Managing integration of pre-closure activities and post-closure safety in the Safety Case for Geological Disposal

C-40 (May 13)

FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." This includes addressing the management of radioactive waste generated through the use of atomic energy.

Disposal in a geological repository is the generally accepted method for the long term management of high level and long-lived radioactive waste. It also represents the most developed option and is being implemented in several Member States in line with the general principles defined in the IAEA Safety Fundamentals.

The role of the safety case to demonstrate and communicate the safety of geological disposal is a central tenet of IAEA Safety Standards and IAEA has produced a wealth of documentation including Specific Safety Requirements and Specific Safety Guides to assist those organizations wishing to implement geological disposal.

This TECDOC has been produced by representatives from regulatory and implementing organizations from those Member States with the most advanced programs for implementing geological disposal. Its objective is to set out a methodology that the operator can use to give assurance that construction and operation of a geological disposal facility will deliver the post-closure safety performance that is claimed within the safety case.

The ideas and concepts described in this TECDOC were generated by the GEOSAF II project which had wide representation from many Member States. The publication was presented to, reviewed by and accepted by participants at a plenary meeting held between 26 and 29 May 2015.

The IAEA wishes to thank all those involved in the preparation and review of this publication. Special mention is due to B. Hedberg (Sweden), M. Tichauer (France), J. Heinonen (Finland), J. Mertens (Belgium), S. Barlow (UK), and S. Nguyen (Canada) for finalizing the publication. The IAEA officers responsible for this publication were G. Bruno, Y. Kumano and A. Guskov of the Division of Radiation, Transport and Waste Safety.

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SUMMARY

The life cycle for most nuclear facilities, such as nuclear power reactors, processing facilities and storage facilities, consists of four phases running in sequence, i.e. design, construction, operation and decommissioning. Safety concerns are mainly focused on the operational phase, i.e. when nuclear material or waste arises. Such facilities are generally constructed above ground and specific design constraints can be identified and addressed early in the design stage.

Development and implementation of a geological disposal facility on the other hand has characteristics that are very different; the geological environment is likely to play an important role for post-closure safety as are the engineered barriers that are delivered during construction and operations. Safety in the long term (what in this publication we refer to as ‘post-closure’) will in fact be provided by the ensemble of activities undertaken during the pre-closure phase. It is the role of the *safety case* to draw together all of the safety arguments and demonstrate and communicate why the operator of the facility has confidence that safety in the long term will be ensured.

From the early beginning, it is of utmost importance that the requirements to be fulfilled in order to assure post-closure safety and (conventional and nuclear) operational safety of the disposal facility are identified and taken into due account. They will have to be taken forward, and when needed further detailed, throughout the development and implementation of the disposal facility, i.e. during conceptualisation, siting, design, construction, operation and closure.

This TECDOC sets out a process that the operator of such a facility can use to give assurance that construction and operation of a geological disposal facility will deliver the post-closure safety performance that is claimed within the safety case.

The process starts at the conceptualisation stage when the operator (or the operator to be) defines a Design Target and a Safety envelope for the state of the disposal system at closure; these specify respectively what the disposal system *is designed* to achieve and what *it must* achieve.

The concept of Design Target can then be used throughout the pre-closure phase (considered to include site characterization, construction, operations and the eventual closure period) to monitor key safety parameters and determine whether the safety case remains “on target” to achieve the performance as planned at the outset. A process for tracking trends and deviations from the target is proposed and guidance offered on the means for taking corrective actions to bring the As-built State of the disposal system “back on track” and/or if appropriate, revision to the Design Target.

The need for and role of the management system within the context of the safety case is explored. It is advised that the operator establishes an integrated management system as an early activity, and that this include systems to record and manage system requirements so as to be able to keep track of the development of refined and/or revised requirements.

1. INTRODUCTION

1.1. BACKGROUND

Throughout the last decade, the International Atomic Energy Agency (IAEA) has convened a number of international inter-comparison and harmonization projects on the safety of radioactive waste management; in particular on the issues related to safety assessment carried out in support of safety demonstration for radioactive waste management facilities and decommissioning projects. These include the projects such as:

- Practical Illustration and Use of the safety case Concept in the Management of Near Surface Disposal (PRISM);
- Evaluation and Demonstration of Safety during Decommissioning of Nuclear Facilities (DeSa);
- Safety Assessment Driven Radioactive Waste Management Solutions (SADRWMS); and
- Environmental Modelling for Radiation Safety (EMRAS).

In the field of geological disposal of radioactive waste, the GEOSAF project on the demonstration of safety of geological disposal was conducted between 2008 and 2011.

During the course of the GEOSAF project, the need to provide more guidance and harmonization at the international level on operational safety for geological disposal was identified. At the request of the participating Member States, GEOSAF addressed operational safety under the form of a pilot study, and produced a companion report on that topic. At the end of GEOSAF, on the basis of the pilot study on operational safety, it was found to be appropriate to pursue working on the development of a safety case for geological disposal, giving a higher focus on the relationship between pre-closure activities and post-closure safety.

The follow-up project, GEOSAF II, was initiated with the objective to reach a common understanding of views and expectations regarding operational safety for geological disposal of radioactive waste and the implications of pre-closure activities on post-closure safety.

This Technical Document (TECDOC) forms one of the outcomes of the GEOSAF II Project.

1.2. CONTEXT

1.2.1. Challenges in managing high level and intermediate level radioactive waste

High level and long-lived intermediate level radioactive wastes have been at the centre of major concerns because of the risk they pose now and in the long term for human beings and the environment. In fact, safe disposal has been seen over the years as one of the major challenges faced by the nuclear industry, disposal facility operators, regulatory bodies and society in general. Ensuring that such waste disposal facilities can be safe during operation and then hundreds of thousands years after their closure has been a major focus for IAEA and has led to the development of a comprehensive suite of safety standards and supporting materials.

Following decades of research and development on the safe disposal of radioactive waste, the IAEA has set safety standards for geological disposal facilities. Geological disposal facilities are underground disposal facilities designed to:

(i) Allow the transfer and emplacement of high and intermediate level radioactive waste during their operational phase; and,

(ii) Provide long term containment and isolation of the waste so that releases would not harm people and the environment should they occur.

Among these standards, IAEA Safety Standards Series SSR-5 [1] "sets out the safety objective and criteria for the protection of people and the environment against radiation risks arising from disposal facilities for radioactive waste in operation and after closure. In order to meet the criteria, measures may need to be taken in site selection and evaluation and in the design, construction, operation and closure of the disposal facility." (IAEA SSR-5, paragraph 1.4).

The IAEA SSR-5 also emphasises that the primary goal of a geological disposal facility is to provide an optimized level of protection [(IAEA SSR-5, paragraph 2.15)] for a very long period of time after its closure by using passive means [(IAEA SSR-5, requirement 5)], and that these means are provided by multiple safety functions, delivered by a number of physical (natural and engineered) barriers [(IAEA SSR-5, requirement 7)] that contain and isolate the waste after closure.

The barriers typically consist of the waste forms, the packaging, the sealing materials (buffer, backfill, shaft seals, drift seals, etc.) and finally the host rock and any overlying geological sequences. Each of these barriers possesses a set of safety functions that can complement other barriers to achieve the primary goal of post-closure safety.

According to (SSR-5 paragraph 3.35) "A safety function may be provided by means of a physical or chemical property or process that contributes to containment and isolation, such as: impermeability to water; limited corrosion, dissolution, leach rate and solubility, retention of radionuclides and retardation radionuclide migration."

For example, in many disposal concepts, the important safety functions of the buffer are to provide structural support to the waste package, to reduce its corrosion potential and to dissipate the heat generated from the wastes to the near-field host rock. In addition, in case of a breach of the package, another important function of the buffer is to retard the movement of radionuclides if they are released.

Although a disposal system is primarily designed and built to deliver safety functions required for the post-closure phase, the system must also provide the safety functions identified as necessary to assure safety during the operational phase (which also includes closure activities). Though safety functions can be delivered by a number of active (before closure) or passive structures, systems and components (SSCs), passive safety features are sought in the post-closure phase. Therefore, it is important that a geological disposal facility is designed, built and operated such as to provide for safe operations during the pre-closure phase.

1.2.2. Characteristics of geological disposal facilities

The life cycle for most nuclear facilities, such as nuclear power reactors, processing facilities and storage facilities, consists of four phases running in sequence, i.e. design, construction, operation and decommissioning. Safety concerns are mainly focused on the operational phase, i.e. when nuclear material or waste arises. Such facilities are generally constructed above ground and specific design constraints can be identified and addressed early in the design stage.

A geological disposal facility on the other hand has specific features that require particular attention, such as:

- It is an underground facility where the geological setting plays a significant role for post-closure safety of the whole disposal system, therefore where great importance is placed on the siting of the facility and on the safety performance of the geological barrier.

- It is a facility with tunnels, limited spaces and a limited number of access routes.

- It is a facility that may be constructed and operated for decades, considering the time needed to build the shafts, ramps and tunnels, emplacement cells and the engineered barriers, emplace the waste and eventually close the facility. This implies a need for consideration of robust records management and measures for facility memory keeping.

- It is a facility where civil engineering works (excavation and equipment installation) and nuclear activities (waste package handling, transfer and emplacement) may occur in parallel (so-called “co-activity”).

1.3. OBJECTIVE

The objective of this document is to present a process for assuring that construction and operation of a geological disposal facility will deliver the expected post-closure safety functions and a structured method for the integration of this process within the safety case.

This document is primarily aimed at those organizations that are engaged in the implementation of geological disposal. These organizations may be termed developers in the early stages of the project and later become operators of a facility: in this document we simply refer to them as operators or the operator.

1.4. SCOPE

This document deals with integration and management of pre-closure operational and post-closure safety requirements in an integrated safety case for geological disposal of radioactive waste.

This document addresses:

- The link between pre-closure activities and post-closure safety and the necessity to address them in an integrated safety case;

- A methodology to manage post-closure safety functions by translating them into quantifiable functional requirements governing construction and operation activities; and

- The need to demonstrate integration of pre-closure activities with post-closure safety and a methodology to manage deviations throughout the construction and operational phase of the disposal facility.

In subsequent chapters, all activities carried out until the disposal facility has been closed are covered by the "pre-closure" phase (pre-operational and operational phase) as indicated in Figure 1.

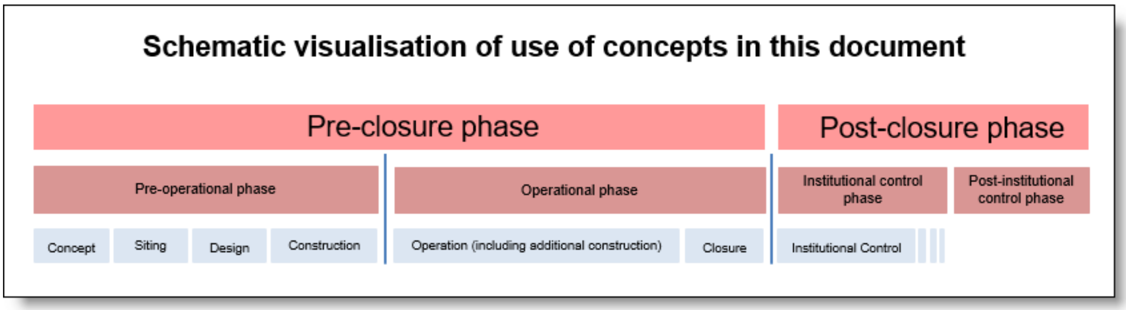


FIG. 1. Visualization of different phases in a geological disposal facility project.

This document does not address the content or scope of the safety case as guidance on these is available elsewhere. It rather indicates key aspects to be addressed during the pre-closure phase to ensure that the post-closure safety objectives as defined can be met.

Although the approach might be applicable also for other types of disposal facilities, this publication is developed specifically for geological disposal facilities for high level and/or intermediate level radioactive waste.

1.5. STRUCTURE

Section 2 of this document highlights the value of an integrated safety case for both pre-closure and post-closure phases. Section 3 presents an approach to understand the link between post-closure safety functions and operational activities. It provides a conceptual view on the concepts of Safety envelope, Design Target and As-built State which should inform the safety arguments presented within the safety case. Section 4 describes a conceptual method for compliance control (e.g. monitoring, management systems and uncertainty management) by taking into account the relationships between pre-closure activities and post-closure safety. Section 5 discusses a process for managing deviations.

2. INTEGRATION OF PRE-CLOSURE AND POST-CLOSURE SAFETY IN THE SAFETY CASE

2.1. THE SAFETY CASE

The concept of the safety case has been IAEA's cornerstone to demonstrate and communicate the safety of a nuclear facility, and this approach is also applicable for geological disposal facilities (see e.g. IAEA SSR-5 [1], SSG-23 [2], SSG-14 [3]). Numerous international harmonization projects have shaped and refined the safety case concept and its review and evaluation by regulatory bodies and technical support organizations. Although the definition of the safety case might vary between different national regulatory frameworks, the common underlying feature is the use of multiple lines of reasoning and arguments to demonstrate safety.

The IAEA (SSG-23, paragraph 1.3) defines the safety case as: "the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal facility, covering the suitability of the site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the safety related work associated with the disposal facility".

As accounted for in section 1.2.1, safety has to be provided by means of multiple safety functions. These safety functions will be provided by waste packages as well as engineered and natural barriers. Therefore pre-closure activities (siting, construction and operation, including closure), participate in delivering the required post-closure safety functions.

An overall safety case embracing all timeframes of the evolution of geological disposal facilities is a key factor for ensuring the success of such a project. A particular challenge to be addressed in the process to implement geological disposal for radioactive waste is to ensure compatibility between pre-closure activities (including those associated to operational safety) and post-closure safety.

At the time of closure of the disposal facility, the operator will have to make a final demonstration that pre-closure activities have delivered the required post-closure safety functions. This means that the operator will have to demonstrate that the safety case provides the necessary level of confidence that the facility and the geological setting will deliver the required level of protection to humans and the environment.

2.2. THE STEPWISE EVOLUTION OF THE SAFETY CASE

The scope of a safety case for a geological disposal facility is defined in requirement 13 of SSR-5, which states that it “shall describe all safety relevant aspects of the site, the design of the facility and the managerial control measures and regulatory controls. The safety case and supporting safety assessment shall demonstrate the level of protection of people and the environment provided and shall provide assurance to the regulatory body and other interested parties that safety requirements will be met.”

The IAEA Specific Safety Guide SSG-23 further develops the concept of the safety case and its supporting safety assessment. Although SSG-23 focuses mostly on post-closure safety, it identifies management systems and operational aspects as an important component of the safety case and the safety assessment (see paragraph 4.4 and Figure 3 and 4 of SSG-23). In the same way, SSR-5 identifies the importance of operational safety and specifies in its paragraph 4.15 that “The safety case for a disposal facility has to address safety both in operation and after closure.” It further states that “All aspects of operation relevant to safety are considered, including surface and underground excavation, construction and mining work, waste emplacement, and backfilling, sealing and closing operations.”.

Requirement 11 of SSR-5 identifies and recognizes the step by step development and evaluation of the disposal facilities, specifically stating that “Each of these steps shall be supported, as necessary, by iterative evaluations of the site, of the options for design, construction, operation and management, and of the performance and safety of the disposal system.”. SSG-23 identifies that the development of the safety case (thus its level of detail) is likely to be the outcome of an iterative process that evolves with the development and operation of the facility.

The exact steps that are taken in the process depend on national practices (see Annex 3 of the final report from the first GEOSAF project). Nonetheless, some main stages that can be found in Member State implementation programs concern the following stages (see Figure 1 above):

- Concept development;
- Site investigation and selection;
- Design development;
- Construction;
- Operation;
- Closure;
- Post-closure.

During the pre-closure phase, collected data, lessons learnt from operational experience and results from research and development will feed into the iterative development of the safety case.

2.3. THE INTEGRATED SAFETY CASE

The need for assurance of operational (nuclear or conventional) safety and radiation protection during the operational phase will require specific measures and these will influence the design and layout of the facility to some extent.

Given the goal of the pre-closure phase and the inherent linkage between pre-closure activities and post-closure safety underlined in the previous section, it is necessary to integrate pre-closure and post-closure aspects in the safety case right from the early stages of development of geological disposal facilities. In this sense, an integrated safety case is needed to ensure that a geological disposal facility can be designed, built, operated and eventually closed in a safe way, taking into account both operational and post-closure safety.

The demonstration of post-closure safety during the course of the pre-closure phase therefore relies on the assumption, supported by safety arguments, that the final configuration of a disposal facility, when it has been closed, conforms to arguments made in the safety case (as that is the starting point of the post-closure safety assessment). However the exact state of the facility will only be known with a significant level of confidence at the time of closure. Therefore this assumption should be reassessed during the development of the geological disposal facility. Lessons learned and increased knowledge on the characteristics and performance of the disposal system will have to be progressively integrated as well. In accordance with the stepwise evolution underlined by IAEA, the safety case will be updated regularly during the pre-closure phase.

A key-issue for the integrated safety case is the identification, characterization and treatment of uncertainties. Two kinds of uncertainties can be underlined:

- Uncertainties associated with the state of the facility (including the exact state of the host and overlying rock), which is inferred but not exactly known at the start of construction. During construction, the condition of the facility might differ from what was originally foreseen due to changes in design, unforeseen issues, etc. The uncertainty on the facility condition is expected to be reduced during the construction and operation of the facility, up to its closure.

- Uncertainties related to the long term evolution of the facility, and uncertainties of the external environment such as climate change, which should be considered within the safety case.

To cope with the evolving situation when going through the construction and operational phase of the disposal facility, and to specifically keep the construction and operational activities consistent with the post-closure safety objectives, a conceptual approach to integrate pre-closure and post-closure safety is developed in the next sections of this document.

3. A PRACTICAL APPROACH TO INTEGRATE PRE-CLOSURE AND POST-CLOSURE SAFETY

3.1. BASIC CONSIDERATIONS

Post-closure safety for a geological disposal facility cannot be fully verified by direct methods. In practice, no witness will confirm that safety functions have been delivered in the long term. Thus, post-closure safety must be demonstrated by other, i.e. indirect, methods.

Post-closure safety is usually demonstrated in the safety case, supported by safety assessments using computational models based on results from scientific observations and research, and/or by the use of natural analogues. The purpose is to assess the potential behaviour of a closed disposal facility. Such assessments would include scenario analysis to address uncertainties about the possible evolution of the disposal system in the long term (see also 3.5).

Assessment of post-closure safety is based on the anticipated configuration of the disposal system at the end of closure. Post-closure safety thus relies on the operator to construct and operate the disposal facility such that the As-built State conforms to what has been anticipated.

3.2. SAFETY ENVELOPE, DESIGN TARGET AND AS-BUILT STATE

The **Safety envelope** represents that set of safety boundary conditions within which the geological disposal facility has to perform, throughout its life cycle, in order to comply with the legal and regulatory requirements. The Safety envelope should be identified by the operator in the safety case by taking into consideration applicable regulatory requirements. The Safety envelope represents an “outer boundary” that must not be violated.

The **Design Target** represents the boundaries within which, at the start of the post-closure phase, the state of the disposal system (i.e. the parameters expressing the safety functions important for post-closure safety) *is designed to fall*. The Design Target is derived by taking into consideration appropriate margins with respect to the Safety envelope, in order to take into account the principle of optimization of protection (and safety) and also the uncertainties associated with the anticipated state of the disposal system and its evolution. This also means that the Design Target is situated within the Safety envelope. Depending on events and conditions during the pre-closure phase, the design might be updated and the Design Target could therefore evolve as the project progresses. The Design Target is derived by taking into consideration similar existing experience, relevant research and development and understanding of the site, and should include appropriate margins with respect to the Safety envelope. In practice, the Design Target is given in the form of technical specifications and site characteristics to be followed and verified, respectively, by the operator during construction, operation and closure of the facility.

The **As-built State** represents the *real state of the disposal system at a given time*. The As-built State is developing during construction, operation and closure. The disposal system at the end of closure represents the As-built State of the disposal system at the start of the post-closure phase.

During construction and operation of the geological disposal facility, monitoring and inspection activities will be carried out to verify that the characteristics of the host rock correspond to what has been anticipated in the safety assessments. Likewise, monitoring and inspection activities will be carried out to verify that the engineered barriers are constructed according to specifications. Results from these activities define the As-built State for the disposal facility/system. Figure 2 below provides a conceptual example for the relationship between Safety envelope, Design Target and As-built State.

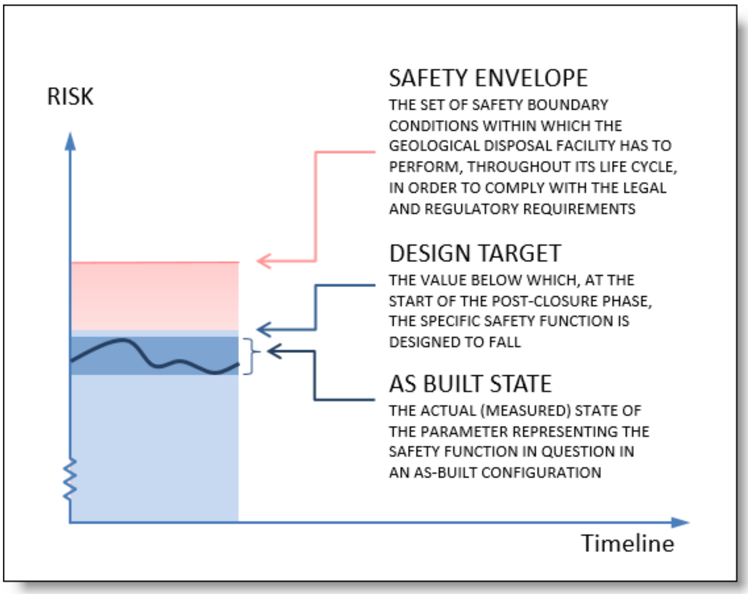


FIG. 2. Conceptual visualization of general relationship between Safety envelope, Design Target and As-built State.

This approach can be used to integrate a facility-specific integrated Safety envelope, Design Target and As-Built State, as illustrated in Figure 3.

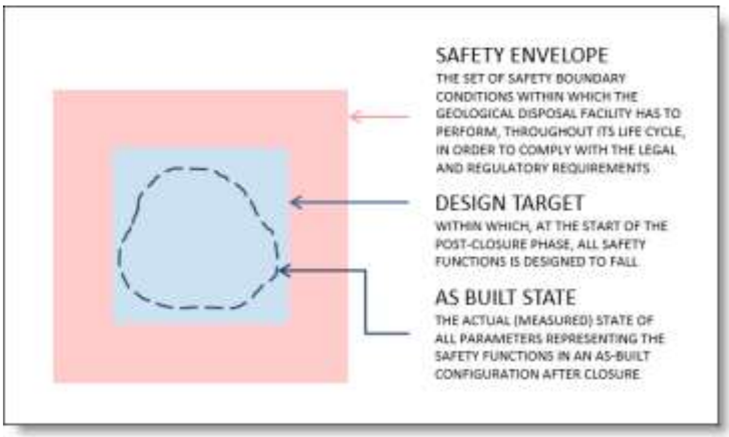


FIG. 3. Conceptual visualization of general relationship between Safety envelope, Design Target and As-built State.

3.3. APPLICATION

In the present context, the state of the disposal system is defined as a set of parameters that are measurable or can be inferred through indirect means (e.g. measurement, expert judgment, calculations, etc.) and provide quantitative or qualitative indicators of the performance of safety functions.

One example is the dry density of bentonite buffer material, in particular when it can be related to the effective montmorillonite dry density, is a parameter that can be measured and provides by correlation estimated values of the permeability, water retention characteristics, swelling characteristics [4]. These characteristics in turn determine the capability of the buffer to slow down the movement of radionuclides and its structural interaction with the waste container and the near-field host rock.

Another example of a parameter that controls the As-built State of the disposal system is the drifts' geometry: mechanical stress imposed by the geological setting on the underground structures may result in changes to the drifts' geometry over time.

Yet another example of a parameter is the absence or presence of major hydraulically conductive fractures in the footprint or vicinity of a geological disposal facility. During the construction of the facility, if such features are encountered and were not expected, a change in the layout of the facility and possibly an update of the safety case might be needed.

The level of protection provided by a geological disposal facility after its closure must be assessed against certain criteria. These criteria, combined with other requirements related to confidence building, public acceptance, and other considerations would then form the basis for developing a safety concept defining the required safety functions. The Safety envelope then gives the boundary for the state of the disposal system at the start of the post-closure phase that would fulfil the above safety functions. Therefore the Safety envelope includes requirements for the disposal system, disposal facility design and facility operation and closure. The chain from safety functions to Safety envelope shows the linkage of post-closure safety and disposal facility design, operation and closure requirements.

The Safety envelope captures the expectations that a geological disposal facility must deliver in the post-closure phase, considering activities and events occurring during the pre-closure phase. This may be in the form of functional and/or design requirements that set out e.g. the inventory of waste to be disposed of, the properties and characteristics of the engineered barriers, or the arrangement of the rooms and access drifts.

In practice, the designer usually tries to include margins in order to take into account uncertainties (including those related to the variability of construction features and/or the geological setting) and to apply the principle of optimization of protection (and safety). These margins are captured at the design phase in a set of target parameters for the geological disposal facility that lies within the Safety envelope and should take into account possible impacts from pre-disposal activities (e.g. waste conditioning prior to shipment to the disposal facility). This set of target parameters is defined as the Design Target.

The actual state of a geological disposal facility that is achieved at a given time during its construction and operation is defined as the As-built State. It is expected that the As-built State will fall within the Design Target although deviations should be expected and planned for (this is discussed further in Section 4).

3.4. EVOLUTION OF AS-BUILT STATES IN THE SAFETY CASE

As construction and operation of the facility progresses through implementation and operation it is expected that the operator will regularly update the safety case taking account of lessons learned and increased knowledge through monitoring, measuring, quality control and acceptance/rejection throughout construction and operational stages.

The parameters that are relevant to safety are compared against the Design Target to determine whether the project is “on track” to deliver the desired values of post-closure safety functions. It may be that some parameters when checked in this fashion are found to fall outside the Design Target but still within the Safety envelope. This means that whilst the safety margins have been reduced, these parameters will not jeopardize the safety of the facility or the conclusions of the safety assessment, as they are still within the Safety envelope. This illustrates the role of the Design Target in providing a margin to accommodate construction and other uncertainties as the As-built State is checked periodically. The fact that they are, however, outside the target will trigger the need to investigate the possibility to bring the parameters back within the Design Target, and to see whether design/construction changes are needed in order to avoid such deviations being reproduced in the future. This is shown in the following Figure 4.

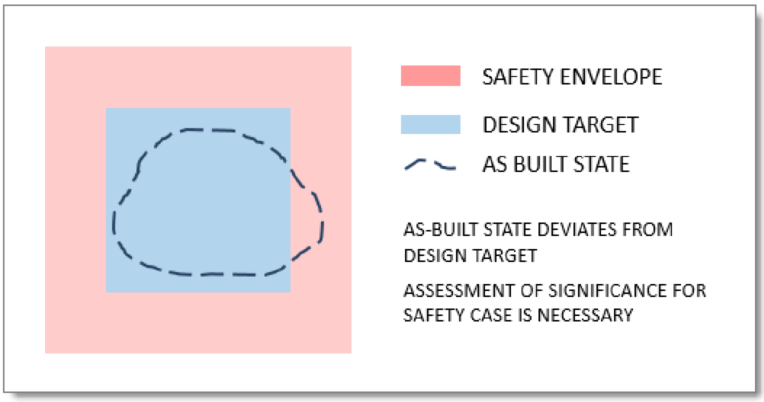


FIG. 4. Visualization of deviation from Design Target.

At some point, it may be that one or more parameters are well outside of the Design Target and also outside the Safety envelope. This would represent an unacceptable situation in terms of post-closure safety (see Figure 5). Such a situation would suggest that one or more safety functions would not be able to deliver what is required at time of closure to achieve an acceptable level of post-closure safety, unless corrective actions can bring the parameters back within the safety envelope.

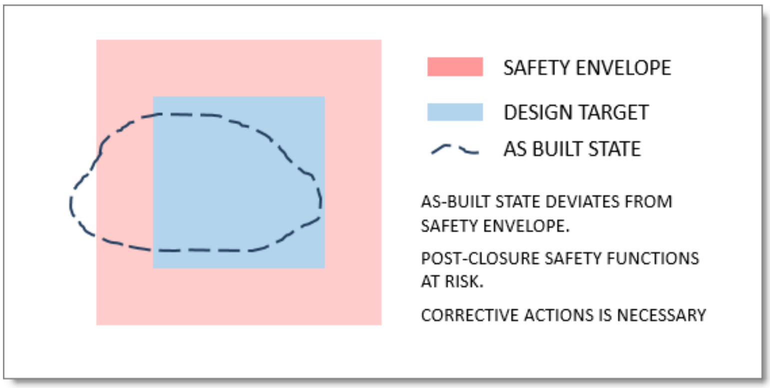


FIG. 5. Visualization of deviation from the Safety envelope.

At the time of closure, the operator will need to demonstrate that the safety functions relevant for post-closure safety have been achieved. This is equivalent to demonstrating that the Design Target has been delivered at the time of closure. Monitoring of key safety related parameters will be undertaken to confirm that the As-built State falls within the Design Target. This is illustrated in Figure 6.

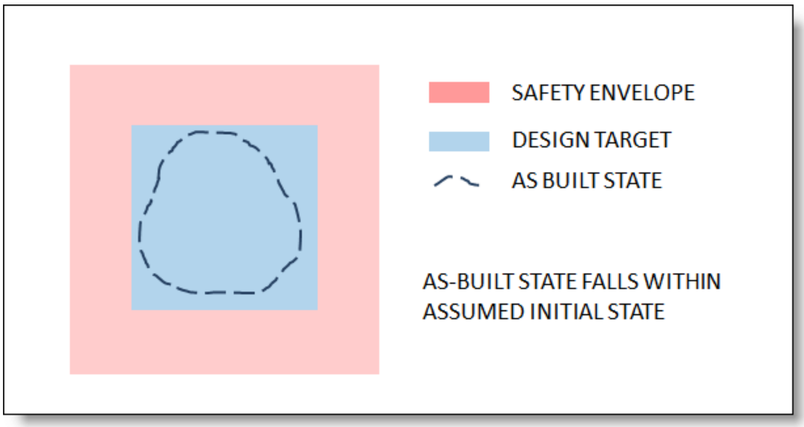


FIG. 6. Visualization of As-built State falling within the Design Target.

When the operator shows that the As-built State at the end of operation falls within the Design Target, and regulatory approval is given, the implementation of the closure works can start.

3.5. ROBUSTNESS

Inherent to the requirement on relying on passive means to the maximum extent possible, is the concept of robustness. Each individual barrier is thus required to retain their safety functions despite disturbances (e.g. earthquakes, glaciation, etc.) that are expected to occur. Therefore, in the context of this TECDOC, the Design Target (and obviously also the Safety envelope) should take into account those disturbances. The overall disposal system must also be shown to be robust. This is usually demonstrated by considering scenarios, including extreme (what-if) scenarios, where the integrity of a barrier or a safety function is lessened or compromised. In other words, for these scenarios, the parameters associated with a barrier may fall outside the Design Target by a large deviation; however it should be shown that the state of the overall disposal system would still be within the Safety envelope.

4. DESIGN COMPLIANCE MANAGEMENT SYSTEM

Waste packages form one (or more) of the multiple barriers contributing to safety and the safety functions that they provide are specified by design specifications determined to provide performance that falls within the Design Target. The operator of the disposal facility will define the performance requirements of waste packages prepared for disposal by means of Waste Acceptance Criteria and check waste packages compliance before acceptance and emplacement. Waste acceptance criteria will address all important parameters for emplacement and disposal to give assurance that waste packages can be safely accepted into the facility for disposal. It follows that the management systems of waste producers and the geological disposal facility have to ensure that the waste packages are correctly manufactured and stored with sufficient and appropriate records so that operator of the disposal facility has confidence that the waste packages have the characteristics attributed to them and are compliant with the safety case during both pre-closure and post-closure phases.

4.1. DEVIATIONS FROM DESIGN TARGET

As already stated the operator has to demonstrate that the Design Target is within the Safety envelope, the Safety envelope is correctly defined and that the As-built State is within the Design Target.

Therefore it is important to implement an effective management system to ensure the quality of all safety related work, develop documented processes and procedures for disposal facility operation, follow operational limits and conditions, and monitor key parameters, to verify this compliance.

The above mentioned elements of management system or monitoring program are the means that the disposal facility operator can use to demonstrate that the state of the disposal system falls within the Design Target. For example, operational limits and conditions are a set of parameter limits, functional capability or performance levels of facility equipment or personnel required for the safe operation of a disposal facility. In case operational limits and conditions are exceeded, the operator has to take measures to ultimately bring the facility back to normal operation.

Examples of limits and conditions could include controls on construction processes, emplacement operations and backfilling materials and techniques, site specific limits on the types, activities and quantities of waste that may be disposed of in order to ensure operational and post-closure safety, and requirements on monitoring and on staff training.

During operation of the facility, deviation from the Design Target should not be unexpected and such anticipated deviations should be reflected in the evolving safety case. It should in this context be emphasized that the impact of local deviations is not likely to have an unacceptable impact on overall post-closure safety if corrective measures are appropriately implemented. It is important that deviations are promptly identified and it is therefore necessary to have an adequate monitoring system both to identify the deviation and to assess its significance.

Similarly, the Design Target may also evolve over time because of new findings, improved knowledge, operational feedback, technological changes etc. This should be reflected in the updated safety case. Figure 7 shows the potential evolution and revision of the Design Target.

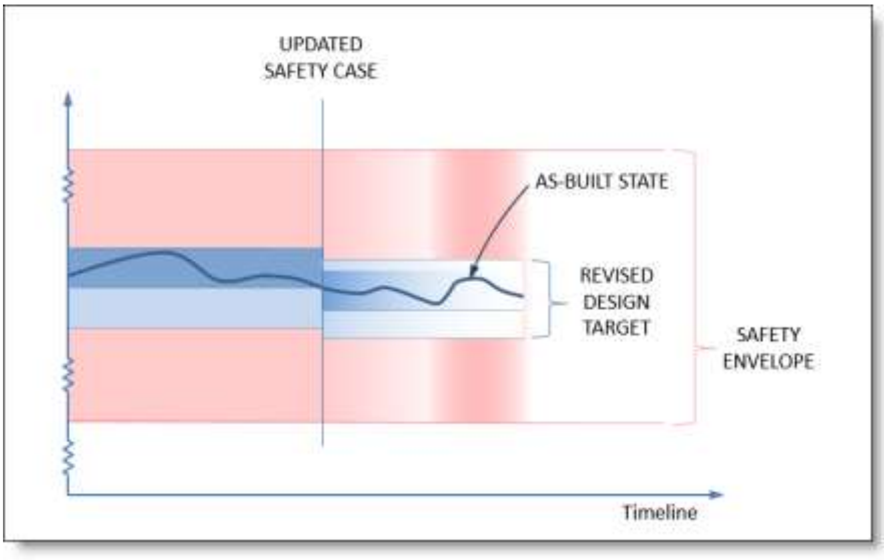


FIG. 7. Illustration of changes in a Design Target as a consequence of a revision of the safety case.

4.2. REQUIREMENTS RELATED TO COMPLIANCE CONTROL AND MONITORING

The objectives of compliance control and monitoring programs are to provide confidence that the facility is being constructed and operated in accordance with original design intent (Design Target) so that any deviations can be detected and corrective actions put in place. Requirements and guidance on monitoring and surveillance with specific reference to radioactive waste disposal facilities are available in IAEA SSR-5 [1] and SSG-31 [5].

The formal decision to start the closing operation is a key milestone in the operation of a geological disposal facility. Such decision requires the operator to present to the regulatory body an updated safety case providing evidence that the facility has been constructed and operated such as to provide for post-closure safety. At this point in time the operator is also required to provide evidence that any deviations from the original design intent (Design Target) have been managed in an acceptable way. The compliance control and monitoring arrangements, being part of the operator's management system, therefore play a key role in confirming the absence of any conditions that could affect post-closure safety.

4.3. REQUIREMENTS MANAGEMENT

An operator may use a management system tool to keep track of the status of the various parameters and components that are significant for safety. At the starting point of the design process requirements are defined setting down the Design Target and construction procedures as well as operational limits and conditions. Further requirements may be set based on the envisaged safety functions and radiological protection targets adopted by the operator and which will inform the safety case. In practice, setting down the requirements and assessment of design feasibility and performance is an iterative process which progresses during the stepwise development of the disposal facility.

It is also possible that there are conflicting requirements, particularly with regards to pre-closure versus post-closure requirements. Therefore, a hierarchy to illustrate the differences in priority or mandatory nature of different requirements is desirable, by e.g. implementing a Requirements Management System (RMS). When developing methods to manage requirements and any associated hierarchy, it is important to assure traceability of the requirements' basis and that there are well defined connections/interfaces between requirements. It should be possible to trace the origin of each requirement. It is also important to document every change made to the requirements in order to achieve traceability. Using a requirements management tool may be a practical approach for operators to identify and record requirements (including changes in requirements and the reasons for these changes). Examples of requirements management in Finland and UK are presented in the sections I.1 and I.2 of the Appendix.

5. MANAGING DEVIATIONS

As stated earlier the As-built State is evolving continuously throughout the construction and operational phase, and monitoring and compliance control will be undertaken to track progress, identify trends and give assurance that the facility is on-track to deliver the required level of safety within the Design Target and so provide the necessary safety functions at the time of closure.

Given that a geological disposal facility may be operated for many decades, the safety case will be periodically updated and resubmitted to regulatory authorities as required by the national regulatory arrangements. Such updates will take account of any changes in regulatory requirements or expectations, any trends noted as a result of the monitoring program and particularly any proposed changes to the Design Target as discussed in Section 4.1.

5.1. TAKING CORRECTIVE ACTION

It has been seen that the compliance control and monitoring program may identify cases where a parameter is trending or has deviated from the design intent. This may trigger the need for the operator to take appropriate corrective actions, such as:

- Redefine construction or operational procedures to reverse a trend that if left unaddressed could cause the parameter eventually to fall outside of the Design Target (and potentially outside of the Safety envelope).

- Commission further investigations and/or research to understand the consequences of the deviation. This may have the effect of expanding the Design Target and consequently bringing the value into compliance.

- Determine whether additional safety functions can be claimed thereby compensating for the deviation from the Design Target.

In some cases the operator may determine that the Safety envelope itself should be redefined. In certain circumstances this may be a justifiable position and an appropriate way forward. However this outcome would suggest that a major reworking of the disposal concept and/or safety case cannot be excluded. This would require submission of a revised safety case for regulatory approval. Changes to the Safety envelope are not expected to be a frequent occurrence and is not further discussed in this document.

5.2. ADDRESSING DEVIATIONS FROM THE DESIGN TARGET

Section 2 of this document describes how pre-closure activities and post-closure safety should be integrated in the safety case in order to deliver the required objectives. Section 3 describes a conceptual approach for determining whether the safety functions, upon which the safety case relies, are “on track” during the course of the implementation of the project. A prerequisite for successfully delivering the planned As-built State at the beginning of the post-closure phase is the operator’s capability to manage construction and operational activities without jeopardising post-closure safety.

A way of providing governance of disposal facility construction and operation is through provision of an integrated management system by the operator. The requirements for such a management system are comprehensively discussed in IAEA Safety Requirements and Guides (GSR Part 2 [6] and GS-G-3.4 [7]). As discussed in Section 4.3 the management system may include a specific system for managing requirements and examples of such approaches are provided in the Appendix. Predefined procedures for working activities, monitoring of key parameters and demonstration of compliance with predefined acceptance criteria are crucial elements in such a governance process.

The iterative process for assessing compatibility with the Design Target and a process for addressing possible deviations in relation to the safety case and Safety envelope is described below and illustrated in Figure 8.

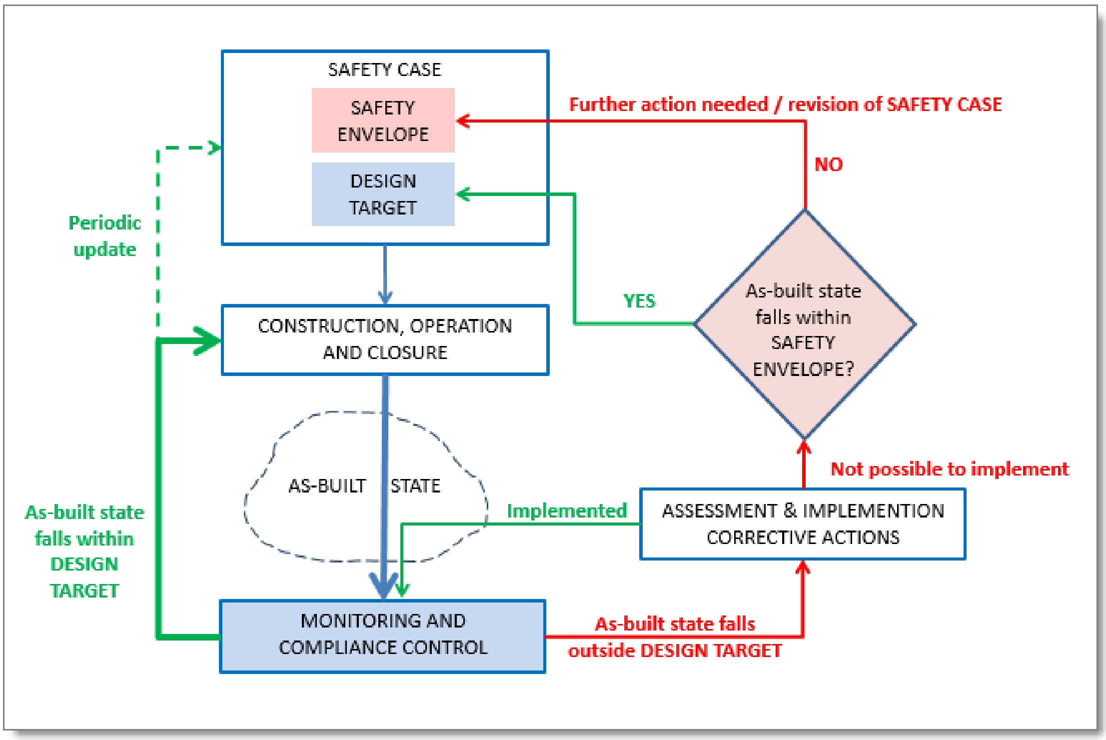


FIG. 8. Schematic flowchart for monitoring key parameters within the context of the management system.

During the construction, operation and closure activities, the As-built State of the facility is developing. By using the monitoring and compliance control system, it is verified that the As-built State lies within the Design Target. As long as this is the case, the activities can carry on and periodic updates of the safety case are undertaken accounting for the developing state of the facility. Whenever a deviation occurs, an assessment needs to be undertaken to determine whether corrective actions are needed and can be implemented, to bring the As-built State back within the Design Target. Whenever corrective actions are possible and are implemented, verification will take place - through the monitoring and compliance control system - to assure that the As-built State now falls within the Design Target. If it appears impossible to implement corrective actions, it has to be verified that the As-built State still falls within the Safety envelope. If it does, the deviation can be treated as explained in section 5.1 and the safety assessment and the safety functions remain valid, although the safety margin may be reduced and the Design Target might be reconsidered. When the deviation causes the As-built State to fall outside of the Safety envelope, the safety assessment might no longer be valid. Further action is needed and at least a revision of the safety case will have to be undertaken.

Paragraph I.3 of the Appendix provides four specific examples of important parameters monitored during construction of a KBS-3 type repository and how these could be managed when deviations from the Design target are identified. Examples are partly illustrative and partly based on real observations from a process for managing deviations from the Design Target that has been developed by Posiva[1].

The conclusion to be drawn from this Section and the examples given in the Appendix is that monitoring of the As-built State should be a continuous activity as it allows trends to be detected and early corrective actions to be implemented. The stepwise construction and

[1] This process was developed as an essential component of the management arrangements governing the construction of the Onkalo Underground Rock Characterization Facility (URCF) and associated geological disposal facility.

operation of a disposal facility implies that new information is gathered throughout the pre-closure phase of a geological disposal facility and that it is in the operator's best interest to use such operational experience within updates of the safety case. As noted earlier, safety case updates may be prompted by a number of reasons including facility extension, periodic safety review, legislative changes, or significant changes to the Design Target or even changes to the Safety envelope.

6. CONCLUSION

Development and implementation of a geological disposal facility is a unique task. The primary objective with such a project is to ensure that a closed disposal facility protects people and the environment from the harmful effects of radioactivity in the future. To achieve this objective, the operator should demonstrate that the As-built State of the facility at the time of closure falls within the defined Safety envelope.

An equally important facilitating objective is to ensure that all activities necessary to establish a closed disposal facility, i.e. activities during the pre-closure phase, are carried out as necessary to deliver the Design Target, and that management arrangements are implemented to ensure that successful delivery can be verified and demonstrated. The Design Target should be specified to lie well within the Safety envelope, to provide a safety margin against inevitable uncertainties. Such pre-closure phase activities encompass all those activities that deliver safety functions of the multiple barriers providing post-closure safety and will include waste packaging, activities to characterize and understand the site and all activities associated with construction and operation (including closure).

While the safety case at the early pre-operational phase is based on a configuration of the disposal system according to the original design intent (Design Target), it will evolve during the construction and operational phase towards a safety case based on the actual As-built State at the start of the post-closure phase. As the pre-operational phase develops and the facility is licensed by the appropriate regulatory authorities, the safety case will be maintained and periodically reviewed and updated based on on-going monitoring and operational experience. At any given time the As-built State can be compared with the Design Target to check that the disposal system remains on track to deliver the planned safety functions necessary for safety in the post-closure phase. At the time of closure the operator will justify to regulatory authorities that they can proceed to the final step of closure, by presentation of a safety case based on the final As-built State.

The development and implementation of a geological disposal facility is a long term commitment and the operational phase may last several decades. During this time it should be expected that the design will evolve as it responds to and is refined to address continuing site characterization, construction and operational experience. The operator may identify that the As-built State is deviating from the defined Design Target and may decide that corrective actions are required, or that changes to the Design Target may be justified.

From the early beginning, it is of utmost importance that the requirements to be fulfilled in order to assure post-closure safety and (conventional and nuclear) operational safety of the disposal facility are identified and taken into due account. They will have to be taken forward, and when needed further detailed, throughout the development and implementation of the disposal facility, i.e. during conceptualisation, siting, design, construction, operation and closure.

It is advised that the operator establishes an integrated management system as an early activity, and that this include systems to record and manage requirements so as to be able to keep track of the development of refined and/or revised requirements.

Such a requirements management system should facilitate disposal system monitoring and compliance control in order to allow any deviations from the defined Design Target to be recorded, their significance assessed and corrective actions implemented.

APPENDIX

I.1. REQUIREMENTS MANAGEMENT: AN EXAMPLE FROM POSIVA, FINLAND

Posiva's requirements management system (known as VAHA) is an information system designed to manage all of the requirements related to the geological disposal facility proposed in Finland. This system provides a rigorous, traceable method of translating the safety principles and the safety concept to a set of safety functions, performance targets, design requirements and design specifications for the various barriers. This system includes all relevant requirements and provides a mechanism to record compliance and dependencies between separate specifications and requirements.

The VAHA database is organized into five levels:

I. Level 1 consists of the Stakeholder requirements. These are the requirements arising from laws, regulatory requirements, decisions-in-principle and other stakeholder requirements.

II. Level 2 consists of the System requirements as defined by Posiva on the basis of Posiva's owners' requirements and the legal and regulatory requirements listed on Level 1. Level 2 requirements define the EBS components and the functions of the EBS and host rock.

III. Level 3 consists of the Sub-system requirements which are specific requirements for the canister, buffer, backfill, closure and host rock and underground openings. The requirements of level 3 set mostly general targets (performance targets and target properties) for EBS and host rock performance.

IV. Level 4 Design requirements further clarify and provide more details to the requirements of Level 3.

V. Level 5 presents the Design specifications. These are the detailed specifications to be used in the design, construction and manufacturing.

The relation of requirement management performance assessment and safety case documentation can be illustrated as in Figure I-1.

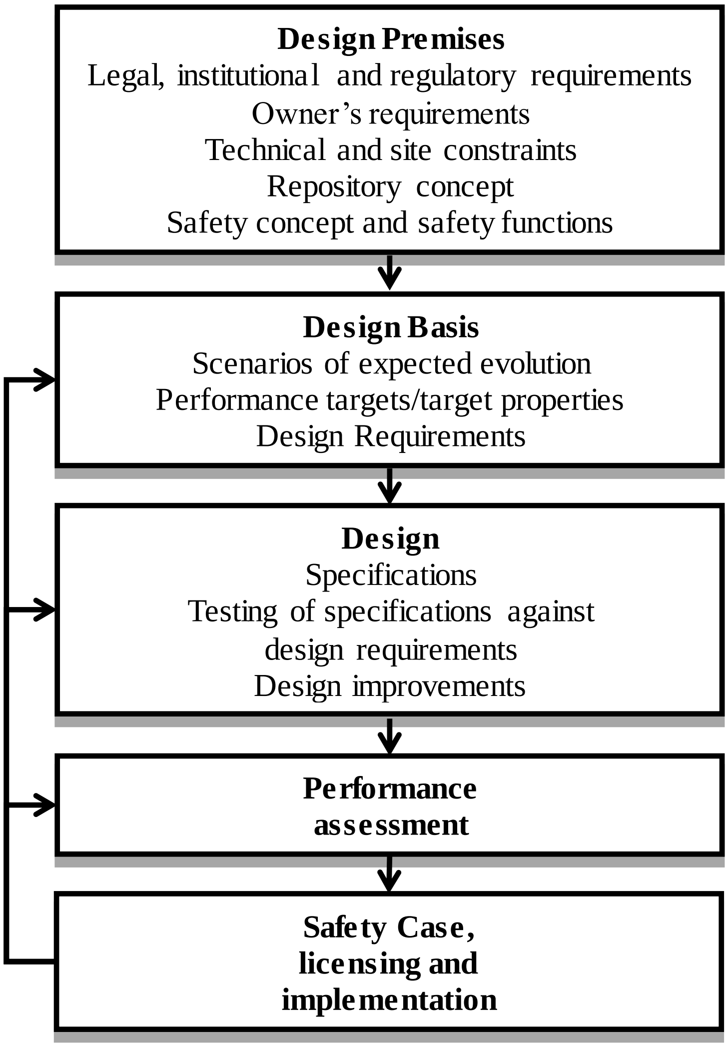


FIG. I-1. Example of iterative process for requirement development for disposal system (a GEOSAF interpretation of Posiva's approach [8].)

I.2. REQUIREMENTS MANAGEMENT: AN EXAMPLE FROM RWM UK

The UK approach is not as advanced as the Finnish VAHA system but shares many of the basic principles. The UK approach adopts a hierarchical structure as shown in the following Figure, leading to a characteristic "V diagram". Figure I-2 illustrates that requirements management is a tool that is not only used to record requirements but also to record verification and compliance checks.

Like the Finnish VAHA system, the UK approach is structured in a number of tiers with the level 1 defining the "user requirement" which is defined as regulatory and stakeholder requirements. At this level the UK defines what is the 'need' that the geological disposal facility is designed to meet. The subsequent lower order tiers are developed based on the 'solution' and lead to the definition of system requirements, sub-system requirements and ultimately to component specifications. Having specified the various requirements, the system provides a systematic way of recording and demonstrating that the specified requirements have been delivered.

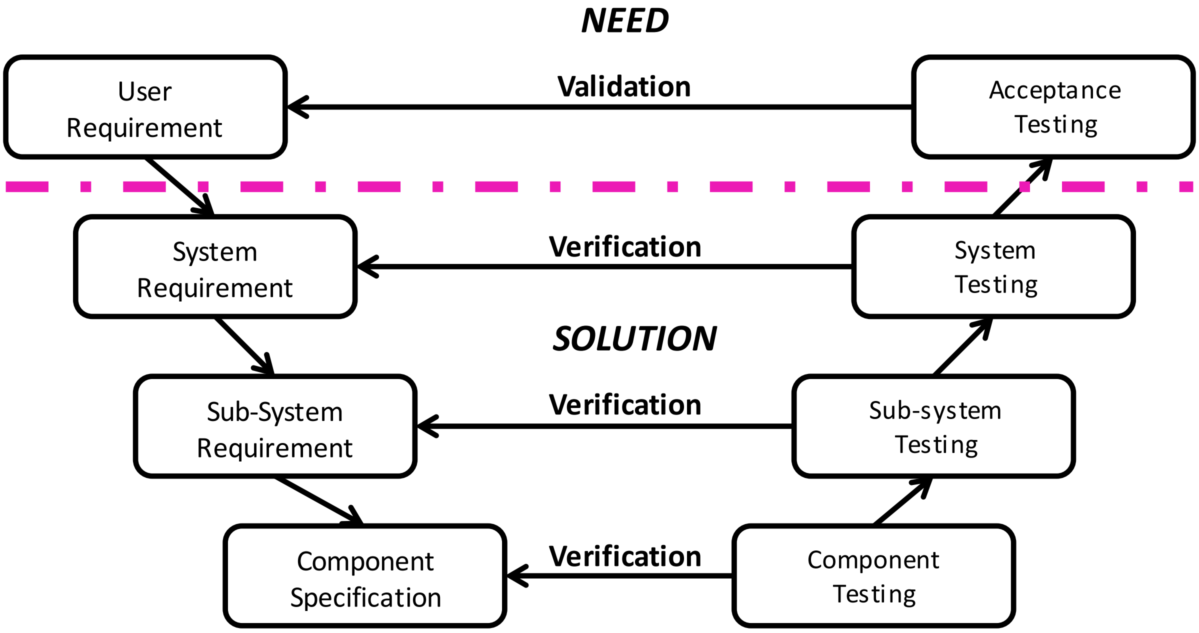


FIG. I-2. Basis for requirements management adopted by Radioactive Waste Management in the UK (Reproduced courtesy of Nuclear Decommissioning Authority © (2016) Ref Radioactive Waste Management UK).

I.3. MANAGEMENT OF DEVIATION: PRACTICAL EXAMPLES

The following material provides practical examples of how parameters related to underground construction are measured and compared to the defined Design Target. Where deviations from the Design Target are identified the examples explain how these may be assessed for significance and the kind of corrective actions that could be implemented. This material is partly illustrative and partly provided from procedures developed in Finland for the Onkalo URCF and geological disposal facility. The approach is consistent with the process described earlier in this document and illustrates the relationship to the safety case: minor deviations do occur in practice and where these are determined to be local in character and thus not affecting radionuclide transport characteristics in the broader scale can be accepted. Examples are also given of situations where the impact on the Design Target may be more significant and require more significant actions.

1. Excavation damaged zone

   Excavation damage zone (EDZ) is identified in many disposal concepts as an important parameter describing what kind of effect excavation is allowed to have for host rock surrounding the disposal space. EDZ can change the hydrological transport routes and therefore the assumptions relating to Design Target and Safety envelope used in the safety case. For example in crystalline rock, EDZ is estimated to be significant if it is continuous and has certain depth. Based on this the disposal tunnel technical specification has determined appropriate parameter values for EDZ. A possible monitoring method for EDZ depth examination is ground penetrating radar that has been verified with EDZ sampling. This is illustrated in Figure I-3.

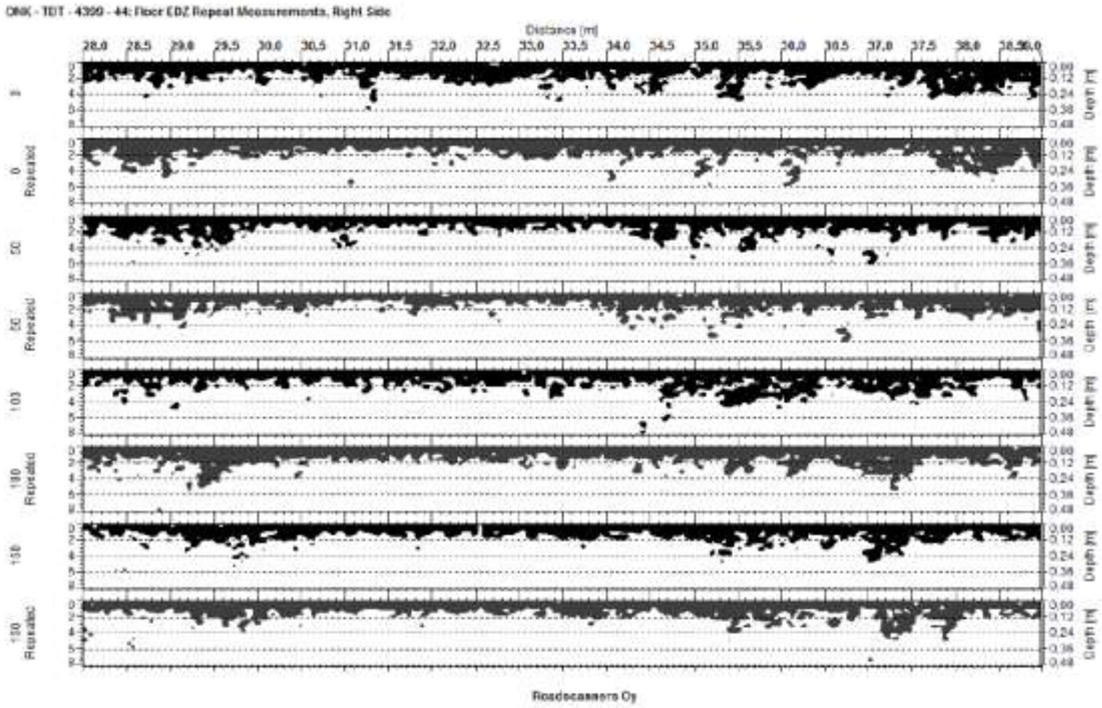


FIG. I-3. Ground penetrating radar used to evaluate EDZ (ref. POSIVA 2012-22, Underground Openings Production Line 2012 Design, Production and Initial State of the Underground Openings. Reproduced by the courtesy of Posiva Oy [8]).

In the case where monitoring reveals that the specified EDZ limit is exceeded, an assessment of the causes (for exceeding the specification) is undertaken. If it is seen the specification will be exceeded only locally then this may be deemed to be acceptable and no further action is necessary. If this is seen as a continuous effect leading to possible safety concerns, a possible corrective action might to be adopt an alternative excavation technique with reduced impact on the EDZ.

On the other hand if the excavation produces a continuous EDZ non-compliance and the excavation technique cannot be further developed, then this may require abandonment of the particular tunnel or re-assessment of the Design Target, and Safety envelope together with re-evaluation of the safety case as discussed in Section 5.1.

2. Tunnel profile

   The dimensions of the disposal tunnel or other excavation is a basic design requirement/specification that needs to be specified for many practical reasons. The dimensions have post-closure safety relevance as the disposal rooms have to be backfilled and closed, and the excavation is likely to affect surrounding host rock properties. If the theoretical tunnel profile is exceeded, it might have an effect on backfill performance after closure. The theoretical tunnel profile is given in tunnel specifications and in design drawings and the As-built State is checked as part of the construction process (see Figure I-4).

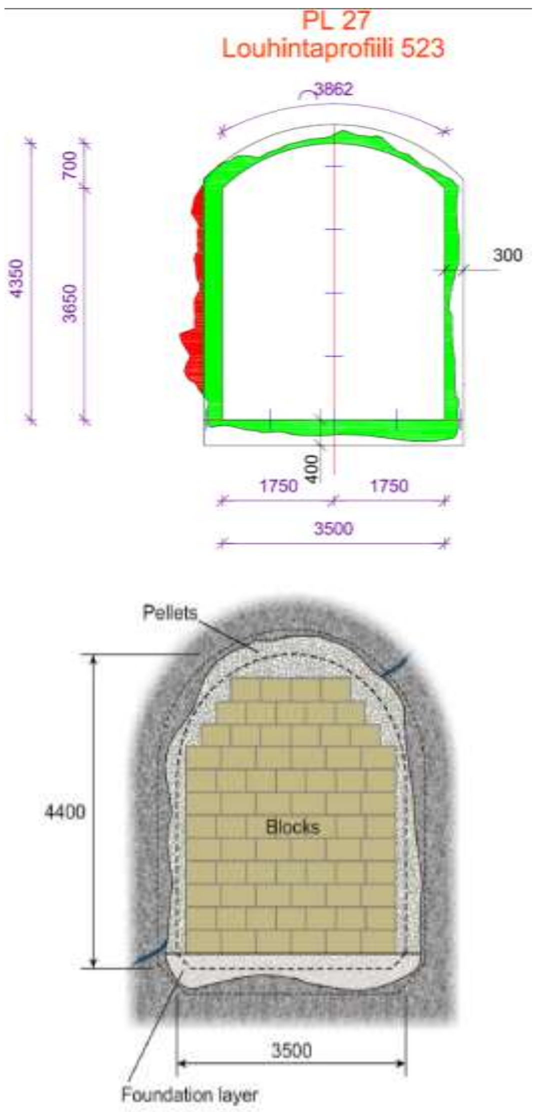


FIG. I-4: Tunnel profile measurements and effect on backfill design. Reproduced by the courtesy of Posiva Oy [8, 9]

In the case of exceeding specified tunnel dimensions, the actions would include an assessment of causes and consequences. The assessment might determine that the consequences are trivial and that the appropriate action would be approval and documentation of the As-built dimensions. This might be the case for instance where the Design Target is not compromised when assessed together with backfill performance or where tunnel backfill could be redesigned for that part of the tunnel and assessment of performance demonstrates that the Design Target is met. The ultimate action would be rejection of the excavated tunnel if no successful mitigations can be implemented.

3. Waste package tested to have non-compliant defects

   The Finnish waste package specification includes the definition of an acceptable defect size and type which can be present in the completed waste package. A defect greater than the acceptable size can have a deleterious effect on corrosion resistance or mechanical integrity in postulated loading cases (operational and post-closure). The waste container is a key safety barrier and deviations from the specification can have significant safety implications for both operational and post-closure safety functions. Illustration of critical defect sizes is shown in Figure I-5.

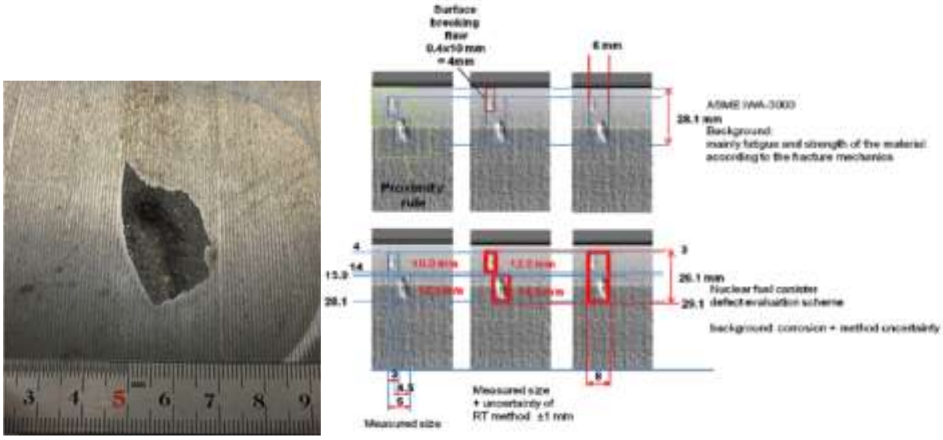
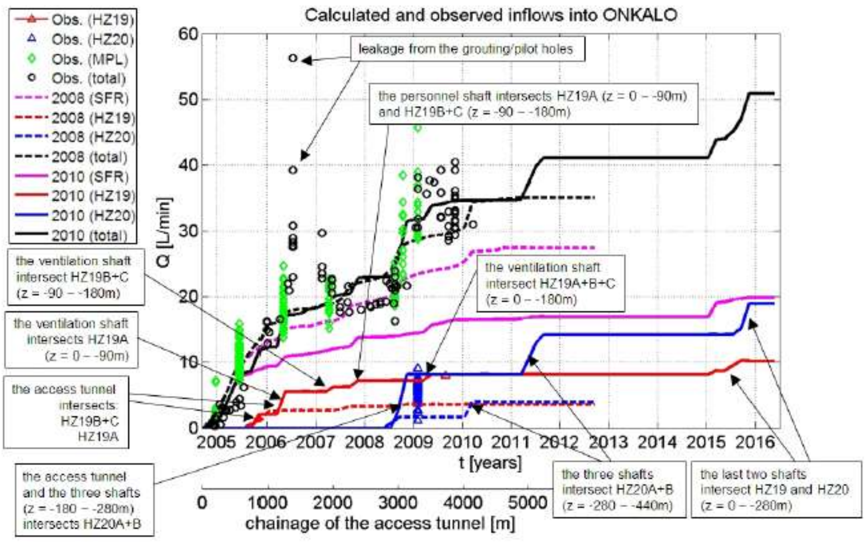


FIG. I-5. Illustration of potential canister manufacturing defects. Reproduced by the courtesy of Posiva Oy [10, 11].

The most straight forward action in the event of a detected non-compliance is rejection of the waste container. In some occasions a more detailed re-evaluation of the defect size and type using more sophisticated non-destructive methods could be possible.

4. Large inflow of groundwater exceeding safety case limits

   A key objective when constructing and operating a disposal facility in crystalline bedrock is to maintain the favorable host rock properties. Two main properties that can be affected in macro-scale by construction activities are host rock hydrogeological and hydrogeochemical properties. Without proper construction processes and procedures the disposal facility might experience large water inflow, which can have an effect on hydrological and geochemical features of the whole site (e.g. water table drawdown, up-coning of deeper groundwater). Measurement and effect of groundwater inflow are illustrated in Figure I-6.



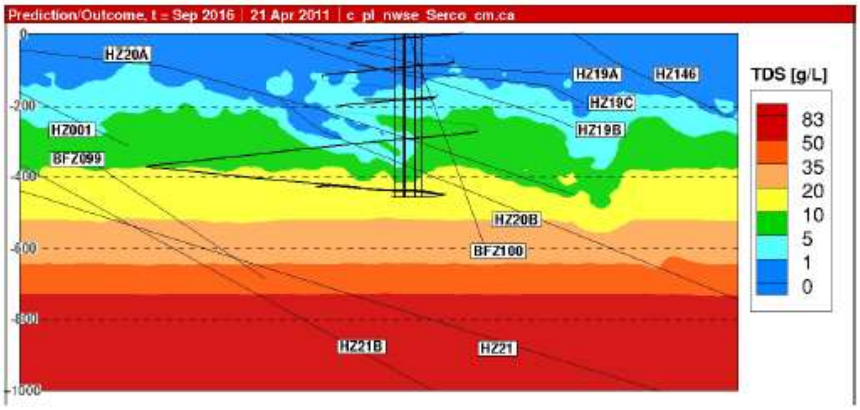


FIG. I-6: Measurements to determine groundwater inflow and modelling of the effect on groundwater chemistry. Reproduced by the courtesy of Posiva Oy [12]

The action limits designed to ensure the (post-closure) Design Targets, particularly in crystalline bedrock, could include the specification of acceptable total inflow and water table drawdown. To be able to take corrective actions during disposal facility construction and operation it is important that the operator monitors trends of inflow and water table change. In the event of an action limit violation in this case, corrective actions to restore favorable hydrogeological properties of the host rock could be difficult or in some cases impossible. In this eventuality the operator could undertake more detailed re-evaluation of the possible change in the site properties and determine the safety significance of the deviation. If this example is found to lead to a long-lasting or irreversible change of host rock properties it might call for a significant re-assessment of the safety case, a change of the disposal system design or even rejection of the site.

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Technical Meeting

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