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A method for independent modelling in support of regulatory review of dose assessments

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ABSTRACT

Several countries consider geological disposal facilities as the preferred option for spent nuclear fuel due to their potential to provide isolation from the surface environment on very long timescales. In 2011 the Swedish Nuclear Fuel & Waste Management Co. (SKB) submitted a license application for construction of a spent nuclear fuel repository. The disposal method involves disposing spent fuel in copper canisters with a cast iron insert at about 500 m depth in crystalline basement rock, and each canister is surrounded by a buffer of swelling bentonite clay. SKB's license application is supported by a post-closure safety assessment, SR-Site. SR-Site has been reviewed by the Swedish Radiation Safety Authority (SSM) for five years. The main method for review of SKB's license application is document review, which is carried out by SSM's staff and supported by SSM's external experts. The review has proven a challenging task due to its broad scope, complexity and multidisciplinary nature. SSM and its predecessors have, for several decades, been developing independent models to support regulatory reviews of post-closure safety assessments for geological repositories. For the review of SR-Site, SSM has developed a modelling approach with a structured application of independent modelling activities, including replication modelling, use of alternative conceptual models and bounding calculations, to complement the traditional document review. This paper describes this scheme and its application to biosphere and dose assessment modelling. SSM's independent modelling has provided important insights regarding quality and reasonableness of SKB's rather complex biosphere modelling and has helped quantifying conservatisms and highlighting conceptual uncertainty.

1. Introduction

Several countries consider geological disposal facilities as the preferred option for high-level nuclear waste and spent nuclear fuel due to their potential to provide isolation from the surface environment on very long timescales. In 2011 the Swedish Nuclear Fuel & Waste Management Co. (SKB) submitted a license application for construction of a geological repository for spent nuclear fuel according to the KBS-3 disposal method. The KBS-3 method involves disposing of the spent fuel in cast iron canisters with an outer layer of 5 cm copper. The canisters will be deposited in vertical deposition holes at approximately 500 m depths in crystalline bedrock. Each canister is surrounded by a buffer of swelling bentonite clay. The license application is supported by a post-closure safety assessment; SR-Site (SKB, 2011).

The SR-Site has been reviewed by Swedish Radiation Authority (SSM) for 5 years. The main method for review of SKB's license application is document review, which is carried out by SSM's staff and supported by SSM's external experts. The review has proven a challenging task due to its broad scope, complexity and multidisciplinary nature. Experiences from regulatory review of SKB's earlier safety assessments have shown that independent modelling provides valuable insight and understanding of the methodology and calculations presented by the applicant (e.g. Xu et al., 2008; Maul et al., 2008). For this review SSM has developed a structured modelling approach with stepwise application of different independent modelling activities, including replication modelling, use of alternative conceptual models and bounding calculations to support the traditional document review (Xu et al., 2015).

This paper focuses on the application of this regulatory modelling approach in the regulatory review of SKB's biosphere modelling and dose assessment in SR-Site.

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The dose assessment methodology adopted by SKB is mainly based on the philosophy to estimate the radiological risk for humans and the environment as realistic as possible and is as far as possible based on conditions measured at the site (SKB, 2010). SKB has developed a rather complex biosphere assessment methodology that, in a detailed way, takes into account the projected future evolution of the landscape resulting from land rise due to glacial rebound and from climate change. Their methodology includes a large number of calculation and derivation steps. It is difficult to penetrate all the details through document review only.

Over the past decade SSM has shadowed SKB's development of biosphere modelling. Modelling techniques have been developed that allow numerical reviews of different aspects of the safety assessment supporting the license application. In order to evaluate the suitability of SKB's biosphere dose assessment model and to explore model uncertainties, two benchmark calculations using alternative models were performed. For the first model comparison a stylised biosphere model was developed (Walke, 2014; Walke et al., 2015). The second model comparison was performed using a model that includes aspects biosphere evolution, known as GEMA-Site model (Kłos, 2015).

In Section 2 we present our integrated modelling approach for independent modelling. In Section 3 we start by describing SKB's methodology for dose assessments and then describe briefly the alternative models used in the benchmarking calculations and our modelling results. Section 4 presents some general findings about biosphere and dose assessment modelling and experiences from the application of the proposed modelling scheme to the licensing review.

2. Regulatory modelling approach

SSM's predecessors (the Swedish Nuclear Power Inspectorate and the Swedish Radiation Protection Institute) set out a goal to develop an independent safety assessment capability already in the 1990ies and carried out independent safety assessments of the KBS-3 geological disposal method (e.g. Dverstorp, 1996). Since then, SSM and its predecessors have for several decades continued this effort by further developing independent models (for a range of applications in post-closure safety assessments) to support regulatory reviews of post-closure safety assessments for geological repositories (e.g. Xu et al., 2008; Maul et al., 2008). Modelling teams have been established, combining both in-house and external expertise (Xu et al., 2010). SSM's independent modelling can be referred to one of the following three categories: i) use of SKB's own models (but with other equation solvers), ii) use of alternative conceptual models, iii) use of bounding case calculations.

Based on the experiences from SSM's earlier regulatory modelling, an integrated modelling approach has been developed (Xu et al., 2015), schematically illustrated in Fig. 1. In addition to the traditional document and data review there are three modelling activities: replication of the applicant's modelling, exploration of uncertainty with alternative conceptual models and bounding calculations. Choices are made by either “yes” or “no” to the question given at the decision point to guide the way forward in the modelling scheme except for Q1, where three choices are given, a: reproducing the results, b: doing the alternative modelling or c: no independent modelling if the applicant's modelling is deemed to be sufficient. Q2 is about the feasibility to conduct replication modelling. For example, if there is not sufficient information for replicating the applicant's model, a request for complementary information is needed. By means of replication of a model calculation one may identify errors, ambiguities or quality problems that require clarification or complementary information from the applicant (Q3). At decision point Q4 it has to be decided whether

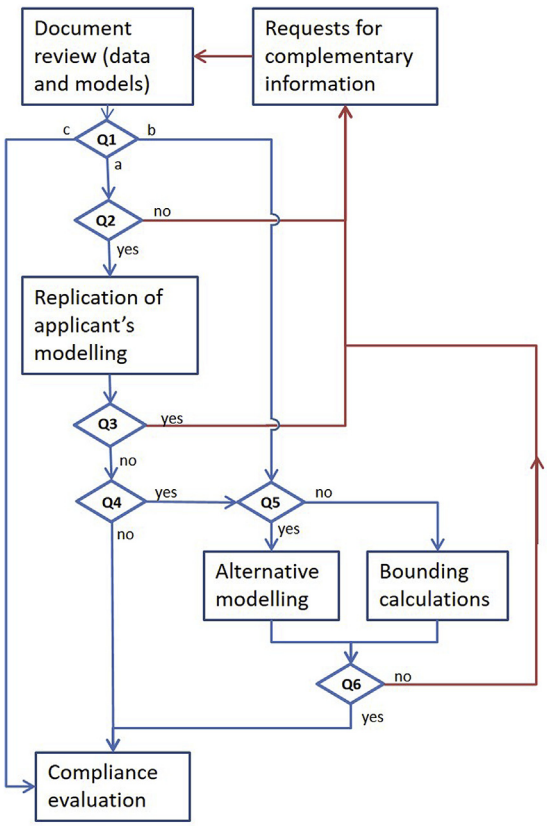

Fig. 1. Schematic of the integrated modelling approach for regulatory review of a consequence analysis, with the following decision points: Q1: Necessary to reproduce? Q2: Feasible to reproduce? Q3: Any errors or ambiguities identified? Q4: Any remaining unresolved review issues, e.g. conceptual model uncertainty? Q5: Does SSM have access to an alternative model? Q6: Sufficient understanding for compliance evaluation? See text for details.

there are any remaining unresolved review issues that require further independent modelling and, depending on availability of regulatory models (Q5), either an alternative (conceptual) model may be used or simplified bounding calculations. Finally, if the independent modelling has not resolved the critical review issues further requests for complementary information must be developed (Q6).

Each of the modelling activities may lead to the identification of review issues that require a request for complementary information (RCI) to be resolved, hence there may be several iterations between document review, independent modelling and requests for complementary information.

3. Application to the regulatory review of biosphere modelling and dose assessment in SR-Site

3.1. SKB's approach to biosphere modelling and dose assessment

SKB's modelling chain for the consequence analysis is shown in Fig. 2, modified from the main SR-Site report (SKB, 2011). The models used for consequence analysis in SR-Site include models for radionuclide transport in the near-field and the far-field as well as models for radionuclide transport in the biosphere and for dose calculations. The radionuclide transport model for the near field describes processes related to radionuclide release and transport in the canister interior, the buffer and the deposition tunnel backfill. The transport model for the far field describes radionuclide transport processes such as advection-dispersion, matrix diffusion and

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