TURVA-2012: Formulation of radionuclide release scenarios

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Introduction

TURVA-2012 is Posiva's safety case in support of the Preliminary Safety Analysis Report (PSAR) and application for a construction licence for a repository for disposal of spent nuclear fuel at the Olkiluoto site in south-western Finland. This paper gives a summary of the scenarios and the methodology followed in formulating them as described in *TURVA-2012: Formulation of Radionuclide Release Scenarios* (Posiva, 2013). The scenarios are further analysed in *TURVA-2012: Assessment of Radionuclide Release Scenarios for the Repository System* and *TURVA-2012: Biosphere Assessment* (Posiva, 2012a, 2012b).

The formulation of scenarios takes into account the safety functions of the main barriers of the repository system and the uncertainties in the features, events, and processes (FEP) that may affect the entire disposal system (i.e. repository system plus the surface environment) from the emplacement of the first canister until the far future. In the report *TURVA-2012: Performance Assessment* (2012d), the performance of the engineered and natural barriers has been assessed against the loads expected during the evolution of the repository system and the site. Uncertainties have been identified and these are taken into account in the formulation of radionuclide release scenarios. The uncertainties in the FEP and evolution of the surface environment are taken into account in formulating the surface environment scenarios used ultimately in estimating radiation exposure.

Formulating radionuclide release scenarios for the repository system links the reports *Performance Assessment* and *Assessment of Radionuclide Release Scenarios for the Repository System*. The formulation of radionuclide release scenarios for the surface environment brings together biosphere description and the surface environment FEP and is the link to the assessment of the surface environment scenarios summarised in *TURVA-2012: Biosphere Assessment.*

Scenario formulation

To assess the impact of uncertainties in the evolution and performance of the repository system and the surface environment, a range of scenarios, each representing one or more possible time histories of conditions, or "lines of evolution", are formulated and analysed.

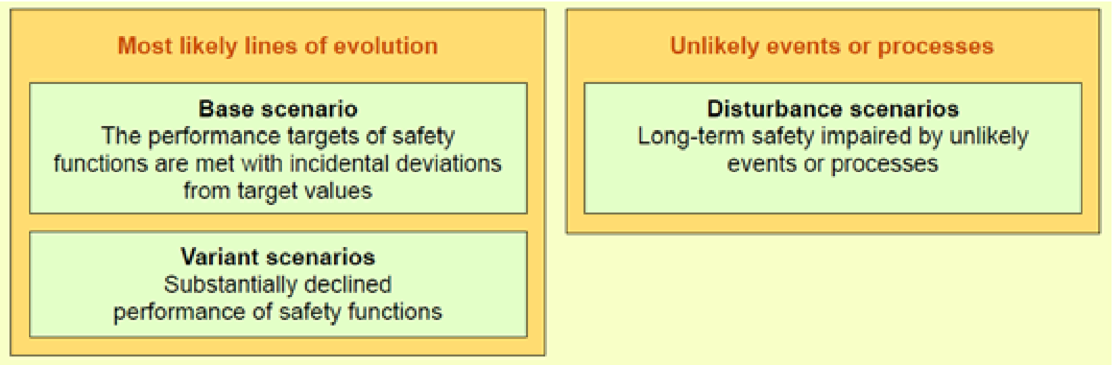
Consistent with Finnish regulatory and international guidance (Guide YVL D.5; IAEA, 2009, 2011, 2012), Posiva distinguishes between the expected evolution of the disposal system and unlikely events and processes. Account is also taken of the time window (or windows) in which releases of radionuclides might occur.

Guide YVL D.5 states: "Compliance with the requirements concerning long-term radiation safety, and the suitability of the disposal method and disposal site, shall be proven through a safety case that must analyse both expected evolution scenarios and unlikely events impairing long-term safety."

The guide goes on to define three types of scenarios (Figure 1):

- *Base scenario:* The base scenario shall assume the performance targets for each safety function, taking account of incidental deviations from the target values.
- *Variant scenarios:* The influence of declined performance of a single safety function or, in case of coupling between safety functions, the combined effects of declined performance of more than one function shall be analysed by means of variant scenarios.
- *Disturbance scenarios:* Disturbance scenarios shall be constructed for the analysis of unlikely events impairing long-term safety.

Figure 1: Classification of scenarios in TURVA-2012, consistent with STUK's Guide YVL D.5



The repository system is designed in such a way that each component of the engineered barrier system (EBS) should, for most likely lines of evolution and in the absence of incidental deviations, meet the safety functions and performance targets assigned to it, and the host rock should conform to its target properties. In this case, the copper-iron canisters remain intact for the whole assessment time frame and there is no release of radionuclides.

The performance assessment shows, however, that there are some plausible conditions and events (incidental deviations) that could lead to reduction of one or more safety functions, and thus may give rise to radionuclide releases. In addition, there are some very unlikely events and processes that could disrupt the repository, e.g. related to human intrusion and rock shear. These incidental deviations and unlikely events are systematically examined to define a set of scenarios that encompass the important combinations of initial conditions, natural evolution and disruptive events.

In the current and past assessments by Posiva, the scenario of a canister with an initial penetrating defect has been considered. This defect is assumed to be located in the canister weld as this is the least amenable component for quality checking once the canister has been loaded with the spent nuclear fuel. Although the likelihood that a canister with an initial undetected penetrating defect will be emplaced in the repository is low, it cannot currently be excluded and provides a useful base scenario for safety assessment (radionuclide release calculations) against which the efficiency of the other technical barriers and the host rock to limit the radionuclide releases can be tested and that also complies with the government decree GD 736/2008.

Thus, as indicated in Figure 1, the *base scenario* addresses the most likely lines of evolution (in which the performance targets and safety functions are met), but takes into account the possibility of one or a few canisters with initial undetected penetrating defects. The *variant scenarios* address situations that are considered reasonably likely and in which there may be reduced performance of one or more safety functions of the barriers. *Disturbance scenarios* address the lines of evolution that are considered unlikely but cannot be completely eliminated.

Methodology for scenario formulation

The repository system

Posiva's methodology for the formulation of radionuclide release scenarios relating to the repository system follows a top-down approach. The starting point for the repository system is presented in the *Design Basis* report (Posiva, 2012c), which accounts for the disposal concept, safety concept and the defined safety functions for the EBS and the host rock with their respective performance targets (PT) target properties (TP), all these considering the regulatory framework. The PT and TP are evaluated against the FEP affecting the system in the performance assessment and the lines of evolution resulting in deviations from the PT are brought further to the scenario formulation. In the scenario formulation the effects of single potentially detrimental FEP or combinations of FEP on the safety functions are considered systematically and also the effect of uncertainties within the expected lines of evolution. This systematic approach is designed to promote transparency and comprehensiveness. It can be summarised as follows:

FEP that could adversely affect one or more safety functions at a given time or place or under specific conditions within the repository are identified (i.e. FEP that are scenario drivers within the evolution of the repository system in time and space; see the *Performance Assessment* report).

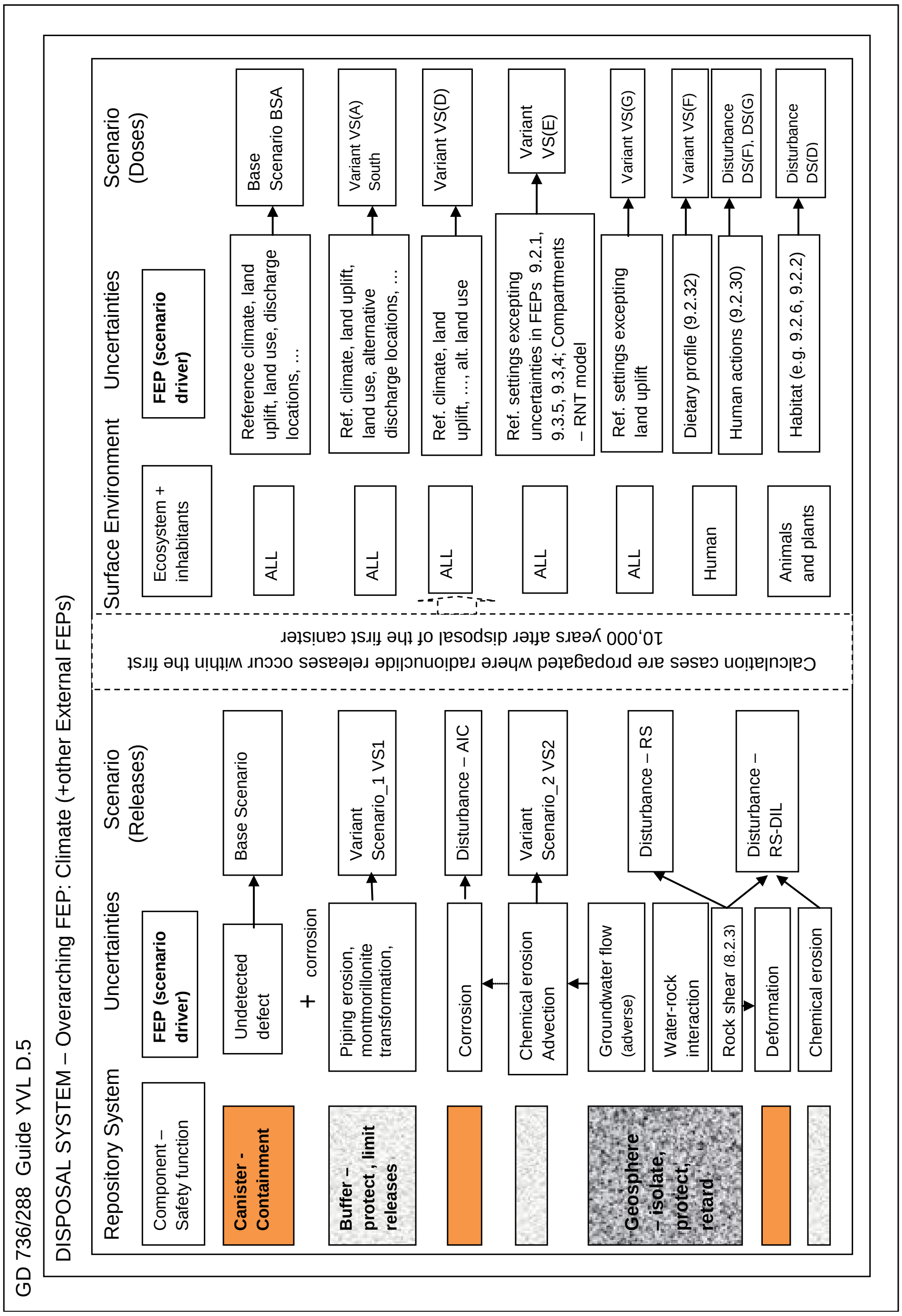
The effects of uncertainties in the expected evolution of the repository system (see the *Performance Assessment* report) are taken into account.

Thus, lines of evolution that describe the evolution of the repository system and ultimately lead to canister failure form the basis for the definition of radionuclide release scenarios. Each line of evolution is then classified using STUK's scenario terminology (Figure 1).

For each of the scenarios a set of calculation cases is defined to analyse the potential radiological impact. The calculation cases take into account uncertainties in model assumptions and data used to analyse the scenarios through variations in the models and parameter values.

The most important evolution-related FEP that may affect the safety functions of the repository system during its evolution, and thus affect also migration-related FEP, have been taken into account in analysing and describing the normal or expected evolution in the *Performance Assessment* report. Climate evolution is the overarching FEP affecting the whole disposal system. The outcome of the application of the methodology of scenario formulation is presented in Figure 2.

Figure 2: Outcome of the application of the methodology in scenario formulation



The surface environment

Formulation of scenarios for the surface environment must be consistent with the regulatory requirements, the methodology used in the formulation of scenarios for the repository system, and the current radiation protection systems for humans and the environment. Posiva's methodology for scenario formulation for the surface environment is somewhat different from that for the repository system, since the surface environment has no safety functions. Therefore, the scenario formulation for the surface environment is based on identifying FEP that may affect the evolution of the surface environment, fate of radionuclides in the surface environment and/or the potential radiation exposure of humans, plants and animals. The regulatory framework is also taken into account, mainly by coupling the scenario formulation to the dose constraints for humans. (GD 736/2008 Section 4: “Disposal of nuclear waste shall be planned so that radiation impacts arising as a consequence of expected evolution scenarios will not exceed the constraints”, for which it is stated in Guide YVL D.5 paragraph 307: “In applying the dose constraints, such environmental changes needs to be considered that arise from changes in the ground level in relation to sea. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to remain unchanged.”)

Thus, Posiva’s methodology for formulating surface environment scenarios can be summarised as follows:

- Constraints on the scenarios arising from the regulatory framework are identified.
- Key scenario drivers with respect to the evolution of the surface environment, fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals are identified. This work also comprises identifying FEP that affect the key drivers, either in isolation or combined, and could induce changes in a timeline of evolution.
- One or several lines of evolution are defined that describe the evolution of the surface environment, from which one or more scenarios are formulated. One credible line of evolution is identified and used to formulate the base scenario for the surface environment.
- Variant scenarios are formulated, mainly by considering reasonable deviations from the lines of evolution underpinning the base scenario. Variant scenarios can include additional scenario drivers with a potentially significant effect on the fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals.
- Disturbance scenarios are formulated, mainly by identifying unlikely FEP or mainly by considering unlikely deviations from the lines of evolution underpinning the base scenario. Disturbance scenarios can include additional scenario drivers with a potentially significant effect on the fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals.

Radionuclide release scenarios

Repository system scenarios

The base scenario

The canister (which provides the safety function of prolonged containment of the spent fuel) is the primary barrier, since radionuclide releases may only occur if the canister has failed. Possible canister failure modes are presence of an initial undetected defect corrosion, and rock shear. The base scenario postulates that one or a few defective canisters are emplaced in the repository. This is consistent with YVL Guide D.5, which states that the base scenario shall assume the performance targets for each safety function, taking account of incidental deviations from the target values.

Thus, in the base scenario reference case, an undetected penetrating defect in one canister is the incidental deviation that acts as the main driver, whereas the performance targets of all other repository components are assumed to hold, as is expected based on the performance assessment. The assumptions regarding the EBS and host rock (and surface environment) are shown in Table 1.

Table 1: Assumptions for the base scenario for radiological assessment

Surface environment	Climate evolution	Constant present climate for several millennia.
	Land use	Sparsely populated area. Crops, irrigation and livestock representative of present day. Forestry and peat land management according to present-day practice.
Bedrock	Rock mass	Rock suitability classification (RSC) criteria are applied successfully and target properties hold throughout the assessment time frame.
	Groundwater	Limited advection or inflows to repository level. Groundwater composition favourable to the EBS and target properties (according to RSC) for the groundwater composition holds throughout the assessment time frame.
Engineered barrier system (EBS)	Closure	Closure backfill and seals, including borehole seals are designed and emplaced according to requirements, and performance targets are fulfilled during throughout the assessment time frame.
	Deposition tunnel backfill	Deposition tunnel backfill and plugs are designed and emplaced according to requirements. The backfill performance targets are fulfilled throughout the assessment time frame.
	Buffer	The buffer is designed and emplaced according to requirements. The buffer performance targets are fulfilled throughout the assessment time frame.
	Canister	Canisters are manufactured and emplaced according to design. As an *incidental deviation* it is assumed that one or a few canisters are present with an initial undetected penetrating defect, whose size does not change in time.
Spent fuel + cladding		Very low dissolution rate; no specific requirements or safety functions.

Variant scenarios

The reduced performance of any single safety function(s) of any component other than the canister does not immediately give rise to canister failure and thus to radionuclide releases.

However, the reduced performance of the buffer may reduce canister lifetime and also subsequently affect radionuclide release and transport. The combined effect of the reduced performance of the canister and the buffer is assessed in two variant scenarios, where the loss of the safety function of the canister (initial penetrating defect or failure by corrosion) is combined with the reduced performance of the buffer.

Disturbance scenarios

In formulating disturbance scenarios, two main unlikely events are taken into account: one is the occurrence of a large earthquake capable of originating a rock shear that can breach the canister. The other is inadvertent human intrusion (treated in the *Biosphere Assessment*) for which an annual probability of occurrence is derived based on current habits and practices. FEP such as corrosion and deformation that are likely to occur, but only detrimentally affect safety functions if their rates are outside the expected range of possibilities, are taken into account in a scenario considering accelerated corrosion of the canister insert once the copper overpack has failed.

Surface environment scenarios

The base scenario for the surface environment and its main assumptions are as follows: The regulations explicitly state that the environmental changes due to sea-level changes relative to the land (i.e. allowing for land uplift) should be considered, and that the climate type as well as the human habits can be assumed to remain unchanged

(Guide YVL D.5, 307). Thus the current climate type in the region of the Olkiluoto site is assumed, as well as present-day demographic data and human habits, such as land use; site-specific or regional-specific information is preferred over national statistics.

Variant scenarios for the surface environment are based on alternative credible lines of evolution arising from reasonable variations of the FEP affecting the key drivers. Consideration has also been given to additional scenario drivers. The variant scenarios are listed in Table 2.

In the disturbance scenarios for the surface environment, unlikely lines of evolution that may have a potentially significant effect on the fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals are addressed. The identified disturbance scenarios are listed in Table 3.

Table 2: Variant scenarios identified for the surface environment, the driver the scenarios address and the uncertainties in the most important FEP affecting the drivers

Variant scenario		Scenario driver	FEP
VS-A	Discharge locations to the surface environment	Discharge locations	Defective canister location in the repository layout
VS-D	Land use (well)	Land use Human habits	Well (occurrence or not)
VS-E	Route of radionuclide transport	Element migration and accumulation	Alternative radionuclide transport routes in biosphere terrestrial and aquatic compartments affect a number of terrestrial and aquatic processes
VS-F	Exposure characteristics	Human habits	Uncertainties in dietary profile
VS-G	Combined scenario	Sea-level change (local) Land use	Agriculture and aquaculture – maximisation of cultivated areas

Table 3: Disturbance scenarios identified for the surface environment, the driver the scenarios address and the uncertainties in the most important FEP affecting the drivers

Disturbance scenario		Scenario driver	FEP
DS(D)	Exposure characteristics	Ecosystem occupancy	Habitats
DS(F)	Inadvertent human intrusion	Human actions	Human actions

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