Design Basis of Plugs and Seals: Summary of WP2 of the DOPAS Project

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Work Package 2 (WP2) of the DOPAS Project was focused on the development of the design basis for the plugs and seals. This paper provides a summary of the main results from WP2. These relate both to the design basis methodology and the requirements on plug and seal performance. The work included identification of the safety functions of the reference plugs and seals conceptual designs, and the design specifications for the experimental detailed designs. Detailed requirements on plugs and seals include those related to the curing temperature of the concrete, the hydraulic conductivity of the sub-system components including the density of bentonite components, the compressive strength of concrete components, and the pH of concrete pore water. The work in WP2 has been used to develop generic guidance on the development of the design basis in terms of a DOPAS Design Basis Workflow. A key observation is that requirements are developed in parallel with designs rather than as a sequential process.

1 Introduction

The Full-Scale Demonstration of Plugs and Seals (DOPAS) Project is a European Commission programme of work jointly funded by the Euratom Seventh Framework Programme and European nuclear waste management organisations (WMOs). A set of full-scale experiments, laboratory tests, and performance assessment studies of plugs and seals for geological repositories are being carried out in the course of the project. The DOPAS Project focuses on tunnel, drift, vault and shaft plugs and seals for clay, crystalline and salt rocks:

- Clay rocks: the Full-scale Seal (FSS) experiment, being undertaken by Andra in a surface facility at St Dizier, is an experiment of the construction of a drift and intermediate-level waste (ILW) disposal vault seal.
- Crystalline rocks: experiments related to plugs in disposal tunnels, including the Experimental Pressure and Sealing Plug (EPSP) experiment being undertaken by SÚRAO and the Czech Technical University at the Josef underground research centre and underground laboratory in the Czech Republic, the Dome Plug (DOMPLU) experiment being undertaken by SKB and Posiva at the Äspö Hard Rock Laboratory in Sweden, and the Posiva Plug (POPLU) experiment being undertaken by Posiva, SKB, VTT and BTECH at the ONKALO Underground Rock Characterisation Facility in Finland.
- Salt rocks: tests related to seals in vertical shafts under the banner of the Entwicklung von Schachtverschlusskonzepten (development of shaft closure concepts – ELSA) experiment, being undertaken by DBE TEC together with the Technical University of Freiburg and associated partners, complemented by laboratory testing performed by GRS and co-funded by the German Federal Ministry for Economic Affairs and Energy.

The French, Czech and Finnish experiments were designed and constructed during the DOPAS Project. The Swedish experiment was started prior to the start of the Project. The German tests focus on the early stages of design basis development and on demonstration of the suitability of designs through performance assessment studies and laboratory testing, and will feed into a full-scale experiment of prototype shaft seal components to be carried out after DOPAS.

Work Package 2 (WP2) of the DOPAS Project was focused on the development of the design basis for the plugs and seals. This paper provides a summary of the main results from WP2. These relate both to the design basis methodology and the requirements on plug and seal performance.

2 Objectives and Approach to WP2 of the DOPAS Project

The main objective of WP2 of the DOPAS Project was to describe the safety functions, the designs, and the design basis of plugs and seals considered in the Project. This included an analysis and discussion of the differences between the design bases for plugs and seals in different repository concepts, focusing on the safety functions performed by each plug and seal, and how these impact on the more detailed requirements.

A further objective was to use the learning from the development of the design bases to provide general guidance on the development of a design basis in the context of repository plugs and seals. In particular, lessons were drawn on the iterative development of the design basis for plugs and seals in parallel with development of the design, as well as the use of hierarchical structures to describe the design basis. This includes the strategies used to demonstrate compliance of the reference designs with the design basis, and in particular with the safety functions captured in the design basis.

The design basis for each of the plugs and seals considered in the DOPAS Project was collated using a bottom-up approach, i.e. no rigid structure was applied during the work, which was approached by extending existing information. This bottom-up approach had the benefit of responding to differences in the manner in which the design basis is developed and/or presented in different programmes.

The collation of the design bases and the development of guidance on the development of the design basis was undertaken in four stages, each one associated with a specific DOPAS Project WP2 task:

- Task 2.1: Design Basis. Collation of the design basis for each plug and seal considered in the DOPAS Project (White *et al.*, 2014).
- Task 2.2: Reference Designs. Documentation of the conceptual designs of the plugs and seals considered in the DOPAS Project (White and Doudou, 2014).
- Task 2.3: Strategies for Demonstrating Conformity of Reference Designs to the Design Basis. Identification and description of the different strategies that are envisaged by WMOs carrying out the DOPAS Project experiments to demonstrate compliance of the designs to the design bases (White and Doudou, 2015).
- Task 2.4: Final Reporting of WP2. In this task all of the WP2 results were compiled in one final report and the guidance on the development of the design basis was developed and presented (White and Doudou, 2016).

3 Background to the Design Basis

3.1 Definition of the Design Basis

In the DOPAS Project, a design basis is defined as the set of requirements and conditions taken into account in design. This definition is consistent with approaches to systems engineering and requirements management (e.g. NASA, 1995; and Robertson and Robertson, 1999). The design basis specifies the required performance of a repository system and its sub-systems, and the conditions under which the required performance has to be provided. It includes requirements derived from regulations, and safety functions that plugs and seals have to fulfil as part of the overall safety objective of a disposal system. Requirements are statements on what the design has to do (i.e., the performance) and what it must be like (i.e., the characteristics). For a plug/seal, this could be, for example, the strength and the hydraulic conductivity of the materials making up the plug/seal. Conditions are the loads and constraints imposed on the design, for example, the underground environment (dimensions, air temperature, humidity, etc.) or controls on the manner in which the design is implemented (e.g., the time available for construction).

The requirements in the design basis form a hierarchy of increasing detail, which is developed in parallel with decisions on the design. At each stage in the design development process, the requirements are used as the basis for more detailed designs. Therefore, although there is a transition from problem specification to solution during design development, requirements are defined at each stage in the process as the basis upon which more detailed designs are developed. For example, development of a disposal system conceptual design requires description of the sub-systems that make up the conceptual design at the same time as developing the statements regarding the functions that these sub-systems must provide. At a more detailed level of design development, designing a specific plug/seal component (e.g., defining a concrete mix) requires information on what the concrete mix must achieve (e.g., strength, curing temperatures, and hydraulic conductivity), but also leads to detailed design specifications (e.g., the acceptable range of constituents that can be used when mixing the concrete). These design specifications can be transferred into quality control statements and construction procedures for implementation during repository operation.

In DOPAS, the requirements contained in the design basis of plugs and seals are described in terms of the following hierarchy:

- Stakeholder requirements: Stakeholder requirements are the top-level statements on, and description of, what must be achieved by a waste management programme and elaboration of specific approaches that must be considered in the repository design.
- System requirements: The requirements on the disposal system that result from adoption of a specific conceptual design, i.e., the safety functions provided by the elements that comprise the disposal system. For plugs and seals, therefore, system requirements are the safety functions provided by plugs/seals.
- Sub-system requirements: A list of the functions that the components of the selected plug/seal design must provide and the qualities that these components must have.
- Design requirements: Statements, usually expressed qualitatively, describing the qualities or performance objectives for plug/seal components.
- Design specifications: A list of quantitative statements describing the requirements on plug/seal components (e.g., their thermal, hydraulic, mechanical, chemical and gas performance; how they should be emplaced; the dimensions of the components; the materials to be used and the acceptable tolerances), prepared as a basis for development of the detailed design.

This approach is consistent with, although slightly modified from, structures used by Posiva and SKB in production reports describing the KBS-3V system (Posiva, 2012; SKB, 2010), and is also consistent with the Vee Model developed by Forsberg and Mooz (1991). At all levels, the design basis includes requirements and the conditions under which these requirements must be met.

3.2 Reference and Experiment Designs

In the DOPAS Project, a distinction has been made between reference and experiment designs:

- The term “reference design” is used to denote the design of a plug/seal within a disposal concept, i.e., the design used to underpin the safety case or licence application.
- The term “experiment design” is used to indicate the design of the plug/seal being tested, e.g. the designs of the plug/seal being full-scale tests conducted in the DOPAS Project.

Experiment designs are typically modified versions of reference designs, with the modifications made to investigate specific aspects of the design during the experiment. In particular, there are differences in the boundary conditions between the experiment designs and reference designs. These include the number of plugs and seals in the actual repository (just one plug/seal for the experiments compared to many tens of plugs/seals for the repository) and the impact on the construction of these plugs and seals (for example cost constraints), and the acceptability, for experiments, to use monitoring instrumentation within the plug/seal structure. Other differences generally arise as a result of experiment-specific objectives, for example to test alternative designs and compare the performance with the reference designs (e.g., POPLU is a test of an alternative conceptual design for the deposition tunnel plug in the KBS-3V concept), or to test planned modifications in the reference design (e.g., DOMPLU, one aspect of which is testing the use of concrete without reinforcement).

During the initial stages of design development, experimental designs are, by necessity, more detailed than the reference designs that they are testing. For example, reference designs may only be developed to the conceptual level. The testing of the conceptual design at the detailed level in a full-scale experiment allows requirements to be clarified and to establish feasibility for one or other design solution. Testing of this sort is sometimes referred to as *concurrent engineering*, i.e. the development of a design at multiple levels of detail at the same time (NASA, 1995; Carter and Baxter, 1992). The results of testing an experimental designs may lead to an updated reference design basis.

3.3 Compliance of Designs with the Design Basis

Compliance of designs with the design basis may be considered as comprising both verification and validation (NASA, 1995). Verification consists of proof of compliance with design specifications, and may be determined by, for example, a test, analysis, demonstration or inspection (e.g. measurement of slump flow to determine rheological properties of a concrete). Validation consists of proof that the system accomplishes its purpose. It is usually much more difficult (and much more important) to validate a system than to verify it. Strictly speaking, validation can be accomplished only at the system level, while verification must be accomplished throughout the entire system hierarchy (NASA, 1995). Using this concept of validation, the term is most readily applied to compliance of plug/seal designs with the safety functions for these sub-systems in the overall disposal concept (i.e., the repository system level).

The strategies and approaches used by WMOs to demonstrate compliance of the reference designs of plugs and seals to the design basis include:

- Full-scale Testing: Full-scale testing is the main strategy adopted by WMOs to compliance demonstration of plugs and seals. Full-scale experiments include demonstration of technical feasibility, tests of performance, and combined technical feasibility and performance tests.
- Quantitative Approaches to Compliance Demonstration: The German programme has developed a quantitative approach to compliance demonstration in which the loads on a

structure are compared to the ability of a structure to perform under the induced loads, with uncertainty accounted for by the application of quantitative performance criteria modified to account for uncertainty and to provide an additional safety margin.

- Construction Procedures: WMOs have different approaches to describing the use of construction procedures for compliance demonstration. Some describe construction procedures as an important element of compliance demonstrations, and others consider it to be part of quality control during repository implementation. In any case, the focus of quality control relies to a large extent on the practical experiences gained during “compliance demonstration”.
- Monitoring: WMOs have different approaches to the use of monitoring as part of compliance demonstration strategies for plugs and seals. Some WMOs have not made firm decisions on how to monitor repository plugs and seals (e.g., SKB), while others are considering monitoring of repository plugs and seals (e.g., through instrumentation) to provide for compliance demonstration (e.g., Posiva).

4 The Design Basis of the DOPAS Plugs and Seals

4.1 Safety Functions and Conceptual Designs

4.1.1 The Safety Functions and Conceptual Designs of the DOPAS Plugs and Seals

FSS Experiment Design Basis

The safety functions of the drift and ILW disposal vault seal are:

- To limit water flow between the underground installation and overlying formations through the access shafts/ramps.
- To limit the groundwater velocity within the repository.

The main objective of the FSS experiment was to develop confidence in, and to demonstrate, the technical feasibility of constructing a full-scale drift or ILW disposal vault seal. As such, the experiment was focused on the construction of the seal, and the materials were not saturated or otherwise pressurised. Other experiments that investigate saturation phenomena (e.g., the REM experiment) were undertaken by Andra in parallel with the FSS experiment.

The design basis for FSS was derived from a functional analysis of the safety functions specified for the seal. The FSS design and construction was contracted to a consortium, and the design basis was captured in the technical specification produced by Andra in the tendering process for the experiment. The design basis contains requirements on each component of the experiment, and also on the site, on monitoring, and on procedures to be applied during implementation of the experiment.

EPSP Experiment Design Basis

The safety functions of tunnel plugs in SÚRAO’s reference design are to:

- Separate the disposal container and the buffer from the rest of the repository.
- Provide a safe environment for workers.
- Provide better stability of open tunnels adjacent to backfilled disposal tunnels containing emplaced waste.

EPSP is an on-going experiment of a tunnel plug, with the focus of the experiment being on development of fundamental understanding of materials and technology, rather than testing of the reference design. This is because the Czech geological disposal programme is in a generic phase and designs are at the conceptual level. EPSP consists of a pressure chamber, an inner concrete plug, a bentonite zone, a filter, and an outer concrete plug. Concrete walls were used to facilitate emplacement of the experiment. The experiment has been pressurised with air, water and slurry.

The design basis identifies requirements on each component of the experiment (including the host rock), plus general requirements on the experiment, on materials, on technology and on the pressurisation system. Key aspects of the experiment are to evaluate the use of glass-fibre-reinforced low-pH shotcrete for the concrete plugs, and pellets composed of Czech bentonite for the bentonite zone.

DOMPLU Experiment Design Basis

In the KBS-3V method developed by SKB for disposal of spent fuel in crystalline host rock, deposition tunnels are closed with a deposition tunnel end plug. The main functions of the deposition tunnel plugs are to provide a barrier against water flow from the backfilled deposition tunnel and to confine the backfill in it during the operational period of the repository of at least 100 years. As such, they only have a "short-term" function.

The main components of the current SKB reference design for a deposition tunnel plug include a dome-shaped reinforced plug made of low-pH concrete, a bentonite watertight seal, a filter made of sand or gravel, and a backfill end zone (or transition zone) used to manage the swelling pressure loads on the plug. The plug also contains drainage, cooling and grouting pipes, as well as concrete beams to aid construction.

DOMPLU is a full-scale experiment of the reference deposition tunnel plug in SKB's repository design. The DOMPLU experiment is part of an on-going testing and demonstration programme and will help to reduce uncertainties in the performance of deposition tunnel plugs, and to decrease uncertainties in the description of the initial state of the deposition tunnel plugs (i.e., the state of the plug when all components of the plug or seal have been constructed). Specific objectives for the experiment include further development of water tightness requirements on deposition tunnel plugs and plug production requirements. The main difference between DOMPLU and the reference deposition tunnel plug is the use of unreinforced low-pH concrete instead of reinforced low-pH concrete for the dome structure.

POPLU Experiment Design Basis

In Posiva's reference concept the deposition tunnel plug and backfill are considered together as "sealing structures of deposition tunnels". The safety functions of the sealing structures are to:

- Contribute to favourable and predictable mechanical, geochemical and hydrogeological conditions for the buffer and canisters.
- Limit and retard radionuclide releases in the possible event of canister failure.
- Contribute to the mechanical stability of the rock adjacent to the deposition tunnels.

Of the above safety functions, the deposition tunnel plug is not required to limit and retard releases, but the plug design should be such that it does not reduce the performance of the backfill. The reference design for deposition tunnel plugs in Posiva's concept is the same as SKB's (i.e., the dome-shaped design).

The design basis for the reference deposition tunnel plug has been captured in Posiva's VAHA requirements management system as a hierarchy of requirements. VAHA concentrates on post-closure requirements and, therefore, the majority of the requirements on deposition tunnel plugs focus on how the deposition tunnel plug contributes to post-closure safety, i.e., by keeping the backfill in place during the operational phase and ensuring that the plug does not significantly affect the post-closure performance of the backfill.

POPLU is an on-going full-scale experiment of an alternative design of the deposition tunnel plug to that of the dome-shaped reference design, which could provide flexibility in both Posiva's and SKB's forward programmes. The POPLU design consists of a wedge-shaped reinforced concrete structure cast directly adjacent to a filter layer, which is positioned in front of a concrete tunnel backwall. The plug contains grouting tubes and bentonite circular strips at the rock-concrete interface to ensure water tightness.

The safety functions for POPLU are the same as those defined for the reference deposition tunnel plug in VAHA. An existing conceptual design for a wedge-shaped plug was used to define the requirements on POPLU.

ELSA Experiment Design Basis

ELSA is a programme of laboratory tests and performance assessment studies that will be used to further develop the reference shaft seal design for the German reference disposal concepts for repositories in salt and clay host rocks.

The reference concept for disposal of spent fuel, high-level waste (HLW), ILW, graphite and depleted uranium in Germany is based on a repository design for the Gorleben salt dome. The Gorleben repository concept envisages two shaft seals, one in each shaft, and four drift seals. The primary safety function for shaft and drift seals is to provide a sufficiently low hydraulic conductivity to avoid brine paths into the repository and the movement of radionuclides out of it. Work in the DOPAS Project has focused on shaft seals.

At the current stage of the German programme, the design basis for the shaft seal is based on regulatory requirements, mining law, experience from the sealing of mine shafts, previous full-scale testing of shafts, and recent performance assessment studies. The design basis captures this understanding at a high level and groups requirements into those relating to regulatory safety requirements, safety and verification concepts (requirements related to the principal safety functions and performance of the seal), technical functional verification (requirements related to the design and demonstration of compliance with safety and verification concepts), site-specific boundary conditions, and other requirements.

The reference conceptual design for a shaft seal at Gorleben includes three sealing elements consisting of different materials to ensure that the performance of the seal system meets requirements. The design of these sealing elements takes into account the different kinds of salt solutions present in the host rock and the need to avoid chemical corrosion. These sealing elements are a seal located at the top of the salt rock and made of bentonite, a second seal made of salt concrete, and a third seal made of sorel concrete which is located directly above the disposal level. The sealing elements are designed to maintain their functionality until the backfill in the repository drifts, access ways and emplacement fields have sealed in response to compaction driven by host rock creep.

4.1.2 Impact of Host Rock on the Design Basis

The safety functions of plugs and seals differ between waste management programmes depending on the geological environment, disposal concept, and approach to the safety case. Typical safety functions include confinement of the tunnel backfill and prevention of groundwater flow through disposal areas. In addition to the plugs and seals considered in the DOPAS Project, other safety functions for plugs and seals may be recognised, e.g., prevention of access to the repository after it is closed.

The type of host rock plays an important role in defining the design requirements for plugs and seals. In clay host rocks, seals need to ensure that low hydraulic conductivities are achieved to match those of the clay until the host rock and backfill have re-established *in situ* hydraulic performance, which may be a period of thousands of years. Removal of host rock lining may be necessary to avoid flow along the interface between the lining and the rock. In crystalline rocks, plugging/sealing shafts and tunnels aims to achieve a low hydraulic conductivity, which requires, amongst other requirements, grouting of the contact between the plug/seal material and the rock. Deposition tunnel plugs are generally required until the backfill saturates (which may be of the order of ~100 years). For salt rocks, any sealing must be introduced in such a way that brine migration through the repository access ways to the waste canisters is avoided until the backfill is sufficiently compacted, which may be a period of hundreds of years.

4.2 Design Specifications

The full design basis for each experiment includes numerous design specifications, which form the basis for the detailed designs of the experiments. Many of these specifications are common to several of the experiments. These specifications can be considered in terms of thermal, hydraulic, mechanical, chemical, gas and radionuclide transport processes. Some key requirements include:

- Thermal Requirements: In the DOPAS design bases, requirements on the maximum curing temperature of concrete components of plugs and seals are specified to limit the development of cracks owing to thermal stress development during hydration of the concrete. For example, the maximum temperature of the concrete and shotcrete containment walls in FSS shall not exceed 50ºC. The DOMPLU design basis requires that cooling pipes shall be installed and cooling of concrete shall be performed from the start of concreting. A requirement for DOMPLU that the temperature of the concrete during concrete hydration shall not exceed 20ºC was also set.
- Hydraulic Requirements Hydraulic requirements have been specified for all plugs and seals in the DOPAS Project. For the Cigéo repository concept, the hydraulic conductivity of the seal must be equal to or less than $1x10^{-9}$ m/s, to meet the performance requirement that groundwater flow is predominantly through the host rock. However, the requirement for the swelling clay core currently set in the Andra programme is $1x10^{-11}$ m/s. This is regarded as a realistically achievable value, and the current testing programme is evaluating whether this target value can indeed be met. For the crystalline rock cases, especially the deposition tunnel plug designs developed by SKB and Posiva, the requirement is that the water flow does not lead to piping and erosion of the deposition tunnel backfill and buffer, leading to a hydraulic conductivity of $1x10^{-11}$ m/s being specified for the plug concrete. This is significantly lower than required to manage groundwater flow across the plug. In addition, requirements on the hydraulic performance of plugs and seals also need to consider the overall flux of water across a plug, including through the (concrete) plug, through the contact zone with the host rock, through the EDZ and through the intact host rock. DOMPLU is investigating the water leakage value that can be achieved for a plug. The

target value for the acceptable leakage through the plug is presently adopted to be "as low as possible". Recent calculations predicted an allowed maximum leakage of 0.1 l/min to prevent loss of bentonite from the buffer and backfill (Börgesson *et al.*, 2015). A water leakage rate has not yet been set for deposition tunnel plugs by Posiva but a rate is likely to be set in the future.

- Mechanical Requirements: The strength of plugs and seals is specified to withstand the loads on them, and is typically expressed as the compressive strength of concrete components. The loads can vary owing to the depth of the plug or seal location (e.g., 7 MPa for SKB, SÚRAO and Andra; 7.5 MPa for Posiva). These loads include contributions from the hydrostatic pressures at depth as well as swelling pressures from the backfill.
- Chemical Requirements: Many of the plugs and seals considered in the DOPAS Project are composite structures with concrete components to provide mechanical strength and bentonite components to provide low hydraulic conductivity. For these plugs the concrete pore water is required to be of low pH to reduce any impact on the swelling pressure of the bentonite. This is either expressed as a pH less than 11, or as a calcium silica ratio.
- Gas Requirements: There are no gas permeability requirements for reference designs of plugs and seals represented in the DOPAS Project. However, SKB and Posiva are considering implementation of requirements concerning gas migration through deposition tunnel plugs, because, should gas/oxygen migrate through the plug and backfill into the tunnel deposition holes, canister corrosion could be affected.
- Radionuclide Migration Requirements: Most of the reference designs of plugs and seals represented in the DOPAS Project do not have radionuclide containment or retardation functions. DOMPLU, POPLU and EPSP are designed to hold the backfill in place, although a low leakage rate through these structures is required. FSS represents a hydraulic structure with a low hydraulic conductivity to ensure that any radionuclide migration is through the host rock and not through the seal. For the shaft seal in the German concept, the safety function includes a statement for the seal to "*avoid … the movement of radionuclides out of [the repository]*". This is reflected in the more detailed design basis by inclusion of a requirement to use material with high sorption capacity in the shaft seal components.

5 The DOPAS Design Basis Workflow

Work on the design basis in the DOPAS Project has allowed assessment of current practice with regard to both the process used to develop and describe the design basis, and the content of the design basis of plugs and seals. The design basis is developed in an iterative fashion with inputs from regulations, technology transfer, tests and full-scale demonstrations, and performance and safety assessments. A generic process, the "DOPAS Design Basis Workflow", has been developed for development of the design basis for plugs and seals (Figure 3.1). This workflow is structured to be consistent with a design hierarchy consisting of Conceptual, Basic and Detailed design stages (IAEA, 2001).

At the conceptual design stage, the design basis for a plug/seal includes the stakeholder requirements that define the overall objectives of geological disposal (e.g., the safety criteria that must be met), safety functions for each of the elements of the disposal system (e.g., for plugs and seals, this may include limiting groundwater flux through the repository), and the sub-system requirements on each of the components of a plug/seal (e.g., the role of a concrete dome or watertight seal and the plug lifetime). The safety functions are dependent on decisions made on the safety concept, and sub-system requirements are dependent on conceptual design options. Consideration of the site environmental conditions and loads acting on the structures allows conduct of a performance assessment, the results of which feed into a compliance assessment used to ascertain whether the system and sub-system requirements have been met by different conceptual design options. The outcome is selection of a conceptual design of a plug/seal, and elaboration of preliminary design requirements to be tested during development of the basic design.

At the basic design stage, preliminary design requirements are used as the basis for developing preliminary basic designs. During the DOPAS Project, basic designs have been tested through full-scale tests. This has required the development of a set of working assumptions for the experiment design specifications, which are used to design the experiment and to assess its performance. The results of full-scale tests provide further support to design decisions, especially the identification of design solutions that represent the most appropriate technique and the most appropriate performance. Compliance assessment at the basic design stage considers the extent to which the experiment results meet the experiment design specifications. Design requirements may be revised based on learning from the experiments, and the result of the compliance assessment can be used to revise the reference design requirements. In parallel, detailed design specifications are prepared based on working assumptions and experiment design specifications used as the basis for the full-scale test. The outcome of a satisfactory compliance assessment is selection of a basic design, and elaboration of detailed design specifications to be tested during development of the detailed design.

At the detailed design stage, the detailed design specification, safety assessment and operational constraints are considered in order to establish quality control procedures and construction procedures. These allow development of a detailed design which may be subject to a commissioning test. In contrast to demonstration testing, the commissioning test is a trial of the plug/seal as it is expected to be implemented in the repository. Consideration may be given to monitoring of these tests over long periods, for example Andra are planning an Industrial Pilot during the early stages of repository operation, which will run for as long as feasible, potentially decades. Compliance assessment of the commissioning test could lead to a revision of the design specifications, for example to write them in a manner that is amenable to checking using quality control or construction procedures. Compliance testing may also identify the need for revisions to the detailed design, which may, therefore, also lead to a need for further testing. Once the compliance assessment is acceptable, the plug/seal detailed design can be finalised.

6 Conclusions

Plugs and seals are generally required to achieve either combined or stand-alone safety functions; these include confinement of the tunnel backfill in place, the need to prevent water flow through waste repository areas, and the need to prevent access to the disposal facility after it is closed. The safety functions of plugs and seals differ between waste management programmes depending on the geological environment and disposal concept.

The design basis is developed in an iterative fashion with inputs from regulations, technology transfer, tests and full-scale demonstrations, and performance and safety assessments. All of these tools have been used to develop an overall “DOPAS Design Basis Development Workflow” consistent with the three design stages (conceptual design, basic design, and detailed design). The development of the design basis is generally undertaken in parallel with development of the design and development of the safety case rather than as a sequential process.

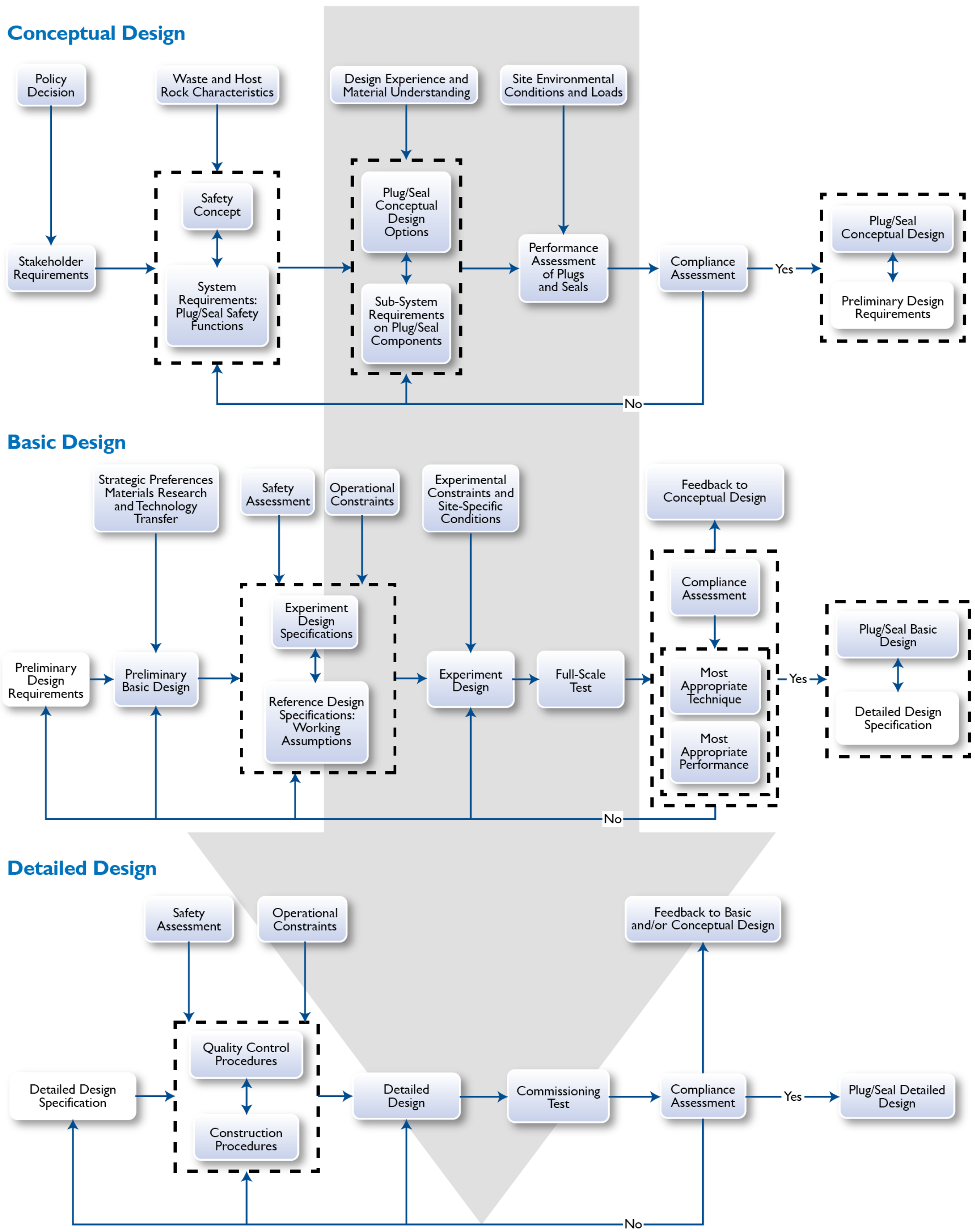

Figure 6-1. The DOPAS Design Basis Workflow.

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