TURVA-2012 safety case for licensing a spent fuel repository at Olkiluoto, Finland

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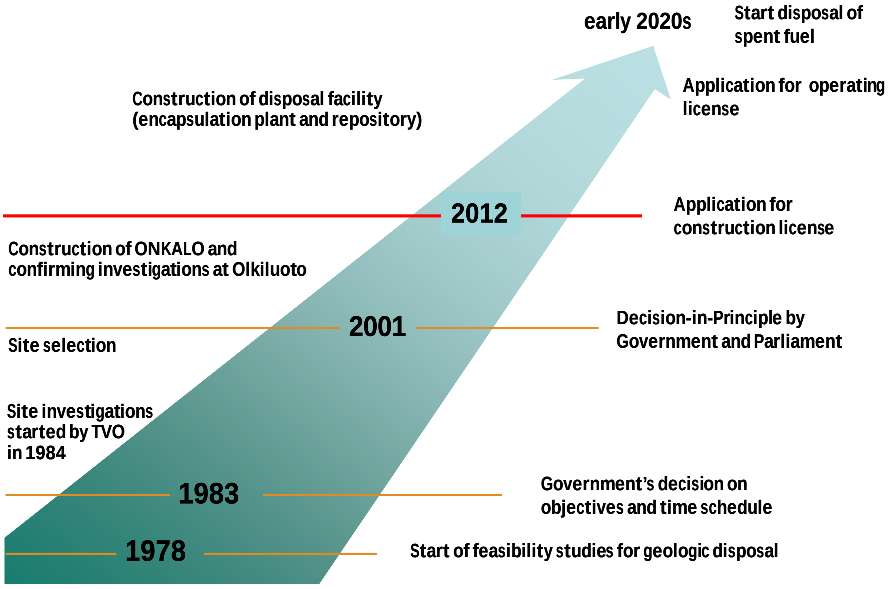
Programme status

In 2001, the Finnish Parliament endorsed a decision-in-principle (DiP) whereby the spent nuclear fuel produced by the operating nuclear reactors at Olkiluoto and Loviisa will be disposed of in a geological repository at Olkiluoto, on the south-western coast of Finland (Figure 1). Subsequently, additional DiPs were issued allowing the extension of the repository to accommodate spent nuclear fuel from additional reactors that are under construction or in planning at Olkiluoto, which means a total of 9 000 tU of spent nuclear fuel to be disposed of. In accordance with the decision of the Ministry of Trade and Industry (KTM) in 2003, Posiva submitted an application for a license to construct a disposal facility at Olkiluoto in 2012, consisting of an encapsulation facility and an underground deep geological repository. The application included a Preliminary Safety Analysis Report (PSAR) and a long-term safety case, TURVA-2012. Assuming a positive outcome of the current licensing review, the next step would be the Final Safety Analysis Report (FSAR) in support of an operational licence application around 2020. A general time line for Posiva's programme is presented in Figure 2.

Figure 1: Olkiluoto Island is situated on the coast of the Baltic Sea in south-western Finland

Figure 2: Time line for spent fuel disposal of the Loviisa and Olkiluoto reactors; the target is to start disposing of spent nuclear fuel in the early 2020s



The disposal method is based on the same KBS-3 concept that the Swedish SKB has used as basis for their license application in 2010. Accordingly, the spent nuclear fuel will be encapsulated in water- and gas-tight copper canisters equipped with a load-bearing insert and emplaced in a deep geological repository constructed in the bedrock. The canisters will be surrounded by a swelling clay buffer material that isolates them from the bedrock. The deposition tunnels and the central tunnels and the other underground openings will be backfilled with materials of low permeability. The repository will be at a depth of about 400-450 m below ground. The primary role of the bedrock is to provide sufficiently stable conditions for the engineered barrier system and to make inadvertent human intrusion unlikely. In case of EBS failure, the bedrock shall also retain and retard the possible spreading of radionuclides from the repository.

Site

Olkiluoto Island has been investigated for siting of nuclear waste repositories for over 25 years; first for siting of a low- and intermediate-level waste repository, later for a deep geological repository for spent nuclear fuel. By 2012 a total of 57 deep boreholes had been core-drilled on the site. Since 2004 the Olkiluoto bedrock has also been subject to underground investigations from the ONKALO underground rock characterisation facility.

Underground characterisation before the application of the construction license is required by Finnish regulations to confirm the results of the surface investigations carried out for the basis of the decision-in-principle. Indeed, the underground investigations have indicated that the structural description of the Olkiluoto bedrock based on the surface investigations was largely correct and the main structural features were found where they were expected. In general, there were hardly any surprises in the geological picture as unveiled. However, some of the bedrock characteristics could only be confirmed with the ONKALO studies. One example is the rock mechanical description, which turned out to be a major challenge before going underground. The picture of fracturing also benefitted considerably from the ONKALO investigations: while the larger hydraulic features were quite well predicted from the surface, the more detailed nature of fracturing could only be determined through underground investigations. For instance, the number of “large” single fractures turned out to be significantly larger than what was predicted on the basis of surface studies. Still another feature that emerged from the underground investigations was the matrix geochemistry. The results of the matrix water investigations are still partly open to discussion.

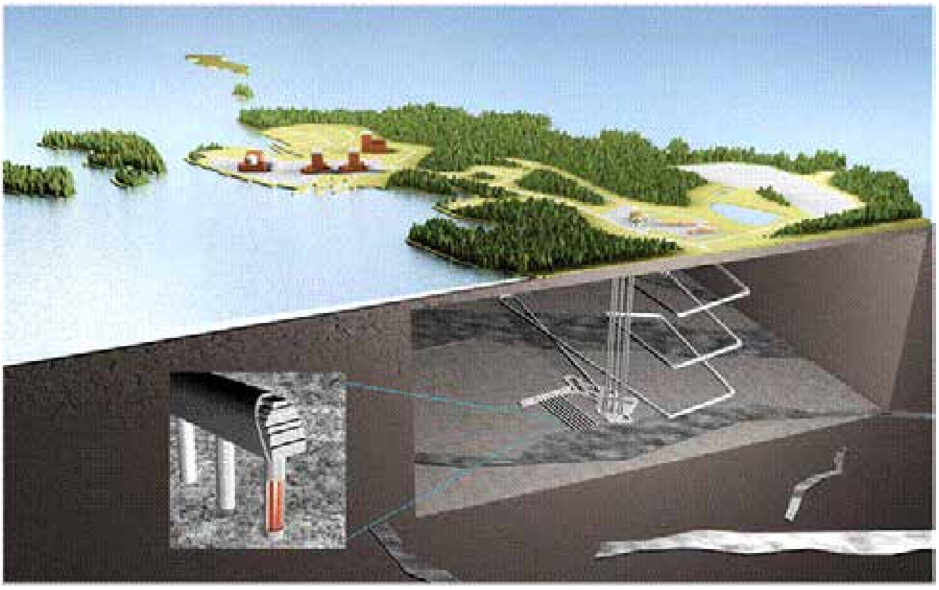
For the future understanding of the evolution of the Olkiluoto bedrock conditions the key features, events and processes taken into account in the assessments of long-term performance and safety include:

- the presence of deformation and fractured zones, displaying mixed geotechnical properties and in some cases increased hydraulic activity;
- higher rock stress at depth, which may cause disturbance to the rock, making underground openings less stable;
- the temperature and thermal conductivity of rock and residual heat output of the spent nuclear fuel;
- the high salinity of groundwater at depth, which may affect the performance of the engineered barriers;
- continuing post-glacial crustal uplift and, in the longer term, climatic cooling and glaciation, leading to changes in rock stress and potential changes in groundwater flow and composition, e.g. influx of dilute glacial melt waters into the host rock.

Design approach

Posiva has developed a detailed design for the Olkiluoto repository (Figure 3) through a formal requirements management system (VAHA). This provides a rigorous, traceable method of translating safety principles and the safety concept to a set of safety functions, performance requirements (performance targets, target properties), design requirements and design specifications for the various barriers, i.e. a specification for the implementation of the disposal concept at the Olkiluoto site.

Figure 3: Schematic illustration of the underground repository features and of the (vertical) KBS-3 design (insert)



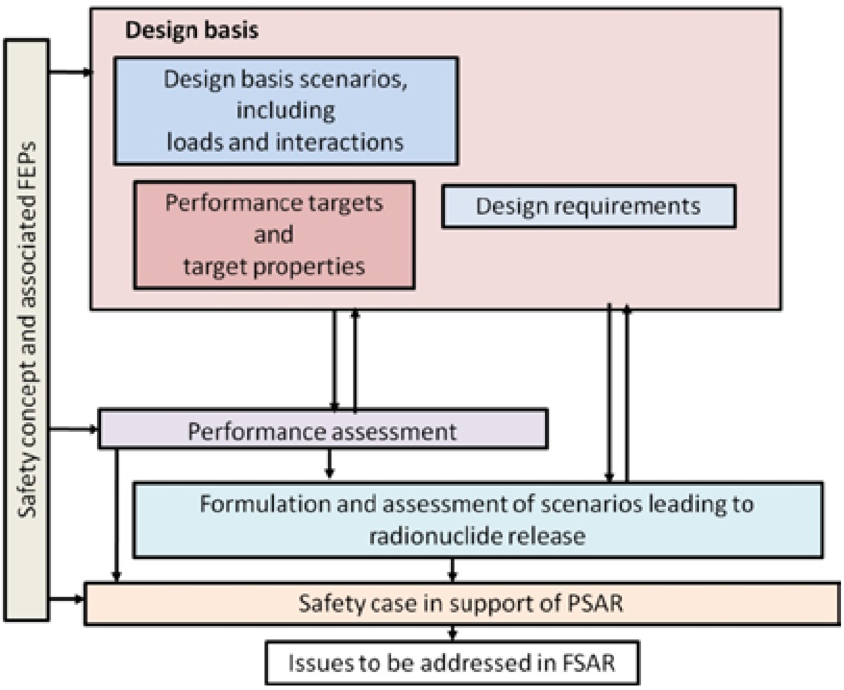
Posiva’s safety concept is based on two basic principles for safe spent nuclear fuel disposal – isolation and containment – provided by a system of mutually complementary natural and engineered barriers and their associated safety functions. In this way, even if the performance of one of the barriers is degraded in some way, other barriers and safety functions will still ensure that isolation and containment of the spent nuclear fuel are maintained. The system of complementary barriers and safety functions also provides robustness with respect to external events and processes, including geological and climatic changes. The conditions needed for the barriers to fulfil their respective safety functions are expressed in terms of performance targets for the engineered barriers and target properties for the host rock.

The performance targets and target properties were then transformed to design requirements for engineered barriers and the definition of a rock suitability classification (RSC) system, by which the local suitability of the rock for deposition tunnels and holes can be assessed.

Figure 4 describes the relationships between the development of the design basis and the formulation of the safety case: the design basis is developed iteratively on the basis of performance assessment and the formulation and assessment of radionuclide releases. At each stage, the available scientific understanding, including the results from earlier assessments, is used to define the current design basis; it may, however, need to be modified as a response to the outcome of the performance and safety assessment.

Figure 4: Approach to the development of the safety case

FEP= Features, Events and Processes, PSAR= Preliminary Safety Analysis Report,
FSAR = Final Safety Analysis Report



Indeed, it is considered likely that some of the current requirements and specifications will still change before the time of submission of the operations license application. Some of the modifications that do not affect the facility construction may be introduced in the Final Safety Assessment Report of the disposal facility. Otherwise, they will go through the change management system, which is part of the configuration management launched in early 2013 as a major activity area at Posiva. A potential change could be the adoption of the horizontal variant of the KBS-3 concept: this option is being studied as a possible alternative to the "classical" vertical KBS-3 concept, but at the moment it is still not possible to judge whether the horizontal alternative would offer safety or other benefits over the vertical option. In any case, the introduction of the new design would require an updated PSAR for approval by the regulator.

TURVA-2012 safety case

TURVA-2012 is the name of Posiva's safety case in support of the Preliminary Safety Analysis Report (PSAR, 2012) and application for a construction licence for a spent nuclear fuel repository at the Olkiluoto site according to the KBS-3 method. The license application was submitted to TEM (former KTM) on 28 December 2012. The Finnish nuclear safety authority, STUK, will review the safety case and related topical reports as part of its evaluation of construction licence application and the PSAR and give a statement on the construction licence application, which will form a basis for the government judgement on issuance of the construction licence.

The TURVA-2012 safety case presents the arguments for the long-term radiological safety of the planned disposal system. A plan for the safety case was first set up in 2005 and was later updated to better focus on quality assurance and control procedures and their documentation as well as on consistent handling of different types of uncertainties. Following Posiva's submission of the Interim Summary Report of the Safety Case 2009 (Posiva, 2010), STUK evaluated Posiva's preparedness to demonstrate long-term safety and operational safety and the fulfilment of the safety requirements for nuclear waste disposal against the governmental decree on nuclear energy (GD 736/2008). STUK's safety evaluation report (2011) provided feedback and advice that has been translated into key issues that are addressed within Posiva's RTD programme and in the development of the TURVA-2012 safety case. The feedback has also been taken into account in the systematic structuring of the safety case and the reports included in the portfolio shown in Figure 5. The portfolio includes:

- a description of the spent nuclear fuel to be disposed of in the geological repository;
- a description of the natural and engineered barrier system that the repository system provides, a definition of the safety functions and targets set for these, and a description of the present understanding of the processes that may affect the evolution and performance of the spent nuclear fuel, engineered barriers, host rock and the surface environment;
- a performance assessment systematically analysing the ability of the repository system to provide containment and isolation of the spent nuclear fuel for as long as it remains hazardous;
- a definition of the lines of evolution that may lead to failure of the canisters containing the spent nuclear fuel and to the releases of radionuclides (scenarios);
- analyses of the potential rates of release of radionuclides from the failed canisters, the retention, transport and distribution of radionuclides within the repository system and surface environment and the potential radiation doses to humans, plants and animals including the associated uncertainties and an evaluation of their impacts;
- the models and data used in the description of the evolution of the repository system and the development of the surface environment and for the analysis of activity releases and dose assessment;
- a range of qualitative evidence and arguments that complement and support the reliability of the results of the quantitative analyses;

- a comparison of the outcome of the analyses with safety requirements;
- a synthesis that brings together all the lines of arguments for safety, including the methodology, results and conclusions.

Aspects related to operational safety are dealt with in other parts of the PSAR.

Spent nuclear fuel must be kept isolated for as long as it could cause significant harm to the normal habitats for humans, animals and plants. In TURVA-2012 an assessment time frame of up to one million years into the future is considered.

Figure 5: The TURVA-2012 safety case portfolio

The portfolio consists of safety case reports (green boxes) and supporting reports (blue boxes); brief descriptions of the contents are given (white boxes). Disposal system = repository system + surface environment.

TURVA-2012

Synthesis
Description of the overall methodology of analysis, bringing together all the lines of arguments for safety, and the statement of confidence and the evaluation of compliance with long-term safety constraints

Site Description — Understanding of the present state and past evolution of the host rock

Biosphere Description — Understanding of the present state and evolution of the surface environment

Design Basis
Performance targets and target properties for the repository system

Production Lines
Design, production and initial state of the EBS and the underground openings

Description of the Disposal System
Summary of the initial state of the repository system and present state of the surface environment

Features, Events and Processes
General description of features, events and processes affecting the disposal system

Performance Assessment
Analysis of the performance of the repository system and evaluation of the fulfillment of performance targets and target properties

Formulation of Radionuclide Release Scenarios
Description of climate evolution and definition of release scenarios

Models and Data for the Repository System — Models and data used in the performance assessment and in the analysis of the radionuclide release scenarios

Biosphere Data Basis — Data used in the biosphere assessment and summary of models

Biosphere Assessment: Modelling reports
Description of the models and detailed modelling of surface environment

Assessment of Radionuclide Release Scenarios for the Repository System / **Biosphere Assessment**
Analysis of releases and calculation of doses and activity fluxes.

Complementary Considerations
Supporting evidence incl. natural and anthropogenic analogues

(green) Main reports
(blue) Main supporting documents

Outcome and conclusions

The TURVA-2012 safety case demonstrates that Posiva’s repository design and analyses of performance and safety are fully consistent with all legal and regulatory requirements related to long-term safety.

The performance of the repository system has been systematically analysed in different time windows. The analyses take account of the uncertainties in the initial state and in the subsequent thermal, hydraulic, mechanical and chemical evolution of the repository system, including the occurrence of unexpected or disruptive events. The analyses show that, under most conditions and lines of evolution of the host rock and engineered barriers, all performance requirements will be met. In this case, the copper canisters will remain intact and no releases of radionuclides will occur over at least one million years. Up to 50 000 years, the only plausible cause of release of radionuclides is that a canister with an initial penetrating defect escapes detection and is inadvertently emplaced in the repository. In the longer term, glacial episodes at the site may cause hydrogeological and hydrochemical changes leading to buffer erosion and increased canister corrosion, as well as seismic disturbances leading to shear movements on fractures intersecting the deposition holes. These changes and disturbances, if they were to occur, could potentially lead to the failure of up to a few dozens of canisters and to the release of radionuclides in less favourable locations within the repository.

Although releases of radionuclides to the environment are not expected, the safety analyses focus on the cases in which releases of radionuclides could occur. In the case of a canister with an initial penetrating defect, it is shown that, even if this happened to be emplaced in a location with relatively unfavourable local rock conditions, peak normalised radionuclide release rates to the surface environment are orders of magnitude below the radionuclide-specific constraints specified in the STUK YVL Guide D.5. In the long term (after approximately 100 000 years or more), the possibility of failure due to corrosion following buffer erosion and of failure due to rock shear need to be considered, but calculated radionuclide release rates remain below the regulatory constraint for the radioactive release to the environment, even for pessimistic and unlikely combinations of damage to canisters by rock shear events and erosion of buffer material due to dilute groundwater conditions.

Overall, it is concluded that the TURVA-2012 safety case demonstrates compliance with the legal and regulatory requirements for the planned and designed disposal facility for spent nuclear fuel at Olkiluoto. Uncertainties still remain in the data and models, and some of these are unlikely to be eliminated by further research. However, the analyses performed have shown that the repository system is robust with respect to these uncertainties and that the conclusions drawn about compliance with safety requirements hold true even when these uncertainties are taken into account.