SAFETY STATEMENTS AS A TOOL TO INCORPORATE GEOSCIENCE IN THE SAFETY AND FEASIBILITY CASE

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Abstract

In a safety and feasibility case, statements concerning the safety and feasibility of a proposed facility need to be substantiated to degree that is adequate to justify a positive decision to proceed from one programme stage to the next. Substantiation takes the form of evidence, arguments and analyses, derived, to a large extent, from geoscience. An important set of safety statements is that describing how the various characteristics of the geological environment underpin the safety functions of a repository. This paper gives examples of safety statements underpinned by geoscience and the potential use of such statements in safety assessment and in the safety and feasibility case. In particular, in order to illustrate the propagation of uncertainties from low-level statements to higher-level statements, the impact of a potential future change to a colder climate is considered. The use of safety statements provides a tool to determine in a systematic manner how the safety functions of the repository might be affected by such a change and to derive assessment cases to quantify the impact on humans of any radionuclides and other contaminants released from the repository.

Background

In Belgium, three main categories of conditioned radioactive waste (termed A, B and C) are defined by radiological and thermal power criteria. Category A waste – short-lived and low and intermediate level waste – will be disposed in a near-surface facility, whereas Category B and C wastes – high-level and other long-lived radioactive waste – will be disposed in a deep geological repository.

The repository design for vitrified high-level waste and spent fuel has been extensively reviewed and modified since the earlier SAFIR 2 report (ONDRAF/NIRAS 2001a,b), although the reference host rock remains Boom Clay. The current design is illustrated in Figure 1 and described in more detail in Bel *et al.* (2005). Carbon steel overpacks containing the wastes are surrounded by a concrete buffer contained in stainless steel envelopes. The entire assemblies are emplaced in galleries located centrally within the Boom Clay layer. The primary containers, overpacks and buffer together comprise the engineered containment barriers. The galleries are lined with concrete wedge blocks and shafts and the access gallery are backfilled with a cement-based material. The safety concept for this design, defined as the integration of the major safety functions, features and measures, and management processes on which the long-term safety of a disposal system rests, is illustrated in Figure 2.

Figure 1. **The disposal gallery design for vitrified high-level waste**

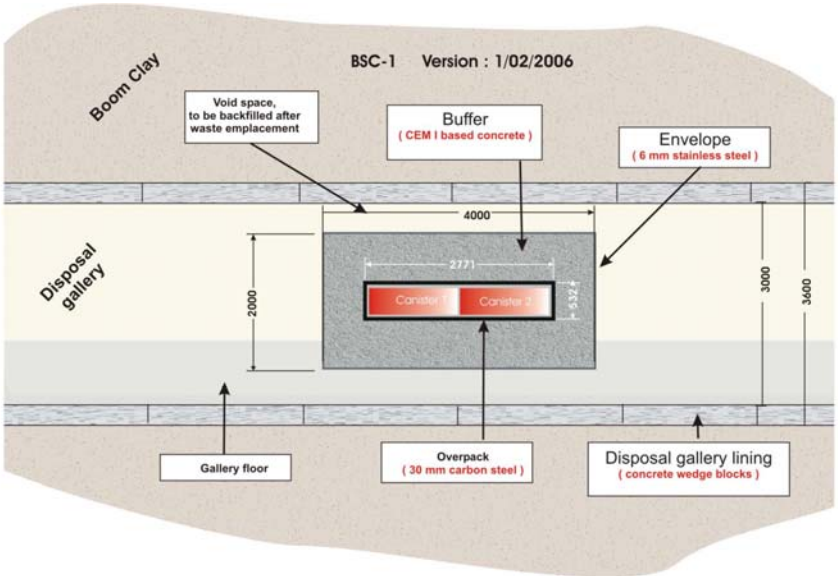
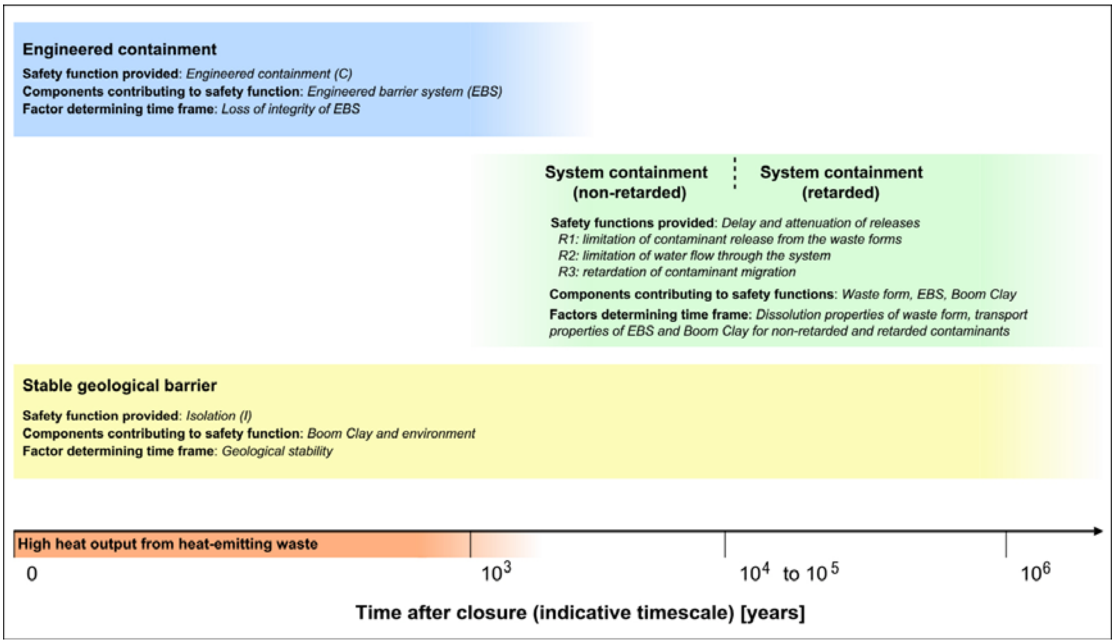


Figure 2. **The safety concept**

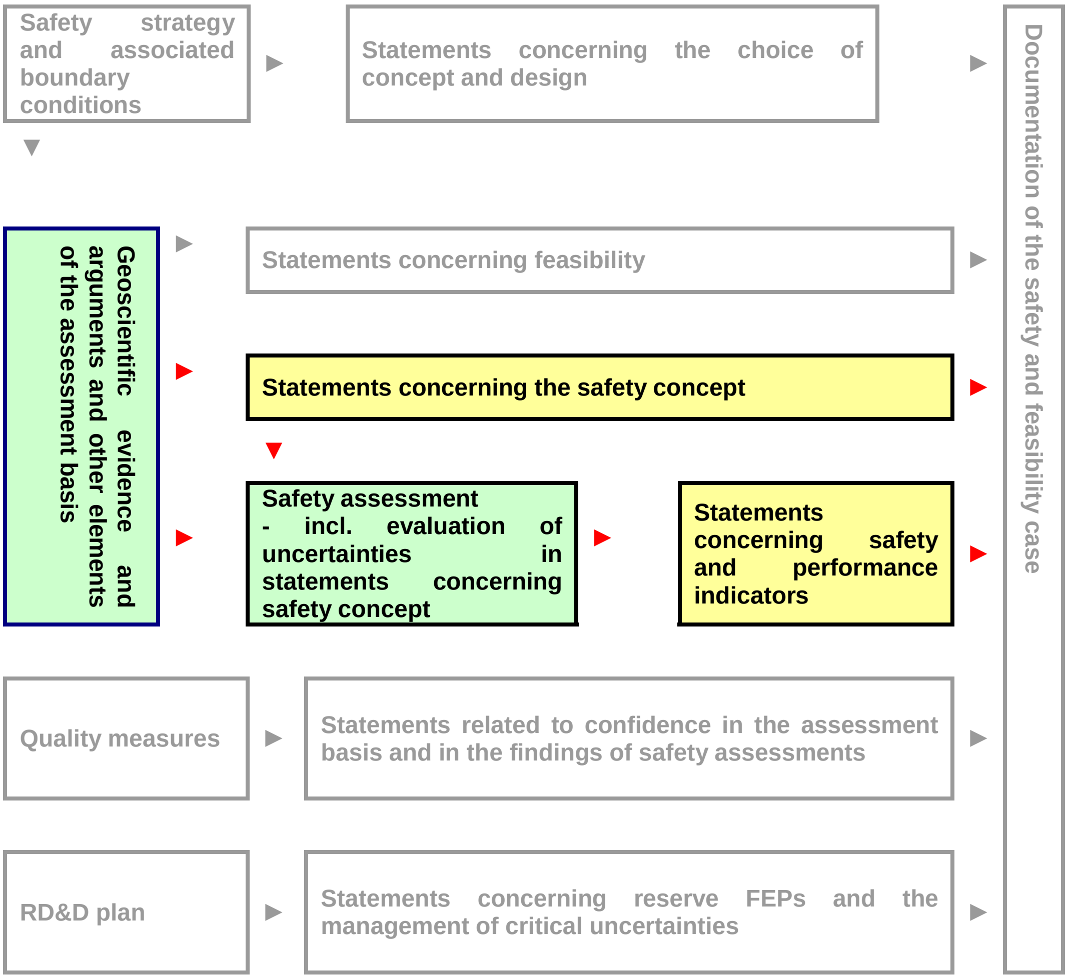


The next major milestone in the B&C programme requiring a formal safety assessment is the development of a safety and feasibility case, SFC 1, planned for 2013. ONDRAF/NIRAS is currently developing a plan for this safety and feasibility case (ONDRAF/NIRAS, 2008), as well as a safety strategy (ONDRAF/NIRAS, 2006) and a safety assessment methodology (ONDRAF/NIRAS, 2007).

Safety statements as building blocks of the safety and feasibility case

At the heart of a safety and feasibility case is a set of assertions regarding the safety and the feasibility of the disposal system, termed safety and feasibility statements, each of which must be supported. The focus of the present paper is on safety statements, although well-substantiated statements must also be made regarding the feasibility of implementing the chosen repository design according to design specifications, with due regard to engineering practicality, operational safety and cost. The types of safety and feasibility statements that will be made in future ONDRAF/NIRAS safety and feasibility cases, including SFC 1, are shown in Figure 3.

Figure 3. **Types of safety and feasibility statements and the evidence and analyses that underpin them – yellow background indicates statements of the type that may be underpinned either directly or indirectly (via safety assessment) by the geoscientific evidence and arguments of the assessment basis**



Safety (and feasibility) statements generally begin as hypotheses (e.g. statements of the type "the repository and/or its components **should** ..."), which may initially be tentative. These are developed into increasingly well-substantiated claims (statements of the type "the repository and/or its components **are expected to** ...") as the design and implementation procedures are developed and optimised, and the evidence, arguments and analyses that underpin each statement are acquired or developed, key elements of which are geological evidence and arguments derived from geoscience.

Figure 3 indicates that geoscientific evidence and arguments and other elements of the assessment basis provide direct support for statements concerning the safety concept. For example, in the current safety concept for a repository for long-lived wastes in Belgium, the safety function of delaying and attenuating releases to the environment is underpinned by a range of favourable features of the Boom Clay, including that diffusion is expected to be the dominant transport mechanism if the rock is unperturbed, and that features of the Boom Clay that provide diffusion and retention are expected to be insensitive to most perturbations. Geoscientific evidence and arguments and other elements of the assessment basis also provide input to safety assessments, in the form of a description of the expected evolution of the disposal system, a description of associated uncertainties, and a toolbox to perform analyses of system performance and of safety. They thus, indirectly, underpin statements concerning the safety and performance indicators evaluated in these assessments.

Hierarchical organisation of safety statements

Safety statements are generally developed in a top-down manner, starting with the most general (highest-level) statements and progressing to increasingly specific (lower-level) statements. Lower-level statements are generally statements about what the proposed repository is designed or intended to do, or properties that it and its geological environment should have, in order to substantiate higher-level statements. Higher-level statements, such as the statements that define the safety concept, being more general in nature, can be formulated, early in the programme. Other more detailed statements gradually emerge as the programme proceeds, that is as the concept and design become better defined and more firmly established, and geoscientific evidence and arguments and other elements of the assessment basis are developed.

Figure 4 shows a preliminary example of a hierarchy of safety statements. All of these statements are of the types indicated with yellow background shading in Figure 3. The highest level safety statement (statement SS) is that:

> "*The disposal system and its environment conform to relevant regulatory targets/standards and general guidance concerning long-term safety via the safety functions that it performs over the required time frame*".

Underpinning this statements are statements SS 1 to SS 4, which concern the safety concept, and statements SS 5 and SS6, which concern the results of analyses of radiological and non-radiological long-term consequences (safety assessment). All the statements (SS1 to SS6) are underpinned by more specific statements based ultimately on geoscientific evidence and arguments and other elements of the assessment basis.

Figure 4 also shows how a "traffic lights" system is used to indicate the level of support judged to exist for each statement at a given programme stage, as a guide for RD&D planning. Three levels of support are distinguished:

- Red: Adequate support for the statement by the next programme milestone is likely to require changes in the planned RD&D Programme, or in the proposed design.
- Yellow: Adequate support for the statement is likely to be available by the next programme milestone, based on current work planned in the RD&D Programme.
- Green: Adequate support for the statement is judged to be already available.

Figure 4. **Example of the hierarchical organisation of safety statements**

- **SS The disposal system and its environment conforms to relevant regulatory targets/standards and general guidance concerning long-term safety via the safety functions that it performs over the required time frame.**
  - **SS 1** The disposal system and its environment **isolate** the waste to minimize the probability and consequences of human intrusion and human actions, and to protect against internal and external geodynamic events and processes.
    - **SS 1.1** The disposal system and its environment isolate the waste to reduce the likelihood and possible consequences of inadvertend human intrusion and human actions.
      - …
    - **SS 1.2** The disposal system and its environment isolate the waste to create stable conditions for the disposed waste and the system components and to protect against internal and external geodynamic events and processes.
      - …
  - **SS 2** The engineered barrier system of VHLW and spent fuel (is expected to) provide complete **containment** of radionuclides during the thermal phase, ensuring zero release.
    - **SS 2.1** The predicted corrosion depth, due to uniform corrosion/passive dissolution, does not exceed the thickness of the corrosion allowance layer.
      - …
    - **SS 2.2** The overpack has been designed to watertight and to withstand mechanical stresses during the thermal phase
      - …
  - **SS 3** The disposal system (is expected to) **delay and attenuate** releases to the environment during the "system containment phase", ensuring that releases remain below regulatory targets/standards and general guidance.
    - **SS 3.1** (In the reference scenario) the release of radionuclides by the HLW and SF waste forms has been quantified.
      - …
    - **SS 3.2** The host rock characteristics ensure a diffusion dominated transport
      - **SS 3.2.1** The host rock has a fine homogenous pore structure and a low hydraulic conductivity. External events and processes are expected not to significantly alter these characteristics.
        - **SS 3.2.1.1** The host rock has a fine homogeneous pore structure
        - **SS 3.2.1.2** The host rock has a low hydraulic conductivity
        - **SS 3.2.1.3** No significant variations of these properties are expected on the long term due to natural processes
        - **SS 3.2.1.4** No significant variations of these properties are expected on the long term due to processes related to the waste emplacement
      - **SS 3.2.2** The hydraulic gradient over the host rock is very low, and future events and processes are expected not to jeopardize this situation
        - …
      - **SS 3.2.3** The host rock possesses a self-sealing capacity to respond to mechanical disturbances. On the long-term, this self sealing is not jeopardised by perturbations
        - …
    - **SS 3.3** The host rock has favorable characteristics to ensure a retarded transport of radionuclides and contaminants.
      - …
  - **SS 4** **Dilution and dispersion** by the environment of the disposal system (biosphere and aquifers) can be sufficiently quantified for the SFC 1
    - …
  - **SS 5** Results from long-term **safety (PA) evaluations** confirm the safety of the disposal system
    - **SS 5.1** The uncertainties are identified and their impact assessed in safety assessment according to a pragmatic and well founded safety assessment methodology
      - …
    - **SS 5.2** Results of the long-term safety assessment calculations do not exceed any regulatory limit or guideline; complementary safety indicators confirm the safety and additional performance indicators explain the functioning of the repository system
      - …
  - **SS 6** **Complementary** (non-radiological) **calculations** show that the environmental impact of the repository system is acceptable
    - …

Figure 5 shows an example of the chain of increasingly more specific statements underlying the statement SS 3, that:

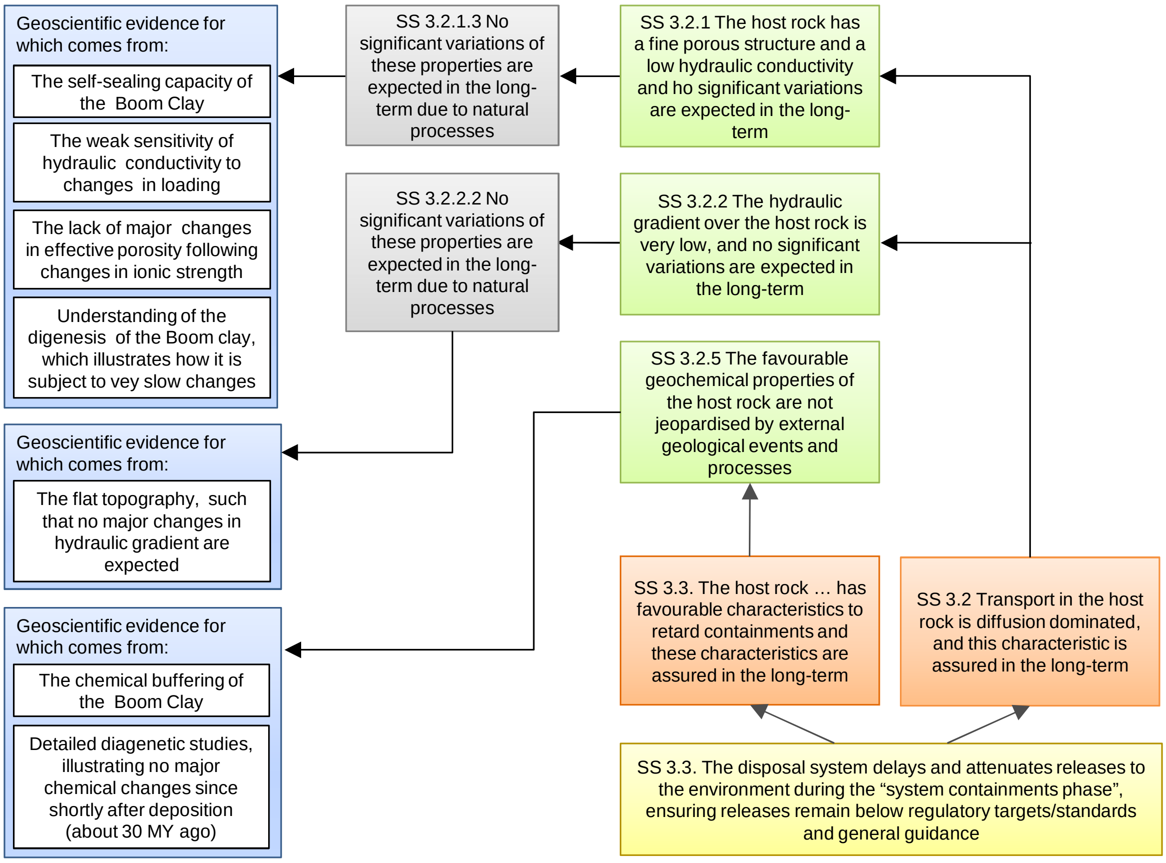
> "*The disposal system delays and attenuates releases to the environment during the "system containment phase", ensuring releases remain below regulatory targets/standards and general guidance*".

It illustrates how this statement is underpinned ultimately by a range of geoscientific evidence regarding the safety-relevant properties of the geological environment.

Propagation and classification of uncertainty

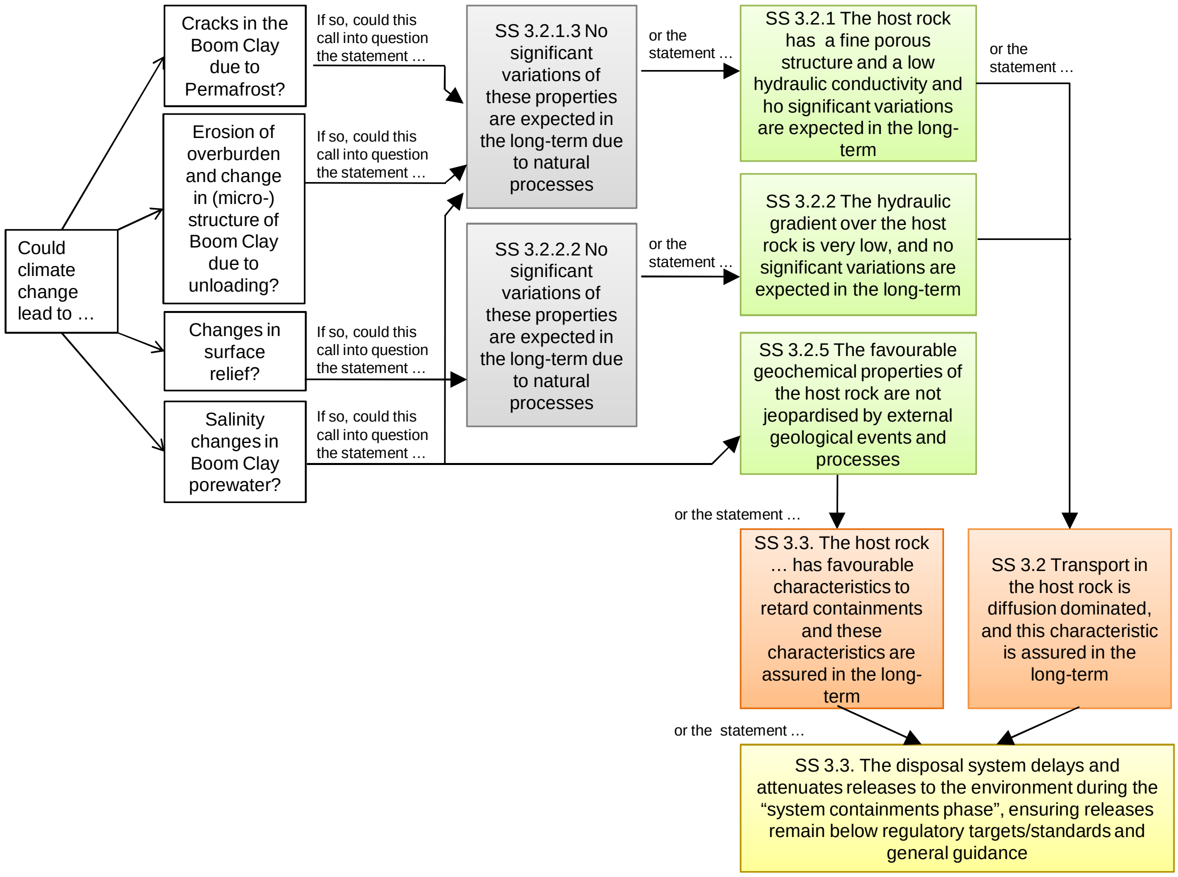
Because of geoscientific and other uncertainties, not all safety statements can necessarily be said to hold true with absolute certainty. Uncertainties generally begin at the lower levels of the hierarchy of safety statements (including uncertainties in the underpinning geoscientific evidence and arguments) and propagate to higher-level statements if they cast significant doubt on their validity. The most critical uncertainties are those that cast doubt on the highest level statements. Figure 6 shows an example of how uncertainties related to climate change (specifically a change to a colder climate) could propagate through the set of safety statements introduced in Figure 5.

Figure 5. **Example of geosciences evidence underpinning safey statements**



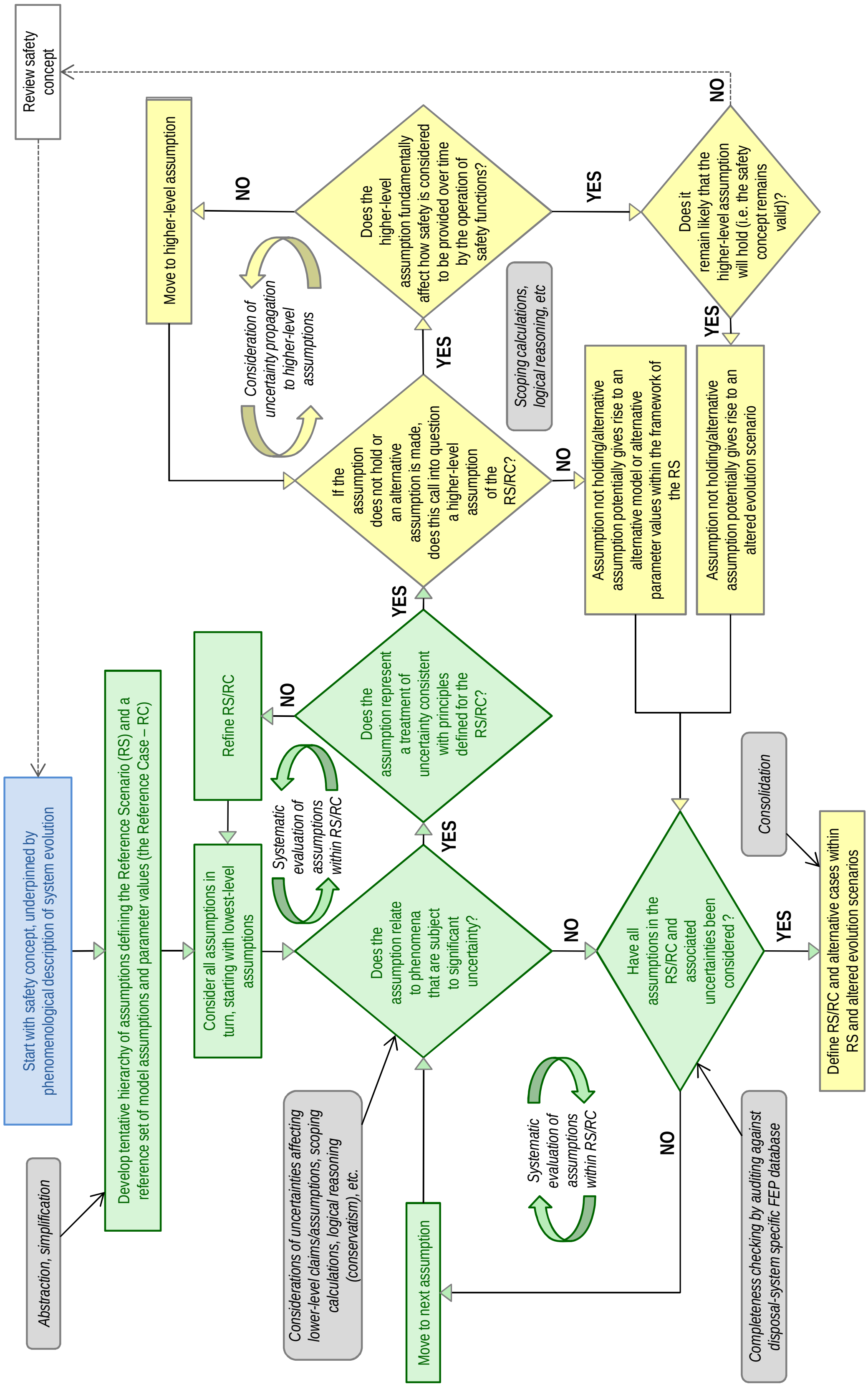
Whether or not a specific uncertainty affects a particular safety statement may be assessed using scoping calculations, more qualitative arguments, or, in the cases of the highest-level safety statements, calculations of performance and safety indicators, including dose or risk. A key task of safety assessment consists essentially of evaluating, by means of suitable calculations, whether specific uncertainties cast significant doubt on the highest level safety statements, such the uncertainties must be reduced (by enhancing the assessment basis), or mitigated or avoided (e.g. by changes to the repository design).

Figure6. **Example of the propagation of uncertainties related to climate change through a hierarchy of safety statements**



In the current safety assessment methodology being developed by ONDRAF/NIRAS, a key step involves the mapping of safety statements onto a set of reference model assumptions (also organised as a hierarchy) for a Reference Scenario. Then, the impact of uncertainties on these assumptions is considered, beginning with the lowest-level assumptions and progressing to the higher-level assumptions that they underpin (Figure 7). If an assumption is deemed to be justified beyond all reasonable doubt, such that there are no reasonable alternative assumptions, then the next assumption is considered. If uncertainties are identified which mean that an assumption may not hold, then the question is asked how high in the structured set of assumptions do the uncertainties propagate. Uncertainties propagating to the highest-level assumptions, e.g. concerning the safety functions of the repository, are those that potentially give rise to alternative evolution scenarios ("scenario uncertainties"). Others may give rise to alternative conceptual models of the Reference Scenario, or alternative parameter values for numerical models. These consequences of the reference assumptions and the various alternatives identified in this way are analysed in the safety assessment.

Figure 7. **Proposed methodology for evaluating the propagation of uncertainty**



Conclusions

The concept of safety statements plays a fundamental role in the ONDRAF/NIRAS approach to the development of a safety and feasibility case. They provide a structured way of organising the various lines of evidence and arguments that constitute the case, beginning with the highest-level statements and progressing, in a top-down manner, to the underlying basis in scientific understanding. They also provide an effective tool to assess the propagation of specific uncertainties, beginning with uncertainties in, for example, the rates of processes and the timing of events, and progressing, this time in a bottom-up manner, through the hierarchy of safety statements towards the most general statements concerning the adequacy of the system from a long-term safety point of view.

While ONDRAF/NIRAS considers that what is presented here forms a sound basis, it is likely that the ideas and methodology will be further developed to some extent (1) as lessons are learnt from their application in practice, and (2) from discussions with the safety authorities.

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