the contents are given (white boxes).

Disposal system = repository system + surface environment.

<table>
<thead>
<tr>
<th>TURVA-2012</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesis</td>
<td>Description of the overall methodology of analysis, bringing together all the lines of arguments for safety, and the statement of confidence and the evaluation of compliance with long-term safety constraints</td>
</tr>
<tr>
<td>Site Description</td>
<td>Understanding of the present state and past evolution of the host rock</td>
</tr>
<tr>
<td>Biosphere Description</td>
<td>Understanding of the present state and evolution of the surface environment</td>
</tr>
<tr>
<td>Design Basis</td>
<td>Performance targets and target properties for the repository system</td>
</tr>
<tr>
<td>Production Lines</td>
<td>Design, production and initial state of the EBS and the underground openings</td>
</tr>
<tr>
<td>Description of the Disposal System</td>
<td>Summary of the initial state of the repository system and present state of the surface environment</td>
</tr>
<tr>
<td>Features, Events and Processes</td>
<td>General description of features, events and processes affecting the disposal system</td>
</tr>
<tr>
<td>Performance Assessment</td>
<td>Analysis of the performance of the repository system and evaluation of the fulfillment of performance targets and target properties</td>
</tr>
<tr>
<td>Formulation of Radionuclide Release Scenarios</td>
<td>Description of climate evolution and definition of release scenarios</td>
</tr>
<tr>
<td>Models and Data for the Repository System</td>
<td>Models and data used in the performance assessment and in the analysis of the radionuclide release scenarios</td>
</tr>
<tr>
<td>Biosphere Data Basis</td>
<td>Data used in the biosphere assessment and summary of models</td>
</tr>
<tr>
<td>Biosphere Assessment: Modelling reports</td>
<td>Description of the models and detailed modelling of surface environment</td>
</tr>
<tr>
<td>Complementary Considerations</td>
<td>Supporting evidence incl. natural and anthropogenic analogues</td>
</tr>
</tbody>
</table>

| Main reports | Main supporting documents |
Switzerland – safety case submitted for GDF construction

The next most advanced geological disposal programme is that of SKB in Sweden, where a construction license application for a spent fuel repository at Forsmark was submitted in 2011 and is currently under regulatory scrutiny and government evaluation. The Swedish Radiation Safety Authority (SSM) announced in February 2016 that the application was sufficiently complete to be examined. The safety case was based heavily on a safety assessment called SR-Site. The Swedish methodology is based strongly on the international studies referred to above. However, the Swedish safety case (and also that of its Finnish neighbour) depends strongly on the main safety function in the concept, which is essentially complete containment provided by a copper canister throughout the 1 million year assessment period. Emphasis is placed on analysing all possible features, events and processes that could lead to canister failure before this time. Where this cannot be excluded, probabilistic calculations of the consequences of radionuclide releases are carried out. Future human actions are treated via a set of stylised scenarios. Given the long time that will elapse before repository implementation, SKB emphasises that changes in the safety case may occur, provided that the consequences are in all cases evaluated and shown not to be detrimental to safety.

France – safety case in preparation for GDF construction

Next in line in progress towards repository implementation is France. The waste agency, Andra, will soon apply for a construction license for a GDF in clay. The project is known as “Cigeo”; the GDF will contain HLW and ILW, and has special requirements on retrievability. Andra claims that post-closure safety issues are effectively solved, based on its 20 years’ experience in long-term radioactive waste management. Work is proceeding on the topic, including development of normal and altered evolution scenarios. Emphasis, however, is on the operational phase of the repository, where a conventional risk analysis of normal and accident scenarios is foreseen.

Switzerland – generic safety case approved; safety case being developed for site selection

A concept level safety case was prepared by NAGRA in Switzerland and submitted to the regulator in 2002. This has since been accepted; details of the Swiss case are included in an accompanying document to the present overview. The geological disposal programme in Switzerland is now at a sensitive stage in which priorities are being set between potential siting regions. The selection process is intended to be based quite heavily on safety assessments. To accomplish this, it was necessary to develop GDF siting criteria and also a set of indicators that integrates more detailed information related to these criteria. The development of these indicators (including development of minimum and enhanced requirements, quantitative scales for evaluation of options, etc.) was based on safety considerations that included quantitative analyses. The NAGRA approach of prioritising potential siting regions on the basis of safety assessments or safety cases goes beyond the uses of safety cases made in other national programmes. The key question here is whether the methodology and the data used in the safety assessments produce results of high enough resolution and robustness to be convincing.

Belgium – host rock specific safety case being used to guide RD&D

Belgium is likely to develop its GDF in a relatively plastic clay formation such as the Boom Clay. Scientists at the disposal agency, ONDRAF, have been at the front in developing safety case methodology. The safety and feasibility strategy involves defining external boundary conditions to be met and the project-specific requirements to be satisfied. Boundary conditions include, for example, relevant international and national regulatory frameworks, institutional policy and conditions required by other stakeholders. The safety assessment methodology that has been developed (and which is also described in more detail in a companion note to this document) aims at a comprehensive and consistent treatment of uncertainties with the goal also of guiding future RD&D. The concept developed in Belgium of analysing multiple safety functions rather than simply the properties of safety barriers is now widely applied in national disposal programmes. The Belgian safety case rests on a series of safety and feasibility statements that must be backed up by appropriate evidence. ONDRAF claims that the introduction of safety and feasibility statements in the Belgian programme resulted in significant changes, especially in the RD&D programme.

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United Kingdom – generic safety case being used to assess GDF implementation options

The UK is developing a generic environmental safety case; it has not yet identified a GDF site, so does not have a preferred disposal concept, nor a preferred host rock. The experts involved acknowledge that the greatest challenge is considering how to perform analyses that are generic but nevertheless produce results that are suitable for deciding between a potentially wide range of options that could arise as the UK enters a siting consultation process with local communities. Given the range of open issues, the responsible organisation, NDA-RWM, is studying how best to communicate to the general public the meaning of the generic safety case and the contribution it can make to eventually narrowing in the range of options.

Netherlands – safety cases used to guide long-term R&D

The Netherlands has a far-future target date around 100 years hence for implementation of a national GDF, with the option of disposal in a shared international facility also being part of the official strategy. Nevertheless, the waste disposal organisation, COVRA, is in the early stages of developing a specific safety case for potential host geological formations and using it in an iterative fashion to guide their long-term R&D programme. Much use is made of collaborative work with their Belgian colleagues, using a similar GDF design concept, since the current phase of the Dutch work is focused on similar clay host rocks. At an earlier stage, the Netherlands also looked extensively at disposal options in salt domes.

5 Some key issues to consider in developing a GDF safety case

The international experience shows that there are various approaches to the use of safety cases and a number of different ways in which national programmes have interpreted and applied the advice given by the international organisations. These need to be considered by any organisation starting to develop a GDF programme. In this section we highlight some of the more important differences.

Scope and content of the safety case

As the safety case methodology has developed over the years, many safety case projects have focused only on the long-term safety of the GDF, since this is the aspect that has led to most public and political debate during the development of geological disposal concepts. Of course, safety cases for the licensing of facilities have to include the operational phase of the repository as well as the long-term safety. In projects nearing realisation, such as in Finland Sweden and France, significant additional effort may be required to develop the operational phase safety case to a similar level as the ‘post-closure’, long-term safety case. The conventional and radiological risks to workers and the public during repository operation can be of more immediate concern. Consequently, including operational safety from the outset is valuable.

The content of the safety case is also not universally agreed. For example, the IAEA standards and guidelines quoted above talk of “a safety case and an accompanying safety assessment”, whereas the NEA guidance diagram clearly includes the safety assessment as an integral part of the safety case. In practice, there is an observable trend for the safety case itself to be a component of a larger environmental impact statement, which looks at conventional hazards and risks, as well as the radiological issues normally addressed in many existing safety cases. For example, the current GDF construction license application in Sweden will be decided on the basis of a recommendation from the national Environmental Court, rather than only the nuclear regulatory authority.

Defining the safety case

There are various definitions of the term ‘safety case’ - none being universally accepted; none being prescriptive or complete. It is, therefore, important for the GDF implementer to state clearly at the outset which definition is being used. In particular, as a project nears implementation the definitions, especially the specification of how uncertainties are being treated, tend to become more extensive. It is also important that the implementer explains the specific purpose and context of the safety case. This can be done by documenting the following items:

- An outline of the programme, including overall goal, safety goals, programme structure and current status.
- An indication of which decision(s) are to be based on the safety case being presented (concept choice; siting; design change; licensing step).
- The stakeholders being addressed (implementer internally; regulator; public; politicians).
The safety case comprises the data and evidence, together with the collection of arguments showing that these give confidence in system safety; it is not simply the documentation as such, which can vary in style and extent. The numerical safety assessment is a central part of, but not all of the safety case. Safety assessment simply tries to quantify the safety level - the safety case, on the other hand shows that the system is safe using the assessment and other multiple lines of argument. There is only one safety case for a given facility or activity but there can be different ways to document or present this safety case depending on the audience.

**Safety assessment methodology**

Some advanced safety cases have developed an approach and terminology in the safety assessment part that is specific to one country. For example, the Belgian programme introduced the concept of ‘safety statements’ and ‘safety functions’. The Swiss programme introduced the concept of ‘reserve FEPS’. These are features events and processes that can be argued at a qualitative level to provide extra degrees of safety, but for which the current status of understanding or of data does not justify using them as part of the main safety analysis.

Another major difference in methodology is related to the use of probabilistic approaches. Some programmes, in particular the US programme that was focused on the Yucca Mountain GDF, rely heavily on probabilistic approaches, whereas other programmes rely most strongly on deterministic analyses carried through for a wide range of scenarios. Differences in regulatory standards can drive this, with some authorities basing their regulations on risk targets, others on radiation dose limits and some using both, plus non-radiological standards such as radionuclide release rates.

**Use of multiple lines of argument**

Safety cases need to be based upon multiple lines or argument to increase confidence in their findings. Multiple lines of argument are valuable because:

- They give ‘strength in depth’ by approaching the demonstration of safety in different ways (quantitative – qualitative; health based – performance based; comparative – illustrative).
- Different people find different arguments compelling, because the level of understanding varies between audiences and the level of belief in each line varies among different people.
- Different stakeholders want different things; the regulator requires quantitative dose or risk compliance data, although many regulations also require ‘supporting arguments’; the public is the key ‘user’ of a range of arguments and needs to feel comfortable that nothing will go wrong; the implementer needs to have sufficient confidence to invest the money in disposal rather than continued storage; the government wants to be able to reassure the public.

The main categories of ‘multiple lines’ of argument are:

- Supporting Evidence - evidence of similar behaviour from other sources at the same size and/or time scales - e.g. analogues: natural and archaeological.
- Supporting Arguments - safety can be provided in multiple, different (possibly independent) ways; other people do it the same way (precedent, good practice, tried & tested); competent, trustworthy people agree (peer review).
- Supporting Analyses - at different levels of detail; using different information; using different mathematical and software tools.

**Impact of disposal system safety concept on the preparation of a Safety Case**

The safety concept for a GDF will be determined by the geological environment in which the facility is to be sited and on the set of engineered barriers that is identified as being the most appropriate for this environment. For example, the Swedish concepts for disposal in relatively fractured rock with non-negligible ground water flows, leads to the choice of extremely corrosion resistant copper sheathed containers. The Swiss concept based on a highly impermeable clay host rock, where transport of corrosive elements or of released radionuclides can only be by very slow diffusion, can rely on simpler iron overpacks. A concept in rock salt might require no overpacks at all for the sealed waste containers. The chosen safety concept will then directly influence the production of the corresponding safety case. The relative importance of specific types of data will be different; e.g., in Sweden much effort is devoted to justifying the long container lifetime and to arguments that manufacturing defects will be sufficiently rare. In Switzerland, characterisation of the clay and understanding of its behaviour under mechanical and
thermal loading is of extreme importance. In a salt host-rock concept, the safety case will have to examine in more detail scenarios involving inadvertent drilling intrusion by people in the future or the unexpected influx of groundwater. The coupling between the choice of safety concept and the robustness of the safety case is so strong that it has been argued that the selection of engineered and natural safety barriers may be more strongly influence by the robustness of the safety case that can be developed than by the specific potential safety impact of a single barrier. This has led to a tendency in national waste management projects to avoid sophisticated concepts, such as multi-layer containers that contain different types of materials designed to capture specific radionuclides released from the waste materials.

**Documenting the Safety Case**

The documentation of a safety case comprises more than just the safety assessment report. Different documentation may be appropriate for different audiences. High-level documentation needs to include all the lines of supporting information; each ‘line’ can tell the safety case ‘story’ from a very different perspective – provided they are consistent and traceable. To do this, the implementer may need a wide range of public material:

- project technical reports
- scientific papers
- popular magazine items
- videos
- advertising in national media

When publishing its review, the regulator should explain how it is using the integrated lines of supporting information and how much weight is put on each.

**Confidence in the results of a safety case**

Demonstrating confidence in the outcome of a safety case is perhaps the most important issue in their preparation and review. The NEA approach is that the safety case should include a ‘statement of confidence’, but there is relatively little guidance about how this should be done. The level of confidence in the safety case will obviously change as the project proceeds. In the early stages (generic, site selection, etc.), there will be gaps in the available data that will directly impact upon the reliability of the calculated results of safety assessment. In fact, the international guidance recognises the existence of open issues and uncertainties, and requires perspectives to be given about how they can be addressed in the next steps.

One approach could be to identify clearly those data that are not yet sufficiently well defined, to document clearly the assumptions being made, to label the safety case based on these assumptions as a ‘conditional safety case’ and to specify the activities that have been undertaken to improve these key data. The IAEA safety guidance uses the expression ‘reasonable assurance’ to describe the level of confidence that the regulator and the public must eventually have in the safety case. This specific term has a long history of usage in the regulatory system of the USA and has proven useful, despite being vague.

6 Conclusion

There is today a developed, broadly accepted and already well-tested approach to incorporating safety cases in the development of a GDF programme. Today, it is the recognized state-of-the-art in GDF projects that planning and development should be structured around the iterative use of the safety case approach. The success of the approach is illustrated by the completion of construction licensing in some programmes, using safety case methodology. A major new GDF project thus has a strong foundation of experience upon which to build and should begin by considering how, when and in what form its initial safety case will be produced and with what audience in mind. At each milestone in the project, it is important that a safety case be prepared as a pre-requisite before proceeding to the subsequent phase. The prime purposes of each safety case are to give all stakeholders sufficient confidence to proceed further and to identify the key activities to be carried out in the next phase.