7. SAFETY CASE; THEME OVERVIEW

Iteratively quantify and demonstrate, the safety of the disposal system and inform strategic design decisions

The safety case is a critical tool for guiding programme development, integrating and synthesising information to build understanding to inform decisions at each stage of the repository development programme and to guide and prioritise R&D activities.

The safety case is a synthesis of the evidence, arguments and methods that demonstrate that a disposal facility will be safe: safe to construct, safe to operate and safe for people and the environment with no further maintenance once it has been sealed and closed. The safety case addresses the suitability of the site and facility design, the assessment of radiation risks and assurance of the adequacy and quality of all safety related work associated with the disposal facility. A formal definition of the safety case is given in IAEA SSG-23.

It is important when considering the strategy for developing the post-closure safety case to recognise that it is not necessary to predict the detailed evolution of the disposal facility, rather the aim is to build confidence that all credible evolutions of the facility will be safe. A safety case should provide robust arguments, including multiple lines of reasoning, to demonstrate the completeness of the evolutions considered and their safety.

Safety is defined by the national regulatory framework, which typically reflects international guidelines, such as those set by the IAEA.

KEYWORDS: Safety Case; Iterative Disposal System Development; Performance Assessment; Safety Integration; Safety Synthesis; Post-closure Performance; Environmental Safety; Long-term Safety

KEY ACRONYMS: Performance Assessment (PA), Safety Assessment (SA)

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Version: 1.0 ; 17 May 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n° 847593.

TYPICAL PROGRAMME MANAGEMENT GOALS PURSUED BY NATIONAL RWM PROGRAMMES

This section provides a goals breakdown structure (GBS) for the EURAD roadmap theme 7 on safety case. It is organised in a hierarchy of three levels according to theme > sub-themes > domains.

Theme (Level 1)	
7. Iteratively quantify and demonstrate, the safety of the disposal system and inform strategic design decisions (Safety Case)	
Sub-themes (Level 2)	**Domains (Level 3)**
7.1 Establish the safety fundamentals as a basis for the safety assessment (Safety strategy)	7.1.1 Establish the requirements that must be met to ensure the protection of people and the environment, both now and in the future (Safety requirements)
	7.1.2 Establish safety indicators to complement dose and risk, defined relative to overall safety requirements (Performance indicators)
7.2 Combine experimental and field data with scientific understanding and qualitative observations to construct models of the possible future behaviour of the disposal system (Integration of safety related information)	7.2.1 Maintain and develop a synthesis of all available information relevant to facility safety, required for regulatory compliance, and to guide forward disposal programme activities (Safety case production)
	7.2.2 Establish a system and adopt international good practice for information, data and knowledge management, modelling, transfer, and preservation (Information, Data, and Knowledge management)
7.3 Assess radiation risks and assure adequacy and quality of all the safety related work associated with the facility or activity (Safety Assessment and Tools)	7.3.1 Quantify how the facility and its components behave and evolve to provide continuing safety (Performance assessment and system models)
	7.3.2 Characterise uncertainties and determine their implications for the outcome of the safety assessment (Treatment of uncertainty)
	7.3.3 Evaluate post-closure features, events and processes relevant to safety to create plausible scenarios of disposal system behaviour (Scenario development and FEP analysis)

RECOMMENDED SAFETY CASE ACTIONS OVER PHASES OF IMPLEMENTATION

The National Programme (see Theme 1) involves identifying those wastes that require geological disposal and selecting an appropriate disposal concept for those wastes. The selection of a suitable site for the disposal facility is discussed in Theme 6 and the design and optimisation of the disposal facility is the subject of Theme 5, requiring an engineered barrier system (see Theme 3) tailored to the waste characteristics and compatible with the geological characteristics and evolution of the site (see Theme 4). The development of the safety case will occur alongside these activities, both using information from the waste characteristics, the concept, design and siting activities and supplying information to them. Thus, the safety case is developed iteratively throughout the disposal facility programme.

In the early phases (Phase 1 and into Phase 2), the safety case will be generic. It may be based on illustrative concept designs and illustrative generic data or it may use example data from a specific site or sites. The R&D programme may also be largely generic. The aim at this early stage is to establish the safety case framework, demonstrate the feasibility of disposal of the national waste inventory in available national geological settings and begin to identify the required information from the R&D programme and the uncertainties that will need to be resolved as the safety case develops.

Once site-specific data become available (Phase 3 onwards), these enable the safety case to become increasingly representative of the site(s) under consideration. The facility design may also be updated to reflect site conditions. In an iterative process, the safety case is used to inform the ongoing R&D and Siting programmes, such that identified uncertainties are resolved or mitigated as the safety case is developed. The safety case is the framework through which understanding of the disposal system and its evolution is developed, impacts of uncertainties are assessed and the disposal facility design is optimised. The safety case will also be used in communication with stakeholders, including regulatory authorities and local communities and will underpin decision-making throughout the disposal facility development programme.

Programme Initiation (Phase 1)

Programme Implementation (integrated actions in theme 7 on safety case linked to activities in other themes)

- The WMO should apply a system engineering approach, involving the use of a requirements management system (RMS) linked to a work breakdown structure (WBS), to identify and organise activities, ensuring the timely delivery of outputs against project milestones (See, 1.1.1 Timetable for decision making).
- Regulators should start developing applicable regulatory requirements in accordance with well-accepted international bases and initiate interactions with the WMO (See, 6.3 Licensing).
- The WMO should identify and put in place plans to develop the critical competences required for delivering the safety case (see ‘Available Capabilities’ section below).

Safety strategy

The safety strategy addresses the strategies for: siting and design; management; and assessment. A robust safety strategy includes multiple safety functions and a defence-in-depth approach in terms of the features and functions of the disposal concept and design. A clear management strategy for the development of the safety case establishes generic procedures for the management of data and assurance of quality throughout the development of the safety case. A generic safety assessment strategy is developed by considering the safety functions of the selected disposal concept (see Theme 1), considering how these safety functions will evolve over time and identifying relevant performance indicators. Generic scenarios for the evolution of the disposal system can be developed by considering the safety functions and the features, events and processes (FEPs) that may affect them over time. The safety assessment strategy should also consider the timescale to be addressed in the safety case, in relation to the properties of the disposal inventory (by reference to half-lives) and by reference to appropriate safety arguments.

At this early stage, it is important to maintain flexibility in the safety assessment strategy, allowing for continual developments and refinements in subsequent phases as the disposal concept is developed into a more detailed system design.

Integration of safety related information

Develop management procedures for the recording and storing of relevant data (including its provenance, quality and scope of validity). Establish procedures for the development, testing and validation of models. Thus, ensure appropriate quality control of all data and models to be used in the safety case throughout its development. Develop / commission appropriate databases for storing all data and associated meta-data. Develop generic conceptual models for the long-term evolution of the disposal concept, including the engineered system (waste-form, containers and buffer / backfill), geological environment and biosphere.

Safety Assessment and Tools

Develop generic reference case scenarios for the expected evolution of all components of the disposal system. Identify FEPs (for example by reference to the NEA International FEP database) that could challenge the safety functions of the disposal concept and hence identify potential credible variations to the reference case. Develop a generic total system model that represents the generic conceptual models for the engineered system, geosphere and biosphere and their evolution, for at least the reference case scenario, aim to represent uncertainties (for example by expert quantification) in this model. Use this model to scope potential post-closure impacts and conduct generic radionuclide screening analyses to determine those radionuclides most significant to the post-closure safety case. Perform preliminary safety analyses to demonstrate the feasibility of safe disposal based on the generic concepts and sites. Analytic "insight" models, even if simplified, may also be helpful for performing preliminary safety analyses, exploring the impacts of potential variant scenarios and identifying any potential mitigations (e.g. design requirements) to bring potential scenarios within the regulatory safety envelope.

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NEA (2002). Establishing and Communicating Confidence in the Safety of Deep Geological Disposal: Approaches and Arguments, ISBN 92-64-09782-1, OECD-NEA 2002. https://www.oecd-ilibrary.org/nuclear-energy/establishing-and-communicating-confidence-in-the-safety-of-deep-geologic-disposal_9789264094451-en-fr

Geological Disposal: Generic Environmental Safety Case – Main Report, NDA Report no. DSSC/203/01, ISBN 978-1-84029-542-9, NDA 2016. https://rwm.nda.gov.uk/publication/geological-disposal-generic-environmental-safety-case-main-report/

Site identification and selection for a DGR (Phase 2)

Programme Implementation (integrated actions in theme 7 on safety case linked to activities in other themes)

- The WMO should update the RMS based on the knowledge gained from the initial assessment of key Design and Safety aspects from Phase 1 (See, 5.1.1 Design Specification).
- In dialogue with the regulatory bodies and other agencies, the WMO should clarify the legal requirements, including security, safeguards, occupational, safety, health and environmental regulations, that are involved in these different steps (See, 5.3.1 Safeguards, 5.3.2 Security and Physical Protection, 5.4 Operational Safety, 6.3.2 Regulatory licensing).
- Continue the dialogue with other relevant stakeholders to explore their concerns and to solicit their input to the site and repository concept selection process (See, 6.3.1 Stakeholder Involvement).

Safety strategy

The generic safety strategy developed at Phase 1 needs to provide a transparent framework for the identification and selection of suitable sites, including being clear about what is expected from a suitable site. The generic safety strategy should be clearly and consistently applied to give confidence and legitimacy to the site selection process. For each site under consideration, the basis for an appropriate disposal facility conceptual design should be presented, explaining how it will provide containment and isolation of the wastes, the role of multiple safety functions and the robustness of the design to relevant environmental factors.

Integration of safety related information

All information used in the site selection decision-making process needs to be clearly identified and accessible. Databases established for this purpose in Phase 1 will be invaluable. Supporting meta-data will assist in addressing any challenge to data provenance, reliability, or relevance. A particular challenge of this phase is the management of geo-scientific information and its integration into the developing safety case. This requires developing a conceptual site descriptive model of the proposed disposal system and its evolution. This site descriptive model should include the evolution of the host rock and surrounding geological environment (including the biosphere) and the evolution of the engineered barriers within this setting.

Safety Assessment and Tools

At this phase there will not yet be sufficient site-specific information for a detailed safety analysis. However, understanding of the site descriptive model will enable identification of the relevant FEPs for the disposal concept and its geological setting. For each site/disposal system under consideration, define the disposal system safety functions that work to isolate and contain the waste inventory (see 'Safety Strategy' above); and hence consider the interaction of relevant FEPs on the safety functions for each disposal system component. From this analysis, identify a reference case or base scenario for the expected system evolution. It is helpful for the base scenario to be as broadly-based as possible, encompassing all likely system evolutions. Assess the base scenario, perhaps using analytic "insight" models or generic total system models populated with available site data, taking account of parameter uncertainties, to demonstrate the extent to which the base scenario meets the national safety standards. Consider credible variant scenarios (uncertainties in system evolution) that may have the potential to challenge the safety envelope of the base scenario and identify what may be required to achieve acceptable safety in these situations: for example, what uncertainties would need to be resolved, what design changes could be used in mitigation and/or what siting constraints may be required. This analysis may be largely qualitative at this stage but should be sufficient to enable a fair comparison between sites/disposal concepts.

References:

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Nagra (2005). Opalinus Clay Project, Demonstration of feasibility of disposal ("Entsorgungsnachweis") for spent fuel, vitrified high-level waste and long-lived intermediate-level waste, Summary Overview, Nagra 2005. https://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/Broschueren%20Themenhefte/e_bro_proj_opa.pdf

COVRA (2017). Summary of the OPERA Safety Case, Covra, 20 December 2017. (https://www.covra.nl/app/uploads/2019/08/Opera-SafetyCase-samenvatting.pdf

Site characterisation (Phase 3)

Programme Implementation (integrated actions in theme 7 on safety case linked to activities in other themes)

- WMO updates the RMS for the DGR, based on the knowledge gained from the assessment of key Design and Safety aspects from Phase 2 (See, 5.1.1 Design specification).
- WMO to develop repository designs adapted to the site(s) (See, 5 Design).
- Waste producers and WMO to confirm agreed approach to pre-disposal management of wastes to ensure eventual disposability in the emerging DGR design (see, 2.1.2 waste acceptance criteria).

Safety strategy

The preliminary safety analysis used as the basis for site selection will guide the safety strategy for site characterisation by identifying the significant uncertainties that need to be resolved during site characterisation. The safety strategy sets out the requirements for a construction licence application in terms of the required safety functions of the engineered and geological barriers, the safety arguments, analyses, and evidence to support these safety functions and the robustness of the system to all credible evolution scenarios. The safety strategy should also explain the design optimisation process.

Integration of safety related information

As site characterisation progresses there will be iterative developments and refinements to the site descriptive model as more site data are gathered. All data should be accessible through the relevant databases and enhancements to these databases may be required. As site understanding develops, refine the design of the engineered barriers as part of an iterative safety assessment process, that will continue and be refined throughout subsequent phases, to demonstrate optimisation of design prior to licensing submission.

Safety Assessment and Tools

Iteratively develop site-specific models for post-closure safety analysis that reflect the updates to the site descriptive model and R&D inputs on the understanding of the thermal, hydrogeological, mechanical and chemical processes that control the safety functions of the engineered barriers and their interaction with the geological environment. Different models will be appropriate for different repository environments; but are likely to include 3-dimensional models for hydrogeology and radionuclide transport, that address groundwater chemistry, including saline intrusion where appropriate and models of the engineered barriers and their evolution within the geological setting. Models on different scales may be required: for example, detailed process models (such as sorption of radionuclides on specific rock types) feeding into regional scale hydrogeology models, which underpin a top-level total system model, in which remaining uncertainties are explicitly represented, in order to calculate safety performance. Use emerging site-specific data to calibrate the regional scale models and determine appropriate boundary conditions. In the latter stages of site characterisation these models can be used to predict the results from successive site investigation phases and thus build confidence in site understanding until there is sufficient confidence to proceed to a construction licence submission.

References:

SKB (2011). Long-term safety for the final repository for spent nuclear fuel at Forsmark, Main report of the SR-Site project, Volume I, Technical Report TR-11-01, Svensk Kärnbränslehantering AB, March 2011. https://www.skb.se/publikation/2345580/TR-11-01_vol1.pdf

Construction (Phase 4)

Programme Implementation (integrated actions in theme 7 on safety case linked to activities in other themes)

- WMO to carry out the DGR construction and prepare for repository operation, including any test and demonstration activities considered necessary.
- WMO to update the RMS for the DGR based on the knowledge gained from the assessment of key Design and Safety aspects from Phase 3 (See, 5.1.1 Design specification).
- Finalise repository design, including the engineered barrier and waste emplacement systems, and further adapt it to the site conditions found as construction progresses. This further design development would be especially important if the repository operational phase includes further construction of the repository (See, 5 Design).
- WMO and regulatory agencies to agree and WMO to implement the underground monitoring programme, see Phase 3, and further update it to cover monitoring needs during the operational phase (See, 5.1.1 Baseline Monitoring, 5.5.2 Monitoring during construction and operations).

Safety strategy

The safety strategy should confirm how the as-built repository design and its geological setting will provide the necessary safety functions to isolate and contain the disposal inventory for a sufficient period of time. This timescale should now be justified in terms of the properties of the disposal inventory (by reference to half-lives), the understanding of the system evolution and by reference to appropriate safety arguments (such as comparison with natural analogues) for the very distant future. Any remaining uncertainties should be identified with an appropriate strategy for their management or mitigation. A robust safety strategy to support repository operations should justify the repository design and provide multiple safety arguments supported by strong evidence to address all outstanding uncertainties. There should also be a clear management strategy, based on the safety case, to control all activities in particular waste handling, during repository operations (See Theme 5).

Integration of safety related information

Further data will be obtained as construction proceeds and this must be recorded in the programme database and relevant archives. As underground excavations proceed, ensure that the site descriptive model is updated to reflect any new information and understanding of the site and its expected evolution. Further design optimisation in the light of any new understanding may be appropriate, or confirmation of the design in the light of excavation data. Provide a detailed disposal inventory analysis (see Theme 1) and ensure transparent and accessible documentation of the safety arguments and evidence to support the safety claims for the isolation and containment of the disposal inventory.

Safety Assessment and Tools

Undertake further refinement of the safety assessment models in the light of any changes to the site descriptive model or disposal facility design and any new R&D results or regulatory changes. Perform detailed safety assessment of the base scenario for the agreed disposal inventory and demonstrate robustness of the disposal system to all credible variant scenarios, to support a licence submission for repository operation.

References:

US DoE (1996). The Waste Isolation Pilot Plant (WIPP) Compliance Certification Application (CCA), U.S. Department of Energy, 1996. **https://www.wipp.energy.gov/library/cra/CRA-2014/References/CCA/CCA.htm**

Operations & Closure (Phase 5)

Programme Implementation (integrated actions in theme 7 on safety case linked to activities in other themes)

- WMO to carry out the DGR operation including deposition activities and further underground construction in a quality-controlled manner (See, 5.2 Constructability, demonstration and verification testing).
- WMO to update the RMS on a regular basis considering experiences from the operation and repeated safety assessments (See, 5.1.1 Design specification).
- WMO to revise repository design specifications, based on updates to the RMS, if judged necessary or beneficial (See, 5.1 Design).

- Regulatory agencies to review and agree proposals from WMO for closure and any post-closure actions, and issue closure license (See, 6 Siting and Licensing).

Safety strategy

A clear and approved safety strategy should explain how repository operations, including any parallel construction and waste emplacement activities will be conducted. The safety strategy should include monitoring requirements and the requirements and appropriate procedures and actions for incident reporting. The safety strategy for repository closure must explain how the facility will remain passively safe without reliance on further human intervention or control. Once closed and sealed it is likely that the disposal facility will enter a period of institutional control, where the site is still licensed and site access controlled (thus preventing any human intrusion, for example). Eventually there may be a final licence submission to terminate licensing, which will need to justify the safety of relinquishing control on the site in terms of support for ongoing passive safety and mitigation of any risk from inadvertent human intrusion into the disposal facility in terms of records management (hence the importance of local and national archives for repository information), inaccessibility of the wastes and radioactive decay arguments.

Integration of safety related information

Throughout repository operations and closure any deviation from the approved safety strategy (for example, inability to emplace sufficient backfill/buffer material) should be recorded and its impact assessed. Maintain programme databases and archives and update with all new information, including monitoring results (e.g., of in situ waste package evolution). Ensure excellent communication with all stakeholders and swift and easy access to all safety-related information, particularly should any unintended incident occur. Ensure all repository information is appropriately archived, including key information files of accessible safety-related information in local and national archives.

Safety Assessment and Tools

Maintain the detailed safety assessment, updating to reflect any changes to disposal inventory, waste emplacement conditions or other potential deviations to the initial state for post-closure. Several safety assessments are likely to be required throughout this phase, reflecting that in reality construction is likely to proceed in parallel with waste emplacement. Prepare a detailed, as-built safety assessment to support a licence application for repository closure.

References:

NEA (2020). Nuclear Power Plant Operating Experience from the IAEA/NEA Incident Reporting System 2015-2017. https://www.oecd-nea.org/jcms/pl_53449/nuclear-power-plant-operating-experience-from-the-iaea/nea-incident-reporting-system-2015-2017

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AVAILABLE CAPABILITIES: STATUS AND OUTLOOK

This section describes programme capability needs (including infrastructure) that are required to successfully complete the activities and actions recommended to achieve the generic safety case goals.

Knowledge and understanding

National organisations responsible for implementation should develop and maintain the in-house capability to:

- Identify and understand the relevant uncertainties that could affect the long-term safety of a disposal facility.
- Identify and understand all FEPs relevant to the disposal system (waste characteristics, engineered barriers, geological environment, and biosphere evolution).
- Understand the safety functions associated with relevant disposal system components and how they may evolve over time.
- Analyse FEP-safety function interactions to understand disposal system evolution.
- Define a base scenario to encompass the expected evolution of the disposal system.
- Identify potential variant scenarios (outside the base scenario) that could challenge the safety envelope.
- Undertake simplified, analytical "insight" modelling to understand the significance of relevant processes and gain a broad-brush understanding of safety performance.
- Identify the need for, commission and review research to fill knowledge gaps to support the safety case – ability to extract relevant understanding from research.
- Commission, review (and ideally run and manipulate) large-scale component models, e.g., for hydrogeology and radionuclide transport.
- Understand the total system model, including all relevant uncertainties, for the disposal facility – this is best achieved if the total system model is constructed in-house. The ability to understand and interrogate the total system model and hence to understand the impact of uncertainties, prioritise R&D activities, demonstrate design optimisation etc, lies at the heart of understanding and "owning" the safety case, which is an essential in-house prerequisite for any licensing submission.
- Communicate the safety case to regulators and other stakeholders – external assistance in writing parts of the safety case is acceptable, but safety case ownership requires the ability to understand and communicate the safety arguments to all stakeholders.

For an early-stage national programme with limited resources, the priority is to develop an in-house understanding of all the factors, particularly those that have uncertainties, that could affect the long-term safety of a disposal facility. This understanding is best formulated in terms of the framework of FEPs and safety functions and their interactions. There is much international collaboration on generic methodologies and by gaining an understanding of these approaches, new staff can apply them to their national situation. A thorough understanding of what actually matters in terms of safety is essential for commissioning appropriate work to assist in developing the safety case. This can be summarised as "total system understanding".

It often takes most of a career to develop the necessary level of understanding across the required breadth of disciplines to gain the knowledge to author and own a detailed safety case. It is important that younger staff have an appropriate career path to develop these technical skills and that acquiring this level of technical skill is appropriately valued in organisations. There seems to be an unfortunate trend for technical staff to be promoted into project management roles in order to achieve career progression, thus putting this critical "total system understanding" knowledge at risk.

As national programmes mature and become focused on delivering their own programme needs there is increasing pressure on these safety case experts to reduce their involvement in international work, which can be detrimental to ongoing knowledge development as well as knowledge transfer between programmes.

Additionally, many staff with this experience will be retiring within the next ~10 years.

Experts and practical skills

Key capabilities that are accessible from the open market, via third parties, contractors or via technology transfer from other programmes include:

- Waste container design and manufacture.
- Design of engineered barriers, including buffer / backfill formulation.
- Construction and implementation technology.
- All site characterisation activities.
- All research activities, including development of 'process' models, such as sorption and corrosion models.
- Development of databases for handling large and diverse data sets, including all relevant meta-data (provenance, quality assurance, limitations on use etc).
- Development of regional-scale hydrogeological and radionuclide transport models.
- Aspects of safety case production – noting that overall authorship / ownership must reside with the developer.

Regarding existing or emerging skill shortages in the safety case theme, enhanced knowledge transfer from advanced to less advanced programmes on performance assessment and system models would be beneficial. Additionally, ongoing networking should continue for treatment of uncertainty, e.g., EC UMAN project, as yet there is no clear internationally agreed approach.

Laboratories and centres of excellence

The NEA's Integration Group for the Safety Case (IGSC) provides a forum for technical generalists with sufficient knowledge and experience to have a holistic overview of the safety case to develop and exchange their ideas thus creating and sustaining a community in this critical knowledge area.

End of document.