Design Basis of Plugs and Seals: The DOPAS Design Basis Workflow

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Work Package 2 (WP2) of the DOPAS Project was focused on the development of the design basis for plugs and seals. Work on the design basis 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 learning provided by WP2 has been used to describe a generic process for development of the design basis for plugs and seals called the "DOPAS Design Basis Workflow". This paper provides a description of the DOPAS Design Basis Workflow. The Workflow is structured to be consistent with the three broad design stages: conceptual design, basic design and detailed design. The key observations are that the requirements and design development processes are integrated and iterative, and that requirements are developed in parallel with designs rather than as a sequential process.

1 Introduction

Work Package 2 (WP2) of the DOPAS Project was focused on the development of the design basis for the plugs and seals. The work in WP2 was used to develop generic guidance on the development of the design basis in terms of a DOPAS Design Basis Workflow. This paper provides a description of this workflow and its components.

2 The Design Basis of Plugs and Seals

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).

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

- Stakeholder requirements: These 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: These are requirements on the disposal system that result from adoption of a specific conceptual design, i.e., the safety functions provided by the disposal

system and that 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 detailed 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.

3 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. The learning provided by WP2 has been used to describe a generic process for development of the design basis for plugs and seals called the "DOPAS Design Basis Workflow" (Figure 1). This Workflow is structured to be consistent with a design hierarchy consisting of conceptual, basic and detailed design stages (IAEA, 2001).

In the descriptions below, terms used in the Workflow are highlighted in ***bold italic*** font upon first use. These terms also defined in the glossary of the DOPAS WP2 summary report (White and Doudou, 2016).

3.1 Design Basis Development during Conceptual Design

Conceptual designs describe the general layout of a repository structure, including the different repository components and how they are arranged, and the type of material used for each component (e.g., concrete, bentonite and/or gravel). In a conceptual design, the environmental conditions (including rock characteristics) are presented in generic terms, for example by describing the nature of the processes occurring rather than quantifying the processes. The performance of the components and the overall structure are described qualitatively.

The starting point for development of a design basis for a plug/seal conceptual design is a ***policy decision*** to manage radioactive waste through geological disposal. Following a national policy decision, ***stakeholder requirements*** that define what must be achieved by geological disposal are established. Stakeholder requirements include principles, regulations and criteria defined in regulatory guides and policy statements. In addition, stakeholder requirements could include specific approaches (e.g., a reversibility principle) that must be considered in the repository design.

Consideration of the stakeholder requirements, and the ***waste and host rock characteristics***, leads to the development of a ***safety concept*** upon which the disposal system requirements can be defined. The main functions of a disposal system are isolation and containment of the waste. These functions are provided by a combination of the geological barrier and the engineered barrier system. Elaboration of this safety concept allows parallel development of the ***system requirements***, including definition of ***plug/seal safety functions***.

Once the safety functions of the plug/seal have been defined, the conceptual design of the structure can be developed. This is typically progressed through consideration of a range of ***plug/seal***

conceptual design options. These design options would be identified through consideration of existing knowledge including ***design experience*** and general ***material understanding***. Development of the conceptual design options allows parallel development of ***sub-system requirements on plug/seal components***, i.e., elaboration of the role of each of the components in the design options of a plug/seal.

Consideration of the ***site environmental conditions*** in which the structure might have to perform, and conversion of these conditions into the ***loads*** that the structure might have to withstand will provide a basis for ***performance assessment of plugs and seals*** focused on the proposed conceptual design options. This performance assessment will take place through a programme of laboratory testing and computer modelling.

Evaluation of the outcome of the plug/seal performance assessment studies, through conduct of a ***compliance assessment***, allows the conceptual design options to be evaluated and a ***plug/seal conceptual design*** to be selected. At this early stage in design basis development, it is expected that the compliance assessment will consider a few key criteria in choosing between the design options. Once a plug/seal conceptual design has been selected and confirmed as appropriate using compliance assessment, the design can be documented. In parallel with the documentation of the conceptual design, ***preliminary design requirements*** can be elaborated. Preliminary design requirements are an initial set of qualitative statements describing the qualities or performance objectives for plug/seal components that will be tested in experiments. These will be identified through analysis of the performance assessment results during the compliance assessment, and by adding further detail to the sub-system requirements on plug/seal components.

3.2 Design Basis Development during Basic Design

In a basic design, the components in the conceptual design are described in more detail with an approximate quantitative specification of geometry and material parameters. The properties of the environmental conditions are presented in detail, which requires characterisation of the site or elaboration of the assumptions underpinning the design. Performance is described quantitatively.

The starting point for development of a design basis for a plug/seal basic design is the set of ***preliminary design requirements*** developed in parallel with the elaboration of the plug/seal conceptual design. ***Strategic preferences***, the results from ***materials research***, and ***technology transfer*** are considered during the development of a ***preliminary basic design*** based on the preliminary design requirements.

The key aspect of the basic design phase for plugs/seals, as undertaken within the DOPAS Project, is the use of full-scale testing as a means of further developing the design basis and the associated design. In order to conduct a full-scale experiment of the preliminary basic design, the requirements on the experiment need to be defined, and these requirements form a set of ***experiment design specifications*** (quantitative statements describing the detailed requirements on plug/seal components) that are developed in parallel with a set of ***working assumptions for the reference design specifications***. The working assumptions will form the basis for detailed design specifications produced as an output of this basic design development process taking advantage of the full-scale testing process. The elaboration of the experiment design specifications and the set of working assumptions for the reference design specifications is supported by the ***safety assessment*** calculations undertaken as part of the safety case, and by consideration of any ***operational constraints*** that affect how the plug/seal must be installed in the repository.

Following the elaboration of experiment design specifications, an ***experiment design*** can be developed. This will take account of ***experimental constraints*** and ***site-specific conditions*** encountered at the actual location of the experiment. Experimental constraints may result in changes to the experiment design compared to the reference design and may also impact the manner in which the experiment is undertaken.

After establishing an experiment design, ***a full-scale test*** may be undertaken. The outcomes of full-scale tests should be evaluated using a structured ***compliance assessment*** methodology. This would involve consideration of the full-scale test results on a requirement-by-requirement basis, and assessment of how closely the test met the specification. Full-scale testing also provides an opportunity for selection of the most appropriate design of plug/seal design through consideration of the ***most appropriate techniques*** applied in the test and the ***most appropriate performance*** for the design being tested.

Should the compliance assessment show that the design does not fully meet the design specifications, or the optimisation evaluation conclude that the experiment design does not represent the most appropriate technique or the most appropriate performance, the iterative design development cycle can be revisited. A decision might be made to change the plug/seal conceptual design, the preliminary design requirements, the preliminary basic design, the experiment design specifications and/or the working assumptions for the reference design specifications, or the experiment design for further full-scale testing.

Once the outcome from the compliance assessment and optimisation evaluations support further development of the preliminary basic design, this option is taken forward as the ***plug/seal basic design*** and the preliminary design requirements are adopted as the final design requirements. In parallel with documentation of the plug/seal basic design, the working assumptions for the reference design specifications are used to elaborate a set of ***detailed design specifications*** upon which detailed design work is based.

3.3 Design Basis Development during Detailed Design

In a detailed design, the concept is presented in such detail that it can be constructed, i.e., it provides precise information on all aspects of the structure's components. The starting point for the detailed design development is the information from full-scale testing of the basic design and the set of ***detailed design specifications*** that describe the expected quantitative requirements on the design.

In order to convert the basic design into a detailed design that can be implemented in the repository, ***quality control procedures*** and ***construction procedures*** need to be written, and the design tested again (if required) to ensure that following these procedures will result in a plug/seal that meets the design specifications. Quality control procedures will define the manner in which the implementer will ensure that the plug/seal meets the design specifications within the given tolerances. This includes listing of the standards that will be followed during construction. Construction procedures will define the manner in which the plug/seal will be implemented. For example, these procedures will define the approach to excavation of the plug/seal location, mixing of concrete and the installation of the components of the plug/seal.

Elaboration of quality control and construction procedures is supported by the ***safety assessment*** calculations undertaken as part of the safety case and will take account of any ***operational constraints*** that affect how the plug/seal must be installed. These would be taken into account during the detailed design stage, and include any processes that respond to requirements from operational safety or other operational constraints including the feasible underground working methods in the limited dimensions of the underground space.

Elaboration of the quality control and construction procedures would provide the additional basis for developing a ***detailed design***. This design would be the basis for a ***commissioning test*** ahead of implementation (if required based on the technical outcome of previous full-scale tests). The results of the detailed design commissioning test will be checked by a final ***compliance assessment***.

Although it would be expected that the commissioning test would be mainly confirmatory, the compliance assessment will check that all of the design specifications in the requirements hierarchy are met, and may therefore lead to revisions in design specifications, quality control and construction procedures, or detailed design. Where these are minor, it would be expected that these can be implemented in the design basis without the need for a further iteration of the design cycle. In such a case, the detailed design specifications would be adopted (with necessary revisions) as the final design specification and the detailed design adopted as the final ***plug/seal detailed design*** (again with revisions identified through the full-scale test). Alternatively, major compliance issues may lead to a need for revision to the design specifications, quality control and construction procedures, and/or the detailed design, and further full-scale testing.

Major compliance issues could also lead to reconsideration and ***feedback to basic and/or conceptual design***, if the full-scale tests identified any fundamental issues with the design. Given the iterative nature of the development of the design basis as described above, in particular the inclusion of an optimisation step as part of the process for developing the basic design, it is unlikely that there would be a need to reconsider the basic and conceptual designs at the detailed design stage.

4 Conclusions

Work on the design basis in the WP2 of 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. As such, there are general conclusions to be drawn that are relevant to the design basis for other aspects of repository design as well as lessons specific to plugs and seals. The learning provided by WP2 has been used to develop and describe a generic process for development of the design basis for 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. 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.

Although the DOPAS Design Basis Workflow is based on the design basis work undertaken for plugs and seals within the DOPAS Project, the Workflow is generic in nature, and could be applied to the design of other repository sub-systems.

5 References

IAEA (2001). Technical Considerations in the Design of Near Surface Disposal Facilities for Radioactive Waste. IAEA-TECDOC-1256.

NASA (1995). Systems Engineering Handbook. SP-610S.

Robertson, S. and Robertson, J. (1999). Mastering the Requirements Process. Addison-Wesley Publishing Co., Inc., Reading, MA.

White, M.J. and Doudou, S. (2016). DOPAS Work Package 2, Deliverable D2.4. WP2 Final Report: Design Basis for DOPAS Plugs and Seals, Version 1, February 2016.

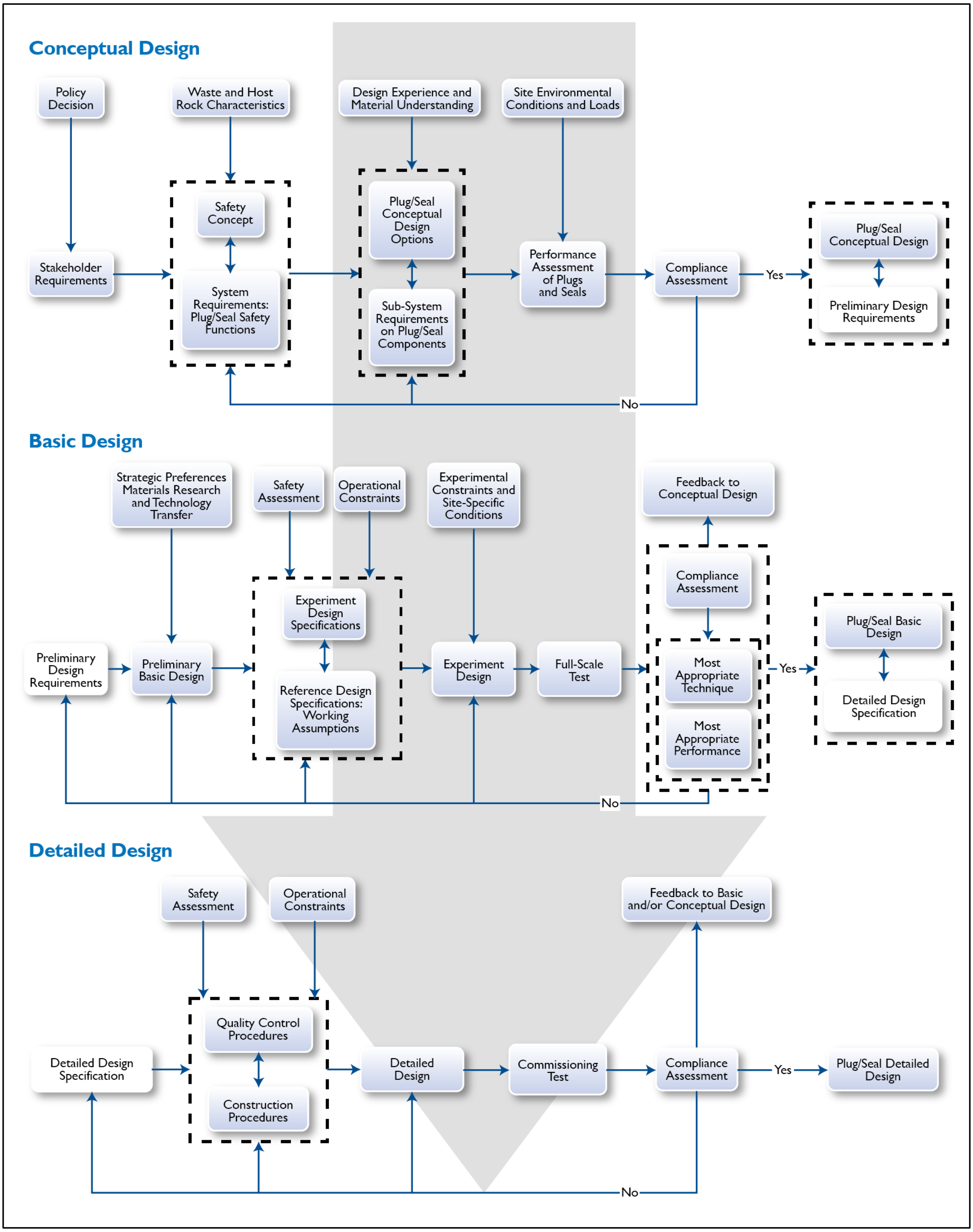

Figure 1: The DOPAS Design Basis Workflow, which illustrates the iterative development of the design basis, undertaken in parallel with the development of conceptual, basic and detailed designs. Dashed boxes are used to show activities undertaken in parallel.