YJH-2012
Nuclear Waste Management at Olkiluoto and Loviisa Power Plants: Review of Current Status and Future Plans for 2013-2015

Posiva Oy

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SUMMARY

Background and purpose of the report

Nuclear waste management in Finland is regulated by the Nuclear Energy Act (990/1987) and the Nuclear Energy Decree (161/1988) that came into force in 1988. These define, for example, the liabilities of a nuclear energy producer, the implementation of nuclear waste management, the licence procedures and the supervision rights. The Nuclear Energy Act was amended in 1994 so that all nuclear waste generated in Finland must be disposed of in Finland.

As producers of nuclear waste, Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat Oy (Fortum) are under the Nuclear Energy Act responsible for implementing the management of nuclear waste produced in the Olkiluoto and Loviisa nuclear power plants as well as for the costs thus incurred. According to the legislation, the Ministry of Employment and the Economy (abbreviated as TEM in Finnish, previously the Ministry of Trade and Industry, abbreviated as KTM) decides on the principles to be followed in nuclear waste management. The legislation provides that the parties with the nuclear waste management obligation must also provide the ministry with regular reports on how they have planned to implement the measures included in nuclear waste management and their preparations. Up to 2008, these reports were submitted to the ministry annually, but following the amendment of the Nuclear Energy Act that entered into force in 2009, the report is submitted at three-year intervals, and it must describe in detail the measures for the next three-year period and also present an outline of the plans for the subsequent three-year period. YJH-2012 is an overall plan referred to in section 74 of the Nuclear Energy Decree.

In addition to the annual nuclear waste management reports, the parties with the nuclear waste management obligation have been preparing three-year plans for nuclear waste management in Olkiluoto and Loviisa since 2003. The plans (TKS-2003, TKS-2006 and TKS-2009) have included the plans for future research, development and planning work, as well as an assessment of the status of nuclear waste management, in particular with respect to the preparations for final disposal of spent nuclear fuel. The report now produced, nuclear waste management programme YJH-2012, follows largely the same lines as its predecessors.

TVO and Fortum are responsible for the on-site storage, processing and disposal of operational waste generated in their own power plants. Both plant sites already feature an operational disposal facility into which the operational waste generated during the operation of the plant is placed. Waste generated from the eventual decommissioning of the power plants is to be disposed of in the same facilities. In order to organise the management of spent nuclear fuel, TVO and Fortum established Posiva Oy (Posiva) in 1995 for the purpose of taking care of the disposal of its owners' spent nuclear fuel.

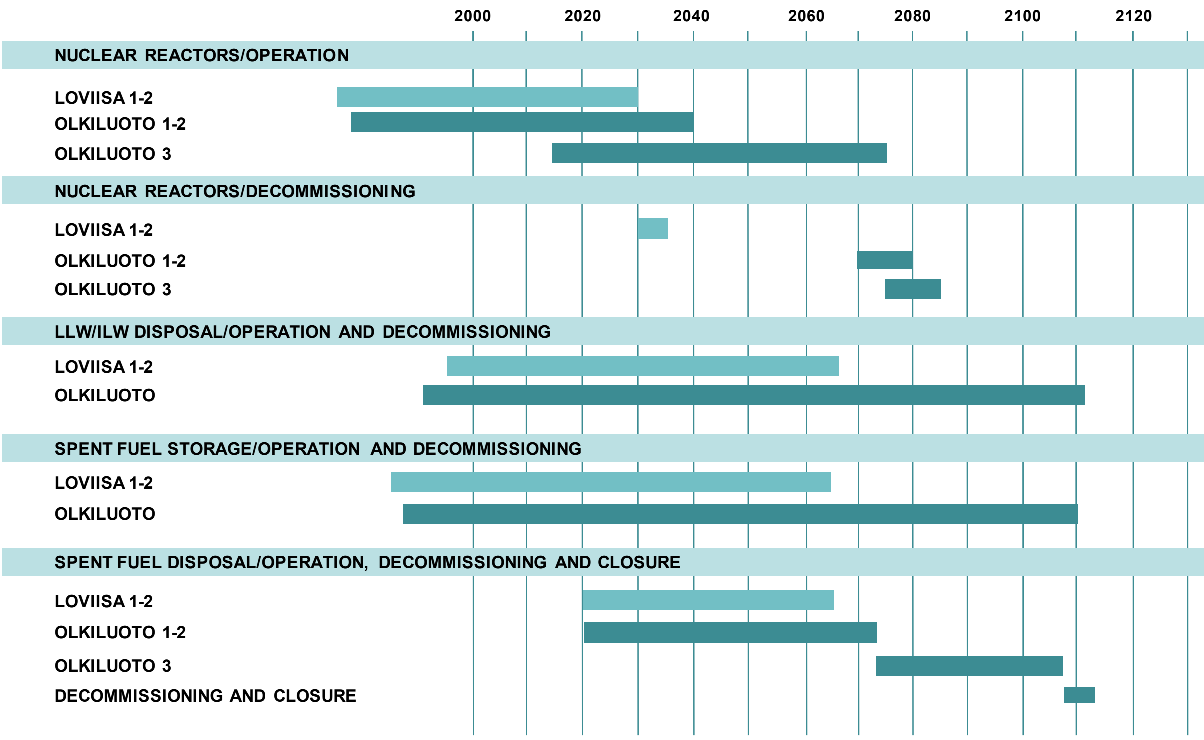
The schedule for the disposal of spent fuel was established in decision 9/815/2003 of the Ministry of Trade and Industry. According to the decision, Teollisuuden Voima Oyj and Fortum Power and Heat Oy, as parties under the nuclear waste management

obligation shall, either separately, together, or through Posiva, prepare to present all reports and plans required to obtain a construction licence for encapsulation plant and disposal facility for spent nuclear fuel as stated in the Nuclear Energy Decree by the end of 2012. They must demonstrate that the operation of the encapsulation plant and disposal facility can begin approximately in 2020.

The processing and final disposal of operational waste follow already established lines, and no significant research needs or changes to existing practices are foreseen for the coming three-year period. Separate reports must be submitted at regular intervals regarding the decommissioning of power plants, and the research and development work required for that is reported separately. TVO and Fortum submitted their up-to-date decommissioning plans to the authority in December 2008. The safety cases regarding the final disposal of operational waste were last updated for both power plants in 2006.

Most of the research, development and planning work during the following three-year period will focus on the disposal of spent nuclear fuel. The main objective of the YJH-2012 programme is to demonstrate how the work to be carried out during 2013–2015 will bring the plans of the construction licence phase to such a state of readiness that implementation of the project can start. The intention is to start preparations for joint functional tests towards the end of the programme period. Their purpose is to demonstrate that disposal of spent nuclear fuel using the KBS-3 method in Olkiluoto is technically feasible.

The work to be undertaken under the programme includes conclusion of the verifying studies of the Olkiluoto repository, design of the required plants and development of the deployed repository technology to the level required for disposal operations, as well as production of the safety case regarding long-term safety to be appended to the operating licence application. Along with the basic plan for final disposal, the feasibility and long-term safety of an alternative, so-called horizontal disposal plan (KBS-3H) will be reviewed in co-operation with the Swedish company SKB. It will be decisive for the timing of the tasks included in the programme, and to an extent also for their contents, how processing of the construction licence application to be submitted during 2012 and its related feedback from authorities progresses and when the construction licence is eventually granted.



Overall time schedule for the nuclear waste management of Olkiluoto and Loviisa power plants.

Investigations for Olkiluoto site confirmation

Characterisation and modelling of the disposal site

The Olkiluoto Site Description to be released in autumn 2012 will be a summary of the site confirmation studies carried out for demonstrating the suitability of Olkiluoto for a disposal site. The studies, which have now continued for two decades, have not revealed any indications of issues that could put the suitability in question. However, further studies will still be carried out regarding certain characteristics of Olkiluoto during the next three-year period.

The main objective of characterising and modelling the bedrock of the disposal site is to produce, by the end of 2016, an updated site description report (Olkiluoto Site Description 2016). It will be used for updating the safety assessment and for producing plant plans. During the programme period, the studies concentrated on investigating the open questions raised in connection with the previous site report, such as improving the structure models of the eastern part of the disposal site, more detailed understanding of the stress status at the disposal depth, description of hydro-geochemical processes and determination of the matrix properties of rock types in the bedrock.

During the programme period now commencing, the current surface hydrology model will be maintained and developed in order to improve the applicability of the model to different calculation cases. Geological and geophysical research data from the eastern part of the investigations area, ONKALO mapping materials and new lineament interpretations are among the sources that will be used for reviewing the geological model. The rock-mechanical model will be revised gradually as new information is accumulated, and it will be developed in order to improve its usability. The intention is to later use the model as an implementation tool for the designers and builders of the disposal facility. During the programme period, the hydrogeological studies will particularly concentrate on investigating the hydrogeological properties of the eastern part of the planning area and on assessing the groundwater effects of ONKALO. The work for bringing the hydrogeological structure model into line with the accumulated data will be completed during 2014. The themes of hydro-geochemical research are linked with the total chemical buffering capacity of the groundwater system, the sulphide circulation as well as with the distribution and paleo-hydrogeological development of salinity. The radionuclide migration concept will be revised on the basis of new geological mapping data and laboratory studies. REPRO, the matrix diffusion test performed in ONKALO's Investigation niche 5, will be completed during the coming programme period. The purpose of the test is to produce site-specific data of the retention capability of bedrock at the disposal depth to be used for migration modelling.

Rock suitability classification (RSC)

The work related to demonstration of the rock suitability classification (RSC) will continue in ONKALO during the early part of the programme period. In 2013, the rest of the planned drill hole studies will be carried out and the rock suitability classification will be finalised. The previously produced small-scale model will be expanded to over ONKALO's demonstration areas, technical rooms and the entire area of the planned first disposal panel. As the work progresses, the feasibility of the RSC will be assessed, and the criteria will be revised as required. A manual describing the RSC method will be produced during the programme period. RSC work aimed at testing the joint functioning of underground systems will begin during the coming programme period. When work on the first disposal panel begins, the studies will be performed in step with the progress of the construction work, in compliance with the RSC procedure. A Posiva report containing a comprehensive account of the experience gained from applying the RSC, the development work carried out and possibly a revised RSC classification procedure is planned for publication before submitting the operating licence application.

Design of the engineered barrier system

The development work of the engineered barrier system is divided into tasks coordinated in the canister and clay lines of development. The canister line includes the tasks related to canister design, development of manufacturing technology, development of sealing technology as well as development of inspection techniques. The clay line involves the coordination of design and development tasks related to the buffer, backfill of deposition tunnels and the end plug, as well as the solutions for final sealing off of the disposal facility.

The disposal canister consists of a copper overpack and a cast iron insert in which the spent nuclear fuel assemblies will be placed. Canister design analyses have been performed in order to investigate the stresses exerted on the canister and strength of the canister, the maximum allowable material defects and residual stresses in the canisters as well as for solving issues related to criticality safety. A summary of canister design work is presented in a design report (Raiko 2012), while the entire canister production line is presented in a document entitled *Canister Production Line Report*. A few areas of canister design, demonstration of its functional capability and specification of the production line still warrant further investigations, and they will be continued during the programme period. The most prominent of these are:

- revision of the canister-related rock displacement analysis (in addition to the previous deterministic method) as a probabilistic risk analysis (PRA) to obtain a more realistic picture of the risk level and the required material ductility and integrity criteria,
- establishing the acceptance criteria for those properties of the canister components and sealed canisters that are important for the safety of final disposal,
- production of quality control programmes for the manufacture of canister components and for canister sealing and handling, and
- the design of the gasket solution for the inner lid of the canister as well as justification of the use of a burnup credit in demonstrating the criticality safety of new fuel types even in the long run.

Preliminary acceptance criteria have been presented in the design documentation for the canister components and the sealing weld. Before starting the operating phase, the preliminary inspection documentation of the canister structures will be submitted for approval, including the acceptance criteria for all parts and manufacturing phases as an essential part of it. These criteria will be used as a measure of acceptability in the inspections included in the quality control programme. The preliminary acceptance criteria will be presented in the construction plan as justified and systematic entities. The third set of documentation required in the construction plan phase consists of manufacturing drawings that will be produced on the basis of the existing preliminary drawings as well as dimensional and tolerance details. The canister component manufacturing tests will continue with respect to the remaining areas of development in preparation of qualifications of manufacturing technology and for the purpose of maintaining the required skills.

The method of sealing the copper overpack will be chosen during the early part of the first three-year period; the alternatives are electron beam welding (EBW) and friction stir welding (FSW). Development work of the chosen welding method will continue with the aim of integrating it into the encapsulation plant systems. Once the method has been chosen, a welding validation plan of a general nature will be produced. A construction plan for the welding equipment will be produced.

The inspection methods for canister components and welds will be further developed with a view to their future use at the encapsulation plant and in canister manufacture. The key areas for development include the determination of defect dimensions and its reliability, the combination of inspection results obtained using different methods as well as development of the consequent approval and rejection process. The areas related to the qualification of canister component inspections (technical rationale, list of defects, assessment of possible types of manufacturing defects) and the acceptance criteria will be further developed. The goal is to have the inspection methods qualified during the first three-year period.

The buffer development work has concentrated on the detailed planning and design of the solution to be implemented as well as on the development and testing of buffer block manufacturing and installation techniques. With the detailed design of the buffer described in section 4.5.2 (Juvankoski 2012), the water content of the buffer blocks has been increased and their installation bulk densities have been changed to block-specific values, the height of the bentonite block under the canister has been reduced, the heights of other bentonite blocks have been changed from equal heights to canister-specific values, and the total height of blocks installed above the canister has been increased. The buffer solution also includes a copper plate to be placed at the bottom of the deposition hole and protection of the buffer from moisture during the installation process. The gap between the bentonite blocks and bedrock has been increased so that moisture protection can be used. In addition, a maximum limit has been set for the montmorillonite content of the buffer material.

The buffer design will be revised during the coming programme period on the basis of modelling, studies related to performance, design and development work, and the results from laboratory-scale tests and a full-scale buffer demonstration in ONKALO. During the first three-year period, the objective of design and development work is to produce the material required for the structural design of the buffer.

A full-scale buffer demonstration compliant with the reference design (Juvankoski 2012) will be installed in the demonstration tunnel excavated in ONKALO. The purpose of the full-scale buffer demonstration is to show the feasibility of the reference design and to monitor the early behaviour of the buffer. The planned and manufactured moisture protection will be among the matters tested in the demonstration. The buffer installations will in the main be done using a prototype installation vehicle to be manufactured as part of the LUCOEX project.

The development work for buffer manufacturing technology moves to testing the manufacture of full-scale buffer blocks using isostatic compression. The serial manufacture of buffer blocks will be tested by manufacturing blocks for different uses including the buffer demonstration. The objective is to investigate the effect of different factors on the properties of pressed blocks and to ensure that the pressing method used is capable of producing blocks that meet the criteria. Suitable inspection and acceptance criteria for block manufacture will be developed in conjunction with the manufacturing tests. The most suitable alternative for buffer pellet manufacture will also be determined. Experience of larger-scale material procurement as well as of buffer manufacture and storage will be gained in conjunction with buffer block manufacture during the first three-year period. This experience can be used for assessing the quality assurance plans produced so far and for making any changes to them when necessary.

A backfill operation compliant with the current basic plan would consist of deposition tunnel foundation layer material, blocks compressed of Friedland clay and pellets filling the space between the blocks and bedrock. The backfill plan issues to be resolved during the first three-year period include choosing the materials for the main backfill components. The need for a foundation layer and its thickness will be assessed by taking into account the requirements but also the evenness of the of the rock face produced by excavation and subsequent machining. Solutions for controlling the leaking waters during the backfill operation will be sought so that backfilling can be performed in spite of possible water inflow to the tunnels.

Manufacturing methods will be developed and tested for the backfill blocks and pellets to produce the required density and dimensional accuracy. Blocks and pellets will be produced for tests performed in ONKALO, and the manufacturing and quality control processes will be developed and optimised at the same time. In the longer run, preparations will be made for industrial-scale manufacture.

Backfill component tests will be performed in ONKALO's demonstration tunnels during the programme period. In the first instance, the tests will be related to the implementation and installation of components in compliance with the requirements. Component-specific tests will be performed for all backfill components: the foundation layer, block and pellet backfill materials and the end plug of the deposition tunnel. After these tests, a full-scale backfill test will be performed where all backfill components are installed together and the end plug is constructed.

The detailed design of the deposition tunnel end plug, including development of the concrete formula, will be performed during the first three-year period. Following the design work, detailed drawings as well as structural and work plans can be produced for the plug. The deposition tunnel end plug will be implemented in ONKALO as a full-scale component-specific test. Its purpose is to test the excavation of the end plug location, the feasibility of constructing the end plug as well as the work and quality control methods, and to monitor the hardening and shrinking of the concrete part of the end plug, and to test the mechanical strength of the concrete part of the end plug and the water-tightness of the end plug. The experience gained from the test will be used to update the plug plan, and the changes made to the plan will be assessed during further development of the end plug. An end plug compliant with the updated plan will be constructed in ONKALO in connection with the full-scale backfill test.

The backfill installation equipment prototypes will be designed and manufactured during the first three-year period. Experience of the installation equipment prototypes will be gained in connection with the component-specific tests, and any development needs will be taken into account in the design/planning of installation equipment to be procured for disposal operations during the latter three-year period.

The possible procurement procedures, manufacturers and manufacturing locations of buffer and backfill components will be investigated during the programme period. Alternatives (or alternative materials) for the Friedland clay to be used as backfill material will be assessed for reasons of reliability of supply. They must comply with the requirements set out for backfill in terms of mineralogical composition and quality.

Part of the disposal panels will already be sealed off during the operating phase. After the actual operating phase, all facilities will be sealed off using various closure structures in order to prevent the formation of flow routes and inadvertent intrusion to the repository. Requirements have been set out for the closure of the repository, and a sealing-off solution has been presented on that basis. International full-scale demonstrations and tests related to the plugging and closure of the repository, tunnels and shafts have been initiated in recent years or are in the process of being initiated. Posiva is participating in them. The work related to closure plans will during the programme period now commencing focus on the preparation of documents required for the operating licence application.

The disposal canister, buffer and backfill solution components can alternatively be purchased from external sources by concluding the necessary supply agreements, or they can be produced in-house, possibly with a partner. The planning for these procurements will begin during the programme period now commencing, and the goal is to make the related decisions in the next few years and to develop the required procedures and production methods.

Demonstration of the long-term safety of the disposal solution for spent nuclear fuel

A so-called Safety Case has been produced for the purpose of demonstrating the long-term safety of the disposal of spent nuclear fuel. According to an internationally adopted definition, "Safety Case" refers to all the technical-scientific documentation, analyses, observations, tests and other evidence that are used to demonstrate the safety of disposal and the reliability of the assessments. A summary of the Safety Case will also be appended to the Preliminary Safety Analysis Report (PSAR).

According to the plan produced in 2008 and updated since, among other things based on the feedback on preliminary licensing documentation received from authorities, the Safety Case consists of several reports, with the key ones presenting:

- a description of the disposal system,
- a description of the processes affecting final disposal,
- performance analyses,
- definitions of the scenarios analysed in the safety analysis,
- a description of the models and data,
- scenario analyses (assessments of the impacts of disposal),
- supplementary analyses supporting the safety case, and
- a summary of the Safety Case.

Compilation of the above reports has been the most important safety case task undertaken during the past programme period. In addition, the work has concentrated on producing the background reports in support of the main reports; these background reports discuss in detail various matters, including the properties of the disposal site and the technical disposal system, as well as the future development of external factors affecting disposal, in particular that of climatic conditions.

Among these basic premises of the Safety Case are the
performance targets and target properties defined for the disposal system. The preliminary performance targets of the engineered barrier system have been defined on the basis of the expected likely evolution in the disposal environment so that when the targets are met, the safety requirements of final disposal are met with a high degree of certainty in spite of possible minor individual deviations. In turn, preliminary target properties have been defined for the bedrock surrounding the repository. These

properties serve as the basis for the rock suitability classification (RSC) applied in the selection of locations for deposition tunnels and holes.

The elimination of any deficiencies and uncertainties that might significantly compromise the reliability of long-term safety assessments has been set as a key task after the construction licence application has been submitted. A key task and goal for the three-year period now commencing is the reduction of uncertainties and the resolution of open questions related to the performance of release barriers (spent fuel, components of the disposal system and the interfaces between them). The issues warranting particular attention are:

- the alteration processes of bentonite materials (montmorillonite), including the interaction between water with a high pH value and the buffer (impact of cement), alteration and cementation of montmorillonite.
- formation of flow channels and erosion (both mechanical and chemical) in clay materials,
- the properties of bentonite in rock displacements,
- microbial activity in buffer bentonite,
- development of the closure plan, including materials and their performance,
- creep and creep mechanism of the canister material,
- corrosion of copper in water,
- residual stresses after electron beam welding, and
- solubility of high burnup fuel

Other key areas for analysis will be:

- the chemical composition and flow of groundwater; general evolution of the composition, colloids, salinity, verification of the sulphide level,
- rock-mechanical load, in particular the impact of rock displacements and
- the impact of EDZ on groundwater flows.

In addition, the report *Models and Data for the Repository System,* forming part of the TURVA-2012 portfolio, will be compiled in 2013.

Posiva is also in the process of acquiring further information for the scenario definitions required for assessing safety. During the programme period now commencing, the international Greenland Analogue Project (GAP) will be completed. Its purpose is to help create a holistic and realistic view of how a layer of ice and permafrost can affect the geological disposal of spent nuclear fuel. The climate scenarios will also be developed more realistically during the programme period.

Horizontal disposal solution KBS-3H

The KBS-3H solution has been developed during the TKS-2009 period in cooperation with SKB. One of the results of supplementary studies is the selection of the so-called DAWE alternative as the design solution. Details related to the plugging and backfill of 3H tunnels, such as the plug and supercontainer materials, have been decided.

Research and development work related to the KBS-3H solution will be advanced during the next three years so that comparison of the 3V/3H alternatives, and preparation of a PSAR, if required, becomes possible. The comparison of design alternatives also includes environmental matters, costs and safety issues (long-term, operational and occupational safety). The work will concentrate on the particular features of the 3H solution, and it will be mainly implemented as a joint project between SKB and Posiva.

The operation compliant with the plans made for the horizontal disposal solution will be verified and demonstrated in a full-scale test (Multi Purpose Test, MPT) at the Äspö HRL (Hard Rock Laboratory). The MPT will test the manufacture, transport and installation of main components, as well as the techniques compliant with the chosen DAWE design solution. Tests related to the straightness of the pilot hole will be performed either in Äspö or in Olkiluoto. The plan is to excavate a dedicated demonstration tunnel for KBS-3H in the Äspö HRL after the pilot hole tests.

In addition to the swelling properties of buffer bentonite (the bentonite included in the supercontainer and the distance plug), other subjects identified in the previous phase of the project are also being investigated. The designs for the buffer and backfill components and other components (supercontainer and plugs) will be further specified during 2013–2015. The layout of the disposal facility will be updated on the basis of a more up-to-date geological model and other information. In addition, the technical solutions for the operating phase of the 3H design and the stepwise construction of the necessary facilities in the Olkiluoto bedrock will be planned. System descriptions and a report on the plant description will be produced during 2013–2015.

The investigations regarding long-term safety of the horizontal disposal solution will be performed in phases during the next few years. The key areas for investigation identified in the preliminary KBS-3H safety analysis in 2008 will be analysed first. The investigation needs particularly related to the 3H design concern cases associated with the breakage of several canisters caused by bentonite erosion induced by dilute glacial water and the resulting canister corrosion and canister breakage caused by a rock displacement. When the results of analysis have been assessed, a more detailed plan will be produced for KBS-3H-related safety assessment work. The purpose of safety assessment regarding the 3H solution is to achieve the required level of knowledge that will allow assessing whether the horizontal disposal solution is at least as safe as the vertical disposal solution. The Olkiluoto-specific safety case for KBS-3H will be compiled in a report portfolio in the same manner as the safety case for KBS-3V.

Planning and implementation of the final disposal of spent nuclear fuel

Planning and implementation of the final disposal of spent nuclear fuel have progressed both with regard to the encapsulation plant and the disposal facility. The plans for the encapsulation plant and its systems have been updated for the construction licence phase. The plans for the disposal facility and its associated facilities and auxiliary buildings have also been updated.

The plant design work will advance to the implementation planning phase during the programme period now commencing. Development work related to the special systems of the encapsulation plant and the disposal process will also be carried out alongside implementation planning. Such systems in the encapsulation plant include the fuel transfer mechanism, the canister transfer trolley and the fork-lift truck for canister transfer. The plan is to manufacture prototypes of these in order to verify their performance.

The development work for repository systems will concentrate on the installation technique of EBS components. Prototypes will be manufactured of the canister, buffer and backfill installation equipment, among other things, for the purpose of verifying the operability of plans and the feasibility of achieving the installation tolerances.

The goal of plant implementation planning is to allow the commencement of construction work soon after the construction licence has been granted. This requires the production of detailed planning documentation during the time the application is being processed, so that the structural plans can be submitted to the authorities at the pace required for the implementation.

Implementation of the hoist building is about to start above ground. Initially, the building will serve for the ONKALO investigations purposes, and later it will be fitted for nuclear facility use. Preparations for the implementation of nuclear facilities will begin in good time before obtaining the construction licence. The preparatory work for the encapsulation plant includes establishment of the site with the necessary road connections and excavation of the plant foundation. The views presented in this programme regarding the implementation schedule are based on the assumption that processing the construction licence application would take about two years and the actual implementation could begin in 2015.

Once the construction licence and other necessary permits have been issued, implementation of the underground part of the disposal facility will begin by excavating central tunnel connections in the area of the first deposition tunnels. Implementation of the necessary shafts will also begin at the same time. The implementation phase will be described in greater detail in the nuclear waste management programme to be published in 2015.

Development of operations

Posiva is committed to absolute adherence to a high standard of safety culture and recognition of safety in all its operations so that safety always takes precedence over other, e.g., financial, aspects in all activities. In the coming years, the focus will be on developing procedures in order to promote the systematic handling of safety matters. Examples of the matters to be developed include the production of a safety development programme for the construction and operation of the plant complex, development of the technical specifications for operational activities and for matching the operational activities with construction activities, as well as development of a tool for assessing the safety culture.

The key tasks regarding quality management include the further specification of procedures for construction quality management and linking them as part of Posiva's operations management system, development of the qualification methods for systems and equipment, security and preparedness arrangements and nuclear material safeguards, detailed planning, organisation and implementation of the systems related to security and preparedness arrangements as part of the plant complex to be built and by utilising TVO's existing infrastructure, implementation of the security arrangements agreed for the construction phase of the disposal facility, as well as development of nuclear material safeguards in compliance with the plan to be submitted to STUK in connection with the construction licence application.

During the coming programme period, the work related to nuclear and radiation safety will concentrate on the detailed design of radiation measurement systems and the development of procedures related to the monitoring of releases and radiation safety, development of the process for acquiring information on the criticality safety of spent nuclear fuel for the needs of waste and nuclear materials accountancy, safety analyses and operational activities, continuation of the analyses on the criticality safety of spent nuclear fuel in cooperation with the power companies, VTT and authorities, as well as to participation on international cooperation aimed at investigating the properties of spent nuclear fuel.

The nuclear material safeguards manual will be developed to include instructions for the notifications, accounting, reports and other monitoring obligations required by international safeguards. The manual will be submitted to STUK for approval.

Nuclear waste management of nuclear power plants

The Loviisa power plant

At the Loviisa NPP, nuclear waste management and operation of the repository for low- and intermediate-level waste have progressed according to plans, and the reports and updates of the safety case required in the terms and conditions of the operating licence have been made. An update of the decommissioning plan for the Loviisa NPP will be submitted to the ministry by the end of 2012. The periodic safety review of the VLJ repository in Loviisa will be done by the end of 2013.

Commissioning of the interim storage facility for operational waste (HJT3) will continue in the VLJ repository in Loviisa. The expansion will facilitate the interim storage and sorting of operational waste barrels. The process for obtaining the licences and permits for the HJT3 for the interim storage of waste barrels is in progress. The changes taking place in the VLJ repository in Loviisa are monitored by dedicated investigation s. In addition to temperature and humidity, the monitoring includes changes in observed groundwater (water inflow volumes, groundwater chemistry and the interface between fresh and saline water) as well as rock-mechanical measurements (rock movements and weathering). The condition of the repository is also monitored visually. The trial operation of the liquid waste solidification plant will continue. The casting backfill methods of solidified waste facilities will be tested before starting the final disposal of waste.

The Olkiluoto power plant

In TVO, waste management of OL1 and OL2, the NPP units in operation, as well as the operation of the VLJ repository, the disposal site for low- and intermediate-level operational waste have progressed according to plan, and the reports and updates of the safety case required in the terms and conditions of the operating licence have been made. The decommissioning plans of the plant units were also duly updated, and they will be further defined towards the end of the service life of the plant units. The expansion of the interim storage for spent nuclear fuel in Olkiluoto is in progress with the needs of OL1 and OL2 as the first priority at this stage, but OL3 has also been taken into account in the expansion.

The most important research programmes are related to the stability of the VLJ repository and on predicting the status of the VLJ repository after its long-time operation and final closure. Monitoring of the VLJ repository will continue, and status reports will be issued annually. The research programmes related to the final disposal of operational waste will primarily be in progress in the VLJ repository, with the most important ones being the gas evolution test, research into the long-term durability of concrete and research into the long-term behaviour of metals included in decommissioning waste. VTT is performing parallel tests for the research programmes, and several expert parties are participating in the analysis and modelling work. In addition, investigations will be carried out in order to specify further the decommissioning plans, and development of the waste treatment techniques will be monitored. Positive experience has been gained from re-melting metal scrap for the purpose of reducing the volume of operational waste, and the experience can also be utilised for planning the decommissioning operation.

The new plant projects, OL3 and OL4, will affect future R&D needs. According to the schedules, an operating licence for OL3 will be applied for during the programme period of 2013–2018 and it will also be included within the scope of nuclear waste obligations at that time, which will affect both the storage of operational waste and the disposal and decommissioning plans. Progress of the OL4 plant unit project will for the time being not affect the plans and research needs. However, the plant unit will be selected and the construction licence applied for during the programme period which means that the first plans for waste management and decommissioning will have to be produced.

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1 INTRODUCTION

1.1 Nuclear waste management responsibilities

Under the Nuclear Energy Act, a producer of nuclear waste is liable for all required nuclear waste management measures and the associated costs. Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat Oy (Fortum), being parties under the waste management obligation, are responsible for the on-site storage, processing and disposal of operational waste generated in their own power plants. Both plant sites feature an operational disposal facility into which the operational waste generated during the operation of the plant is placed. Waste generated from the eventual decommissioning of the power plants is to be disposed of in the same facilities. Both parties under the waste management obligation will also arrange the interim storage of their own spent fuel.

In order to provide for the measures required after the interim storage of spent nuclear fuel, TVO and Fortum in 1995 established Posiva Oy (Posiva) for the purpose of seeing to the disposal of the spent nuclear fuel produced by its owners' NPPs currently operating or to be built in Finland. In the first phase, the company's tasks involve the performance of research, technical development and design work serving this end. Later, the company will assume the responsibility for the construction of the encapsulation plant and disposal facility and its operation until the closing of the facility. Posiva is also responsible for establishing and maintaining communication with the authorities relevant to the performance of its tasks as well as acquiring the required permits for the facilities it constructs and operates. The establishment of Posiva did not affect the responsibility for nuclear waste management; instead, TVO and Fortum are still responsible for all the spent fuel they produce.

According to the legislation, the Ministry of Employment and the Economy (abbreviated as TEM in Finnish, previously the Ministry of Trade and Industry, abbreviated as KTM) decides on the principles to be observed by the parties under the nuclear waste management obligation. The decisions, originally based on the Government decision-in-principle on the objectives of nuclear waste management research, investigation and design work issued 10 November 1983, were presented in KTM's letters 7/815/91 (19 March 1991), 11/815/95 (26 September 1995) and 9/815/2003 (23 October 2003) to TVO and Fortum. These decisions form the starting point for both the practical implementation of nuclear waste management and the research and development work concerning future measures.

1.2 Acts, decrees and other regulations

Nuclear waste management in Finland is regulated by the Nuclear Energy Act (990/1987) and the Nuclear Energy Decree (161/1988) that came into force in 1988. These define, for example, the liabilities of a nuclear energy producer, the implementation of nuclear waste management, the licence procedures and the supervision rights. The Nuclear Energy Act was amended in 1994 so that all nuclear waste generated in Finland must be disposed of in Finland. The Nuclear Energy Act also prohibits the import of nuclear waste into Finland and its export from Finland, albeit that the legislation (amendment 348, issued on 23 May 2008) allows nuclear waste with low radioactivity to be exported to another country for appropriate treatment.

The legislation concerning nuclear energy was reformed in 2008. Parliament approved the Government's legislative proposal for amending the Nuclear Energy Act (Government Bill 117/2007) on 7 May 2005, and the reformed act came into force on 1 June 2008. In the legislative reform, some of the Government decisions concerning the nuclear industry were changed into Government decrees. The decrees entered into force on 1 December 2008. The new decrees are: the Government decree on the Safety of Nuclear Power Plants (733/2008, issued 27 November 2008), the Government Decree on the Security in the Use of Nuclear Energy (734/2008, issued 27 November 2008), the Government Decree on Emergency Response Arrangements at Nuclear Power Plants (735/2008, issued 27 November 2008), and the Government Decree on the Safety of Disposal of Nuclear Waste (736/2008, issued 27 November 2008).

The Government issues the general safety regulations concerning nuclear waste management. The safety regulations concerning the processing and storage of nuclear waste are included in the Government Decree on the Safety of Nuclear Power Plants (2008/733, issued on 27 November 2008). Regulations concerning the encapsulation plant and disposal facility for spent nuclear fuel are included in the Government Decree on the Safety of Disposal of Nuclear Waste (736/2008, issued 27 November 2008).

The work for revising the YVL Guides issued by the Radiation and Nuclear Safety Authority (STUK) is in progress. With the publication of the new YVL guides, the guidelines will be updated and the number of separate guides will be reduced. The drafts indicate that the instructions for nuclear materials and nuclear waste will be included in the YVL-D series that will include five guides concerning nuclear waste. Guide D.1 will deal with nuclear non-proliferation control; D.2 with the transport of nuclear material and nuclear waste; D.3 with the processing, storage and encapsulation of spent nuclear fuel; D.4 with the management of low-and intermediate-level nuclear waste and decommissioning of NPPs; and D.5 with the final disposal of nuclear waste. The most recent drafts of these guides were used for producing the YJH-2102 report. In its letter to Posiva, STUK has stated that the company may use the draft guides bought to the draft level (L4) in its planning and preparation of the construction licence application.

The schedule for the disposal of spent fuel was established in decision 9/815/2003 of the Ministry of Trade and Industry. According to the decision, Teollisuuden Voima Oyj and Fortum Power and Heat Oy, as parties under the nuclear waste management obligation shall, either separately, together, or through Posiva Oy, prepare to present all reports and plans required for obtaining a construction licence for encapsulation plant and disposal facility for spent nuclear fuel as referred to in section 32 of the Nuclear Energy Decree by the end of 2012, on the basis of which the encapsulation plant and disposal facility can be constructed so that disposal operations can commence in 2020. In this connection, the above decision set out the requirement that the parties under the nuclear waste management obligation had to present, by the end of 2009, the reports required for the construction licence listed in section 32 of the Nuclear Energy Decree so that they indicate the parts where the documentary material required for the construction licence is incomplete as well as the manner and schedule in which the material is to be supplemented. The so-called pre-licence material referred to in the requirement was submitted to the Ministry of Employment and the Economy in September 2009. The ministry organised an extensive assessment by authorities, and the feedback received as a result was taken into account when producing this YJH-2012 programme. The matter is discussed in greater detail in section 4.1.7 of this programme.

In its letters TEM/2963/08.05.01/2009 and TEM/2967/08.05.01/2009, the Ministry of Employment and the Economy requires the parties under the nuclear waste management obligation to see to it that in addition to the description of management of spent fuel, the next three-year reports also include a description of the management of other nuclear waste that complies with the requirements set out in section 74 of the Nuclear Energy Decree. The ministry also requires the reports to clearly indicate how the comments made in the statements of opinion were taken into account in the work carried out.

In addition to the earlier decisions, the following decisions as well as statements and letters by authorities concerning the parties under the nuclear waste management obligation and Posiva were taken into account when producing the YJH-2012 programme:

- the Government's decision-in-principle (6 May 2010) regarding TVO's application to build an NPP unit (OL4) in Olkiluoto,
- the Government's decision-in-principle (6 May 2010) regarding Posiva's application to construct a spent nuclear fuel disposal facility with an expanded layout,
- statements by the Ministry or Employment and the Economy entitled*"Ydinjätehuoltoa koskevat selvitykset vuosille 2010–2015"* (TEM/2963/08.05.01/2009, TEM/2967/08.05.01/2009),
- statement by the Ministry of Employment and the Economy entitled *"Käytetyn ydinpolttoaineen loppusijoitushanke - alustavat selvitykset ja suunnitelmat liittyen tulevan rakentamislupahakemuksen valmisteluun"* (TEM/2950/08.05.01/2009, TEM/2961/08.05.01/2009, TEM/2966/08.05.01/2009),
- letter by STUK 5/H48112/2009 entitled *"Olkiluodon ja Loviisan voimalaitosten ydinjätehuollon tutkimus- ja kehitystyön sekä teknisen suunnittelun ohjelma 2010–2012"* with its appendices Y811/123,
- STUK letter 2/H42212/2011 entitled "*Säteilyturvakeskuksen turvallisuusarvio Posiva Oy:n alustavasta rakentamislupahakemusaineistosta*", and
- decisions, statements of opinion and letters from authorities received by Fortum and TVO.

1.3 Reports prescribed in the Nuclear Energy Decree and the obligation to submit them

Section 74 of the Nuclear Energy Decree contains provisions regarding the reports that the parties under the nuclear waste management obligation must produce and submit. The power companies' nuclear waste management reports (YJH reports) must be submitted to the Ministry of Employment and the Economy every three years at the end of September. According to section 77 of the decree, the parties under the nuclear waste management obligation must submit a report on the nuclear waste management actions taken during the year by the end of March on the following year.

The nuclear waste management report must contain the following accounts:

1. a description of how the licensee with a waste management obligation has planned to carry out nuclear waste management measures and their preparation; the plan shall include at least the following parts:
   a) an overall plan for carrying out nuclear waste management, with the relevant timetables and specifications, including the necessary preparations and research measures and the administrative arrangements and other duties required by the waste management obligation;
   b) an estimate of the current status of research, development and planning activities alongside a detailed plan of measures intended for implementation within the next three years; and
   c) an outline plan for the measures planned for implementation in the course of the next six years;
2. a description of the agreements and other arrangements that the licensee has made to arrange nuclear waste management; and
3. any other information considered necessary by the authorities.

The authority mentioned in section 28 of the Nuclear Energy Act can require that the licensee draw up a plan on the matters referred to above in paragraph a) of subsection 1 at other times, too, when this is deemed necessary. If some significant changes take place in nuclear waste management, the party with the nuclear waste management obligation must notify the said authority thereof without delay.

The three-year plan referred to in the decree used to be entitled the TKS programme. As the disposal programme for spent nuclear fuel advances to the construction licence phase and the focus of work aimed at final disposal changes from R&D to implementation, it has been deemed appropriate to change the name of the document into a nuclear waste management programme, and consequently, this document is entitled YJH-2012 programme. In compliance with the decree, the programme covers the years 2013–2018. The programme focusses on describing the measures to be taken during 2013–2015. Preliminary plans are presented of the measures to be taken during 2016–2018, and these plans will be further specified in the YJH programme to be submitted in 2015.

Chapter 1 of the programme discusses the responsibilities for nuclear waste management, the associated legislation and the obligation to submit reports. After that, Chapters 2 and 3 describe the current overall plans for nuclear waste management by the Loviisa and Olkiluoto power plants. Chapter 4 assesses the achievement of TKS-2009 programme goals and presents the current status of planning/design work and progress of the ONKALO construction work. Chapters 5–6 discuss the goals after the construction licence phase, aimed at progressing to the operating licence phase. Chapter 5 describes the R&D work associated with these goals. Chapter 6 describes the implementation work following the construction licence phase, including the construction of nuclear facilities. The management of operational waste and decommissioning are discussed in Chapters 7–8 of the programme.

1.4 General objectives of the YJH-2012 programme

The waste management measures regarding operating and decommissioning waste will continue during the 2013–2018 programme period in accordance with the established procedures at the Loviisa and Olkiluoto nuclear waste facilities. The long-term tests currently in progress will also continue. The period now commencing will also include the periodic safety assessment of the Loviisa disposal facility and commissioning of the solidification plant in 2013, as well as an update of the decommissioning plan in 2018. The next decommissioning plan for TVO's plants in operation will be produced in 2020 at the latest, and it will include the plans for the plant units Olkiluoto 1 (OL1), Olkiluoto 2 (OL2) and Olkiluoto 3 (OL3). It is likely that this combined plan will be produced before 2020, because the first decommissioning plan for OL3 will be submitted at the time the operating licence application for OL3 is submitted, and it must be updated within six years from that moment.

The overall time schedule regarding preparations for the spent nuclear fuel disposal project is shown in Figure 1-1. The work aimed at final disposal was initiated by TVO as a response to the requirements set out in its operating licence conditions for organising the nuclear waste management of the OL1 and 2 plant units. After the Government's decision-in-principle of 2000, the work has concentrated on the verification studies regarding the bedrock of Olkiluoto as the chosen disposal site, on developing the final disposal solution and on designing and planning the nuclear waste facilities so that they are suitable for Olkiluoto.

The work regarding final disposal of spent nuclear fuel will during 2013–2018 advance to the implementation of the project. During the programme period, the authorities will process the construction licence application submitted by Posiva, and the time schedule of the project will become more specific after this processing phase. The goals for this programme are set on the basis of the current time schedule for the disposal of spent fuel, which is aimed at initiating disposal operations around 2020.

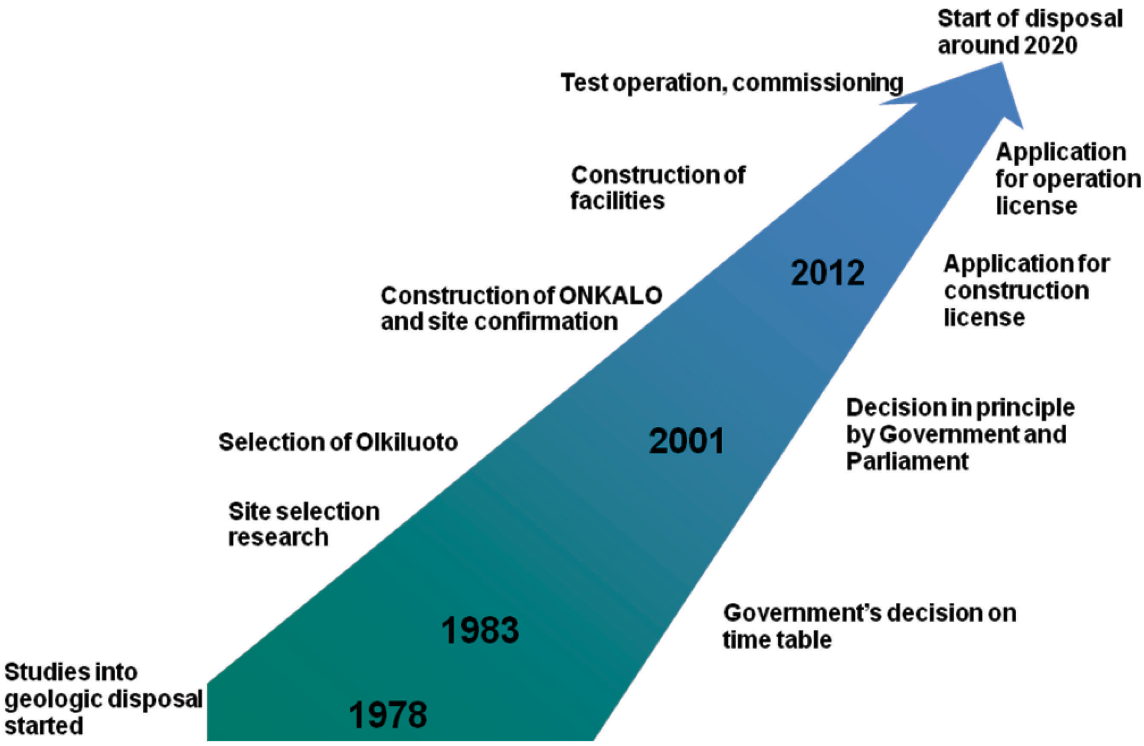

Figure 1-1. *Phases of the action plan aimed at initiating the final disposal of spent fuel since 1978. Selection of the disposal site was linked to the Government's decision-in-principle regarding Posiva's application in 1999. The construction of ONKALO has made it possible to verify the characteristics of the Olkiluoto bedrock and to acquire detailed information for planning final disposal.*

Posiva's actions are aimed at receiving a construction licence on the basis of the application it submits in 2012 and at becoming a holder of a nuclear facility licence. The goal of the subsequent work to be carried out during 2013–2015 is to bring the plans of the construction licence phase to such a state of readiness that implementation of the project can start in all respects. With this, the next main target is to become ready to submit an operating licence application. In order to achieve that, Posiva's operations will increasingly be directed towards the implementation of final disposal, which will be reflected in the focal areas of planning and research work taking place during the programme period now commencing. In order to obtain an operating licence, the necessary nuclear facilities must be built to a stage where they are ready to operate. The same requirement of operational readiness also applies to other production facilities required for starting final disposal operations.

It is vitally important for achieving such readiness for submitting an operating licence approval that:

- the feasibility of implementing a disposal system compliant with the requirements has been demonstrated by analyses and tests,
- the safety case required for obtaining the operating licence has been prepared,
- the plants and equipment have been designed and constructed to a degree or readiness that allows for their trial use,
- Posiva's organisation meets the requirements set by disposal operations,

- the technical capabilities for starting fuel transportation have been achieved, and
- the production and procurement chain of materials and components required for final disposal have been established.

The following task entities reflect the achievement of the target status described above:
- Construction of plants, advanced far enough to allow the licence application to be submitted, and
- The completion of R&D tasks so that operational tests can be performed to demonstrate the feasibility of implementing the KBS-3 solution and achievement of an initial state essential for long-term safety.

A significant target for R&D work is the elimination of any uncertainties possibly surfacing in connection with the construction licence application – in particular of those affecting long-term safety – or raising them to such a level that they can be excluded in the plans to be appended to the operating licence application and in the associated safety analyses. The aim is also to plan an alternative for the KBS-3V solution (the basic alternative), the horizontal disposal solution KBS-3H, to a level that allows these design alternatives to be compared and a justified selection to be made.

Figure 1-2 is a schematic illustration of the targets for the programme period now commencing. The intended readiness to submit the operating licence application will be achieved by implementing the nuclear facilities above ground and underground and by the associated research and development work. R&D work will produce results for use in the implementation and help assess the performance and safety of the KBS-3 system. The testing and development work carried out in the demonstration tunnels constructed in ONKALO constitutes an essential part of the acquisition of information aimed at achieving the target. The readiness to submit the operating licence application will be achieved when joint operation tests have been successfully carried out in both the encapsulation plant above ground and in the underground disposal facility, demonstrating that final disposal operations can begin. The joint operation tests are part of the trial operation of nuclear facilities required in the regulations.

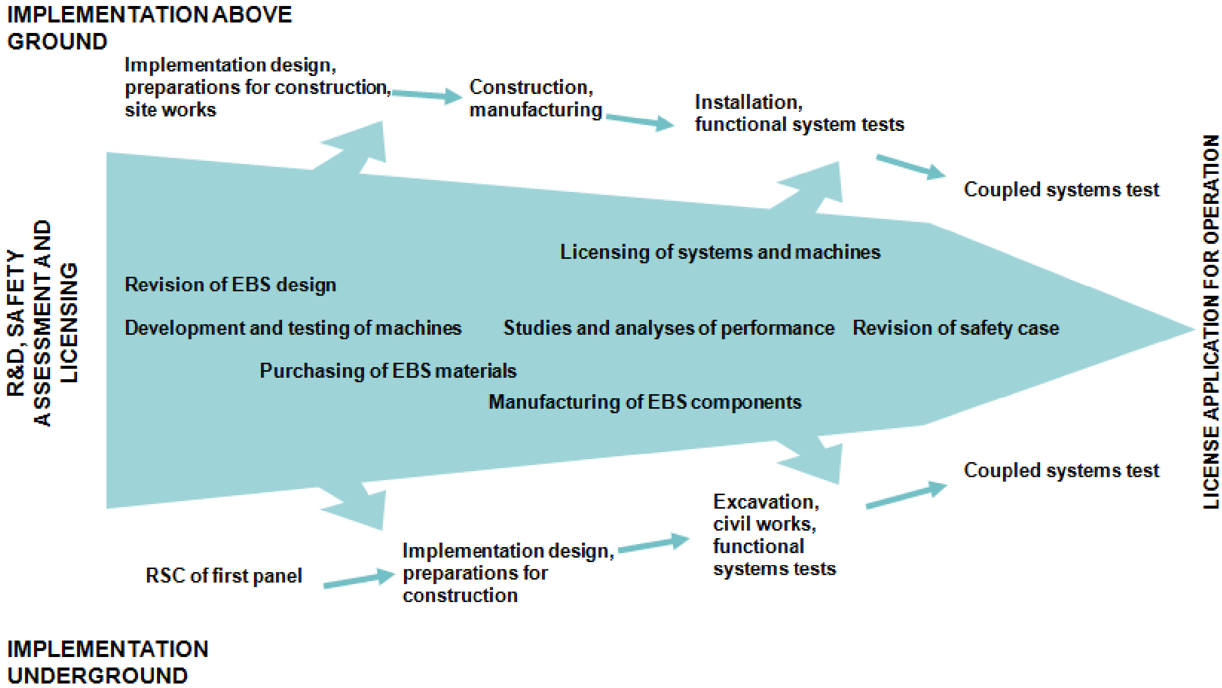

Figure 1-2*. Key task entities and phases aimed at achieving the intended readiness to submit the operating licence application so that final disposal can commence around 2020. The required research and development work serves both the implementation and the Final Safety Analysis Report to be appended to the operating licence application. During implementation, separate licences and permits will be obtained for systems and equipment, and procurement and manufacturing methods will be developed for the components of the engineered barrier system.*

The decision-in-principle of 2000 made it possible to excavate the Underground Rock Characterisation Facility ONKALO in Olkiluoto. The intention is to eventually integrate these facilities as part of the disposal facility to be built. For this reason, the implementation planning of ONKALO has been coordinated together with the design work for the disposal facility, and the design requirements applicable to nuclear facilities have been taken into account in its design and implementation. STUK has been overseeing the construction of ONKALO and its associated implementation work in the same manner as it oversees nuclear facilities. ONKALO plays a key role in the performance of task entities shown in Figure 1-2. The plan is to carry out most of the development work aimed at the operation of the disposal facility in tunnel facilities provided by ONKALO, in conditions similar to actual final disposal.

2 AN OUTLINE OF THE OVERALL PLAN FOR NUCLEAR WASTE MANAGEMENT AT THE LOVIISA POWER PLANT

The Loviisa power plant consists of two power plant units in operation, Loviisa 1 (LO1) and Loviisa 2 (LO2). In addition, there is an interim storage for spent fuel (KPA storage) and a disposal facility for operational waste (VLJ repository) at the power plant site. The Government has granted Fortum Power and Heat Oy the licence to operate the first NPP unit of the Loviisa power plant (LO1), having a rated thermal power output of 1 500 MW, until the end of 2027, and the other NPP unit (LO2) until the end of 2030. In addition, the Government has granted the licence to operate the nuclear fuel buildings belonging to the plant units as well as the buildings and storage facilities necessary for nuclear waste management with their required expansions until the end of 2030. The company will dispose of the low- and intermediate-level waste generated during the operation of the NPP in the repository built at the power plant site; its operating licence is valid until the end of 2055.

2.1 Overall time schedule of nuclear waste management measures by the Loviisa power plant

LO1, the first power plant unit of the Loviisa NPP, started the commercial operation in 1977, followed by the second unit LO2 in 1981. The radioactive waste generated during plant operation was kept in intermediate storage facilities and tanks at the plant site until the completion of the Loviisa repository in 1997. The first excavation operations were for access routes from ground level to the repository, two operational waste facilities (HJT1 and HJT2) and a space for the solidified intermediate-level waste facility (KJT) to be constructed later. The KJT facility was completed in 2008. Placement of operational waste in the HJT1 and HJT2 facilities began immediately when the repository had been commissioned. At the moment, the KJT facility is not used for disposal yet. It will be commissioned when the trial operation of the liquid waste solidification plant in Loviisa has been successfully completed.

During the early days of operation of the Loviisa power plant, spent nuclear fuel was returned to the Soviet Union (and later to Russia) after a brief period of interim storage. In 1994, the Nuclear Energy Act was amended so that the export and import of nuclear waste was prohibited. The amendment led to cooperation between TVO and Imatran Voima, the company now called Fortum, in the final disposal of spent nuclear fuel and led to the establishment of Posiva in 1995. The last batch of spent nuclear fuel was transported from Loviisa to Russia in 1996. Since then, spent nuclear fuel has been stored in a KPA storage at the Loviisa power plant site. The KPA storage in Loviisa is a water-cooled facility with 11 storage pools. The storage facility was expanded during 1997–2000 in order to have sufficient storage capacity until the commencement of final disposal, i.e. approximately until 2020. So-called high-density racks have also been introduced to the storage facility. They allow storing larger quantities of fuel in the pools.

During 2011–2012, the Loviisa repository was expanded by constructing HJT3, the interim storage facility for operational waste, and by completing the connecting tunnel shown in orange in Figure 2-2. The tunnel facilitates the movements of vehicles in the repository. The plan is to later obtain a licence for using the HJT3 as a repository for operational and decommissioning waste.

The operating licences of the Loviisa power plant units are currently valid until 2027 for LO1 and until 2030 for LO2. The planning work leading to decommissioning of the plant will be initiated in good time before the end of the service life of the plant units so that dismantling of the plant units can be started immediately when their service life ends. The current plan is to complete the first phase of decommissioning the plant around 2035. Parts of the plant unit systems, such as the liquid waste storage and processing systems, will not be dismantled at that stage, because they will be further needed during the independent operation of the KPA storage. All fuel from Loviisa will be disposed of by around 2065, after which the KPA storage will be decommissioned and its systems dismantled. The accumulated waste will be placed in the low- and intermediate-level repository in Loviisa, and the repository will be finally sealed off around 2068. Figure 2-1 shows the timing of the planned operation and nuclear waste management measures of the Loviisa power plant.

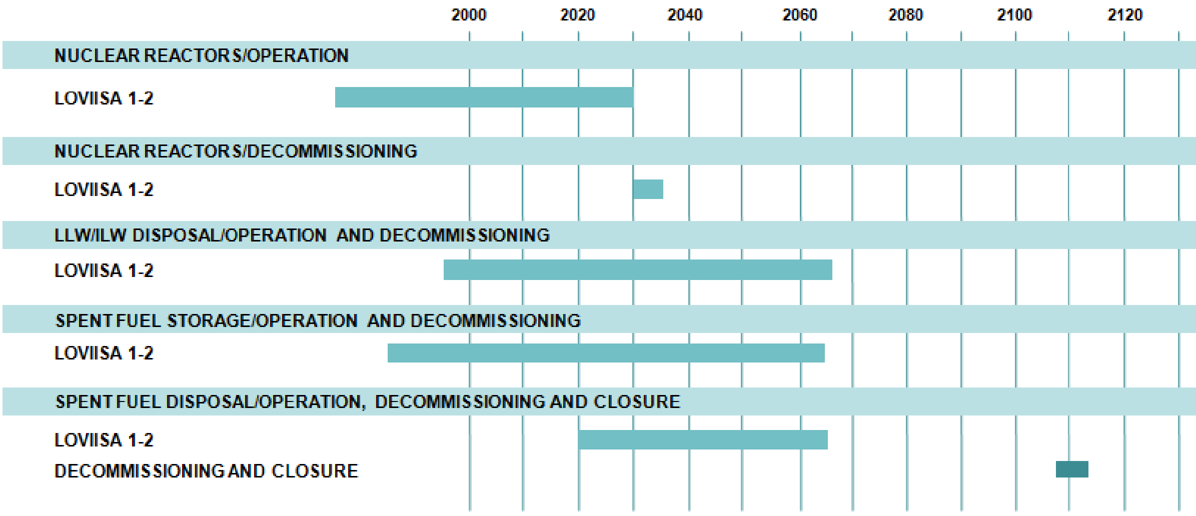

Figure 2-1. *Overall time schedule for nuclear waste management at the Loviisa power plant.*

2.2 Handling and storage of spent fuel

Spent fuel produced in the two Loviisa NPP units (LO1 and LO2) is stored at the power plant units and in the interim spent fuel storage (KPA storage). New spent fuel storage pools were last constructed at the Loviisa site in 2000. A decision has been made to equip the current pools with some high-density racks. This will provide additional capacity until 2020 when the transportation of spent fuel for disposal in Olkiluoto is expected to begin. Equipping all pools with the high-density racks would provide enough storage capacity until around 2030.

In 2007, two new high-density racks were procured for the spent fuel storage at Loviisa, and this was repeated in 2009 and 2011. At the end of 2011, the quantity of spent fuel stored at the Loviisa power plant amounted to a total of 4,339 assemblies, corresponding to an approximate quantity of 522 tonnes of fresh uranium. Of that number, 360 assemblies were stored at LO1 and 293 at LO2. Spent fuel storages 1 and 2 held 480 and 3,206 assemblies, respectively. Additionally, 313 assemblies were in use in the LO1 reactor, with another 313 in use in the LO2 reactor.

2.3 Processing, storage and disposal of operational waste

The low-level and intermediate-level operational waste generated at the Loviisa NPP is processed, stored and disposed of at the plant site (Figure 2-2). The used ion exchange resins and evaporator bottoms are stored in tanks in the liquid waste storage. Caesium is separated in special campaigns from the evaporation residue in order to reduce the volume of liquid waste. The liquid waste solidification plant based on mixing the waste with concrete was completed in 2007, and it is currently in trial operation.

The dry operational waste generated in power plant maintenance and repair work is packed into 200-litre steel drums. Compressible waste is pressed into the drums using a baling press; in this way, one drum may be made to hold about five times more waste than without compression.

Operational waste released from control is taken to a landfill site and Ekokem Oy. Metal waste generated in the controlled area is exempted from control in campaigns, as the situation requires, and collected into suitable waste batches. In addition to storage facilities in the controlled area, radioactive metal waste is also kept in interim storage in a separately licenced container in a storage hall at the plant site. The hall is reserved as a place for storing operational waste barrels released from control. This metal waste will eventually be disposed of in the VLJ repository.

2.4 Planning for decommissioning

The most recent decommissioning plan for the Loviisa power plant was submitted to the Ministry of Employment and the Economy in December 2008 (Kallonen *et al.* 2008). The decommissioning plan for the Loviisa power plant is based on immediate dismantling after the plant units have operated for 50 years.

The decommissioning plan for the Loviisa power plant includes, among other things, an activity inventory, dismantling work-plan, radiation dose estimates, the amounts of components and packages for disposal, estimates of work and costs, as well as a safety case for the disposal of waste. The plans are based on the currently used dismantling, handling/processing and transport techniques and technologies. The decommissioning plan is based on the idea of dismantling immediately after the operation is finished with those radioactive parts which are not necessary for continuing the nuclear functions remaining at Hästholmen (spent fuel storing, wet waste solidification and disposal of low- and intermediate-level waste).

The next update of the decommissioning plan is due in 2012. After that, the decommissioning plan will be updated in line with the requirements of authorities, at six-year intervals, The updates will follow the development of technology and specify further the plan towards the final decommissioning plan to be implemented.

So far, no decisions have been made regarding continuation of the operation of the Loviisa power plant beyond its planned 50-year service life. The current plan involves an immediate dismantling of the plant. The final decision on whether the plant will be dismantled immediately or according to a delayed schedule will be made towards the end of operation before starting decommissioning.

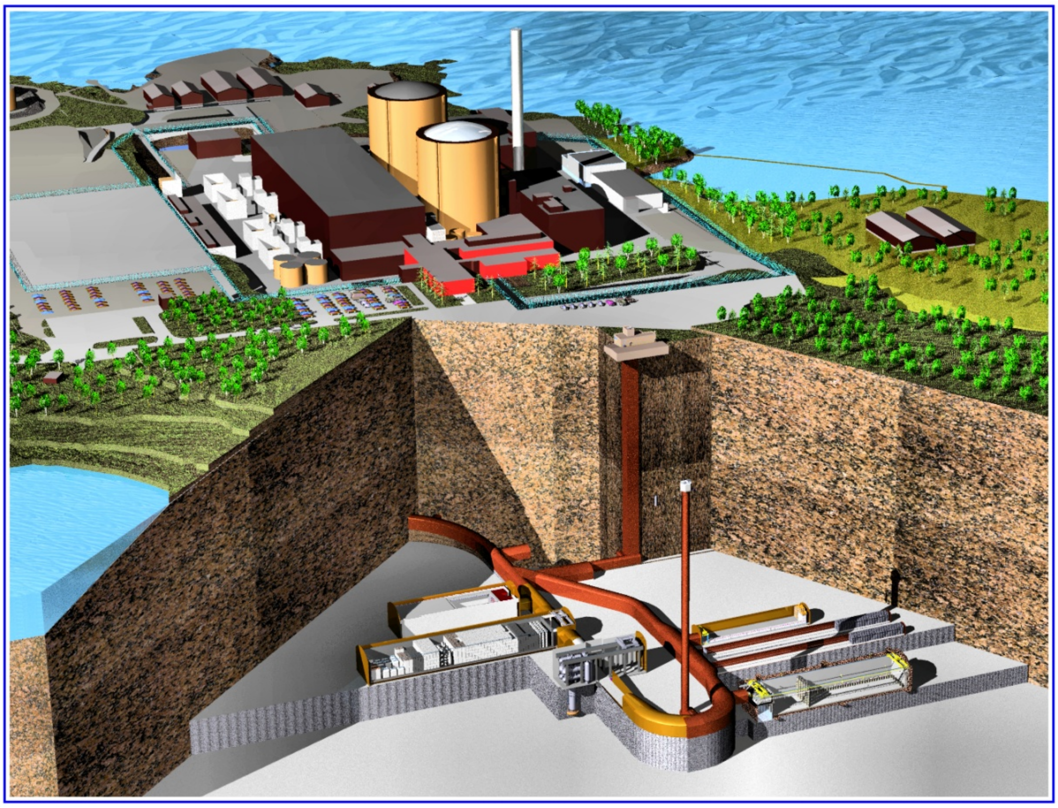

Figure 2-2. *Repository and its extensions at the Loviisa power plant (Kallonen et al. 2008).*

3 AN OUTLINE OF THE OVERALL PLAN FOR NUCLEAR WASTE MANAGEMENT AT THE OLKILUOTO POWER PLANT

3.1 Overall time schedule of nuclear waste management measures by the Olkiluoto power plant

OL1, the first power plant unit of the Olkiluoto NPP, was started in 1978, followed by the second unit OL2 in 1980. The plant units' operating licences are valid until 2018. The operating licences of the OL1 and OL2 plant units include the plant site storages and final repositories for intermediate-level waste (KAJ) and low-level waste (MAJ) as well as an interim storage facility for spent fuel (KPA storage). A description of the waste management measures and final disposal of waste with respect to the new OL3 plant unit has been made for the operating licence application to be submitted with a view to its future commissioning.

The Olkiluoto repository for operational waste (VLJ repository) was commissioned in 1992. The operating licence of the VLJ repository is valid until the end of 2051. The licence was granted pursuant to a Government decision dated 9 April 2002. In its statement issued on 26 March 2008, the Ministry of Employment and the Economy approved the report specified in the licence conditions regarding the safety of and operating experience from the VLJ repository as well as the new packing and disposal techniques for operational waste. A preliminary design for the extension of the VLJ repository was prepared in 2008 (Nykyri et al. 2008) to correspond to the increase in the operating life of OL1 and OL2 from 40 years to 60 years, and in order to implement the disposal plan for operating and decommissioning waste from the OL3 plant unit. The decision has also been made to take the needs of the fourth power plant unit (OL4), which has now received a positive decision-in-principle, into account in the future expansion plan for the repository facilities.

The Olkiluoto NPP decommissioning plan updated in 2008 (TVO 2008) shows that safe decommissioning is possible. The plan takes into account the extension of service lives of the OL1 and OL2 plant units to 60 years. The plan partially takes into account the decommissioning of OL3 and the future plans for OL4 as well. Figure 3-1 shows the timing of the planned operation and nuclear waste management measures of the Olkiluoto power plant.

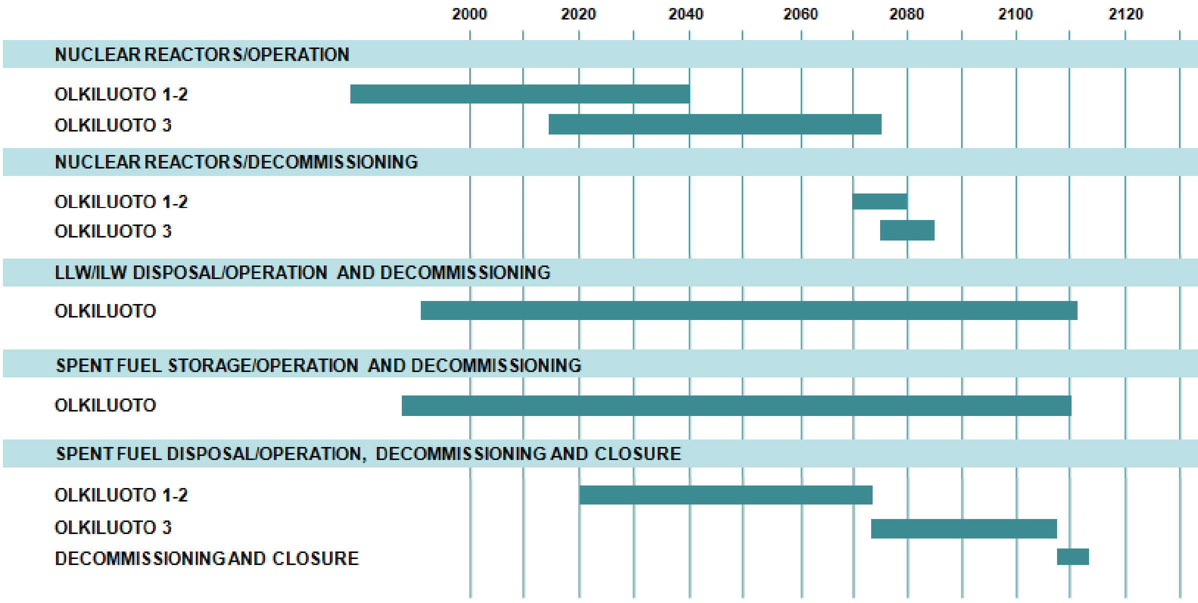

Figure 3-1. *Overall time schedule for nuclear waste management at the Olkiluoto power plant.*

3.2 Handling and storage of spent fuel

The fuel spent in the two plant units during their operation in Olkiluoto (OL1 and OL2) is first stored at the power plant units and after 3–4 years stored in the interim spent fuel storage (KPA storage) at the power plant site until the final disposal. The KPA storage facility can accommodate the spent fuel from approximately 30 years of production at the plant units. At the end of 2011, the available storage capacity in the KPA storage amounted to 7,146 storage positions. The work for expanding the storage facility, allowing the OL3 unit fuel as well, is in progress, and the extension will be commissioned in 2014.

At the end of 2011, the quantity of spent fuel in storage amounted to a total of 7,670 assemblies containing an approximate total of 1,290 tonnes of uranium. Altogether 6,556 assemblies were placed in the KPA storage and 570 in the water pools of OL1 and 544 at OL2. Additionally, 500 assemblies were in use in the OL1 reactor, with another 500 in use in the OL2 reactor. The figures are inclusive of fuel placed in fuel rod racks (one per plant) used for the storage of damaged fuel rods.

3.3 Processing, storage and disposal of operational waste

At the Olkiluoto power plant, the majority of operational waste is immediately packed for processing, storage and disposal. The intermediate-level ion exchange resins, used for the purification of circulating water at the OL1 and OL2 plant units, are solidified in bitumen, and the composition is poured into steel drums. At the OL3 plant unit, the waste will be dried and placed into steel drums. Compressible low-level waste is compacted in steel drums using a hydraulic press, while the non-compressible part is packed, without compaction, in steel and concrete cases and steel drums. The drums containing compressible waste are compressed so that the final height of the drum is approximately one-half of the original, with the diameter of the drum remaining unchanged. Scrap metal may also be processed before packing to reduce its volume. Scrap chopped up with a metal chopper may be used to fill up any empty space in the concrete cases transported to the repository. This improves the packing efficiency of metal waste. Miscellaneous liquid waste and slurry is solidified by mixing the waste with a binding agent in a drum that forms the packaging of the solidified product. If applicable, the volume of liquids and slurries is reduced through evaporation prior to solidification.

Operational waste is temporarily stored in the storages and fuel pools of the power plant units, the low- and intermediate-level waste interim storage facilities (the KAJ and MAJ storages) and, in small quantities, in the KPA storage at the Olkiluoto power plant site. Low and intermediate-level waste accumulating during the operation of the OL1 and OL2 plant units is disposed of in the current waste silos of the repository for operational waste (the VLJ repository, Figure 3-2). Waste with very low activity concentration, below the extemption level, is further exempted from control and taken to the landfill area located at the Olkiluoto power plant site or handed over to another party for recycling or other purposes.

3.4 Planning for decommissioning

The most recent decommissioning plan for the Olkiluoto power plant was submitted to the Ministry of Employment and the Economy in December 2008 (TVO 2008). The Olkiluoto decommissioning plan is based on the delayed dismantling of the OL1 and OL2 plant units after 60 years of operation. The preliminary basis foreseen for the OL3 and OL4 plant units is immediate decommissioning so that all four plant units could be dismantled around the same time. The intention is to start dismantling in the 2070s. The decommissioning plan includes plans for the required extension of the disposal facility that also takes into account the OL3 and OL4 plant units, as well as an assessment of the long-term safety of decommissioning waste disposal taking into account the conservatively estimated volume and radioactivity of decommissioning waste from the OL3 plant unit. So far, only the decommissioning costs for OL1 and OL2 have been analysed.

In the future, an alternative will be investigated with Posiva where the KPA storage decommissioning waste would be placed together with the operational waste from Posiva's nuclear facilities. In this alternative, the final closure of the VLJ repository would take place several decades earlier than what is shown in Figure 3-1, after the decommissioning waste from the OL3 and OL4 plant units has been finally disposed of.

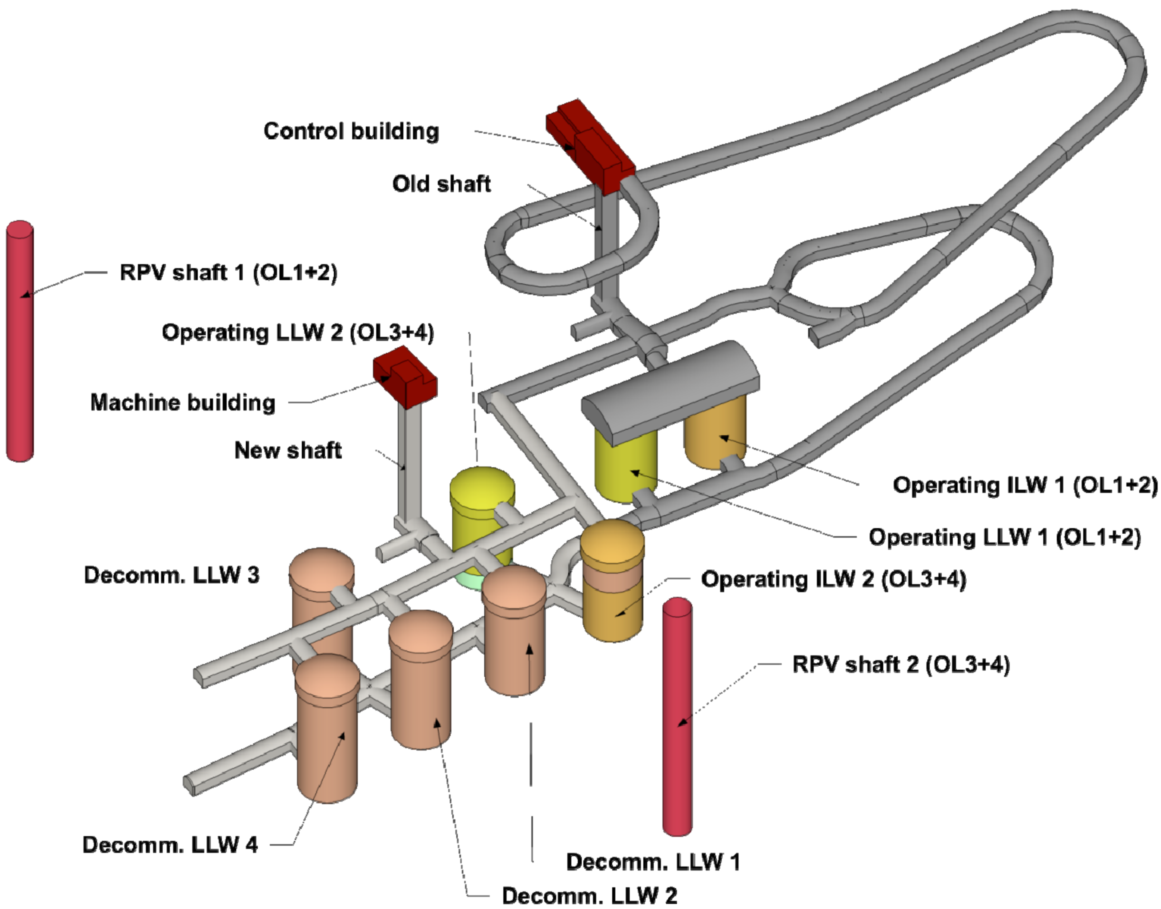

Figure 3-2. *Repository and its planned extensions at the Olkiluoto power plant (Nykyri 2008).*

4 STATUS OF PREPARATIONS FOR THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL

The KBS-3 solution has been chosen as the final disposal solution for spent fuel both in Finland and Sweden. Two alternative configurations of this solution, the vertical alternative KBS-3V and the horizontal alternative KBS-3H, are currently under consideration, the former being the basic solution for final disposal (Figure 4-1).

Because spent nuclear fuel remains harmful for a long time, it also has to be isolated from the environment above ground for a long time. Safe disposal is based on long-term isolation and containment. The solution is based on the multiple barriers principle. It ensures that no individual harmful phenomenon or uncertainty can compromise the safety of the entire system. The safety and performance targets of the KBS-3 disposal solution are discussed in more detail in section 4.6 of this report.

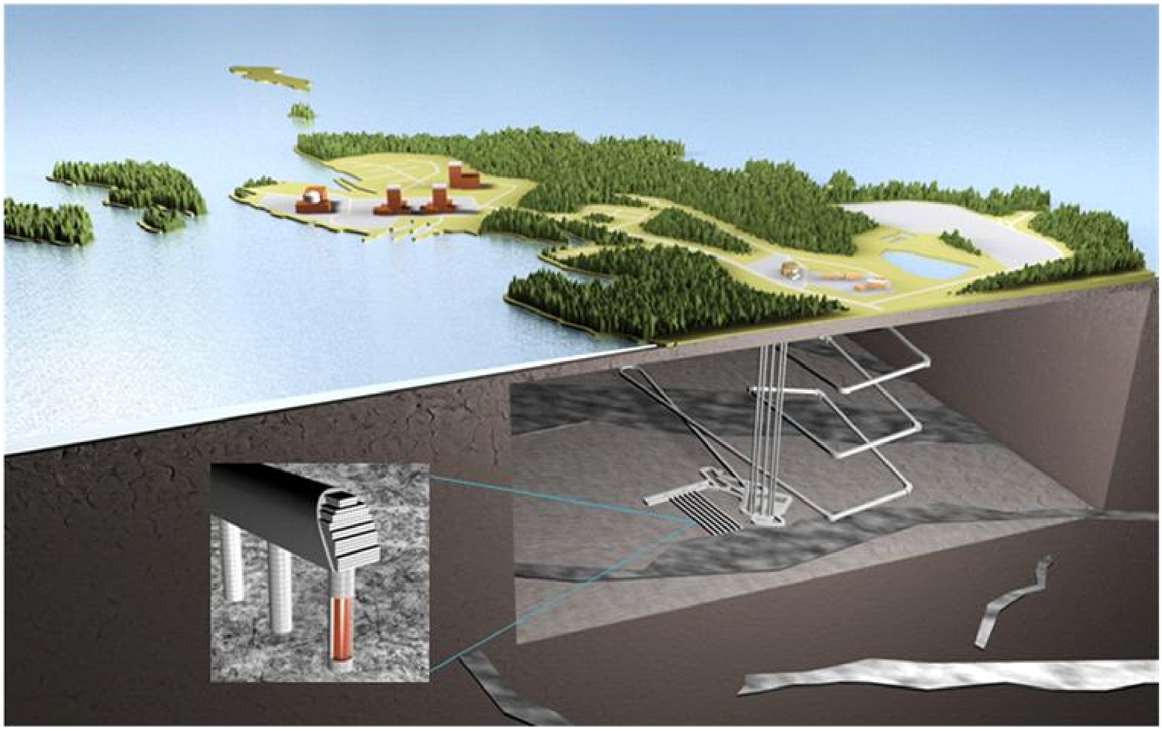

Figure 4-1. *Computer image of the KBS-3V disposal solution.*

In the KBS-3 solution, isolation of the radionuclides contained in spent fuel is primarily ensured by sealing the fuel in gas- and water-tight copper-iron canisters. The probability of radionuclide releases from the canister is considered to be small, because the canister surroundings will improve the longevity of the canisters thanks to the favourable conditions in the immediate surroundings and the verified high quality of the engineered barrier system (EBS). The engineered barrier system consists of canisters, surrounding clay buffer that protects the canisters from bedrock movements and the potentially harmful substances contained in groundwater, as well as the depositionl tunnel backfill material that supports both the buffer and the bedrock. The release barriers also include other components, such as the backfills of other facilities, as well as the plugs and seals of the deposition tunnels, central tunnels, shafts, access tunnels and investigation holes, and in the KBS-3H alternative, the backfill components, spacer plugs and end plugs of the deposition drifts. They have been designed to be compatible with the canister, the buffer, the deposition tunnel backfill material and the bedrock and to support their safety functions. For example, the backfill and closure of underground openings (including the tunnels, shafts and drill holes) will improve the safety functions of the bedrock by mechanically supporting the bedrock and by preventing the formation of migration routes (water-conducting flow paths). They will also prevent any inadvertent entry of people to the disposal facility. The surroundings above ground are of no significance as release barriers, and therefore no safety functions or target properties have been defined for them.

The properties of the engineered barrier system are compliant with section 4.5 of STUK's draft YVL Guide E.5: "*The engineered barrier system can include a waste matrix that binds radioactive substances, a leak-proof vessel resistant to corrosion and mechanical stresses inside which the waste is sealed, chemical conditions limiting the solubility and migration of radioactive substances around the waste packages, isolating media surrounding the waste packages that absorbs minor bedrock movements (buffer material), other isolating structures, backfill materials and sealing structures in the disposal facility that limit the migration of radioactive substances via the excavated facilities*."

The robust design is based on sufficient depth, favourable and predictable bedrock and groundwater conditions as well as on thoroughly investigated properties of the bedrock and the engineered barrier system. The work for characterising the Olkiluoto disposal site and for designing the repository concentrates on a rock volume at the depth of -400...-500 metres. At this depth, the bedrock and groundwater conditions are favourable and predictable; the conditions are reducing and groundwater flow velocities low, while the probability of inadvertent entry by people is small. The depth complies with the requirement set out in section 4.11 of STUK's draft YVL Guide E.5, according to which "*the repository must be placed at a depth of several hundred metres so that the impacts of above-ground natural phenomena, such as formation of glaciers or the impacts of human activity, are sufficiently dampened.*"

If there are canisters with an initial defect penetrating the copper overpack or if a canister breaks at a later stage, the consequences of radionuclide releases for humans and the rest of living nature would be mitigated by the slow migration of radionuclides released from the fuel matrix: the migration is slowed down by the buffer and backfill materials as well as the bedrock itself. The engineered barrier system and the bedrock will together both contain and slow down the radionuclides. Radioactive decay will also continue during the migration.

4.1 Basic premises

4.1.1 Status of licensing for the encapsulation plant and disposal facility

Posiva's facilities are nuclear facilities of considerable general significance referred to in the Nuclear Energy Act (990/1987), the construction of which requires a decision-in-principle from the Government showing that the construction of these plants benefits society as a whole. Following the issuance of a decision-in-principle by the Government and its ratification by Parliament, the construction licence and operating licence applications concerning the nuclear facility are submitted to the Government for decision; the detailed descriptions and safety reports associated with these applications are submitted to STUK at the same time. The key issue during the construction licence and operating licence phase is, that the safety assessment produced by STUK for the Government on the basis of the licensing material does not indicate any reasons why the plans should not be built or operated.

4.1.1.1 Environmental impact assessment and decision-in principle

During 1998–1999, Posiva carried out the environmental impact assessment procedure required by the application for the decision-in-principle. The assessment concerned the final disposal of a quantity of nuclear fuel corresponding to 9,000 tonnes of uranium (tU) (Posiva 1999a). Posiva submitted its application for a decision-in-principle concerning the construction of encapsulation plant and disposal facility to the Government on 26 May 1999 (Posiva 1999b). The decision-in-principle was applied for the disposal of spent fuel generated by the four NPP units in operation and the two NPP units being planned, corresponding to a maximum of 9,000 tU. After submitting its application for the decision-in-principle, Posiva asked for the decision-in-principle to be considered in two stages and limited its application to only concern four NPP units in operation and one under planning.

The Government processed the application for decision-in-principle in two stages. On 21 December 2000, the Government issued its decision-in-principle in which it found that the construction of the encapsulation plant and disposal facility will benefit society as a whole (Valtioneuvosto 2000). This decision-in-principle concerned the spent fuel from the Olkiluoto and Loviisa plants in operation, corresponding to the final disposal of a maximum of 4,000 tonnes of uranium. For the second stage, the Government issued its decision-in-principle on 17 January 2002, regarding the construction of the spent fuel disposal facility in extended form with a view to the spent nuclear fuel from the new Olkiluoto 3 NPP unit, i.e. a quantity corresponding to a maximum of 2,500 tU (Valtioneuvosto 2002). Parliament upheld both decisions as they were.

On 25 April 2008, Posiva submitted an application for a decision-in-principle concerning the disposal of spent fuel from the Olkiluoto 4 NPP unit, a quantity corresponding to a maximum of 2,500 tonnes of uranium (Posiva 2008a). In conjunction with the application for the decision-in-principle, Posiva submitted the updated environmental impact assessment report requested by the Ministry of Trade and Industry regarding the final disposal of a quantity of nuclear fuel corresponding to 9,000 tonnes of uranium. The focus area of the update was on the environmental impacts of the spent fuel from the new NPP unit. The Government issued a decision-in-principle for the application on 6 May 2010 (Valtioneuvosto 2010), and Parliament upheld it as it was.

Posiva also carried out an environmental impact assessment in 2008 concerning the final disposal of a quantity of nuclear fuel corresponding to 12,000 tU (Posiva 2008b) and submitted an application for a decision-in-principle on 13 March 2009 concerning the disposal of spent fuel from the Loviisa 3 NPP unit, which at that time was at the decision-in-principle phase (Posiva 2009a). The Government did not issue either decision-in-principle.

In summary, it can be stated that there is a valid decision-in-principle concerning the construction of an encapsulation plant and a disposal facility that covers the disposal of spent fuel from the OL1–4 and LO1–2-NPP units. The decision-in-principle concerns a quantity of nuclear fuel corresponding to a maximum of 9,000 tonnes of uranium, and it is valid until 19 May 2016.

4.1.1.2 Preliminary application for a construction licence

In 2003, the Ministry of Trade and Industry required Teollisuuden Voima Oyj and Fortum Power and Heat Oy, the parties with the nuclear waste management obligation, to present either separately or jointly or thorough Posiva Oy by the end of 2009 the reports required for the construction licence listed in section 32 of the Nuclear Energy Decree so that they indicate the parts where the documentary material required for the construction licence is incomplete as well as the manner and schedule in which the material is to be supplemented. Later on, Posiva agreed with STUK that the above procedure can also be applied to the documents submitted to STUK pursuant to section 35 of the Nuclear Energy Decree.

The Ministry of Employment and the Economy issued its statement of opinion regarding the preliminary construction licence documentation in 2010, while STUK issued its statement in 2011. Posiva has taken the received feedback into account in the planning/design work for the encapsulation plant and disposal facility as well as in the preparations for the construction licence application to be submitted during 2012.

4.1.2 Construction of ONKALO and research-related needs

Posiva has been constructing an underground rock charactarisation facility called ONKALO in the future disposal site since 2004. In addition to actual investigation niches, ONKALO includes shafts, structures above ground and technical systems necessary for the safe use of the facilities. Most of the excavation work related to the ONKALO rock volume will be completed during 2012. Minor excavation work may be required even after that due to research-related needs. System installations and construction work above ground are expected to continue until late 2014. The intention is to eventually integrate ONKALO as part of the disposal facility during the construction licence phase.

ONKALO is constructed on the strength of the Government's decision-in-principle issued in 2000. STUK's decision from 2001 also concerns the construction work: it states that the future use of the underground facility as part of the disposal facility requires that the construction work is overseen using the procedures prescribed in the Nuclear Energy Act. The construction of ONKALO has taken place in the manner described above, in compliance with the regulations of the Nuclear Energy Act and under the regulatory oversight of STUK.

ONKALO helps collect the further data needed for the encapsulation plant and disposal facility construction licence application to be submitted in 2012. The research work will continue in ONKALO even after that. The bedrock is studied using geophysical, geological, rock-mechanical, hydrogeological and geochemical research methods. In addition to facilitating bedrock research, ONKALO also provides an opportunity to develop and demonstrate rock construction and final disposal techniques in realistic conditions.

4.1.3 Overall time schedule of the project, areas critical to its implementation and the owners' needs

In accordance with its strategic plan, Posiva will submit the construction licence application during 2012 and prepare itself to commence disposal operations around 2020, as required by the Ministry of Trade and Industry decision of 2003. Adherence to the overall schedule is also important from the point of its owners for having sufficient interim storage capacity for fuel.

The critical issues for the feasibility of obtaining the licence and for the project schedule are:

- The construction licence application must be sufficiently comprehensive and detailed in order to demonstrate that the encapsulation plant and disposal facility can be implemented in compliance with the safety regulations. The key issues include matters affecting the operational and long-term safety of the plant complex and the disposal operations. At that stage, the planning and design work for the plant and its systems must be so far advanced that no significant changes to the presented solutions are expected. For system-level design, this means that any changes are limited inside the system concerned. The main system-level issues to be discussed at the construction licence stage are the fixation of design bases for the fuel and canister handling equipment (including the canister lift) and ensuring the feasibility of obtaining the licence. At this stage of the licensing process, the applicant must be able to present preliminary plans for the entire construction phase. The preliminary commissioning plan is also one of the plans to be presented. The contents of the construction licence application and of the documents to be submitted simultaneously to STUK are indicated in sections 31, 32 and 35 of the Nuclear Energy Decree. Content requirements for the documents to be submitted are presented in the Government Decree on the Safety of Disposal of Nuclear Waste and in STUK's YVL Guides.
- It is vitally important for adherence to the construction schedule that the plans and implementation required at each phase of work with their associated official approvals are completed according to the planned schedule. However, the plans will be supplemented in some respects while the construction licence is being processed.
- The operating licence application must be sufficiently detailed and comprehensive in order to demonstrate that the plant complex to be implemented allows safe disposal in compliance with the requirements. This demonstration will be accomplished both by the arguments presented in the application documents and by the procedures compliant with the commissioning plan to be submitted to STUK. Part of the joint operation tests included in the plan can be performed already before submitting the application. The part to be performed using actual nuclear fuel can only take place after the (trial) operating licence has been obtained.

4.1.4 Fuel types and other waste to be disposed of

In accordance with the decision-in-principle, the encapsulation plant and disposal facility will handle, process and finally dispose of the spent nuclear fuel from the four NPP units in Olkiluoto and two NPP units in Loviisa. The operating and decommissioning waste from the encapsulation plant and disposal facility will be disposed of in the low- and intermediate-level waste repository located adjacent to the fuel repository.

The fuel types of the NPPs to be disposed of at the disposal facility are called BWR fuel (OL1−2), VVER fuel (LO1−2) and EPR fuel (OL3) in line with the respective NPP units. The types of plant and fuel to be used for the OL4 NPP unit have not been chosen yet. Each fuel type is further divided into several fuel assembly types, with their construction and reactor-physical properties varying depending on the manufacturer and date of manufacture.

4.1.4.1 BWR fuel

Structural properties of BWR fuel assemblies

The OL1−2 plant units have several different BWR fuel assemblies manufactured by different fuel suppliers. Their external dimensions are very close to each other, but there are differences in their internal construction. For example, the number of rods included in the assemblies has increased during the operation of the NPP units. Initially, each assembly contained 64 rods (8 x 8), the next step was 81 rods (9 x 9), and now 100 rods (10 x 10) are used.

Each BWR fuel assembly is surrounded by a fuel channel consisting of a box and a conical end piece at the lower end. The fuel rods in the assembly are supported inside the channel by 6 to 8 intermediate supports and by top and bottom end disks. The current 10 x 10 fuel types also have water channels or water rods inside the assembly; they improve the behaviour of the reactor core at high power levels and during possible operational transients. They also serve as load-bearing structural parts of the assembly. The assemblies currently in use also contain shorter fuel rods which improve the operational characteristics of the reactor. The typical material compositions of fuel assemblies have been presented in a separate report by Anttila (2005a).

The degree of enrichment used for the fuel assemblies in BWR fuel assemblies is usually between 0.7–4.95 % of fissionable U-235 isotope. In some rods, so-called neutron poison (Gd_2O_3) is used for burnup credit. It is added to part of the fuel pellets contained in the fuel rods. These details of the rods and assemblies are recorded in the fuel database.

Accumulation and burnup of BWR assemblies

The OL1−2 reactors contain 500 fuel assemblies each, of which roughly a quarter is replaced every year with fresh fuel. Spent fuel is stored at the power plant units and in the interim spent fuel storage located at the power plant site. At the end of 2011, the quantity of spent fuel in storage in Olkiluoto amounted to a total of 7,670 BWR assemblies, corresponding to an approximate total of 1,290 tonnes of uranium. It is expected that a total of some 14,000 BWR assemblies will be accumulated during the operation of the OL1−2 reactors.

The maximum discharge burnup value of the fuel assemblies permitted in the licensing conditions is 50 MWd/kgU for the plants operating in Olkiluoto in 2011; the previous maximum burnup value was 45 MWd/kgU. However, it is planned that the maximum licenced burnup value for the Olkiluoto plants will increase to 55 MWd/kgU by 2018. The average burnup values of fuel assemblies removed each year will correspondingly increase to about 52–53 MWd/kgU. The plans and safety analyses for the encapsulation plant and disposal facility have been made assuming an average burnup value higher than that, 60 MWd/kgU.

4.1.4.2 VVER-440 fuel

Structural properties of VVER-440 fuel assemblies

The fuel assemblies used at the Loviisa NPP originate from two suppliers, Russian TVEL and British BNFL. The fuel assemblies are inside hexagonal protective boxes and consist of 126 fuel rods with an instrumentation rod in the middle. The Russian and British VVER-440 fuel assemblies differ from each other in a few details related to the quantity of uranium and the degree of enrichment. In addition, the VVER-440 reactors have 37 control rods with a fuel extension fitted on them. The control rod extension is similar to an ordinary fuel rod, but its active fuel area is shorter. The typical material compositions of fuel assemblies have been presented in a separate report by Anttila (2005a).

Accumulation and burnup of VVER-440 assemblies

The LO1−2 reactors contain 313 fuel assemblies each, of which roughly a quarter is replaced every year. Spent fuel is stored at the power plant units and in two interim spent fuel storage facilities located at the power plant site. At the end of 2011, the quantity of spent fuel in storage at the Loviisa power plant site amounted to a total of 4,339 VVER-440 assemblies corresponding to an approximate quantity of 522 tonnes of uranium. It is expected that a total of 7,700 VVER-440 assemblies will be accumulated during the operation of the LO1−2 reactors. The amount of spent nuclear fuel from the Loviisa NPP units to be finally disposed of in Olkiluoto is smaller than that coming from the Olkiluoto NPP units because the spent fuel from the early years of operation of the Loviisa plant was returned to the Soviet Union. The maximum discharge burnup value of the fuel assemblies permitted in the licensing conditions of the Loviisa NPP units is 57 MWd/kgU.

4.1.4.3 EPR fuel

Structural properties of EPR fuel assemblies

OL3, the third NPP unit currently under construction in Olkiluoto, is a pressurized water reactor (PWR) of the EPR type. The initial fuel for the OL3 will be supplied by AREVA NP, and the assembly type is AGORA HE. Each assembly consists of 265 fuel rods and 24 control tubes (17x17) as well as end pieces and 10 intermediate supports placed at even intervals. The assemblies are not surrounded by a box.

It is probable that the first refuelling charge will be of the same AGORA HE type, but the assembly type used in subsequent refuelling operations may be different.

Accumulation and burnup of EPR assemblies

The OL3 reactor will contain 241 fuel assemblies at any one time. The annual fuel consumption will be about 60 assemblies, corresponding to about 32 tonnes of uranium per year. The highest licenced discharge burnup of EPR fuel is expected to be 50–53 MWd/kgU, with the average discharge burnup being about 52–53 MWd/kgU. It is expected that a total of 3,800 EPR assemblies will be accumulated during the operation of the OL3 reactor.

4.1.4.4 Operating and decommissioning waste from the encapsulation plant and disposal facility

The low- and intermediate-level operational waste generated during the operation of the encapsulation plant and disposal facility as well as the decommissioning waste of these plants will be finally disposed of in a dedicated underground disposal facility located adjacent to the fuel repository. All radioactive waste is disposed of in solid or solidified form. The operating and decommissioning waste from the encapsulation plant and disposal facility will need thousands of cubic metres of disposal space.

4.1.5 Alternative implementation methods and preparations for them

Several choices, or reference designs, guiding the design work have been made in the planning and design work for the encapsulation plant and disposal facility. In spite of that, several alternatives have been investigated in parallel, and the final selection has been postponed to a later stage as the research and development work advances. The current planning is based on vertical disposal (KBS-3V), but the alternative horizontal solution KBS-3H is still being developed.

The main differences between the alternative disposal concepts are related to the orientation of disposal canisters and the number of canisters in each deposition hole or deposition drift. In the KBS-3V solution, vertical holes are bored at specific intervals in the floor of the central tunnels, and one disposal canister is placed in each hole. In the alternative KBS-3H solution, the canisters are placed in long horizontal deposition drifts bored from the central tunnel, each drift accommodating several canisters. The KBS-3H solution is described in greater detail in section 4.7 .

In addition to the disposal concept, alternative implementation methods are also under consideration for other operations including welding (electron beam welding or friction stud welding) as well as the transportation of spent fuel (road, rail or sea transport). The development work for welding methods is discussed in greater detail in sections 4.5.1 and 5.4.1.1 , while the transport alternatives are discussed in section 6.7.

4.1.6 Construction licence application and subsequent development work

The construction licence application to be submitted to the Government will describe the planned nuclear facilities as they are intended to be built. However, the reports to be submitted to STUK in compliance with section 35 of the Nuclear Energy Decree will be supplemented and further specified, both as a result of research work undertaken by Posiva and the inspections performed by STUK, while the application is being processed and while the plants are being constructed. STUK has announced that it will take into account both the documentary material submitted in 2012 and the amendments made to it while the application is being processed when making its safety assessment. STUK has expressed the wish that the application material submitted to it includes Posiva's schedule for finalising any uncompleted reports.

Regarding plant design, it is to be expected that the system descriptions related to the PSAR will be further defined as implementation planning progresses. The development of equipment required for the joint operating tests to be performed after submitting the construction licence application will presumably also result in − even major − modifications to individual systems and devices. Such modifications will be discussed internally in Posiva and with STUK in compliance with the plan amendment procedures.

It is vitally important for the overall schedule that construction of the encapsulation plant and disposal facility starts immediately after the construction licence has been obtained. This will require the achievement of both organisational and contractual capabilities, as well as the completion of most of the implementation planning during the time the construction licence application is being processed. The actions required for achieving construction capabilities will be investigated in the TOVA-2012 project to be implemented during 2012.

4.1.7 Feedback from authorities

The feedback received by Posiva from authorities has been compiled in this section as received. It was extracted from the statements by authorities that concerned the first preliminary version of the documentary material for the construction licence application, submitted by Posiva in 2009 (the so-called pre-licence material). The comments and other text in this section describe the status in 2009. The authorities' comments on the material have guided Posiva's R&D activities and the implementation of ONKALO during the past three years. The disposal project has made significant progress during the three years, and development work will continue as described in Chapters 5 and 6 of this programme document.

In September 2009, TVO and Fortum submitted to the Ministry of Trade and Industry the TKS-2009 programme, a plan primarily prepared by Posiva, that had the main objective of describing how Posiva intends to achieve the capabilities required for submitting the construction licence application by the end of 2012. The programme described the plans for conclusion of the verifying studies of the Olkiluoto disposal site, design of the required plants and development of the repository technology to be deployed to the level required for the construction licence application, as well as the work required for producing the safety case regarding long-term safety (TURVA-2012) to be appended to the construction licence application. It was also stated that one of the main tasks for the period would be preparation of the documents required for the licence application. In addition to the work related to the basic plan for disposal, the programme also included R&D work regarding the feasibility and long-term safety of the alternative solution (KBS-3H). The research, development and planning work undertaken during 2009–2012 largely corresponds to the plan presented in TKS-2009.

According to the decision of 2003 by the Ministry of Trade and Industry, the parties under the nuclear waste management obligation had to present, by the end of 2009, the reports required for the construction licence listed in section 32 of the Nuclear Energy Decree so that they indicate the parts where the documentary material required for the construction licence is incomplete as well as the manner and schedule in which the material is to be supplemented. In late 2009, Posiva submitted the first version of its construction licence application material (the so-called pre-licence material) to the Ministry of Employment and the Economy.

In order to provide as comprehensive a picture as possible of the construction licence application, Posiva also appended the material to be submitted to STUK pursuant to section 35 of the Nuclear Energy Decree to the pre-licence material in addition to the reports listed in the decision of the Ministry of Trade and Industry. The pre-licensing material and the feedback received from it have served as the basis of Posiva's licence application preparations.

The Ministry of Trade and Industry sent both the TKS-2009 programme and the pre-licensing material prescribed in section 32 of the Nuclear Energy Decree for an extensive round for comments, after which the ministry issued its statement concerning them on 30 December 2010. STUK issued separate statements regarding material submitted pursuant to section 35 on 27 September 2010 and regarding the TKS-2009 programme on 5 October 2010. STUK's safety assessment regarding the preliminary construction licence material was completed on 6 June 2011. The assessment includes requirements and comments which Posiva has taken into account both in the implementation of the nuclear waste management programme and its further planning as well as in the preparations for the construction licence application. In addition, STUK has during its inspections made comments that are of significance to the YJH programme.

In particular, the safety assessment by STUK contains a lot of comments. Posiva has compiled the comments made on the material into detailed lists with an appended plan for taking the comments into account in planning and development work. The following sections present an outline of the major policy decisions and development subjects that have been brought up by the feedback of authorities during the TKS-2009 period. The feedback received previously has also been taken into account when planning Posiva's activities.

4.1.7.1 Statement by the Ministry of Employment and the Economy, dated 30 December 2010

On 30 December 2010, the Ministry of Employment and the Economy issued a statement concerning the preliminary construction licence application material and the TKS-2009 programme. In its statement, the ministry restated that in addition to the comments in this statement, comments have also been made during 2008−2010 in connection with the EIA and decision-in-principle procedures. The statement pointed out deficiencies or scope for further specifications in the following reports:

- population and other functions and local planning arrangements on the plant site and its surroundings,
- quality and maximum quantities of nuclear materials or nuclear waste,
- technical operating principles and solutions as well as other arrangements for ensuring the safety of the plant,
- the safety principles to be adhered to and an assessment of adherence to them,
- the environmental impacts of the plant and the design principles that the applicant intends to follow in order to avoid any environmental damage and to reduce the environmental load,
- cost estimate and financing plan for the plant project,
- other report: retrieveability, and
- other report: transports.

The deficiencies pointed out will be rectified for the actual licence application.

4.1.7.2 Statement by STUK regarding the TKS-2009 programme

STUK issued a statement regarding TKS-2009 to the Ministry of Employment and the Economy on 5 October 2010. The statement was also sent for information to the parties under the nuclear waste management obligation and to Posiva. STUK's presentation memorandum was appended to the statement

The canister

According to STUK, there are several open issues related to the fulfilment of the canister's safety functions. Solving them by the time the construction licence application is to be submitted will be a demanding task that requires extensive research and development. In its presentation memorandum, STUK raises various issues, including those related to the corrosion of copper, residual stresses in the welds and mechanical strength. However, STUK points out in its statement that the canister-related research subjects presented in Posiva's TKS-2009 programme are largely the same ones that have been brought up in the dialogue between STUK and Posiva regarding open safety issues.

Buffer, tunnel backfill and end plugs

According to STUK, the selection of performance targets for the buffer and tunnel backfill and the related criteria and rationale have not been presented in the preliminary construction licence application, nor does the TKS-2009 report include any plan for compiling a rationale for the above. Among other things, STUK stresses the importance of work aimed at investigating the erosion, swelling pressure, freezing and stability of the buffer. Posiva will also investigate the use of alternative buffer materials and present a plan regarding the studies on alternative materials. If Posiva ends up changing the buffer material, the procedure for changing the material and for verifying its performance must be presented.

Bedrock and disposal site

According to STUK, the major deficiencies in the characterisation of disposal site in Posiva's research programme are, on the one hand, related to research work carried out at the disposal depth and, on the other, to investigations of the eastern area of Olkiluoto. It is vitally important for long-term safety to be able to demonstrate that the disposal facility is sufficiently well isolated from the environment above ground, that the bedrock is sufficiently stable mechanically and chemically and that the groundwater flow rates are sufficiently small around the repository.

The main issues in the programme for more detailed characterisation of the bedrock include the tight schedule of testing and reporting the RSC system, investigation of the total buffer capacity of the bedrock as well as the open questions related to the mechanical stability of the bedrock and consequently to the layout of facilities, which may significantly affect the suitability of the disposal site. According to STUK, there are still open questions regarding the properties of the bedrock, such as those concerning flow and containment properties. Also, Posiva does not present an unambiguous programme for assessing the impacts of construction work and open spaces or harmful substances on the preservation of long-term safety of the bedrock any more comprehensively than just by monitoring the changes taking place.

Rock suitability classification has been one of the focus areas during the past three-year period. The impacts of construction work on long-term safety will be taken into account when preparing the safety case for final disposal.

Plant design

Regarding plant design, STUK's assessment concentrates on the prevention of transients and accidents in the design work for the plant and its systems. In this regard, STUK is of the opinion that Posiva has not sufficiently described (in the preliminary construction licence application) the implementation of defence-in-depth or other nuclear facility design bases. The principles of preventing and managing transients and accidents, the interdependencies of systems and the design requirements due to the risk of transients and accidents have not been presented to a sufficient level of detail. The TKS-2009 programme does not present in detail the progress of system design and the schedule in which Posiva will produce the system descriptions and subject-specific reports. No plan is presented in TKS-2009 for the probabilistic risk analysis either.

The principles of prevention and management of transients and accidents are presented in Chapter 9 of the preliminary safety analysis report (PSAR) to be submitted to STUK. The PRA for the planning phase is included in the documentary material to be submitted to STUK. Plant design work has progressed so that the required subject-specific reports and system descriptions are included in the licensing documents to be submitted to STUK. The system descriptions will be supplemented in some respects after the application has been submitted.

Long-term safety

STUK raises the following important deficiencies or development subjects related to the long-term safety case.

- The performed safety analysis does not cover the entire disposal system; instead, it is largely based on analysing one single canister. No detailed plans are presented in TKS-2009 for taking care of this matter.
- The formed scenarios must cover, in compliance with the requirements, the analysis of the entire disposal system and take into account, where appropriate, the joint effects caused by the interdependencies of safety functions. Taking transient-type phenomena into account when forming and analysing the scenarios will also require further efforts.
- The development work will require more extensive deployment of stochastic methods. Posiva is presenting the advantages and disadvantages of the probabilistic approaches without presenting any plans or promises regarding utilisation of the approach. Posiva's analyses do not include any improbable events either.
- The total quantity of waste to be disposed of has increased since Posiva's last reported analysis, and it may change further in the future. This will affect at least the total number of manufacturing defects present in the canisters.
- In particular, the rationale behind the achievement of performance targets for the buffer and tunnel backfill has been presented incomprehensively. Presenting the rationale will also require the climate scenarios and condition models to be updated.
- Updates are expected for the initial data, expert assessments and natural analogies. Development of the Olkiluoto-specific database will in particular require further efforts.
- So far, the uncertainties have not been analysed and reported in a compiled, thorough and comprehensive manner.

Posiva has updated its safety case plan after publication of the TKS-2009 programme and taken into account the feedback from STUK in the update.

Nuclear non-proliferation control

According to STUK's statement, Posiva was to present during the TKS-2009 period the actions for facilitating the nuclear non-proliferation control by STUK and international bodies (the IAEA and the European Commission). At the time STUK produced its statement, Posiva's nuclear non-proliferation manual was not sufficient for organising the nuclear non-proliferation control for the entire encapsulation plant and disposal facility in a manner compliant with official requirements.

During the construction phase of the encapsulation plant and disposal facility, nuclear non-proliferation control will be implemented on the basis of the current nuclear non-proliferation manual approved by STUK. A separate preliminary nuclear material manual will be extracted from this and appended to the construction licence application. It will cover the transport, encapsulation and disposal phases. The intention is to merge the above manuals at the operating licence stage.

Other nuclear waste

STUK is of the opinion that TVO and Fortum have presented sufficient plans for the management of low-and intermediate-level waste from the NPPs for the TKS-2009 period.

4.1.7.3 STUK's statement regarding the preliminary application material and the preliminary safety assessment

On 27 September 2010, STUK issued a statement regarding the comprehensiveness of Posiva's preliminary construction licence application. The safety assessment concerning the material was completed on 6 June 2011. The matters pertaining to nuclear safety are discussed in STUK's safety assessment in the same order as they are presented in Government Decree 736/2008. In addition, the safety assessment analyses, as applicable, the matters related to Government Decrees 734/2008 (security arrangements) and 735/2008 (emergency response arrangements), nuclear waste management during plant operation, decommissioning of the plant and organisation of nuclear non-proliferation control. The most salient conclusions in STUK's safety assessment are presented here following the structure of the safety assessment.

Radiation safety

STUK considers the material in Posiva's preliminary construction licence application to be sufficient regarding operation of the nuclear waste facilities, but requires Posiva to update the analyses of normal operation as well as transients and accidents for the construction licence application so that they correspond to the final plan.

Regarding long-term safety, STUK finds that the preliminary application material does not yet meet the safety level prescribed in section 4 of Government Decree 736/2008. Regarding radiation dose restrictions, the analysis does not cover the dose paths required in draft YVL Guide D.5, such as the use of ground well water as an exposure path. The analysis method has been changed from ecosystem modelling to transfer factor modelling, which will pose additional challenges to collecting the required initial data. Furthermore, the analysis is not totally transparent, because some of the key reports supporting the main report have not yet been submitted to STUK. According to Posiva's assessment, after several thousand years the releases will be lower than the release limits set for that period. The assessment will be updated in connection with developing the safety case, before submitting the construction licence application. Regarding the preservation of the rest of living nature, the plan shows that Posiva is closely monitoring international developments in the field and also participates in its development. The plans seem sufficient regarding preservation of the rest of living nature.

Regarding the way in which unlikely events are taken into account, STUK points out that the submitted material is incomplete, in particular with respect to dealing with the scenarios of people entering the repository.

These issues have been taken into account in the licence application and its supporting safety case.

Design requirements of the nuclear waste facilities

The preliminary application material submitted to STUK does currently not meet the requirements set out in section 6, subsection 1 of the Government Decree with respect to the handling and packing of nuclear fuel, because Posiva's grounds and conclusions regarding the requirements to be set for the manufacturing technology and properties of canisters are not comprehensively shown. However, STUK finds, on the basis of available material and information received, that Posiva is in the process of producing detailed requirements which the disposal canisters must meet.

The radiation protection arrangements in the nuclear waste facilities are shown incompletely, because Posiva is yet to submit detailed descriptions of the systems or dimensioning of the structures. One deficiency highlighted by STUK is the fact that the radiation protection of the liquid waste processing facility in the encapsulation plant is not discussed in the preliminary licensing material.

The material submitted by Posiva is highly deficient with regard to the prevention of damage to nuclear fuel as there are deficiencies with respect to transfers, fault tolerance analyses, the PRA and system descriptions. The time schedule for system descriptions is critical, which is partly due to the iterative process of planning and procurement decisions.

A description of the disposal process including fuel transfers will be included in Chapter Y5 of the general part of the PSAR. The system descriptions will be submitted to STUK with the rest of the application material during 2012. The descriptions will discuss the fault tolerance of systems and the safety implications of faults. The fault tolerance analyses referred to in draft YVL Guide B.1 will be produced for the key systems during 2012. The above analyses for other safety classified systems will be completed during 2013. The work will continue during the detailed system design work.

Safety classification

STUK finds that Posiva's classification document does not yet meet the requirements set for the construction phase. The structural and functional safety classification have been implemented in compliance with the requirements in the classification document, and preliminary inspection indicates that the safety classes shown are basically correct. Posiva has identified the quality requirements set, but some quality classes of systems, structures and equipment are missing from the document. Likewise, the specifications of quality classes and their correlation with the safety classes are missing. There are deficiencies in the way the systems are grouped in the system list and in the way their IDs and classification codes are shown. STUK finds that the seismic classification produced by Posiva appears rational. The material also has deficiencies regarding the main electrical diagram and the principal I&C diagrams as well as the flow diagrams of process systems and air conditioning.

The classification document has been further developed during the preceding TKS period, and requirements of the new classification included in draft YVL Guide B.2 have also been taken into account as far as possible. A proposal regarding the correlation between safety class and quality management has been produced as part of the application material. System-related diagrams have been produced for appending to the system descriptions.

Prevention of transients and accidents

In its statement, STUK points out that Posiva has not shown in its material how the planned plant and its systems will prevent transients and accidents. The material does not indicate how the encapsulating plant and disposal facility will cope with single failures. STUK stresses that the safety principles of new types of safety-critical encapsulation equipment must be verified in connection with processing the construction licence application. Posiva has not indicated the design requirements set for the plant and its systems for the purpose of preventing transients and accidents. The preliminary application material is also largely missing the accounts on implementation solutions and an unambiguous description of the system's relation to the entire plant complex. For the construction licence application, the following details of the systems must be presented: their safety-critical functions, the requirements set for them, fulfilment of the requirements, implementation solutions, transient analyses and failure analyses.

No material related to management of external threats has been submitted to STUK for producing a preliminary safety assessment. Regarding the plant's internal threats, STUK will require, among other things, plans related to the prevention and management of fires. In addition, Posiva must present, in greater detail, the solutions for implementing the redundancy, diversity and separation principles at the encapsulation plant and disposal facility.

Methods for preventing transients and accidents have been presented in the system descriptions included in the PSAR. Implementation of the redundancy, diversity and separation principles has been discussed in the system descriptions to the extent that these methods have been used in the plant's systems. Subject-specific reports have been produced regarding the management of fires and included in the PSAR.

Disposal operations

STUK finds that Posiva's PSAR documentation indicates the design bases of canister transfer installations to be appropriate. However, Posiva has not included in its preliminary application material the documents described in draft YVL Guide B.1 that would allow verifying that the transfers are implemented in a safe manner. Posiva will submit to STUK in connection with the construction licence application the preliminary systems descriptions of canister transfer equipment; they will describe, among other things, the transfer operations.

Regarding criticality safety, Posiva has in its preliminary application material not discussed the risks associated with criticality safety which may in a very long time span be caused by disposal canister corrosion, crumbling of fuel and release of the pellets into the empty spaces at the bottom of the canister as a result of corrosion in fuel rod claddings. Further efforts will be required for ensuring the criticality safety of OL3 fuel.

Posiva's current understanding of criticality safety is based on a report by Anttila (2005b), which mainly concentrates on operational safety. However, Posiva will perform analyses supporting the above report and concentrating on criticality safety, and their results will be appended to the application material. The work for investigating the criticality safety of OL3 fuel has begun in a working group with representatives from the owners, Posiva, VTT and STUK, and the work will continue, in particular with respect to OL3 fuel with a high degree of enrichment, also after 2012.

The submitted material is an outline regarding excavation and construction work. The detailed staggering of work phases (separation of disposal operations from the transfers of quarried material, backfill material and major equipment) has not been presented, nor have the measures for ensuring the functionality of facilities during the work phases.

Separation of the excavation and construction work phases from disposal operations will be discussed in the disposal facility plan, including separation of the areas into controlled and uncontrolled areas. The separation of operations will also be briefly discussed in the construction licence application. The functionality of facilities will be investigated by making prototype tests, for example.

Regarding the research and monitoring programme during operation, STUK finds that the submitted material does not comply with the documentation requirements set out in different regulations. The preliminary application material submitted by Posiva does not contain any concrete material yet for fulfilling these requirements. According to STUK, the research, verification and demonstration work has not been completed in this respect, and the plans, instructions and process descriptions are incomplete. The design work has not been completed, and the monitoring development plans included in the preliminary application material with respect to demonstrations are not clear and comprehensive. The monitoring programmes associated with the operating phase must also be presented as an outline at the construction licence phase, and, for example, the monitoring of release barriers must be presented in detail, at the latest during the operating licence phase. In order to rectify this deficiency, Posiva has produced an updated monitoring programme that answers the questions and requirements set out. The programme will be published by the end of 2012.

STUK points out that draft YVL Guides D.3 and D.5 set out requirements regarding the determination of properties and identifying details of spent nuclear fuel. However, Posiva has not presented a plan for waste accounting in compliance with the draft YVL Guide. Posiva must present in its construction licence application a plan and the principles for collecting the required information and for waste accounting. The capability for implementing the required measurements and functions must be in place when the operating licence is being issued. Posiva will present a description of nuclear waste accounting and software for its implementation in its construction licence application.

According to STUK, Posiva must add to the construction licence application material a proposal for the protective zone referred to in section 85 of the Nuclear Energy Decree and of its significance to long-term safety. However, Posiva is of the opinion that the planning for long-term safety must not be based on protective zones, and protective zones have not been taken into account when assessing the long-term safety. On the other hand, a protective zone could further reduce the probability of inadvertent entry by people, in particular during the period immediately after final closure when such entry would have extremely harmful consequences, which is why it is sensible to specify a protective zone. However, such specification should only be made after the exact layout of the disposal facility and the final closure solutions have been specified.

Long-term safety of disposal

STUK finds that Posiva's plan meets the general requirements regarding final disposal. The safety concept based on the multi-barrier principle has on a general level been described comprehensively, but a significant part of the necessary initial data, models, plans, justifications and summaries related to safety functions are missing. With respect to safety functions, the objectives set by authorities and Posiva correspond to each other. Posiva has recognised the need for further information and research related to safety functions and the performance targets of release barriers. The preliminary application material has the significant deficiency that achievement of the performance targets for release barriers has not been demonstrated.

There is the performance-related concept of "initial state" as well as evolution from the initial state to the target state where the performance targets of release barriers are met and therefore also the safety functions are implemented unless such processes are present during the evolution that compromise the release barriers. These processes potentially compromising the release barriers are not clearly described in the preliminary application material.

Posiva has not yet demonstrated the conformity with requirements or feasibility of implementation of any of the release barriers. The work for demonstrating the above has advanced the furthest with the canister, but significant further efforts are still required for the buffer and tunnel backfill.

With regard to safety functions and setting the performance targets, STUK points out that Posiva still has the opportunity to specify further, on the strength of its research material, the performance targets and target properties it has set for the release barriers.

Regarding the material related to the location of the disposal site, STUK finds that Posiva has in many respects sufficient material for drawing conclusions regarding the suitability of the disposal site and their appropriate grounds, but these conclusions and grounds are not presented in the preliminary application material. STUK stresses the importance of the following issues as future subjects for development:

- The migration characteristics of the bedrock, investigation of the eastern area and uncertainties related to the interpretation of pore waters must be cleared up before the operation phase.
- The work related to establishing the boundaries of the excavation damage zone (EDZ) and demonstration of its significance to long-term safety have not yet been completed.
- The work for developing grouting mixes with a low pH value for rock reinforcement purposes has not been completed. There have also been problems with the tested injection mixes.
- The changes in bedrock properties during operation and the impacts of such changes have not been sufficiently discussed in the preliminary application material. Posiva must also present a procedure to be followed if the properties become less favourable or non-compliant with the requirements.
- It seems insufficient to merely demonstrate the functionality of rock suitability classification in the demonstration tunnels before the construction licence phase.

Posiva has continued the development of performance requirements for the disposal system and the associated rock suitability criteria. The performance requirements have been compiled in a hierarchical form in the requirements management system (VAHA), and they are also presented in a separately published report entitled *Design Basis*. The rock suitability classification and practical classification methods will be presented in the licence application being prepared. However, testing of the procedure will still continue during 2012–2013.

Demonstration of fulfilment of safety requirements

Regarding demonstration of fulfilment of safety requirements concerning the nuclear waste facilities, STUK requires Posiva to supplement and update the analyses of normal operation as well as transients and accidents so that they correspond to the final plan and take into account the results of the PRA.

STUK finds that with respect to long-term safety, the safety case available at the time of making the safety assessment was incomplete and it was therefore not possible to perform a comprehensive assessment of how the fulfilment of safety requirements has been demonstrated. The importance of demonstrating the suitability of the disposal site and method is stressed. Presenting the grounds for long-term safety will also require the climate scenarios and condition models to be developed. The performed safety analysis does not cover the entire disposal system; instead, it is largely based on analysing one single canister. The development work will require more extensive deployment of stochastic methods. The scenarios to be formed must take into account the combined effects of events and processes compromising the safety functions. Taking transient-type phenomena and events into account when forming and analysing the scenarios will also require further efforts. The choices made when forming the scenarios must be justified in greater detail.

Regarding the reliability of the safety case, STUK finds that the application material is largely compliant with the safety level required in Government Decree 736/2008. Posiva's modelling work and initial data are of a high scientific standard, albeit that the initial data are constantly being qualified and updated. The justification, traceability and transparency regarding the suitability of initial data needs to be further improved. The safety analysis must cover the entire disposal facility instead of analysing just individual canisters, and the uncertainties must be analysed in greater detail.

As stated above, these comments have been taken into account in the licence application and its supporting safety case.

Construction and operation of the nuclear waste facilities

STUK finds that the preliminary licensing material submitted by Posiva does not show how the principles of quality management are implemented in the construction of the encapsulation plant and disposal facility. A more comprehensive description of project management and its key procedures and organisation must be supplied.

Plans for the preparation of safety instructions and technical specifications required during the operating phase, ageing management principles and radiation measurement systems must be presented in connection with the construction licence application.

The matters concerning the operating phase are included in Chapters Y5 and Y11 of the general part of PSAR. A subject-specific report on the principles of radiation measurements will be produced for appending it to the PSAR. A system description will be produced for each radiation measurement system for appending them to the PSAR.

Organisation and personnel

STUK finds that Posiva's safety culture meets the requirements. All required documents related to safety and quality management have not been submitted to STUK. The description of organisation included in the preliminary application materials is also incomplete.

The organisation descriptions concerning construction and operation will be presented to the Ministry of Employment and the Economy as part of the material appended to the application documentation. In the material to be submitted to STUK, the formation of organisation for the construction operations will be described in a separate report referred to in YVL Guide 1.1.

Security arrangements

The preliminary application material does not describe the planned implementation of security arrangements extensively enough. The plan must be supplemented in connection with submitting the construction licence application so that it covers the requirements of security arrangements for nuclear facilities prescribed in the YVL Guide A.11 being prepared.

A preliminary security plan compliant with the requirements of draft YVL Guide A.11 will be included in the application material to be submitted to STUK. The plan will include a description of the security arrangements during construction work.

Emergency arrangements

STUK points out that Posiva's plans regarding emergency arrangements are incomplete and that Posiva must supplement the material for the construction licence application.

A preliminary emergency plan referred to in YVL Guide C.5 will be included in the material to be submitted to STUK in connection with the construction licence application.

The plant's own nuclear waste management

STUK finds that the material submitted regarding nuclear waste management is sufficiently detailed for the purpose of the construction licence application The construction licence application must include a plan regarding the disposal activities and facility for operational waste. The material dealing with decommissioning is sufficiently extensive.

A plan regarding the final disposal of operational waste will be presented in connection with the construction licence application. The final disposal of operational waste will be taken into account in plant design, inventories and safety analyses.

Organisation of nuclear material safeguards

As part of the preliminary licensing documentation, Posiva has submitted to STUK a preliminary plan regarding organisation of the necessary safeguards for ensuring the prevention of proliferation of nuclear weapons and received feedback for it. It is pointed out in the feedback that Posiva's plan does not give a sufficiently detailed picture of how nuclear safeguards are to be arranged. In particular, it is missing the identification of tasks under Posiva's responsibility and the procedures for organising nuclear material safeguards. A description of how regulatory oversight by STUK and international bodies (the IAEA and the European Commission) is to be facilitated is also missing from the plan. The procedures have been described for the ONKALO phase in a nuclear non-proliferation manual produced by Posiva and approved by STUK, but it is not sufficient for assessing the entire nuclear material safeguards of the encapsulation plant and disposal facility.

The feedback will be taken into account in the plan, compliant with section 35 of the Nuclear Energy Decree, for arranging the safeguards control that is necessary to prevent the proliferation of nuclear weapons to be submitted as part of the construction licence application. During the construction phase of the encapsulation plant and disposal facility, nuclear non-proliferation control will be implemented on the basis of the current nuclear non-proliferation manual approved by STUK. A separate preliminary nuclear material manual will be extracted from this and appended to the construction licence application. It will cover the transport, encapsulation and disposal phases. The intention is to merge the above manuals at the operating licence stage.

Other requirements

The submitted material is partly incomplete with regard to transportation. The grounds for the transport solution (mode of transport, vehicles, alternative routes, security measures, etc.) must include an assessment of different modes of transport from the point of view of feasibility and effectiveness of security arrangements and from the point of view of ensuring the overall safety of transports.

The required reports will be included in the material to be submitted to STUK as subject-specific reports.

4.2 Suitability of the disposal site

Assessment and demonstration of the suitability of the disposal site have key elements of the research and development work aimed at preparing the construction licence application. Construction of the Underground Rock Characterisation Facility ONKALO and the research work as well as method and equipment tests carried out in it have constituted an important part of the work. The assessment of suitability is roughly divided into two areas, the suitability of the Olkiluoto bedrock for disposal use in general and the suitability classification of rock volumes. The results of the former will mainly be utilised in disposal planning and overall assessment of long-term safety. The results of the latter are vitally important for identifying the bedrock volumes suitable for implementation and for ensuring safe conditions and characteristics for this. Underground R&D work has played an important role in this work.

The site investigations, initiated as early as in the 1980s, have been able to demonstrate that favourable conditions exist in the Olkiluoto bedrock for the final disposal of spent fuel. The bedrock is stable in terms of geology, rock mechanics, hydrogeology and geochemistry. The focus of research has shifted from the general characterisation of the site to the detailed investigation of bedrock properties and to seeking to gain a thorough understanding of the bedrock processes. The research and modelling work carried out during the TKS-2009 period is described in section 4.2.2 .

The end result of rock suitability classification (RSC) will be used as the basis for determining the locations of disposal panels, tunnels and canisters in the bedrock. i.e. the final availability of bedrock for disposal purposes. The current status of rock suitability classification is described in section 4.2.3 .

4.2.1 Underground Rock Characterisation Facility ONKALO

The excavation work for ONKALO has progressed according to the overall plan in 2010–2012, although there have been some delays in work. The factors causing delays in work phases include the changes made in 2011 in the way shotcreting is implemented (spraying after each excavated round). It is estimated that the change in the way work is implemented has extended the total duration of work by several months. Because of the delays in phases of work, the decision was made to change the order in which

ONKALO is to be built, and this has been separately negotiated with STUK, the authority responsible for regulatory oversight. The work has advanced by an average of 80 metres per month. Excavation work was suspended for a while as the excavation contractor changed, and at times excavation was suspended while holes were bored. In addition to excavation of the access tunnel, the excavation work done during the programme period now ending has included technical rooms to the extent required at this stage at level -437 m plus the maintenance tunnel connection and shaft connections to level -455 m. The excavated extent has also included sedimentation pool facilities for leaking waters and space for a pump station.

As an important separate operation, two demonstration tunnels were excavated during 2011 and 2012 utilising the experience gained in the EDZ09 project regarding control of excavation damage. The demonstration tunnels are 52 and 105 metres long, respectively. Specific design requirements were defined for the demonstration tunnels, but there has been no need to change the design requirements defined for ONKALO as the work has progressed and experience accumulated. One of the tunnels penetrated a water-conducting structure, allowing the silica injection method foreseen for the repository to be tested during the tunnel excavation work. During spring 2012, the boring of four test deposition holes was completed in the first demonstration tunnel. The deposition holes will be utilised later for other tests and demonstrations, discussed in greater detail in section 5 .

Up to now, the exhaust air shaft is the only one of the three shafts to be bored in ONKALO where the raise boring operation has been completed. The boring has not been completed for the two other shafts due to the sealing operations required for penetrating structures BFZ- and HZ20A and B. Grouting and preparations for raise boring of the lowest parts of the inlet air shaft and the personnel shaft (between -290...-437 metres) will take place during 2012. The rest of the raise boring operations will be completed during 2013.

The construction work for ONKALO began in 2004. Before the work began, its possible impacts on the bedrock of the site and further on the long-term safety of disposal were assessed. The disturbance caused by the planned rock facility to its surroundings was assessed (Vieno *et al.* 2003). The objective was to use the assessment for identifying the safety-critical functions which are to be monitored during the construction process and the control measures which have been the subject of research and development work. The safety-critical functions include:

- control of groundwater,
- introduction of foreign materials to the bedrock in a permanent manner,
- excavation disturbance to the bedrock, and
- boring of drill holes from underground facilities.

The safety-critical functions have been the focus when continuing the research and development projects related to rock construction work, including the construction of ONKALO.

The water inflow quantities in ONKALO are monitored in a dedicated programme. The work has involved monitoring the changes in the groundwater conditions of the surrounding bedrock and comparing the water inflow quantities and their development with the predictions and existing limit values. The water inflow quantities have been well below the limit values.

The use of foreign materials for implementation requires an approval for the planned materials. Due to the impact of materials on long-term safety, the bedrock sealing materials to be deployed (grouting mix with a low pH value and colloidal silica) (Arenius *et al.* 2008) have been developed, and the development work will continue, for example, with regard to grouting mortar with a low pH value for rock bolts.

The significance of excavation disturbance in the bedrock and the ways to improve the controllability of excavation work have been investigated in separate projects and in connection with excavating the demonstration tunnels. The most recent of these separate projects was implemented in 2009 and reported in 2010 (Mustonen *et al.* 2010). The purpose of this reported continuation project was to develop further the excavation procedure in order to control the extent and nature of the disturbance caused. As part of the development work, characterisation methodology tests were carried out with the objective of creating a method for controlling the excavation results. In addition to its own research work, Posiva has participated in producing a joint experience report with SKB, a compilation of excavation experience accumulated by Posiva and SKB (Olsson 2010).

The objective has been to avoid drilling/boring work outside the tunnel profiles (> 5 m) if there are no specific reasons for it. A separate assessment of the geological and hydrogeological conditions of the area has been produced for drilling or boring long holes to serve as the basis of assessing the impact of these holes on long-term safety. The holes drilled for grouting in the demonstration tunnels have been planned entirely inside the excavation profile (some of the holes have veered outside the profile). In addition, the grouting holes drilled outside the shaft profiles, found necessary for shaft grouting, have been drilled for each grouting operation, where they have been required, only after a separate assessment.

The research and development work carried out in ONKALO is described later in this report together with the research and modelling work aimed at assessing the suitability of the disposal site.

4.2.2 Characteristics of the disposal site

The research, modelling and reporting work during the TKS-2009 period in 2010–2012 was guided by the needs of the construction licence application. In the TKS-2009 programme, the focus of site investigations was set at the open questions defined in the report entitled *Olkiluoto Site Description 2008* (Posiva 2009b). These included the spalling of bedrock, the state of stress in the Olkiluoto area, the degree of bedrock alteration and its possible effects, and the hydro-geochemical stability of groundwater conditions. In addition to these, site investigations have continued above ground in the eastern part of Olkiluoto and underground in ONKALO. The rock-mechanical properties of bedrock, hydrogeological interactions, reduction of sulphates and matrix diffusion have been investigated in its investigation niches. The field research operations implemented during the TKS-2009 period are discussed in section 4.2.2.1 .

One of the main objectives of site investigation work during the TKS-2009 period was to produce the *Site Description* by mid-2011. However, production of the report has been delayed, mainly due to the additional research and interpretation work required for matrix pore water studies. However, the main findings of the report are already available, and they are presented in section 4.2.1.2.

The updated disposal site description is mainly based on the research results that were available at the end of September 2010. Some research results produced later, such as those of rock mechanics and hydro-geochemistry, have also been included. The site models (Figure 4-2) mainly describe the present conditions and properties of bedrock. In addition, the objective has been to use modelling to predict the bedrock conditions in the near future as well as the presence and extent of disturbances possibly caused by ONKALO. The comparison of model predictions with actual observations gives valuable information on the reliability of models and helps develop them further.

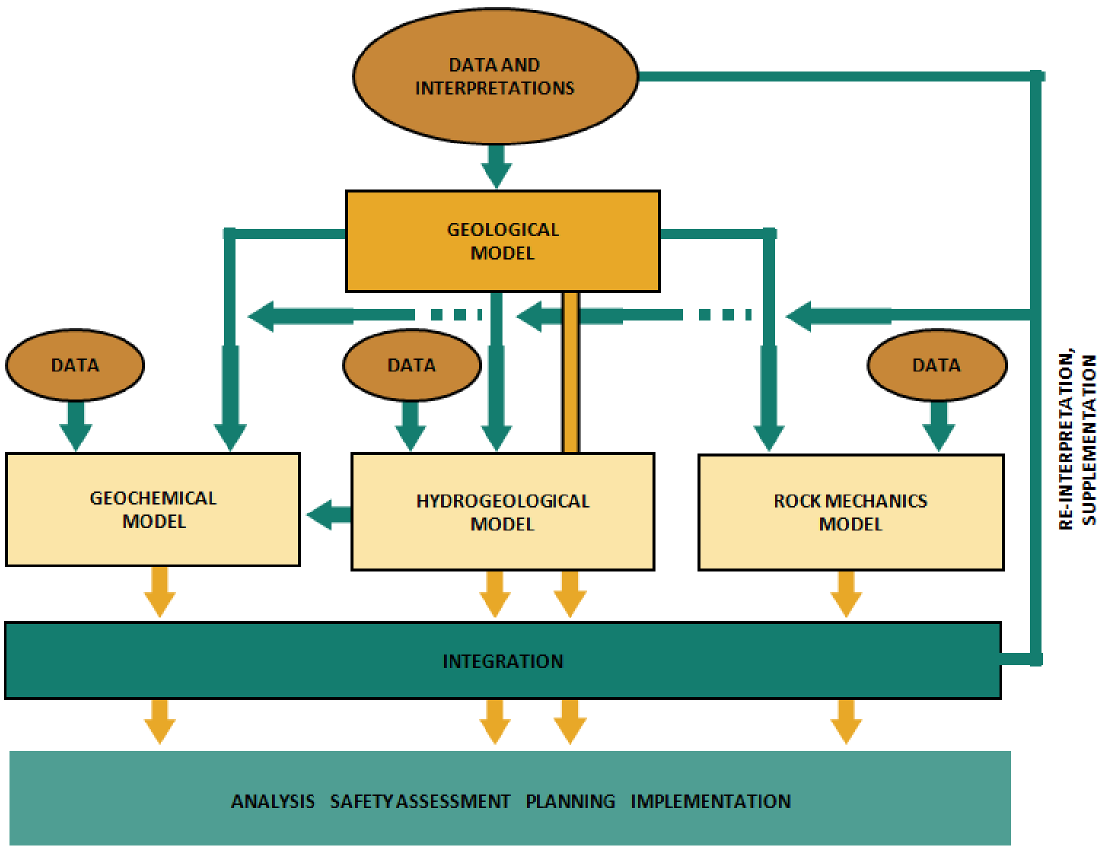

Figure 4-2. *Schematic diagram of the progress of site modelling, the relationships between models and further use of the models.*

The Olkiluoto monitoring programme (OMO) produces plenty of initial data for the models describing the properties of the disposal site. The goal during the TKS-2009 period was to update the monitoring programme by submission of the construction licence application to meet future needs. The updated monitoring programme will be published during 2012. A summary of the programme and the most recent monitoring observations are presented in section 4.2.4.

4.2.2.1 Summary of field research during 2010–2012

Field and drillhole investigations from the surface

This section primarily concentrates on bedrock investigations conducted from the ground surface. Investigations of the surrounding environment above ground are discussed in sections 4.6.5 and 5.5.

Figure 4-3 shows the investigated disposal planning area in Olkiluoto. The planned drill hole investigations in the eastern part of the area were completed during 2009–2012. The investigations included a total of six investigation holes, the deepest one, OL-KR56, reaching a depth of about 1,200 metres. There are now 57 drill holes in the area shown in Figure 4-3. The investigation trenches in the area, excavated for obtaining further information about the bedrock surface, are shown in Figure 4-4.

An extensive drill hole research programme has been implemented in the investigation holes (standard geophysical measurements, optical imaging, difference flow and EC measurements as well as water sampling) The results could not be fully utilised for the Site Description 2011 report, but they will be utilised for the following model updates. The drill hole studies have been reported in the following documents: Tarvainen 2010a and 2010b, Väisäsvaara 2010, Pekkanen *et al.* 2011, Tarvainen & Heikkinen 2011 as well as Komulainen *et al.* 2012a and 2012b. They include comprehensive accounts of the research methods and descriptions of the direct results. In addition, the research work and its results have been presented in the nuclear waste management reports for 2010 and 2011.

In addition to standard measurements, HTU measurements have been carried out in selected holes at depths ranging from 300 to 700 metres. Transverse flow measurements have been made in a hole near ONKALO and in conjunction with monitoring the infiltration experiment. When selecting the water sampling locations, the focus has been, in line with the plans, on fractures with low water conductivity. Several water samples have been taken, for example, in hole OL-KR47, concentrating on hydrogeochemical characterisation of fractures with low water conductivity. Microbiological analyses and gas analyses have also been done for the water samples. The microbiological studies have continued to focus on identifying the species of microbes present in groundwater and the species of functional microbes. A summary and interpretation report of the microbial studies carried out will be completed during 2012.

The matrix pore water studies with samples from deep drill holes continued, and a sample was also taken from one of ONKALO's pilot holes (ONK-PH9). Drill core samples have been taken for laboratory tests from holes OL-KR39, OL-KR47, ONK-PH9, OL-KR54, OL-KR55 and OL-KR56. Of these, the results for holes OL-KR39 and OL-KR47 are available and have been reported (Eichinger *et al.* 2006, 2010a). The samples from ONK-PH9 were taken in a profile-like fashion from hydrogeological structure HZ20B and its surroundings. At the same time, samples were also taken for determining the gases present in pores (Eichinger *et al.* 2010b). The sampling from holes OL-KR54 and OL-KR55 in spring 2010 covered the entire depth profile 0–1,000 m, and the impact of boring water contamination on the pore waters was studied at the same time using a NaI tracer (reporting in progress). The samples taken in late 2011 from hole OL-KR56 will be used to characterise the bedrock from 700 to 1,200 metres in depth. The goal of the study is in particular to investigate the distribution of salinity between pore water and fracture water in deep bedrock conditions. The results of studies on the first three holes were available for the *Site Description 2011* report. The results will in particular be utilised for the paleo-hydrogeological interpretation of Olkiluoto for which a summary report will be completed during 2012.

A groundwater infiltration experiment was initiated in the area of drill holes OL-KR14–OL-KR18 in 2008. The test has involved pumping the top section of the hydrogeological zone in hole OL-KR14 and monitoring the effects of pumping on the flow and chemical properties of infiltrated water in the surrounding investigation holes and groundwater pipes. A basic state report (Aalto *et al.* 2011a) has been published for the test, presenting the initial state and predictions regarding possible changes. In addition, a report is being prepared for the results of 2009, presenting the measurements, test arrangements and study material of the infiltration experiments during 2009, the updated hydrogeological model of the studied area, as well as the results of flow modelling and reactive migration modelling (Käpyaho *et al.* 2012). A final report of the test will be completed by the end of 2012.

Investigation trench OL-TK17 and studies in it were implemented, as planned, during 2009 (Lindberg 2010 and Huhta 2010). The trench is located to the north of drill hole OL-KR51 and runs roughly in the same direction as the hole (Figure 4-4). In 2010, investigation trench OL-TK18 (about 55 m) was excavated between trenches OL-TK4 and OL-TK12 (Figure 4-4) (Engström 2012).

Figure 4-3. *Deep investigation drill holes in Olkiluoto.*

Aerial and ground studies in geophysics were conducted in 2008 and 2009 in an area beyond the Olkiluoto planning area. The results of these studies were presented in reports Leväniemi 2008, Kurimo 2009 and Kukkonen *et al.* 2010, and utilised during the past programme period for different purposes, including lineament interpretation and soil modelling.

A report was published in 2010 presenting a uniform interpretation of conductive zones on the basis of individual conduits modelled on the results of separate mise-a-la-masse measurements (Ahokas & Paananen 2010). The results were used for updating the geological and hydrogeological model and for planning its supplementary measurement campaign. Mise-a-la-masse measurements were continued in 2010 in the eastern investigation area using nine drill holes and 76 ground profiles (Tarvainen 2010c). Several electrically conducting zones were modelled on the material; many of them are connected to known brittle zones, but indications of a few so far unknown zones were also found (Ahokas 2010).

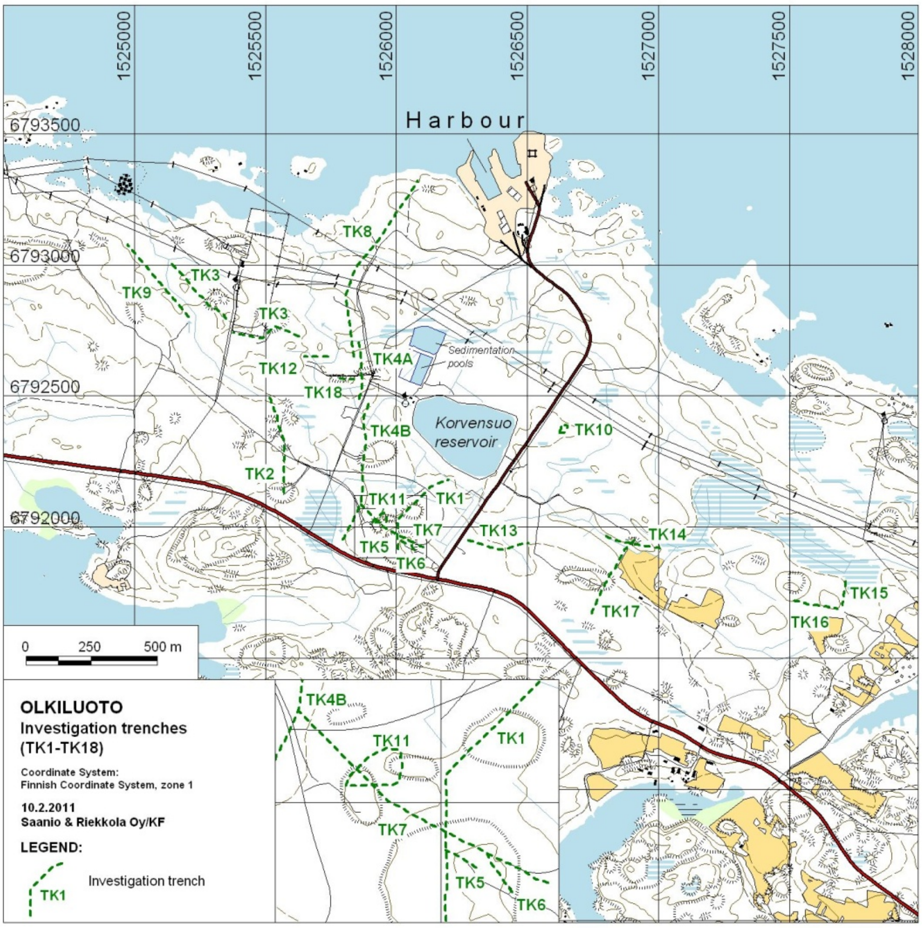

Figure 4-4. *Investigation trenches in Olkiluoto.*

Electromagnetic tomography imaging was tested in drill hole intersection OL-KR40–OL-KR45 (Korpisalo & Niemelä 2010). The study indicated that the used EMRE instrument is suitable for locating extensive conductive and isolating volumes between holes in Olkiluoto. These include lithological units and extensive deformation zones.

The plan was to conduct hydraulic pumping tests as part of the TKS-2009 programme, in particular for investigating the hydrogeological connections in the eastern investigation area. Large-scale interaction tests could not yet be started during 2010–2012 because the drilling operations in the eastern area and the studies in the open holes were nowhere near completed.

The work for determining the thermal properties of rock, in particular using TERO76 equipment, continued in three holes (Kukkonen *et al.* 2011c), while the more empirical method based on the inverse value of the temperature gradient and thermal flux was used in one drill hole (Kukkonen *et al.* 2011b). In addition, more laboratory determinations of thermal properties were performed in 2010, and all laboratory measurements made of the drill core samples from Olkiluoto during 1994–2010 were reported (Kukkonen *et al.* 2011a). Thermal expansion of the rock types present in Olkiluoto was studied using a separate series of samples. The results will be reported during 2012. The thermal expansion coefficient was determined for the temperature range of 20–60 °C (Åkesson 2012).

Underground research

Diverse geo-scientific research has been conducted in ONKALO's access tunnel, shafts and other facilities as well as in the central tunnel, demonstration tunnels and experimental deposition holes for the purpose of obtaining initial data for planning before excavation work, immediately as excavation work progresses and later. The research activities included drill hole studies and mapping of facilities. The characterisation of ONKALO involves geological, rock-mechanical, geophysical, hydrogeological and hydro-geochemical studies.

The initial purpose of geoscientific studies is to produce detailed information regarding the suitability of the rock volume intended for disposal use, and later to produce appropriate initial data for planning and design work. In order to achieve that, a lot of research work has been performed during the implementation of ONKALO, and the results have been used as initial data for bedrock-related planning.

Several investigation niches have been established along the access tunnel. During the period, long-term tests have been initiated in them for the purpose of investigating, in a programme-like manner, the properties of bedrock essential for disposal operations, as well as the processes present or phenomena taking place in it. Such tests include POSE, HYDCO and REPRO.

Posiva has developed mapping methods for mapping ONKALO and for collecting geological and geotechnical data, and they have been applied to all facilities excavated in ONKALO, including the demonstration tunnels. However, the mapping methods will be further developed on the basis of excavation planning, RSC (section 4.2.3) as well as needs observed as the work progresses and the feedback received from geological modelling. The work for mapping underground facilities can be divided into three parts: so-called round-specific mapping, systematic mapping and supplementary mapping.

Round-specific mapping has been performed after each five-metre round of excavation (Engström & Kemppainen 2008). Its main purpose is to produce geological information on the excavated rock volume for carrying out a geotechnical assessment and for assisting immediate reinforcement planning. Information from the round mapping has also been used for assessing whether pre-grouting will be required before excavating the next round. Large fractures intersecting the tunnel profile are measured with a tachymeter and systematic stereo photograph sets are also taken of each round in this phase.

Systematic geological mapping trails excavation work by tens or hundreds of metres (Engström & Kemppainen 2008). Systematic mapping is also performed in five-metre rounds. Significant amounts of geological mapping data are collected in this phase, including descriptions of rock types, foliation and other structural observations such as fractures. The systematic mapping data allows the Q classification based on round-specific mapping to be further specified so that the final reinforcement plans can be revised on the basis of more accurate information to better suit the conditions.

The supplementary mapping work includes the mapping of deformation zones and measuring their coordinates by using a tachymeter as well as measurements made using a Schmidt hammer. (Engström & Kemppainen 2008). Samples are taken systematically from the underground facilities for petrological studies. Mineralogical and hydro-geochemical sampling has been performed in campaigns from certain facilities. Part of the supplementary mapping work, such as the descriptions of large fractures and deformation zones, were transferred in 2011 to be performed in connection with round-specific mapping. This was done because the pace and timing of reinforcement was changed.

A hydrogeological water inflow measurement has been conducted in ONKALO two or three times a year for the purpose of investigating construction work-induced changes in groundwater conditions. The information thus obtained has been used as initial data for research, but also for the follow-up of grouting and shotcreting.

The ONKALO construction site is being characterised ahead of the excavation work by drilling pilot holes. As the excavation work advances, the pilot holes have been bored inside the tunnel profile. Their length has varied from tens of metres to 150 metres. The research work has verified the correspondence of rock mass with the predicted data before excavation. The research results are used, among other things, for identifying fractured and water-conducting rock sections, and the information obtained on them can be used to modify the existing excavation plans. Pilot holes have been drilled in most sections of ONKALO's access tunnel.

The results from twenty pilot holes will be available by the end of 2012. A working report will be published on the results for pilot holes ONK-PH1–PH15, a compilation of all measurement data obtained from the pilot holes (geological mapping, geophysical measurements, hydrogeological measurements and results from groundwater sampling). Starting from the hole ONK-PH16, single-hole interpretations are and have been compiled on the results for use in rock suitability classification. The pilot holes drilled in ONKALO are shown in Figure 4-5.

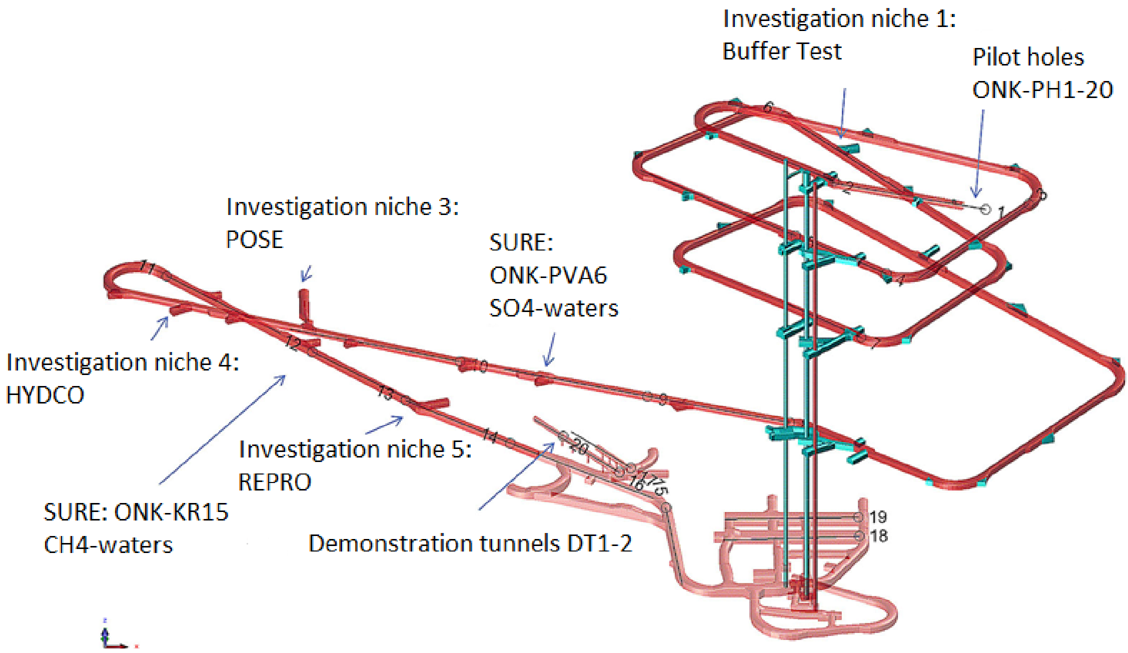

***Figure 4-5**. Pilot holes drilled (ONK-PH1–19) and investigation niches excavated in ONKALO, and the research work in progress.*

Geophysical measurements have produced detailed information on the bedrock for use in all research projects in progress in the investigation niches (POSE, HYDCO, REPRO) (Tarvainen 2011b, Tarvainen 2011c, Tarvainen 2012). Drill hole measurements related to the EDZ research programme have also been performed in several short drill holes in Investigation niche 3 (Figure 4-5) (Sacklén *et al.* 2010).

The seismic reflection sounding carried out in 2009 produced projected seismic reflection images of the tunnel from 12 different angles to the sides, upwards and downwards. The reflection images reach an approximate distance of 200 metres out of the tunnel (Cosma *et al.* 2011). The study was continued with an interpretation aimed at investigating the geological and geophysical properties affecting the generation of reflections and at assessing the suitability of the method for characterising crystalline bedrock (Sireni 2011). In most cases, it was possible to correlate the reflection to a long fracture intersecting the tunnel and having an undulating slickenside surface (a polished slip surface), thick fracture infillings and water conductivity. The degree of alteration and mineralogical alterations also affected the reflexivity. In addition to extensive deformation zones, it was also possible to detect individual fractures and contacts between different types of rock. However, all the predicted structures could not be detected by seismic investigation, which is primarily due to the resolution of seismic data and possibly also due to the uncertainty of interpretations.

Several measurement campaigns have been performed in ONKALO using the focused mise-a-la-masse measurement technique between drill holes or between a drill hole and the tunnel. The mise-a-la-masse measurement method has been tested in pilot-type tests in the shaft grouting holes (Heikkinen *et al.* 2010) and used in Investigation niche 4 in support of hydrological studies (Ahokas *et al.* 2011) as well as in the demonstration tunnels area in support of detailed-scale modelling (Ahokas & Heikkinen 2012).

Four research projects were initiated in the investigation niches of ONKALO: a rock-mechanical test (POSE), a hydrogeological interaction test (HYDCO), a sulphate reduction test (SURE) and a matrix diffusion test (REPRO). Each project has progressed in keeping with its schedule, and they will continue during the coming three-year period.

In Olkiluoto, the relationship between the state of stress and strength of the rock is an essential factor when predicting the behaviour of facilities to be excavated, such as the probability of damage to tunnels caused by the state of stress at the disposal depth. Rock fractures when the state of stress present at its surface exceeds its spalling strength. A set of rock-mechanical tests entitled POSE was initiated in 2010 for the purpose of investigating the spalling strength of rock in Investigation niche 3. The test was started by boring three test holes with a diameter of 1.5 metres, two of them located next to each other in the middle of the investigation niche and the third closer to the end, in the middle of the tunnel. The first two holes were bored by leaving a thick pillar of about 0.9 metres between them to which the stress field was to be concentrated. The field work of phases 1 and 2 of the POSE test was done during 2010 and 2011, and the test holes were broken, as planned, by heating during the test. Due to the heterogenic and anisotropic nature of the bedrock, the results were more complicated than expected, and the final interpretation of the test is waiting for the completion of field work in the third phase of the POSE test.

The purpose of the hydrogeological HYDCO test is to investigate the interconnections between water-conducting fractures in a rock volume that resembles the surroundings of deposition holes as closely as possible. Two holes have been drilled in Investigation niche 4 for the test, and various studies for investigating the connections between fractures have been conducted between them. At the same time, groundwater samples have been taken from the studied fractures with low water conductivity (so-called water sampling from leak-tight bedrock). The results have been reported in separate working reports (Ahokas *et al.* 2011, Tarvainen 2011c, Hurmerinta *et al.* 2012, Toropainen 2012). The empirical part will last at least until 2013, and the final report will not be available before 2014.

Nine short drill holes were drilled in late 2011 for the REPRO matrix diffusion test. Drill core samples were taken from them for matrix pore water, permeability, matrix diffusion porosity and retention studies to be conducted in the laboratory. Implementation of the test has been delayed from the timing planned in the TKS-2009 programme because completion and fitting of the investigation niche have taken longer than expected. Preliminary testing of the water vapour diffusion test equipment for the REPRO studies was performed in 2011 at the opening of Investigation niche 4. Tracer tests began in Investigation niche 5 in early 2012.

The objective of the SURE test concerning the factors limiting the reduction speed and reduction of sulphates is to investigate the formation of sulphides and the anaerobic oxidation of methane. The test was arranged both in sulphate-containing and methane-containing water because it has been assumed that sulphides are in particular formed at the interface of these waters. The first phase of the test involved studying sulphate-containing water in hole ONK-PVA6. Flow cells were installed in ONK-PVA6, and a strain of microbes corresponding to the conditions in the hole was planted in them by circulating the groundwater in the hole through the cell array. After an incubation period of less than four months, the flow cell arrays were taken to the laboratory where the test was continued by activating the microbial strains with CH_4 and H_2 gases. During the test, the changes in microbial strains and chemical composition of water were monitored. The preliminary results indicate that the reduction of sulphates began when methane was present. When hydrogen was also introduced in the system, the reduction of sulphates to sulphides speeded up considerably. The preliminary results indicate that the reduction speed of sulphates with methane and hydrogen present was five-fold to that with only methane present. The microbial populations evolved as a result of these reactions were different from each other. The results and interpretations of the tests carried out in sulphate-containing water will be reported during 2012.

The previous *in situ* stress state interpretations of the ONKALO area, done by overcoring, hydraulic cracking and convergence measurements, have included major uncertainties (Posiva 2009b). During 2009–2012, a new stress state measurement system based on LVDT (Linear Variable Differential Transformer) sensors and overcoring has been developed, and it has been successfully used at various depths in ONKALO. In addition, the measurement accuracy of the device has been tested in the Äspö HRL in well-known stress conditions. The preliminary stress state measurement results from ONKALO are shown in Figure 4-6. The results show how the state of stress varies when going deeper. A summary of the state of stress measurements is shown in document *Site Description 2011*.

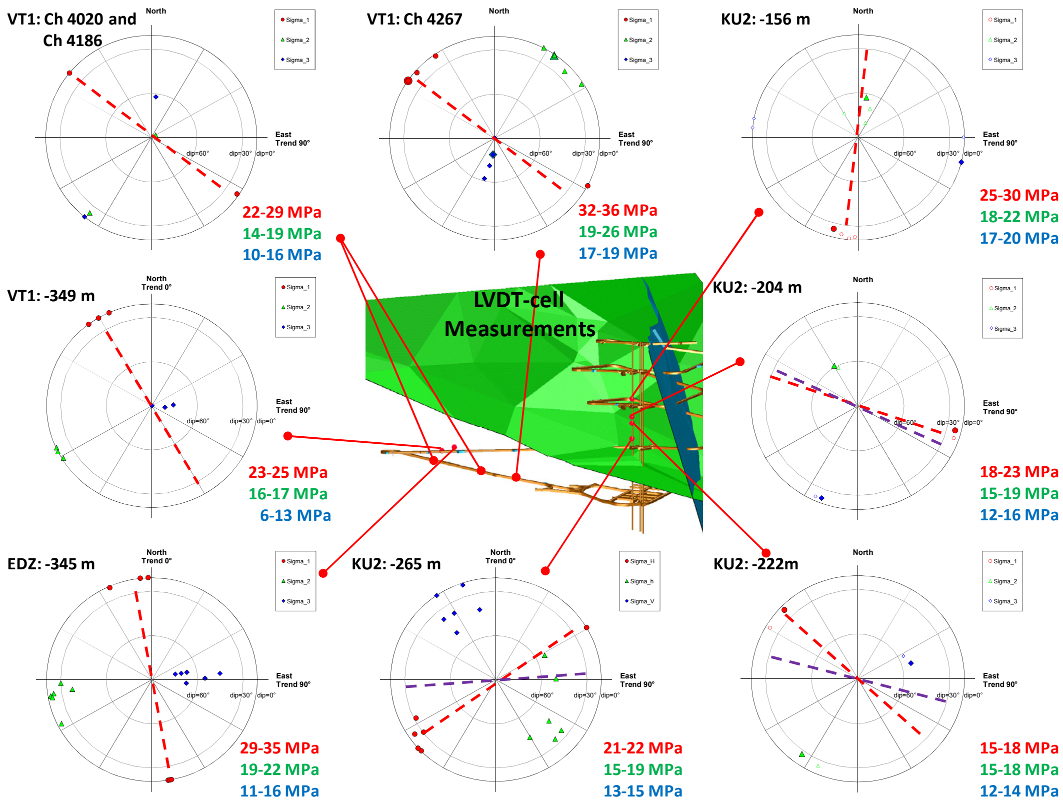

Figure 4-6. *Preliminary results of stress measurements made using an LVDT cell in ONKALO (Site Description).*

The indicators of state of stress in the drill holes (hole breakouts and shape changes) have been studied using acoustic hole imaging, and a working report of the results will be published during 2012. The Deformation Rate Analysis (DRA) method has also been tested for determining the state of stress (Dight *et al.* 2012). In addition, the observation of stress-induced damage has continued in ONKALO in connection with the geological mapping work.

The strength and deformation properties of intact rock have been investigated at depths ranging from -350 to -450 m with systematic point load tests and four-point bending tests on drill core samples (*Site Description*).The distribution of point load test results corresponds to the distribution of strength values obtained from uniaxial tests, but the correlation of adjacent samples from the same geological unit is poor (R^2=0,3...0,4). Therefore, the point loading test is only suitable for investigating possible variations in strength within an area. Such variations have so far not been observed in the ONKALO area. The four-point bending tests have primarily been used for investigating the deformation characteristics of intact rock, but the distribution of test results is essentially different from those of the uniaxial tests, and therefore the results cannot be considered reliable.

Probe holes are also included in the underground tests carried out. They are usually about 30 metres long, and four such holes are always bored inside the tunnel profile after a stretch of 25 metres of tunnel has been excavated. The probe holes bored in ONKALO have been used for water loss measurements, flow measurements and water inflow quantity measurements in order to investigate the need for grouting.

Following the rock suitability classification carried out in the demonstration tunnel on the basis of detailed tunnel mapping, the locations were selected for drilling pilot holes for the experimental deposition holes. The final experimental deposition hole planned for the location is either approved or rejected on the basis of geological, geophysical and hydrogeological information obtained from the drill samples and holes and on the basis of rock suitability classification. The need for investigations to be carried out using the pilot holes drilled both in the tunnel and in canister locations have been decided on the basis of the RSC programme.

4.2.2.2 Interpretation and modelling

The main objective of modelling in Olkiluoto is to describe the geometry of the disposal site, the properties of bedrock and groundwater as well as the processes and mechanisms of interactive relationships between different fields of research. The main areas of description are the environment, geology, rock mechanics, hydrogeology, hydro-geochemistry and migration (see also Figure 4-2).

Surface hydrological model

During 2010–2012, the main development work for surface hydrological modelling has been (Karvonen 2010 and 2011a):

- production of a short-term prediction system for the hydrogeological impacts of ONKALO construction work,
- the addition of salinity calculations to the surface hydrological model,
- further specification of the infiltration experiment and the provision of limiting conditions for the reactive migration model,
- modelling of the impacts of the Korvensuo basin,
- description of the paleo-hydrological developments in Olkiluoto from the past to the present,
- simulation of hydrological developments in Olkiluoto until the year 52000 A.D.,
- analysis of the limiting surface condition between soil layers and bedrock surface and the provision of these limiting conditions for use in the FEFTRA model (paleo-hydrology and future development of the Olkiluoto island), and
- the addition of a part intended for planning the observation network into the surface hydrological model (simulated annealing + kriging).

Surface hydrological modelling has in the main been implemented in line with the plan included in the TKS-2009 programme. Some development projects included in the plan (migration of particles and age of water) have been delayed due to development work related to the salinity model (not included in the original plan). Salinity calculations have now been added to the surface hydrological model, and the calculation model has been applied to the determination of water inflow limit values for ONKALO and the repository. The work will be reported during 2012.

A so-called short-term prediction system (Karvonen 2011a, Chapter 6) has been produced for assessing the hydrogeological impact of ONKALO. The system utilises the measurement data produced by the monitoring programme and the surface hydrological model. Both so-called permanent leaks present in ONKALO and temporary leaks, caused by, among other things, boring of grouting holes, can be fed into the prediction system. The prediction system can provide printouts of the impact of water inflow on the groundwater levels in soil layers (about 45 groundwater pipes), on the pressure heads in short bedrock holes (about 50 observation points) and on the pressure heads in plugged drill holes (almost 200 plug sections). The predictions regarding the impacts of ONKALO water inflows are updated at 1–2-month intervals. Among other things, the prediction system provides printouts of the reducing impact of ONKALO on the pressure head in all hydrogeological zones and the rock matrix.

The surface hydrological model has been used to calculate both the paleo-hydrological development of the Olkiluoto island (Karvonen 2011a, Chapter 3) and the hydrological predictions until the year 52000 A.D. (reporting during 2012). These models have produced the limiting surface condition for the deep bedrock groundwater model (FEFTRA)

Modelling of particle migration and the age of water has been done both for the infiltration experiment and the Korvensuo basin, but modelling work has been somewhat delayed from the original schedule due to the salinity model development work. The TKS-2009 plan for the geochemical model has been implemented so that the results of the surface hydrological model have been used as initial data in reactive migration modelling of the infiltration experiment.

A more detailed modelling analysis of the increase of water level in the Korvensuo basin will be completed during 2012, and the impact of horizontal flow velocities in soil layers and upper parts of the bedrock on the water balances and quantities of water discharged from the basin are among the matters to be assessed at that time (a goal set in the TKS-2009 programme).

Assessment of the probability distribution of the key parameters of the surface hydrological model (TKS-2009 objective) has not been completed yet, and it will be continued in connection with calibrating the salinity model (development work to be undertaken during 2013−2018).

Geological model

The geological model describes the bedrock properties and geological conditions in the Olkiluoto investigation site. The model produces a description of the geometry and properties of deformation zones in the bedrock. This description is further needed as a starting point for rock-mechanical, hydrogeological and hydro-geochemical models (Figure 4-7). In addition, the geological model constitutes a key piece of initial information for planning the repository facilities through the rock suitability criteria.

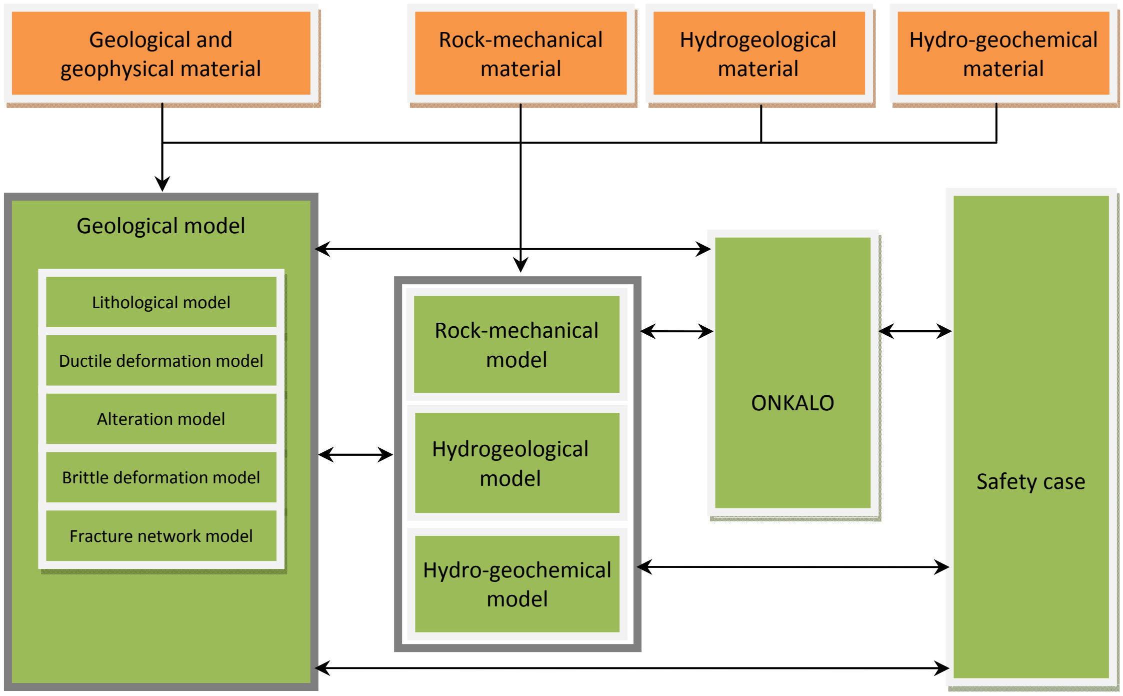

Figure 4-7. *Flow diagram of the interaction between the geological model and other fields of research, according to Aaltonen et al. (2010).*

Update 2.0 of the geological model was reported as a working report (Aaltonen *et al.* 2010). A summary of version 2.1 of the model was reported in Olkiluoto Site Description 2011 *(Site Description)*. A map of rock types present in Olkiluoto according to version 2.1 of the geological model is shown below (Figure 4-8). Partial models describing brittle deformation zones and distribution of rock types were updated during 2011 into version 2.2 that has been put at the disposal of other fields of research as a memorandum. The work for preparing a report entitled *Geology of Olkiluoto* began in early 2012. The purpose of the report is to produce version 3.0 of the geological model. Stochastic fracture network modelling has been performed alongside the deterministic geological modelling work. The first version of the geological discrete fracture network model is presented in concise form in the *Site Description,* while version 2 of the discrete fracture network model, updated using new mapping material, is presented in a dedicated Posiva report (Fox *et al.* 2012). This stochastic fracture network model is used, among other things, for producing an assessment of rock suitability and as initial data for hydrological modelling and migration modelling. The ductile deformation model where Olkiluoto is divided into tectonic units (Figure 4-9) is used as the initial data for both the discrete fracture network model and for hydrogeological structural modelling.

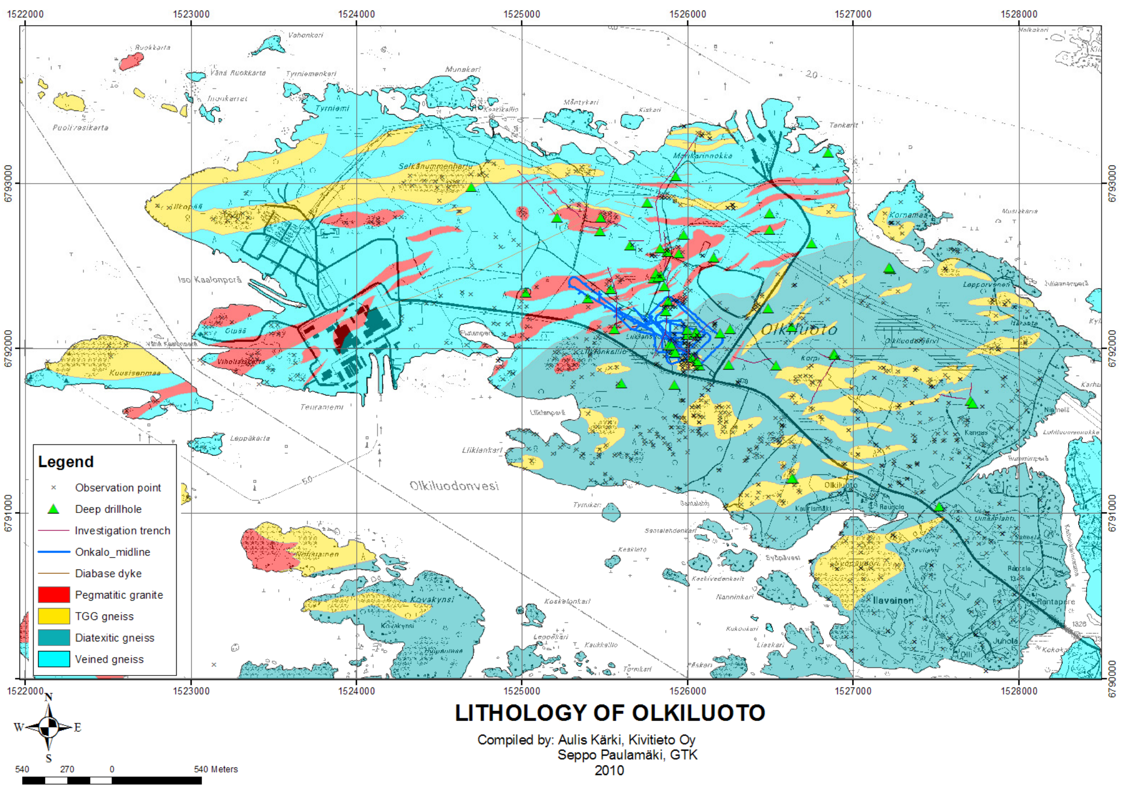

Figure 4-8. *Map of rock types in Olkiluoto (Site Description, Chapter 4).*

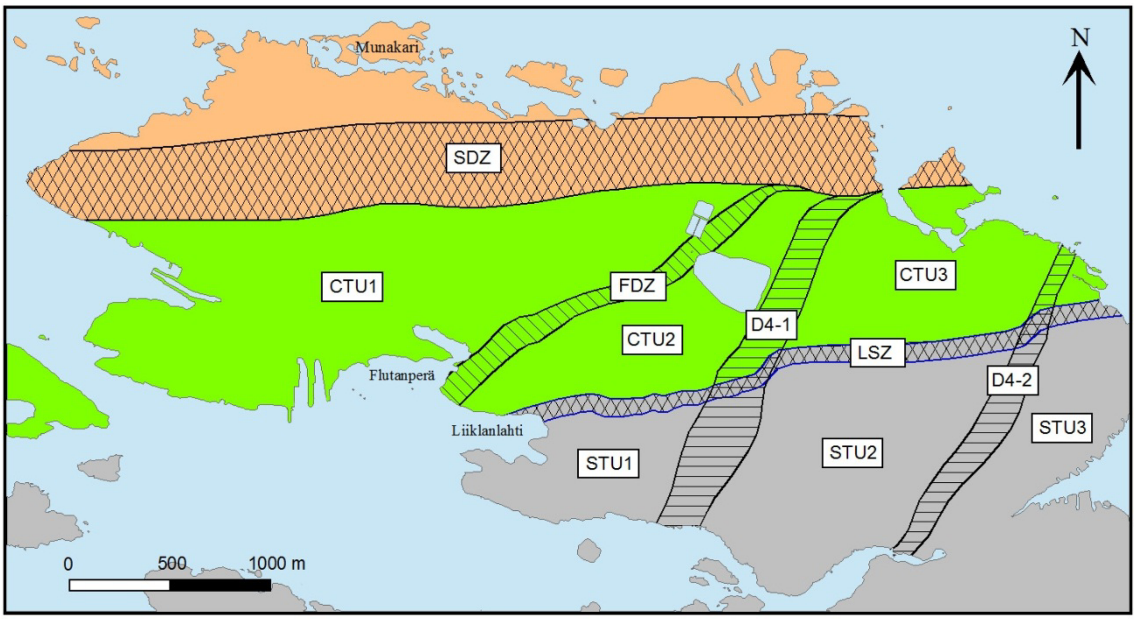

Figure 4-9. *Tectonic units and sub-units in Olkiluoto. Brown marks the northern, green the central and grey the southern tectonic unit (Site Description, Chapter 4).*

The new drilling operations as well as the geological and geophysical studies regarding holes and ground level have helped specify further the geological model, in particular for the eastern part of Olkiluoto.

The work for producing a detailed model for the demonstration facilities area began in 2010. The purpose of detailed modelling is to produce a model more detailed than the *Olkiluoto Site Description* of the geological and hydrogeological characteristics of the demonstration facilities, in particular for rock suitability classification (RSC) purposes. In accordance with the description in the TKS-2009 report, detailed modelling has been developed into a detailed model description of the bedrock properties for use in assessing the suitability of bedrock.

The detailed modelling work has mainly concentrated on modelling brittle deformation zones and long, water-conducting fractures. Geological, hydrogeological and geophysical mapping and measurement data available from the rock volume to be modelled has been used as the initial data for modelling. Once completed, the different versions of the model have been immediately passed on as memorandums and 3D files to the RSC process for use as the basis for carrying out a rock suitability assessment. The first four versions cover the demonstration facilities. The volume to be modelled during 2012 was expanded to cover also the surroundings of these facilities, the access tunnel, vehicle connections and all technical rooms at depths ranging from -370 to 470 m as well as the area planned for the first repository panel at the approximate depth of -407...-419 m (Figure 4-10). The detailed-scale modelling will be described in connection with RSC reporting, while the methods used and the actual model will be reported as part of the Posiva report (*Geology of Olkiluoto*) currently being prepared.

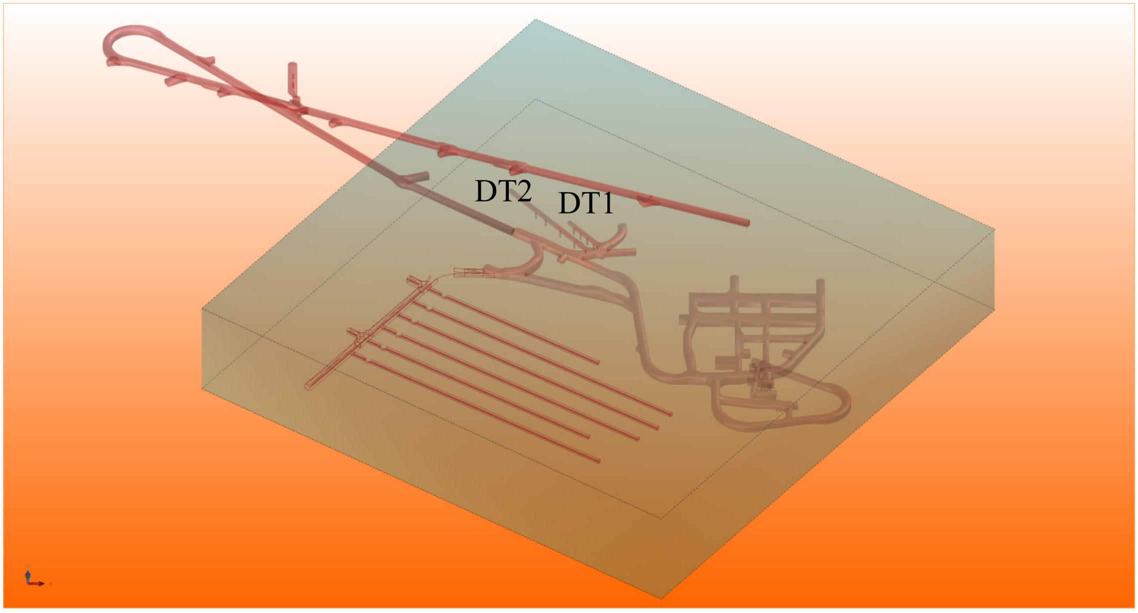

Figure 4-10. *Expanded detailed-scale model volume, part of the access tunnel in ONKALO, technical and other facilities and the planned first disposal panel. The first detailed-scale model only covered the two demonstration tunnels (DT1 and DT2) shown above the centre of the figure and their central tunnel. View towards the north.*

The metamorphic petrology of migmatitic rocks in Olkiluoto was investigated during 2010 (Tuisku & Kärki 2010). The microstructure of fractures typical of the Olkiluoto bedrock and their surroundings was also investigated during the TKS period 2010–2012. The samples were analysed using conventional petrographic methods, electron microscopy, the C-14-PMMA (C-14-polymethyl-metacrylate) method and X-ray tomography. By combining methods, detailed information can be obtained, for example, of the porosity of fracture surroundings and the structure of alteration halos of fractures (Kuva *et al.* 2012).

Rock-mechanical modelling

The TKS-2009 programme had modelling of the state of stress in the investigation site as one of the key tasks. Stress state modelling covering the entire investigation area was performed during 2010 and 2011 (Valli *et al.* 2011) where the effect of brittle deformation zones and limit conditions on the status of stress in the Olkiluoto bedrock was investigated. In addition, a simplified model of the impact of an ice age on the direction and magnitude of stresses was produced. In ice age modelling, directions of the main stresses varied greatly up to a depth of 300 metres. Deeper down, the impacts of an ice age were smaller and the situation closer to that before the ice age. The key results of simulations indicated a strong variation in the state of stress up to a depth of about 300 metres, after which the direction of the main stress assumes the direction of the regional state of stress (Figure 4-11).

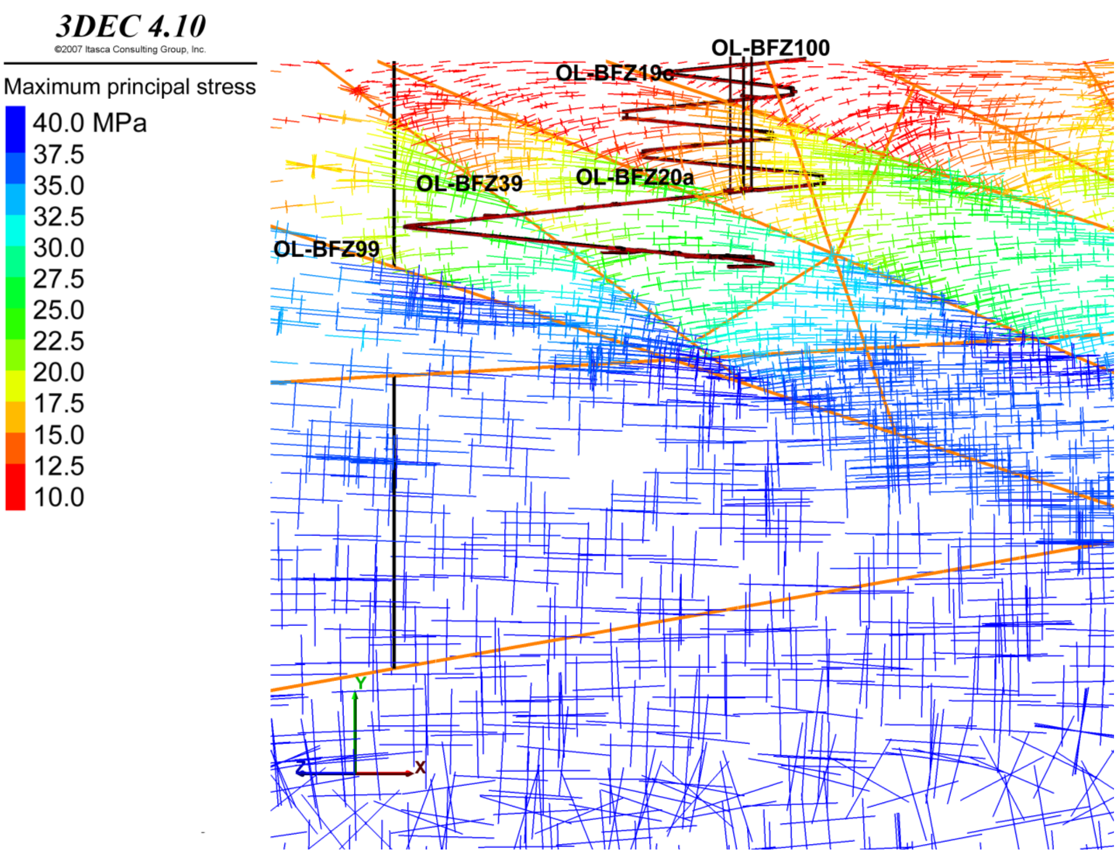

Figure 4-11. *The direction of horizontal main stress assumes the direction of the regional state of stress below the approximate level of -300 m.*

The second version of the rock-mechanical model of ONKALO was published at the beginning of 2012 (Figure 4-12) (Mönkkönen *et al.* 2012). Its partial models included a block model of rock quality, brittle deformation zones defined in the geological model and their properties, the strength of rock, the *in situ* stress of bedrock and the thermal properties of bedrock.

During 2010, earthquake-related analysis work was initiated. Its purpose was to analyse the behaviour of the zones and fractures known in the Olkiluoto area during possible post-glacial earthquakes (Fälth & Hökmark 2012). The work analysed the dislocations caused by the activation of zones in the surrounding fractures. The state of stress during earthquakes was estimated on the basis of the current state of stress and the state of stress caused by ice formation, arrived at using computational methods.

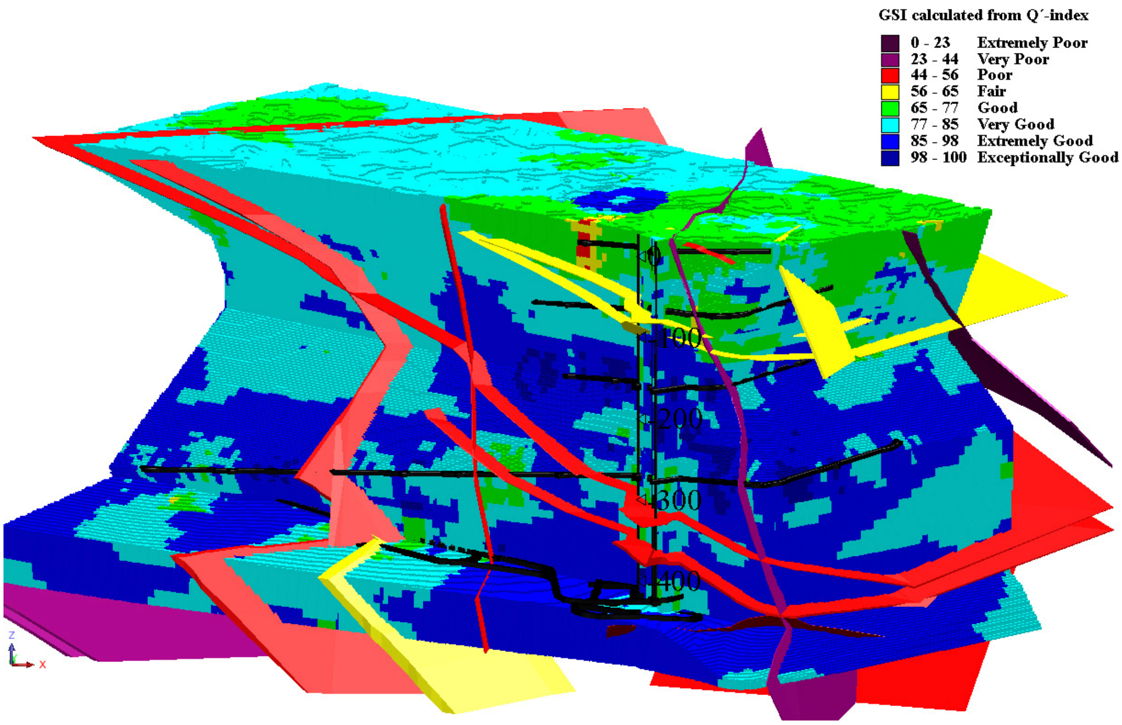

Figure 4-12. *Estimated bedrock quality according to the GSI classification in the ONKALO area and the most important brittle deformation zones.*

The results of phase 1 and phase 2 of the POSE test were subjected to a P/O (prediction/outcome) analysis in order to develop the work: a fracture-mechanical prediction was produced using a 2D modelling program (Siren 2011), while a 3D modelling program was used to produce elastic and elastoplastic predictions (Siren 2011), where the rock is assumed to behave in a brittle fashion. The interpretation of the POSE test will be completed in 2013 when phase 3 of the test has been implemented.

Comprehensive spalling predictions have been produced for the construction of ONKALO (Siren *et al.* 2011), both using conservative assumptions (5 % of the cases more serious) and using average calculation parameters (50 % of the cases more serious). The observations made in ONKALO support the use of average calculation parameters. The three-dimensional analyses have predicted that with the average parameters, spalling would only occur around the shafts (Figure 4-13).

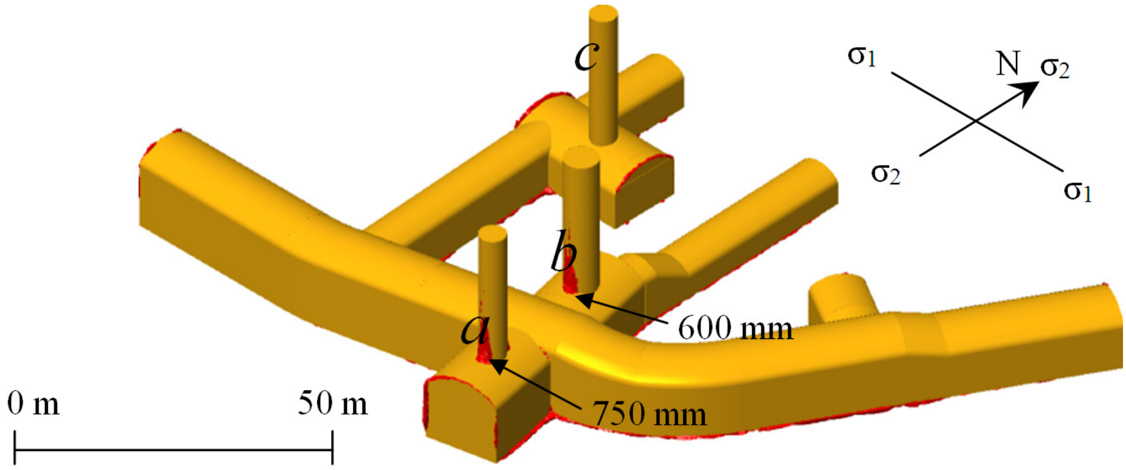

Figure 4-13. *Predicted spalling in ONKALO in a stress field with an east-west orientation (Siren et al. 2011).*

Hydrogeological modelling

Hydrogeological field observations were interpreted for the needs of hydrogeological modelling in the following partial lots:
- Analysis of hydraulic pressure responses
- Assessment of the representativeness of water conductivity and transmissivity data
- Analysis of the flow responses observed in flow measurements
- Identification of water-conducting fractures and determination of their properties
- Analysis of small-scale water conductivity properties

The work for analysing the observation material regarding hydraulic pressure responses continued during the TKS-2009 period (Vaittinen *et al.* 2008, Vaittinen & Pentti 2012, Vaittinen 2010) so that the observation material available by the end of 2009 will be analysed by the end of the period. The objective of analysis work regarding pressure responses has been to develop methods for determining the effect of natural fluctuations in groundwater level, tidal phenomena and fluctuations of atmospheric pressure on the basis of the pressure data and to process hydraulic pressure data systematically using the developed methods. The processed material has been used to interpret hydraulic connections between drill holes and ONKALO, to compare the observed connections with the structural model and to analyse also the results against the geological model and the general hydrogeological understanding.

The representativeness of water conductivity values and transmissivity values observed at different times and using different methods (Posiva Flow Log, HTU and long-term pumping tests) were analysed to support (numerical) flow modelling (Ahokas *et al.* 2012). The primary objective of the work has been to identify the most representative transmissivity value among the material that in some cases has been disturbed by events taking place in ONKALO or in nearby holes. In addition, the increased water flow due to the hydraulic connection to an open nearby hole was taken into account when assessing the material. The measurement data from holes OL-KR1−OL-KR57 will be analysed by the end of the TKS-2009 period. In parallel with assessing representativeness, the transient material obtained using the HTU method has also been analysed in order to investigate the flow dimension of fractures. Analyses have been made for data from holes OL-KR1, -KR2, -KR4, -KR8 and -KR10. This work will be reported in connection with reporting the representative analysis of transmissivity data.

Primary analysis of flow responses observed in flow measurements has been performed in connection with reporting the monitoring observations and in connection with hydrogeological structural modelling (Vaittinen *et al.* 2010a, Vaittinen *et al.* 2012a and Vaittinen *et al.* 2012b). The systematic analysis work began in 2012. The particular objective of the work is to analyse the bedrock section between the main hydrogeological zones with the help of the observed responses and to analyse the connections from the zones to ONKALO and to different holes. The first report on the subject is scheduled for completion by the end of 2012.

Identification of water-conducting fractures and determination of their properties began during the TKS-2006 period. The work continued during the TKS-2009 period so that by the end of the period, material from holes OL-KR1−OL-KR57 and ONKALO holes OL-PH1, ONK-PH2−PH18 will have been analysed (Tammisto *et al.* 2009, Palmen *et al.* 2010, Tammisto & Palmen 2011). The objective of the work is to produce a database of water-conducting fractures for linking it with the geological fracture material. The material will in particular be utilised for the hydrogeological characterisation of Olkiluoto and as initial data for fracture network modelling. In addition to identification work, separate interpretations have been made in order to link the fractures mapped in the pilot holes and the tunnel with the geological material (Palmen *et al.* 2011)

The structures in the investigation site-scale hydrogeological model (Vaittinen *et al.* 2011) were updated during 2010 and 2011. The starting point of this update was geological model 2.0 (Aaltonen *et al.* 2010) together with the new hydrogeological observations made in the investigation site. The work was based on a description of hydraulically significant features and their geometry, dimensions and hydraulic properties, primarily interpreted on the basis of the brittle and ductile deformation models and hydraulic observations. Compared to the previous update (Vaittinen *et al.* 2008), the zones were described, on a drill hole-specific basis, in greater detail than before, paying particular attention to the significance of transmissivity of individual fractures when determining the zone sections intersecting with a drill hole. The model includes 13 hydrogeological zones of investigation site scale (Figure 4-14). Of these, the most significant in terms of water conductivity are the two almost horizontal zones HZ19 and HZ20 in the central part of Olkiluoto island. The bedrock sections between the hydraulically significant zones, characterised by a network of individual hydrogeological fractures, are rather leak-tight.

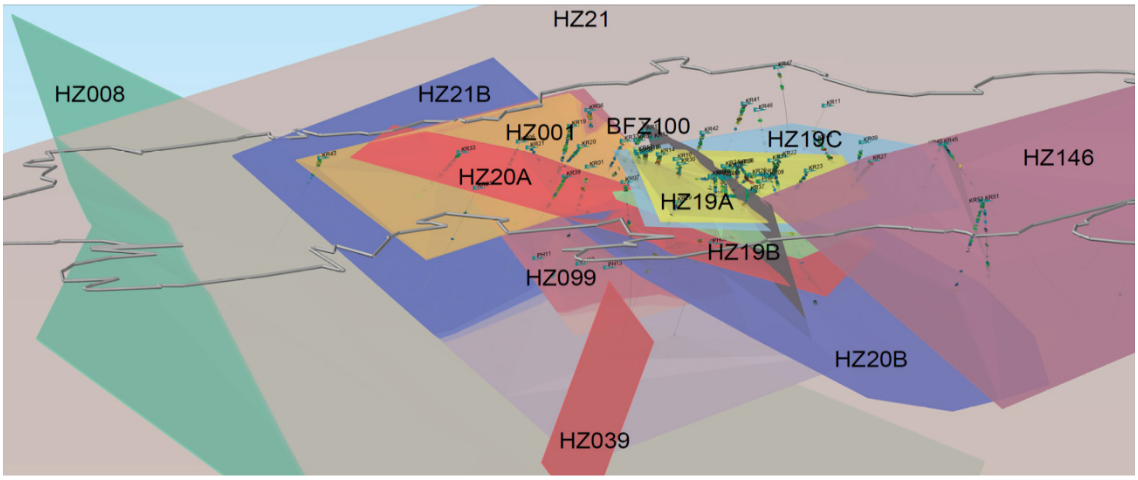

Figure 4-14. *Structures in the hydrogeological model.*

The hydrogeological fracture network model (HydroDFN) was also updated in 2012 (Hartley *et al.* 2012a). It describes the presence of water-conducting fractures even outside the zones. The modelling work was based on an update of the geological discrete fracture network model (GeoDFN) made during 2010–2011. GeoDFN produces a stochastic description of small-scale fracturing of bedrock on the basis of statistical observation data on individual geological fractures. The modelling work has shown that only some of the fractures described by GeoDFN are measurably significant for the flow of water. Identification of such hydrogeological fractures purely on geological basis has proven to be a challenging task. In order to deal with the associated uncertainty, HydroDFN analysed different alternatives that were seen as sensible ways of describing the properties of bedrock with few fractures. The HydroDFN model used the same division of Olkiluoto into tectonic areas as the GeoDFN model. In addition, the HydroDFN model described the strong vertical trend apparent in the hydrogeological material where the abundance and transmissivity of hydrogeological fractures reduce when going deeper. At the same time, their links with the flow paths also become weaker (Figure 4-15). In addition to such a general trend characterising the hydrogeology of bedrock, the HydroDFN model also included assumptions regarding correlation between the size of the fracture (expressed, for example, in terms of the length of the fracture edge) and its transmissivity. There are indications that bigger fractures have higher transmissivity values, although there may not be a direct link between the size and transmissivity of a fracture. In a partially correlated case of the HydroDFN model, the transmissivity values of bedrock fractures are lognormally distributed around the average value that depends on the size. In turn, the size of the fracture is exponentially distributed in accordance with GeoDFN. Each partially correlated case of HydroDFN was adjusted for the flow responses observed in the drill holes (Q/s, Q=flow velocity, s=decrease) (Hartley *et al.* 2012a, Fox *et al.* 2012).

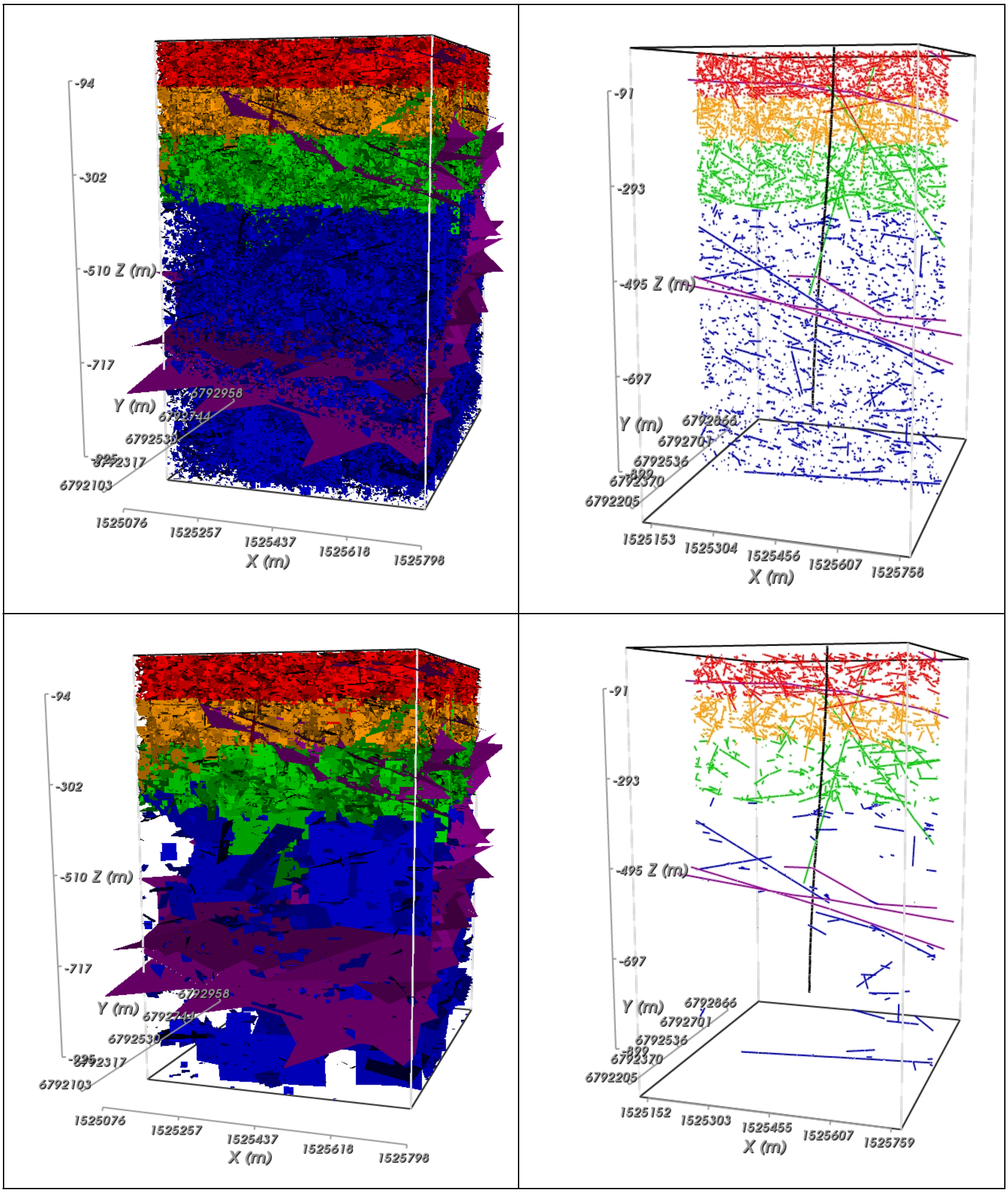

Figure 4-15. *An example visualisation of the hydrogeological fracture network model. The figure shows the open fractures produced by one stochastic realisation around drill hole OL-KR1. The hydrogeological fractures of the topmost depth zone (depth range 0...-50 m) are shown in red, the ones below that in orange (depth range -50...-150 m), then in green (depth range -150...-400 m) and in blue (depth over -400 m). The (deterministic) site-scale hydrogeological zones of investigation site scale are visualised in purple. The top line shows all open hydrogeological fractures (with transmissivity exceeding the detection limit of the flow meter, about 10^{-9} m^2/s), while the bottom line shows the hydrogeological fractures linked with water flow paths. The right-hand column shows the hydrogeological fractures on a cross-section intersecting a drill hole.*

The groundwater flow model of investigation site scale was used to simulate the sequence of developments in the bedrock groundwater of Olkiluoto during the last 8,000 years. Due to technical reasons, the developed HydroDFN model was not used in this paleo-hydrogeological modelling work as it was; instead, a so-called stochastic continuum model was used, where the effective water conductivity values are calculated for the calculation boxes used (e.g. for elements in the element model) using the HydroDFN model (Figure 4-16). Although this means a compromise regarding the degree of detail in the model, the 50-metre element resolution of the stochastic continuum model allows it to take into account the heterogenic nature of the hydrogeological fracture network description used as the basis. It became apparent during the modelling work that the boxes (elements) of the deepest zone in the flow model are only connected to a continuous chain when the modelling also takes into account the information produced by the deep pilot holes in ONKALO regarding very low transmissivity values. In addition to the flow properties of bedrock, the paleo-hydrogeological modelling work included descriptions of the initial state and time-dependent limiting conditions that followed the procedure of the previous site modelling operation. The time-dependent limiting surface condition relied in particular on land uplift data for the Olkiluoto island starting from the situation some 2,500 years ago when Olkiluoto started rising from the sea. The numerical results indicate that the groundwater conditions in Olkiluoto have been very stable at a depth of 400 metres and deeper during the period covered by the modelling work (Figure 4-17).

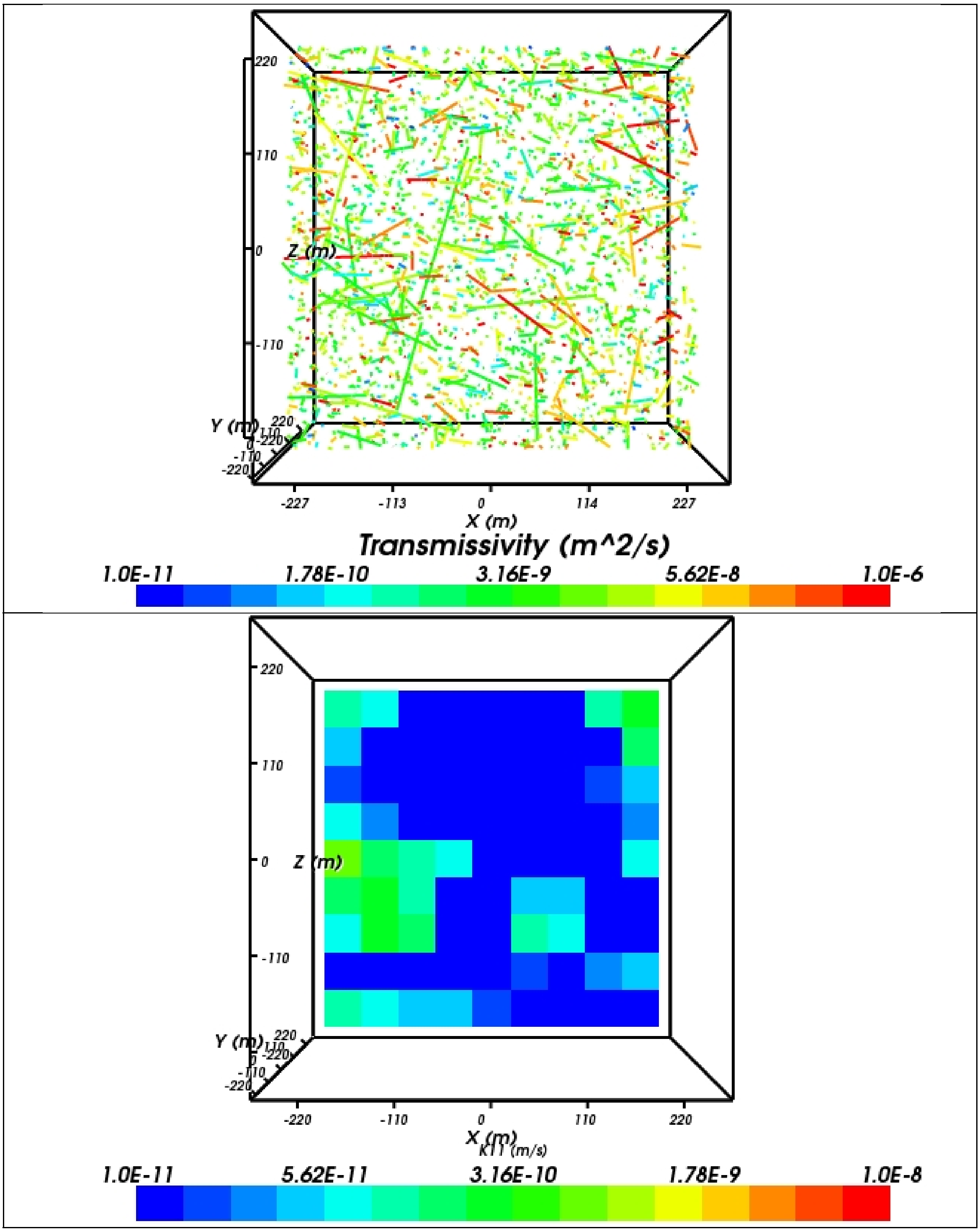

Figure 4-16. *Example presentation of effective water conductivity associated with hydrogeological fractures (component K_{11} of the water conductivity tensor in the figure). The top figure shows the fracture images on a cross-section with an east-west orientation at a depth range of -150...-400 m (the coordinates shown in the figure are its internal coordinates only). In the bottom figure, the effective water conductivity values of 50-metre calculation boxes correspond to the transmissivity of these fractures.*

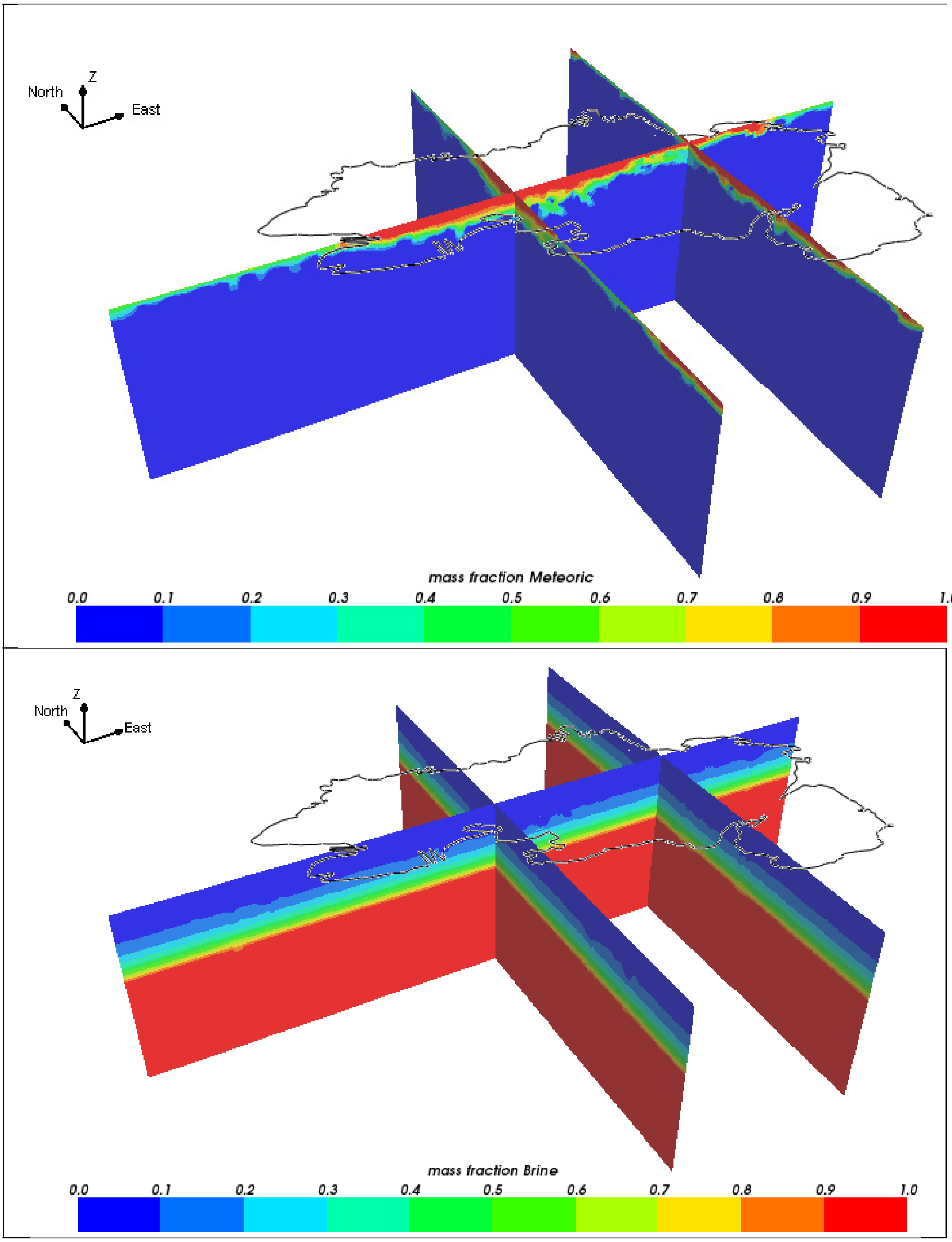

Figure 4-17. *The top figure shows the share of modelled fresh water and the bottom figure the share of modelled deep saline water in 2000, visualised by three vertical cross-sections. According to the results, fresh water has only penetrated the top section of bedrock, while deep saline groundwater has in practice remained unchanged. The depth of the model is about 2 km. The model covers the developments during the last 8,000 years.*

Hydro-geochemical model

The hydro-geochemical model has been updated for the most recent Olkiluoto Site Description (Chapter 7); it is more detailed than the previous site reports and is based on considerably more extensive material. The description shows different partial models concerning the basic state of the site for the distribution of salinity, paleo-hydrogeological development as well as chemical interactions and buffer properties, and they are supplemented with the results from the monitoring and infiltration experiment. The understanding of hydro-geochemical conditions at the basic state has largely remained unchanged (Figure 4-18), but the new material has provided more detailed information on the prevailing processes and hydro-geochemical evolution.

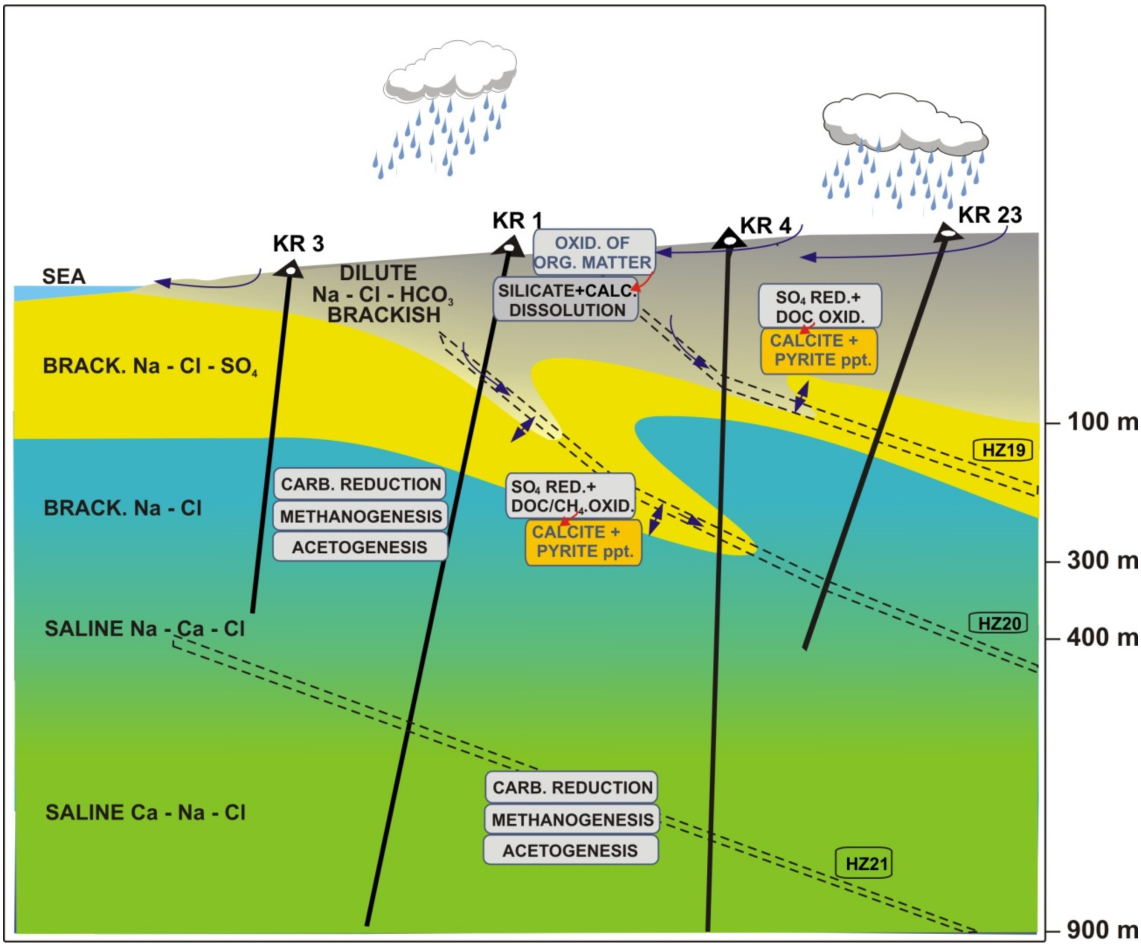

Figure 4-18. *Hydro-geochemical model of Olkiluoto, describing the distribution of groundwater types in the present flow conditions (blue arrows). The main geochemical-microbiological processes regulating and buffering the pH and redox conditions of groundwater are shown in the boxes (Site Description, Chapter 7).*

The salinity data based on groundwater samples was supplemented for the salinity distribution model by utilising the results of fracture-specific electrical conductivity (EC) measurements performed in connection with the PFL measurements. The EC data (converted into total salinity, TDS) was subjected to a quality assessment based on the hydrological behaviour of fractures, corresponding to the approach used earlier regarding groundwater samples (Pitkänen *et al.* 2007). The material was classified in order to identify the fracture-specific salinity values representing the natural basic state of Olkiluoto. They formed a network of a total of 414 points covering different parts of the bedrock (Ahokas *et al.* 2012). In the model, the distribution of salinity and different types of groundwater have been analysed in relation to depth, hydrogeological structures and transmissivity values of the fractures. The three-dimensional distribution of fracture salinity in the bedrock has also been predicted using a function based on the Gaussian regression process. The work will be published as a working report. On the basis of the description, the structures with a significant water conductivity control the fluctuation of salinity in the top part of the bedrock (0–300 m), but deeper down, the variations in salinity do not seem to depend on the transmissivity of fractures or on more extensive structures.

The model describing the past development of groundwater conditions in Olkiluoto (*Site Description*) is primarily based on geochemical information consisting of analyses made of bedrock fracture minerals (calcite and pyrite), empirical determinations of matrix pore water and groundwater samples. The results of fracture mineral analyses indicate that the groundwater filtrating from above ground has already been reduced and neutralised in the soil or a couple of meters down in the bedrock. The bedrock groundwater has been dominated by an alternation of reduced, so-called sulphidic conditions (sulphate-containing groundwater) and methanic conditions (groundwater without sulphides). Apparently, very saline groundwaters (brine) have been formed during the Paleozoic Era over 250 million years ago, and the residual solutions of these waters still constitute the saline groundwater in Olkiluoto. The matrix pore waters indicate that after the saline period, meteoric water has infiltrated in the bedrock in climatic conditions much warmer than the present (probably during the Tertiary Period), and this water has replaced the saline groundwater in the surveyed bedrock volume. Clear indications of melting waters from Quaternary Period ice ages are only found in the groundwaters of the top layers of the bedrock (0–250 m) and to a very small degree in matrix waters. The waters infiltrated after the most recent ice age currently constitute most of the groundwater inside the top layer of bedrock at a depth of 300 metres, while saline groundwater diluted from the ancient, very saline groundwater (brine) before the last ice age is dominant deeper down.

However, the chemical results indicate that the matrix pore waters and fracture groundwaters are not in balance in spite of the apparently very long duration. The difference may be due to anionic exclusion that prevents the anions from filling the matrix pores of nano-scale as a result of negatively charged pore surfaces and electrostatic forces. In other words, anionic porosity is lower than water porosity. The studies on matrix porosity have shown that the micro-porosity of bedrock is often sericite-filled, which substantially reduces the pore aperture of the matrix. The possible low rising of saline groundwater from deeper down than the surveyed bedrock, from depths which meteoric water of the Tertiary Period would not have reached, could also result in a situation indicated by different chemical results. On the other hand, no regional component has been observed in the hydrological pressure measurements that would cause an upward flow from the depths.

In addition to groundwater sampling and the monitoring of ONKALO, the chemical processes related to water-mineral interactions have been investigated in microbiological studies and field tests. The infiltration experiment has been used to analyse the buffering capacity of the groundwater system against acidic and oxidising water filtrating in the bedrock (Pitkänen *et al.* 2008, Aalto *et al.* 2011a, Käpyaho *et al.* 2012). In a test that has been in progress for three years, the flow of rain water into groundwater to a fracture zone near the surface (at a depth of about 10 metres) has been accelerated by pumping, and the hydrological and geochemical developments in the system have been monitored via nearby groundwater pipes and drill holes. The test results are simulated using both a flow model (Karvonen 2010) and a reactive migration model (Trinchero *et al.* 2012b). The results of tests and modelling support the opinion that the surface groundwater system of Olkiluoto has a considerable buffering capacity against reactive surface waters. The infiltrating surface water is primarily neutralised by calcite, and the calculations indicate that an extremely minute part of calcite has been consumed in the test. Therefore, it is not probable that the buffering capacity provided by calcite will be exhausted during the operation of the repository, or as a result of future climatic changes, for example. This conclusion is also supported by the observations of calcite in fractures. In spite of the pumping, oxidising water has not filtrated in the test system. Oxygen is probably already reduced in the soil that has a considerable reduction potential consisting of organic matter and mineral sulphides.

The amount of dissolved sulphides has been observed to increase considerably at times in some bedrock groundwater sampling locations. The tests regarding ^{13}C isotope indicate that these increased sulphide concentrations do not seem to be related to the anaerobic oxidation of CH_4; instead, the microbes seem to use some other dissolved organic matter or hydrogen for their source of energy, and the groundwater results show that the groundwaters of Olkiluoto contain far less of these than they contain methane. The monitoring data indicates that high sulphide concentrations seem to be related to the sudden mixing of groundwater types as a result of hole flows. After the groundwater conditions have stabilised following the installation of multiple plug systems in the drill holes, the sulphide concentrations have begun to decrease. On this basis, it has been suggested (*Performance Assessment*), that the high sulphide concentrations are metastable and will gradually reduce (over a few years or decades) as a result of precipitation of FeS phases, for example. In stabile hydrological conditions, the formation of sulphides may also be slower due to the limited availability of source materials. The groundwater of Olkiluoto contains very little iron and iron minerals suitable for precipitating sulphides (iron oxy/hydroxides); they are only present at a depth of a few metres near the ground level. Some silicate minerals, such as micas, contain iron, but the availability and release of iron from them will require further investigations.

Modelling of migration properties

The studies on matrix pore water in drill core samples continued during the TKS period (Eichinger *et al.* 2010, 2012); they produce information on the migration properties of the Olkiluoto bedrock, among other things. The analyses of samples from pilot hole ONK-PH9 produced matrix diffusion porosity values in the range of 0.54–1.05% for pegmatite granite and 0.46–0.58% for diatexitic gneiss. Porosity was clearly higher in samples with visible alteration, ranging from 0.87 to 2.13% in altered pegmatite granites and from 0.88 to 2.53% in altered diatexitic gneisses. The pore diffusivity values determined for these rock types (20 °C) varied in the range of 2.5–6.0×10^{-11} m^2/s for pegmatitic granite and in the range of 2.3–2.5×10^{-11} m^2/s for diatexitic gneiss.

As part of the site model update in 2011, the migration properties of Olkiluoto bedrock were described comprehensively, basing them for the first time on site-specific data. This description links the flow concept of fracture network modelling and the description of bedrock retention properties. Accordingly, the description includes the definition of bedrock fracture migration properties based on extensive material (of over 32,000 fractures), where three groups of main fracture minerals can be seen: clay minerals, calcite and sulphides. Usually, the same fracture contains two of the main fracture minerals (see, for example, Figure 4-19; Aaltonen 2010). The fractures in Olkiluoto can be divided into four categories on the basis of fracture minerals (Figure 4-20):

1. Fractures with calcite as the main mineral.

2. Fractures with hydrothermal clays as the main minerals.

3. Slickenside fractures.

4. Other fractures. This includes a group of fractures that may contain several fracture minerals, or they may be predominantly filled by a mineral other than one of the main minerals (clay, calcite, sulphide).

Furthermore, it has been found that the porosity of rock is different in the immediate vicinity of the fracture. This is thought to be due to hydrothermal alteration of the rock. This would indicate that the description of migration properties must also include a characterisation of typical alteration halos surrounding the fracture.

Figure 4-19. *Fracture with calcite and sulphide minerals. Sample from hole ONK-PH2 at the depth of 153.12 m.*

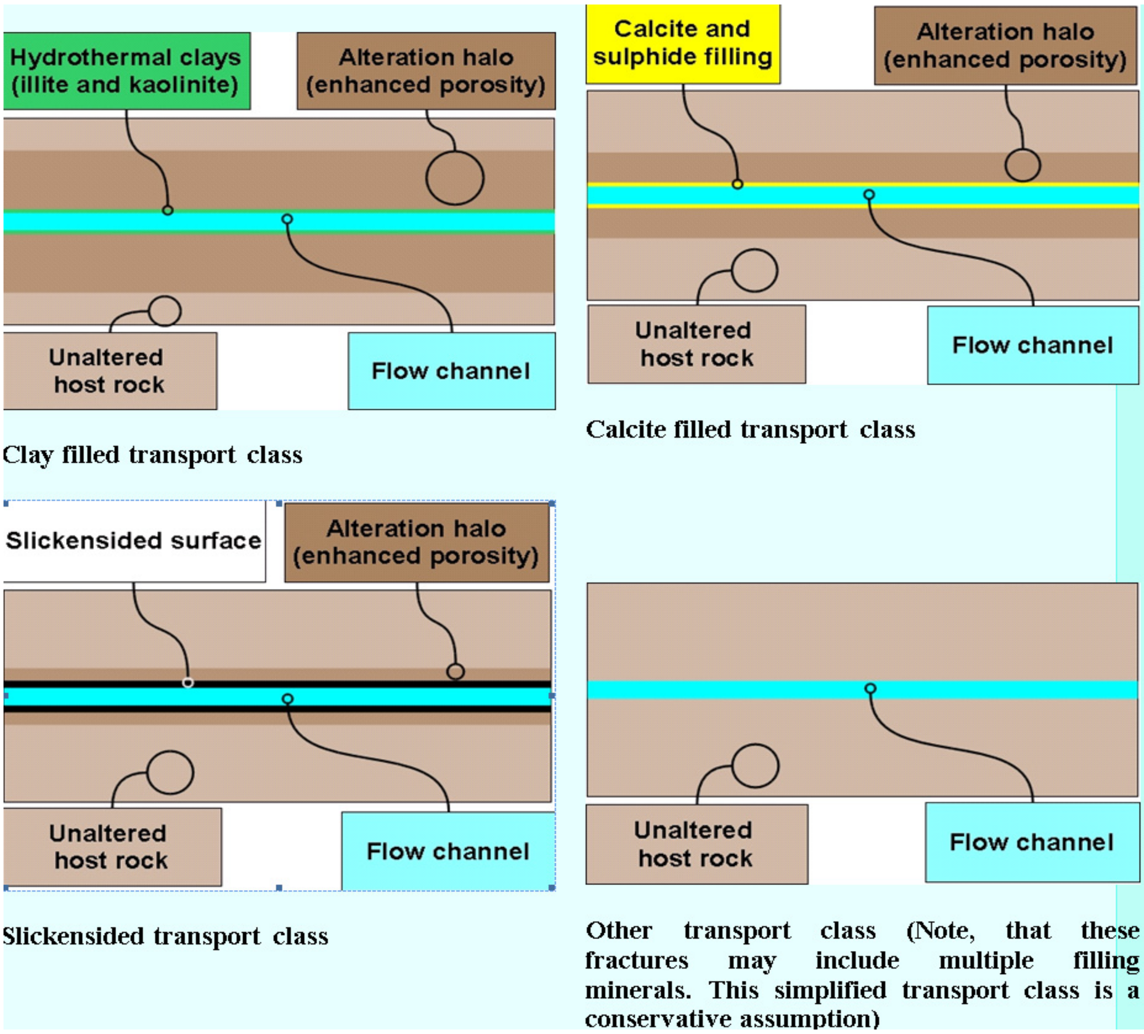

Figure 4-20. *Four simplified type descriptions of migration properties related to fractures in Olkiluoto (Site Description).*

The retention properties of rock surrounding the fracture depend on its diffusion properties and porosity as well as on the thicknesses of zones surrounding the fracture. Production of the data on which the figures in Table 4-1 are based was possible using the so-called PMMA method where C-14-polymethyl-metacrylate is absorbed in the rock sample, polymerised inside the rock by radiation and located using the autoradiography method, after which the porosity is determined with the help of digital image processing. In addition, helium diffusion tests could also be used.

Table 4-1. Properties of matrix zones in the different type cases of fractures in Olkiluoto.

Clay-filled (and possibly sulphide-filled) fractures, 30.9% of all fractures in the drill hole samples			
	Layer 1 Illite and kaolinite	**Layer 2** Alteration edge	**Layer 3** Unaltered rock
Thickness	0.2 mm	10 mm	-
Porosity	6%	4%	0.5%
Effective diffusivity	$1 \cdot 10^{-12}$ m²/s	$7 \cdot 10^{-13}$ m²/s	$6 \cdot 10^{-14}$ m²/s
Calcite-filled (and possibly clay- and sulphide-filled) fractures, 19.4% of all fractures in the drill hole samples			
	Layer 1 Calcite (and sulphide)	**Layer 2** Alteration edge	**Layer 3** Unaltered rock
Thickness	0.2 mm	5 mm	-
Porosity	6%	2%	0.5%
Effective diffusivity	$1 \cdot 10^{-12}$ m²/s	$3 \cdot 10^{-13}$ m²/s	$6 \cdot 10^{-14}$ m²/s
Armoured fractures, 18.5% of all fractures in the drill hole samples			
	Layer 1 Armoured surface	**Layer 2** Alteration edge	**Layer 3** Unaltered rock
Thickness	2 mm	3 mm	-
Porosity	1%	5%	0.5%
Effective diffusivity	$1 \cdot 10^{-13}$ m²/s	$1 \cdot 10^{-12}$ m²/s	$6 \cdot 10^{-14}$ m²/s
Other fractures, 31.2% of all fractures in drill hole samples			
	Layer 1 Unaltered rock		
Thickness	-		
Porosity	0.5%		
Effective diffusivity	$6 \cdot 10^{-14}$ m²/s		

4.2.2.3 Uncertainties associated with the Olkiluoto Site Description

The Olkiluoto Site Description 2011 is the fourth in the series, and it will be completed during 2012. The model description presented in it can be used to demonstrate that the bedrock is stable and sufficiently intact for disposal operations at the planned depth. Only minor groundwater flows are present at the disposal depth in the selected disposal bedrock. The groundwater conditions are reductive, and other chemical conditions of the groundwater (pH, sulphide content, alkalinity, salinity) are favourable for disposal purposes. Retention of dissolved substances in the bedrock will limit the mobility of any radionuclides possibly released. It can be deducted on the basis of research and modelling work that the stable conditions will also prevail in the future.

The model description of the Olkiluoto site can be considered reliable with respect to the key issues affecting safety. This conclusion is based on the substantial amount of research data and on the mutual uniformity of different fields of research, independent of each other. Nevertheless, uncertainties still remain in certain areas, and these will be further investigated. Most of these uncertainties are of no importance to long-term safety, but the reliability of the safety case can be further improved by the following further studies:

- Further investigations and interpretations are still required at the disposal depth for a fuller understanding of the state of stress and strength of the bedrock.
- The understanding of hydro-geochemical processes/stability can be improved by detailed further studies where the mechanisms related to the formation and precipitation of sulphides and the reduction of oxygen in the infiltration zone can be investigated.
- The reliability of migration modelling can be improved by eliminating uncertainties and different interpretations associated with the matrix properties of bedrock.
- Further information will be required outside the key areas of research, in particular for the purpose of investigating the existence and continuity of brittle deformation zones and hydrogeological structures, at the latest when the disposal operations advance to those areas. However, the general suitability of these areas for final disposal can already be demonstrated on the strength of the existing research data.

The research and modelling work to be carried out for investigating these and smaller subjects still having uncertainties associated with them is described in section 5.3.1 .

4.2.3 Suitability classification of the disposal bedrock

Posiva presented in the TKS-2006 programme a plan for the development and application of requirements for the bedrock to be used for disposal purposes. To this end, an RSC (Rock Suitability Criteria) programme was initiated in 2007. It was based on the preliminary Olkiluoto-specific suitability criteria developed in the HRC (Host Rock Classification) project (Hagros *et al.* 2005, Hagros 2006). The objective of the RSC programme was to develop a suitability classification based on certain criteria for designing the layout of the disposal facility and for choosing the locations of deposition holes (Hellä *et al.* 2009). When the programme aimed at developing the criteria advanced to the actual suitability classification process, the RSC work in its present form has been re-named Rock Suitability Classification. Suitability classification and its application are presented in a report by McEwen *et al.* (2012).

4.2.3.1 Suitability classification criteria development work

Update of target properties

The target properties for the bedrock have been updated, and they are presented in a report entitled *Design Basis*. The most significant changes compared to the previous target properties are further specifications of groundwater geochemistry parameters, reduction of the threshold value of permitted dislocation of the buffer-canister system from 10 to 5 cm and to a protective distance of 0.5 m between the canister and potentially dislocating fracture for reasons related to possible future water conductivity. The rock suitability criteria have been updated on the basis of revised target properties, criteria tests during the RSC-I phase and site-specific modelling work. The updated criteria are presented in a report by McEwen *et al.* (2012).

Update of the criteria

Following the update of target properties for bedrock and criteria tests, the RSC-II criteria were developed to correspond to the updated target properties for bedrock. The criteria are described in a report by McEwen *et al.* (2012). The most significant changes compared to the previous version (RSC-I) were the inclusion of geochemical parameters of the deposition tunnel in RSC criteria, the addition of a water leakage criterion for local leaks observed in the deposition tunnels as well as reformulation of the so-called FPI (Full Perimeter Intersection) criterion. The FPI criterion means that a fracture intersecting the entire tunnel profile must be deemed a so-called large fracture unless it can be shown with a suitable method to have a radius of less than 75 metres. The locations of deposition holes will be selected so that large fractures do not intersect any locations of disposal canisters in the holes (so-called FPI criterion). In addition to updating the criteria, the database of hydrogeological and brittle structures limiting the layout of the disposal facility in Olkiluoto (the LDF, or Layout Determining Features) and their protective volumes was updated and published (Pere *et al.* 2012). At the same time, the definition of LDF was also updated.

Sufficiency and effectiveness of the criteria

The sufficiency and functionality of RSC-II phase criteria have been assessed in a report entitled *Performance Assessment*. The report shows that the RSC-II criteria are effective and functional from the point of view of meeting the target properties, and therefore their application will considerably reduce the risk of damage to the engineered barrier system in the long run. The current opinion is that the FPI criterion included in RSC-II is rather conservative, which may also lead to unnecessary rejection of rock volumes meeting the target properties, mainly due to uncertainties associated with the determination of the size of fractures. Therefore the work for developing the FPI criterion will continue (see section 5.3.2).

4.2.3.2 Testing the suitability classification method in ONKALO

During 2010–2012, the RSC-I criteria as well as characterisation and research methods producing information for rock suitability assessment purposes were tested in the access tunnel of ONKALO (*Site Description*). The particular focus of testing work was on the following issues important to the RSC criteria and suitability classification (TKS-2009, pp. 126–127):

- long (large) fractures,
- local small-scale deformation zones and water-conducting features, and
- rock volume beneath the tunnel floor.

Testing the criteria

During 2010–2012, the RSC-I criteria (Hellä *et al.* 2009) and the RSC classification methodology have been tested using material from pilot holes ONK-PH10, ONK-PH11 ONK-PH12 and from Investigation niche 3. Of these, the latter two pilot hole tests concerned in particular assessment of the FPI criterion and the protective distance between the fracture and canister hole or between the fracture and the canister and their impact on the degree of availability of the deposition tunnel (McEwen *et al.* 2012). The results of these tests indicated that definition of the FPI criterion has a major impact on the degree of availability of bedrock suitable for disposal purposes. The measurements of fracture-specific water leaks, both in the tunnel and the deposition hole, have also been developed and tested in conjunction with the RSC work.

The practical application of RSC-I criteria for assessing the suitability of the tunnel was tested in the ONKALO access tunnel between chainages 3460 and 3640 by utilising the research data obtained from pilot hole ONK-PH10 and the tunnel research material. Investigation niche 3 and the investigation holes drilled in it (about 85% of the size of deposition holes) (Aalto *et al.* 2009, *Site Description*) were used for testing the suitability criteria and the classification process at deposition hole-scale. The impact of FPI criterion on the degree of utilisation of the tunnel was tested with the help of pilot holes ONK-PH11 and ONK-PH12. The results were utilised for the development work of RSC criteria.

The RSC-I criteria and the classification process have been tested in the tunnel in the area of pilot holes ONK-PH10–12 and Investigation niche 3. The focus of testing has been on the identification and modelling of small-scale zones in the pilot holes and beneath the tunnel floor. The pilot hole data and geophysical scanning results of the tunnel were utilised in these tests.

Testing research methods

The suitability of geophysical and geological methods for the location of individual large fractures and for investigating their continuity has been studied in a cooperation project with SKB. In the cooperation project, FPI fractures detected in the tunnel were connected during 2011 to fractures mapped in the pilot holes. The results of the work were presented in a report by Joutsen (2012). The study also investigated the geological properties of FPI fractures in ONKALO.

In turn, the geophysical signals of FPI fracture properties have been discussed in a report by Heikkinen *et al.* (2011). According to Heikkinen *et al.* (2011), the sum total of anomaly indices of geophysical signals usually describes the FPI fractures better than individual geophysical methods as such. In many cases, an indication of significant FPI fractures is obtained from the compilation of geophysical anomalies, but it should be noted that these anomalies may also be present in fractures that are insignificant regarding the RSC classification criteria. Then again, no anomalies can be detected for certain FPI fractures with any method (Heikkinen *et al.* 2011).

The reflectors interpreted from the down-hole radar material of ONKALO pilot holes have been correlated with FPI fractures (Döse & Gustafsson 2011). The analysis shows that only 10% of the reflectors can be explained by FPI fractures. Of this population of 10%, two-thirds may also be explained by foliation. Consequently, only 3 % of the reflectors can be reliably correlated with the FPI fractures.

The above studies indicate that it is not possible, at least for the time being, to link individual geological characteristics or geophysical indicators with FPI fractures but the predictions made on the basis of pilot holes regarding FPI fractures can possibly be improved by using combinations of them. For this purpose, an index classification system was created in 2012 for FPI fractures. It will be tested and further developed during 2013.

Of the geophysical research methods, the ground-penetrating radar techniques were tested in 2010–2012 for characterisation of the rock volume beneath the tunnel floor. The investigation used data measured with 100 MHz and 270 MHz equipment from the right wall of ONKALO at chainages 3344–3578 and from the floor of the POSE investigation niche. An impulse radar was mainly used for the measurements, but the suitability of a ground-penetrating radar with a stepwise changing frequency has also been tested (Mustonen *et al.* 2010). As a conclusion, it can be said that the ground-penetrating radar method can be used to detect reflections when the measurement is made on a clean and dry floor or wall. The method reaches about 8–12 m inside the bedrock when a 270 MHz antenna with a good resolution is used and the interference level is low thanks to a good contact. Using equipment with the lower frequency of 100 MHz, the penetration depth is 20–24 m, but the level of interference is higher due to weaker antenna protection and poorer contact. The reflection images of ground-penetrating radar show different reflective surfaces and scattering. These may be caused by fractures, borders between types of rock and shear zones, for example. An efficient way to use the method is to analyse the results in connection with geological mapping so that the origin of reflections can be verified (Heikkinen & Kantia 2011).

The low-frequency ground-penetrating radar investigations performed in demonstration tunnel 1 were repeated in early 2012 on the floor and walls of demonstration tunnel 2. In addition to these basic measurements, ground-penetrating radar measurements were also performed using a 270 MHz ground response antenna in the experimental deposition holes bored in demonstration tunnel 1.

Reflection-seismic methods were tested in ONKALO during 2007 (Cosma *et al.* 2008) and 2009 (Cosma *et al.* 2011) for identifying large fractures and small-scale zones. It can be stated as a summary of the results of the two reflection-seismic investigations that the method is suitable for the detailed mapping of crystalline bedrock, but it must be supported by geological, hydrogeological and geophysical comparison material so that the detected characteristics can be connected with known structures or the existence and location of unknown structures can be predicted. The method can verifiably detect even small features, but, on the other hand, detection of some extensive and significant structures is uncertain (see 4.2.1.1) (Sireni *et al.* 2011).

The experimental holes in Investigation niche 3 were mapped using both conventional geological mapping methods and laser scanning (McEwen *et al.* 2012, Paragraph 3). A similar method was also utilised for experimental deposition holes in the demonstration tunnels. Photogrammetry methods were also tested during 2012 for deposition hole imaging.

The correlation between pilot holes and leaks observed in the tunnel was investigated in a report by Palmén *et al.* (2011).

The work for defining the impact areas of water-conducting structures on the basis of drill hole material is described in a report by Pere *et al.* (2012), and the practice has been applied to mapping the demonstration tunnels. On the basis of RSC-II criteria, the protective distance to be left in the zone is identical with the influence zone of the zone.

4.2.3.3 Suitability classification method

The RSC method includes the assessment of bedrock suitability based on the criteria as part of the repository planning/design and implementation work for the purpose of identifying rock volumes suitable for laying out the facilities. The four phases of the suitability classification (disposal facility, panel, tunnel and hole) progress from an extensive general scale to smaller and more detailed scales as the construction of facilities progresses and research work produces increasingly detailed information of the properties of bedrock.

The phases of the RSC suitability classification method are described below in an outline fashion; a more detailed description is included in a report by McEwen *et al.* (2012). Application of the method is also shown as a concise flow diagram at the end of this section (Figure 4-22). The method has been tested in connection with the design and construction work of the demonstration deposition tunnels and holes at the disposal level in ONKALO (see 4.2.3.4).

Disposal facility

Bedrock classification performed at disposal facility scale produces information for the design of the disposal facility. At this stage of the suitability classification, the bedrock volumes suitable for laying out the disposal facility are determined. The layout determining features (LDF) and their surrounding protective volumes are determined using the available site investigation data and models describing the investigation site (see section 4.2.2) (Aaltonen *et al.* 2010 and Vaittinen *et al.* 2011). These must be avoided in the layout of deposition tunnels (and holes) (Figure 4-21). Such features include extensive, possibly unstable deformation zones and main water-conducting features in the bedrock (Pere *et al.* 2012). The information on LDFs and their respect volumes are produced for use in the design and layout of the disposal facility and above all in the design and layout of the disposal panels.

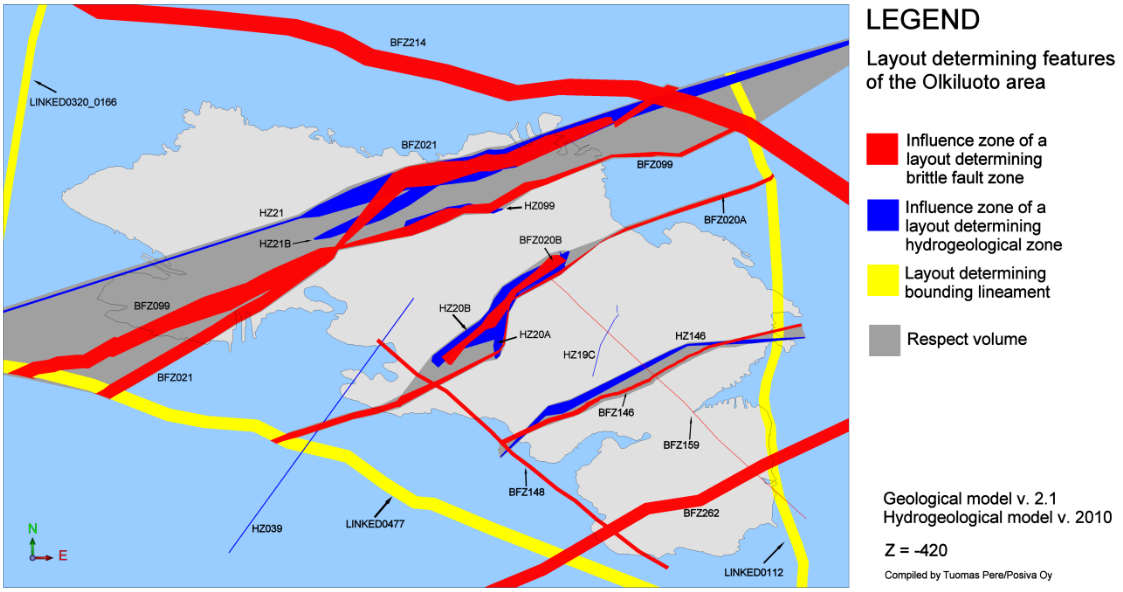

Figure 4-21. *Layout determining features according to Pere et al. (2012).*

Disposal panel

A disposal panel consists of a central tunnel and a number of deposition tunnels starting from it, intended for excavation as one entity. The suitability classification of the corresponding bedrock volume seeks to verify the suitability of the selected volume (no LDFs are found in the planned panel area), to produce information on the bedrock characteristics affecting the layout of deposition tunnels for more detailed design of the panel and layout of the deposition tunnels, and to produce an assessment of the degree of utilisation of the panel. In addition to LDFs, the suitability classification of panels takes into account the bedrock structures which, on the basis of RSC criteria, will affect the layout of deposition tunnels and holes. Such structures include local dislocation and fracture zones and water-conducting structures as well as individual large fractures.

The models describing the investigation site do not contain information of detailed-scale local features of the bedrock; instead, a so-called detailed-scale model covering the panel area must be created where the structures significant to classification are described as accurately as possible. A preliminary version of the model will be created on the basis of preliminary investigations regarding the panel area – for example, on the basis of information produced by investigation holes and geophysical measurements – and the model will be updated on the basis of new research data and their interpretations as the construction work advances.

The preliminary suitability assessment of the disposal panel rock volume will be made on the basis of a detailed-scale model updated in accordance with the research data obtained from the pilot hole drilled in the planned central tunnel. The preliminary suitability assessment will be based on a plan covering the entire disposal facility and focus on verifying the suitability of the bedrock volume chosen for the panel. The preliminary suitability assessment will be revised after the panel has been excavated when the investigations carried out in the excavated tunnel have produced more detailed information on the structures in the area and the small-scale model has been updated again. The panel plan may be further defined and updated on the basis of the suitability classification results – for example, by changing the locations of deposition tunnels, by shortening them, etc.

Deposition tunnel

The suitability of planned deposition tunnel locations (rock volumes) will be preliminarily assessed on the basis of investigations in the pilot holes drilled in the tunnel profiles and the detailed-scale model updated on the basis of their results. The preliminary suitability classification focuses on the fulfilment of criteria set for the deposition tunnels in the selected rock volumes, but the factors affecting the layout of deposition holes will be taken into account when assessing the suitability ratio of the planned tunnels. The pilot holes will be drilled at the same time for several planned deposition tunnels so that the geophysical and hydrological studies between the holes can also be utilised for bedrock characterisation. The tunnel design can be further defined on the basis of the preliminary tunnel-specific suitability assessment made following the pilot hole investigations. For each planned deposition tunnel, the decision to start the excavation work will be made on the basis of the preliminary suitability assessment and the technical assessment made for the tunnel (e.g. regarding the possible need for grouting).

The suitability of each deposition tunnel for disposal use (fulfilment of the criteria set for deposition tunnels) will be verified on the basis of investigations carried out in the excavated tunnel and the subsequent update of the detailed-scale model. Another purpose of the tunnel investigations is to produce information on the rock volume beneath the tunnel (including floor mapping, ground-penetrating radar investigations) (see section 4.2.2), because in addition to verifying the suitability of the tunnel, the suitability assessment made for the excavated deposition tunnel also contains information of tunnel sections that are suitable for laying out deposition holes and of tunnel sections that are not. When analysing the suitability of tunnels and the detailed location of deposition holes to be located in them, different technical aspects are taken into account in addition to aspects aimed at optimising the costs.

Deposition hole

The suitability of locations (rock volumes) selected for the deposition holes will be preliminarily assessed on the basis of investigations in the vertical pilot holes drilled in the locations and the detailed-scale model updated on the basis of their results. The preliminary suitability assessment seeks to verify the fulfilment of criteria set for the deposition holes in the selected locations. The intention is to drill and investigate all pilot holes in one deposition tunnel before producing the preliminary assessment in order to facilitate the use of research methods between the holes, when required. For each deposition hole, the decision to start drilling or to reject the location will be made on the basis of the preliminary suitability assessment. In some cases, an individual hole may also be relocated.

The suitability of each drilled deposition hole for disposal use (fulfilment of the criteria set for deposition holes) will be verified on the basis of investigations carried out in the hole and the consequent update of the detailed-scale model. In addition to the RSC criteria, each hole approved for disposal use must also meet the technical quality requirements regarding, among other things, straightness of the hole and smoothness of the surface.

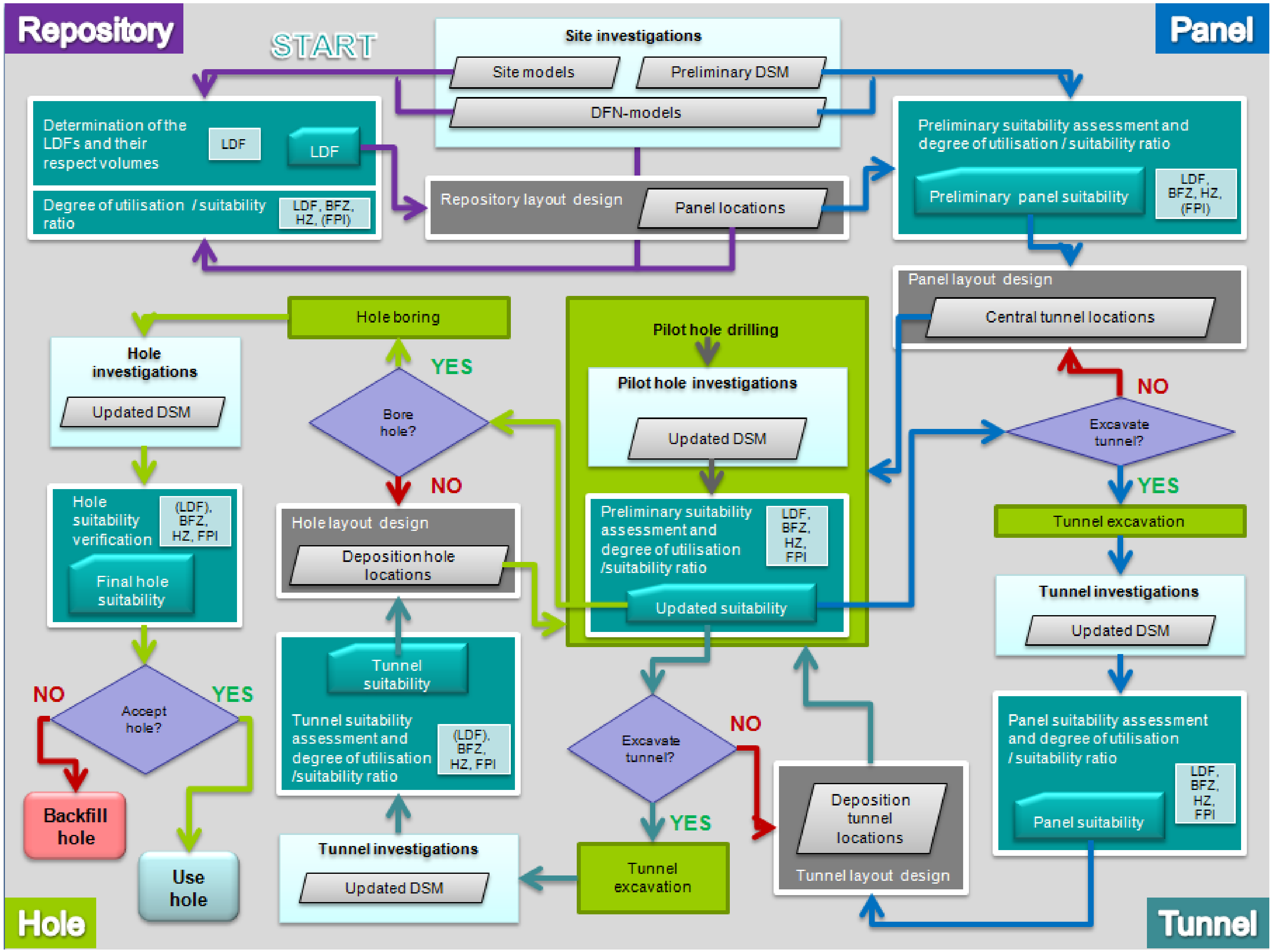

Figure 4-22. Draft of a general flow diagram regarding rock suitability classification (RSC) for the KBS-3V concept.

4.2.3.4 RSC demonstration

The RSC method has been tested in connection with constructing the demonstration facilities of ONKALO at the disposal depth (see sections 4.2.3.2 and 4.2.3.3). The demonstration facilities consist of a central tunnel, two demonstration tunnels and a number of test deposition holes (see section 4.3.4), and rock characterisation and suitability classification as well as matching the characterisation and suitability classification process with planning/design and construction work have been tested in connection with constructing these facilities. The bedrock characterisation methods used in connection with constructing the demonstration facilities and small-scale modelling of the rock volume are described in section 4.2.2 . An outline of the progress of the RSC demonstration is shown below; a more detailed description is included in the report by McEwen *et al.* (2012).

The first preliminary suitability assessment was produced in June 2010 for planning the layout of demonstration tunnels. The assessment was based on preliminary RSC-I criteria (Hellä *et al.* 2009) and on bedrock structures described in the geological model (Aaltonen *et al.* 2010). On the basis of the suitability assessment, the required length of the tunnels was determined to be 85 metres each.

The suitability of bedrock in the demonstration facilities area was re-assessed in October 2010 when excavation of the ONKALO access tunnel had passed the demonstration facilities area and part of the central tunnel had also been excavated (no pilot hole was drilled for the central tunnel). A preliminary version of a so-called detailed-scale model, more detailed than the geological model, was produced by utilising the new information obtained from the excavated tunnels for use as initial data for the suitability assessment (see section 4.2.2.2). The aim was to describe the bedrock features essential from the point of view of the RSC classification (brittle deformation zones, water-conducting features, individual large fractures) as closely as possible in this detailed-scale model. The RSC-I criteria were further used in the suitability assessment. On the basis of the assessment, the length of each demonstration tunnel was confirmed at 85 metres.

The first suitability classification for the planned demonstration tunnels was produced in July 2011. The classification was preceded by drilling pilot holes in the planned demonstration tunnel profiles, pilot hole investigations with their interpretations as well as an update of the detailed-scale model. In addition to the pilot hole investigations carried out by Posiva as a standard measure (see, for example, Aalto *et al.* 2011b) mise-a-la-masse measurements between the pilot holes and tunnels and a hydraulic interaction test between holes were conducted in the area (see section 4.2.2.1), but the results of these were only utilised in the next suitability assessment round due to the time taken by interpreting the results. In addition to the pilot hole material, the investigations conducted in the central tunnel of demonstration facilities (including, among other things, measurements of structure-specific water leakage quantities) were also utilised for updating the detailed-scale model. The suitability assessment was produced for the planned demonstration tunnels using both the RSC-I criteria and the preliminary updated criteria (RSC-II) (*Site Description*). Following the assessment, the decision was taken to excavate the tunnels in the planned locations, but the plans were updated: demonstration tunnel 1 was shortened to 52 metres in order to avoid penetrating the brittle deformation zones intersecting the tunnel profile at this stage, as the pilot hole investigations indicated that the zone would need grouting. In order to make up for the lost space, demonstration tunnel 2 was extended to 105 metres.

After the plans were updated, excavation work started with demonstration tunnel 1 and continued with demonstration tunnel 2. Due to delays caused by grouting tests, it was decided to deviate from the previous plans and proceed with the boring of experimental deposition holes in demonstration tunnel 1 as soon as possible, before excavation of demonstration tunnel 2 was completed (section 4.3.4).

When the excavation of demonstration tunnel 1 and the subsequent tunnel investigations (including geological mapping of the tunnel, water inflow measurements and ground-penetrating radar investigation of the tunnel floor) had been completed, the detailed-scale model was updated. In addition to the material from tunnel investigations, the model update utilised the results of investigations conducted between the pilot holes and earlier excavated tunnels that were not yet available for the previous update of the model. In August 2011, a suitability assessment was produced for demonstration tunnel 1 on the basis of this material. It involved determining the tunnel sections suitable for boring the experimental deposition holes. The suitability was assessed on the basis of updated RSC-II criteria (*Site Description*) that were used after that for all subsequent suitability assessments. The suitability assessment was forwarded to the designers who used it as the basis for selecting the locations of the experimental deposition holes to be bored: it was possible to place two holes in the tunnel sections approved in the RSC assessment, in addition to which it was decided to place two additional holes in tunnel sections classified as unsuitable so that the prototype of hole boring equipment could be tested (see section 4.3.4).

The suitability of experimental deposition hole locations selected in demonstration tunnel 1 was verified in October 2011 on the basis of investigations performed in the pilot holes drilled in selected locations and an update of the detailed-scale model. The locations selected on the basis of the suitability assessment (the two holes in the above approved tunnel sections) fulfilled the requirements set for deposition holes, and permission was given to start boring the holes in the selected locations.

When the holes had been bored, a final suitability assessment was produced for each test deposition hole bored in demonstration tunnel 1 on the basis of investigations conducted in the holes in spring 2012. The purpose of this was to ensure fulfilment of the RSC criteria set for the deposition holes before finally approving (or rejecting) each hole.

In February 2012, a pilot hole was drilled for the end part of demonstration tunnel 2 (between the chainages 85–125 m) to cover the extension section of the tunnel. After pilot hole investigations and the appropriate update of the small-scale model, a suitability assessment was produced for the end part of the tunnel. Excavation of the tunnel was continued up to a length of 105 metres. When the tunnel had been excavated, its suitability was assessed, locations for test deposition holes selected and their suitability assessed in the manner described above.

4.2.4 Olkiluoto monitoring programme

The Olkiluoto monitoring programme (OMO) is in progress for the purpose of monitoring the long-term developments in the disposal site and facility. The programme was initiated in 2004, and its main objective is to monitor the impacts of ONKALO construction work on the bedrock and surroundings above ground (Posiva 2003b). The observations have been used for the purposes of long-term safety assessment, site investigations and environmental impact assessment. The results of the monitoring programme are reported annually in Posiva's series of working reports. A separate report is produced for each area of monitoring (rock mechanics, hydrology, hydro-geochemistry, surrounding environment above ground and foreign materials), presenting the investigations conducted during the year and comparing the results with those of previous years.

4.2.4.1 Rock mechanics

Bedrock transition measurements

The measurements of bedrock transitions began with two extensometers and convergence lines in early 2010 in Investigation niche 3 at the approximate depth of 345 metres (Lahti & Siren 2012). The results of the measurements have been in line with the progress of excavation phases. The extensometer measurements indicate that the bedrock at the investigation niche wall has moved horizontally less than one millimetre during the expansion of the investigation niche. The measurement was made immediately behind the new wall line from an anchor in the access tunnel rock face to a fixed point some 30 metres away. The results were about half of the predicted values. The results of convergence measurements made during the expansion of the investigation niche were about 0.75 mm on a horizontal line, as predicted.

In autumn 2011, two extensometers with three monitoring points were installed in the pillar between ONKALO's technical rooms and the parking hall. The extensometers were installed before excavating the hall, and the purpose of the investigation was to monitor the deformations caused by the hall excavation work. The work for reporting the results is still in progress. The monitoring will continue for 5–10 years depending on the durability of equipment and the measurement results.

The convergence measurements of shaft ends planned in the TKS-2009 programme have been replaced by measurements to be done using LVDT cells, because the instrument used for convergence measurements (distometer) did not withstand the humid conditions in the tunnel. The measurement accuracy of the instrument was also not sufficient for measuring very small deformations. The plan to install extensometers around the shaft ends has also been rejected, because the tunnel geometry is unfavourable as the installation distances would be very long.

GPS measurements and precision levelling

Expansion of the GPS station network was started in 2010 by establishing four new stations located on both sides of the Olkiluoto straits. The station network will also be updated by modifying old stations for continuous measurement.

The purpose of GPS measurements is to monitor the horizontal and vertical movements of large blocks in the Olkiluoto bedrock. For better vertical accuracy, the GPS measurements are supplemented by precision levelling measurements. The Olkiluoto GPS network, established in 1994, has typically been measured in two campaigns per year, every spring and autumn. By the end of 2012, there will have been a total of 32 campaigns. The most recent results reported for 2011 indicate that in 80 per cent of the points of the local network in Olkiluoto (10 stations), the distance has changed by less than 0.10 mm per year. About one-third of the distances between pillars had moved an amount that is statistically significant, the maximum movement being -0.20 ±0.05 mm per year. In the outer network in the Olkiluoto surroundings (5 stations), the maximum movement is 0.39 ±0.06 mm per year between two pillars, one on either side of the Eurajoensalmi straits (Koivula *et al.* 2012). The results seem to indicate that the GPS pillar located in Olkiluoto is slowly moving.

Precision levelling measurements have been performed in particular for monitoring the development of the largest movements measured on the Olkiluoto island and across the Olkiluoto straits. The 1.9 mm change across the Olkiluoto straits observed in 2007 was observed to have decreased in 2008 and 2009. The fixed point above ONKALO has continued to rise, and small changes in elevation, less than 1 mm, can be seen in the points near the power station (Lehmuskoski 2010). The precision levelling campaigns of 2010 and 2011 will be reported in 2012.

Micro-seismic network

The purpose of seismic monitoring is to observe seismic events in Olkiluoto and its near-fields and the possibly resulting movements of large bedrock blocks. Each year, the seismic station network detects over one thousand events, most of these explosions during the blasting work in ONKALO. The other seismic events are typically caused by construction work either above or below ground. The observed events are reported monthly. Furthermore, annual reports are compiled of the results. A total of 1 089 seismic events were identified in 2010, nearly all of them blasting explosions. Three events could be classified as micro-quakes induced by construction work. They were associated with pre-grouting of shafts through drill holes (Figure 4-23). The events took place 50–80 metres above the nearest already excavated ONKALO volume. The calculated movements in the rock were smaller than 5 µm, and the radii of calculated transition planes were smaller than 5 metres (Saari & Malm 2011).

The micro-seismic station network was expanded during 2010–2012 with underground stations installed in ONKALO Investigation niches 3 and 4. At the beginning of 2012, the monitoring network included 15 permanent stations and the local stations in Investigation niche 3 which were installed for the purpose of monitoring the *in situ* spalling test. In 2012, local stations around the shafts at levels -290 m and -437 m will be added to the network. The main purpose of these stations is to monitor the rock-mechanical events caused by opening the shafts.

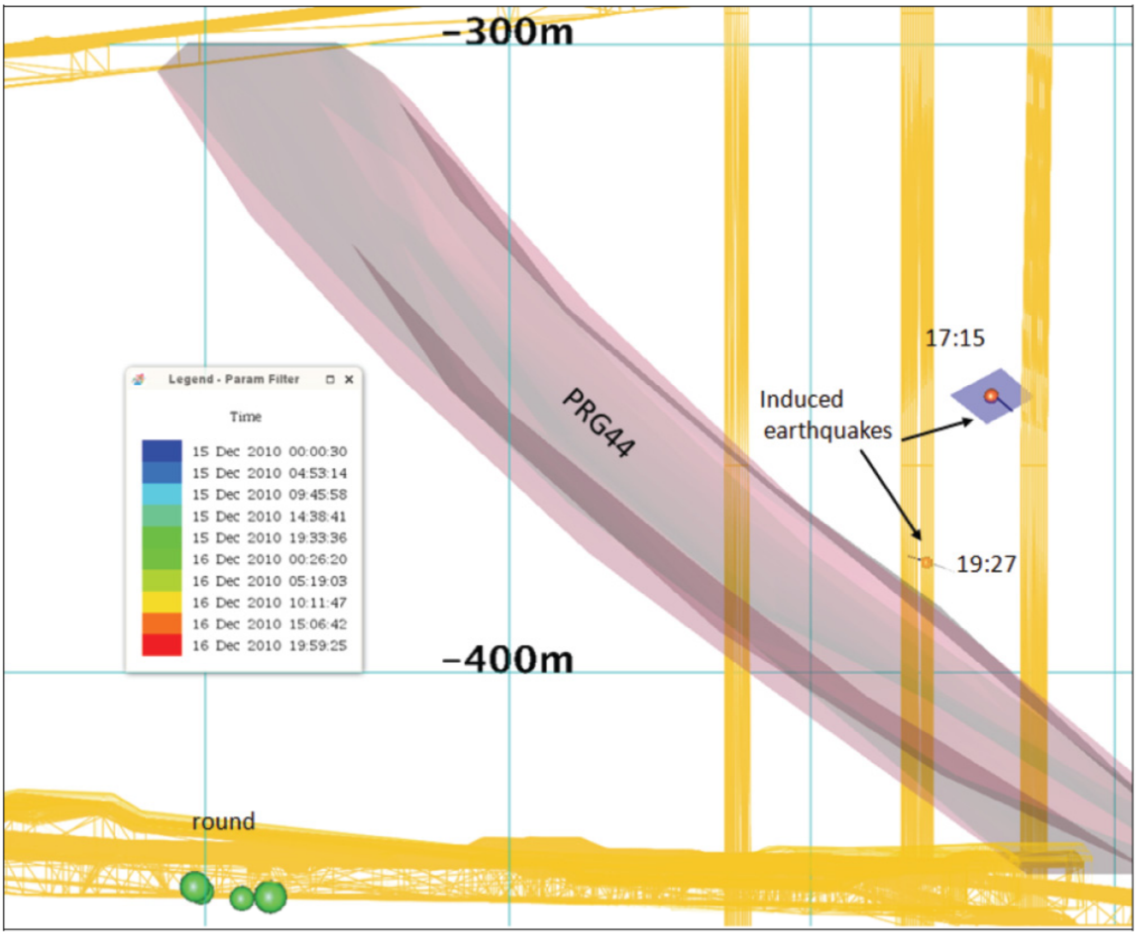

Figure 4-23. *The micro-earthquakes observed in connection with shaft grouting operations on 16.12.2010 show that the micro-seismic network is sensitive and operational.*

4.2.4.2 Hydrology

The hydrological monitoring has mainly been implemented as planned during 2009–2011. The monitoring programme includes the following targets:

- groundwater level,
- groundwater pressure head,
- flow conditions in open holes,
- transverse groundwater flows,
- hydraulic conductivity of bedrock,
- salinity of groundwater,
- inflow into ONKALO,
- surface water runoff*,
- rainfall (including snow)*,
- seepage*, and
- ground frost*.

(* Background parameters in hydrological monitoring, reported in the environmental monitoring summary report.)

Groundwater pressure head values are monitored using a continuously operating measurement system that allows sudden changes in groundwater pressure to be detected. Such changes are indications of possible hydraulic connections to ONKALO. The groundwater level and pressure head measurement results for 2009−2011 are reported in summary reports by Vaittinen *et al.* (2010b, 2012a and 2012b).

The pressure head measuring network has been expanded every year by installing multi-packer equipment into drillholes. Another purpose of multi-packers is to prevent the negative impacts of open drillholes on groundwater chemistry by preventing the groundwater flow from one depth to another. Groundwater level observation pipes have been installed and more short bedrock holes drilled, mainly near the Korvensuo reservoir and in the eastern part of the island, in order to expand the surface water monitoring network and for investigating the leaking waters from the Korvensuo reservoir.

The water balance and water level of the Korvensuo reservoir have been monitored on an annual basis in order to find out the volume of leaking waters from the basin to groundwater and its possible impacts on groundwater chemistry.

New measuring weirs have been installed in ONKALO as the tunnel excavation work has progressed (Figure 4-24). By the beginning of 2012, nine measuring weirs had been constructed to chainages 208, 580, 1255, 1970, 3003, 3125, 3356, 3941 and 4580, respectively. The measuring weirs are used for measurements of total inflow preformed once or twice a month. During the TKS-2009 period, the average total inflow into ONKALO has been about 33 litres/min. The ONKALO inflow assessment programme (WARVI) established in 2008 monitors the inflow observations and the impacts of inflow on the groundwater environment from the perspective of functions critical to long-term safety (inflow management).

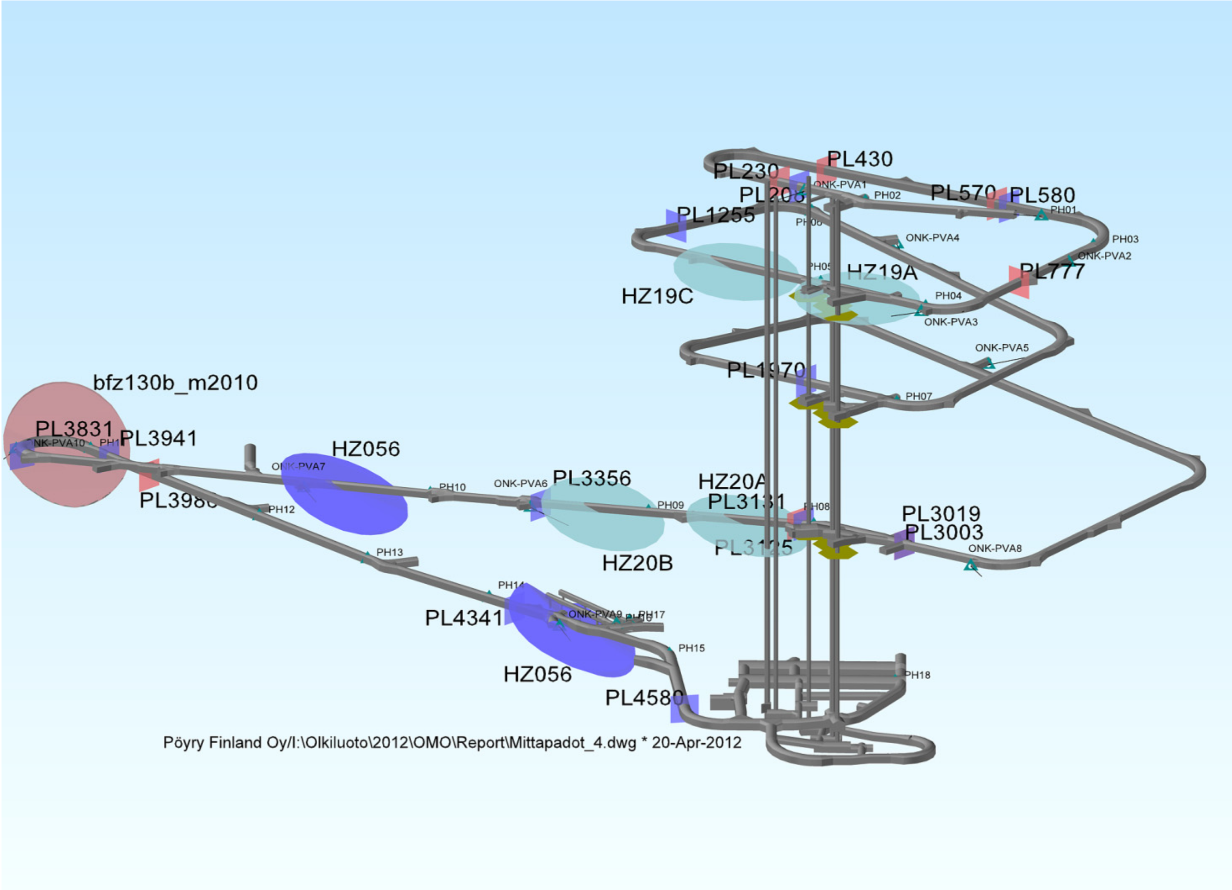

Figure 4-24. *Locations of measuring weirs (purple), local collectors (red) and shaft inflow measurement points (yellow) in ONKALO. The locations of the most important hydrogeological structures have also been illustrated in the figure.*

The observations made in the monitoring programme have been used as background information of the surface hydrological model and the hydrogeological structural model. The observations have supported the modelled structures and provided additional information on their properties and continuity. The discovery of new local connections between ONKALO and drillholes OL-KR39 and OL-KR3, as well as the additional observations of HZ056, the most recent structure in the structural model, deserve a special mention.

The most important observations made during 2009−2011 are (Vaittinen *et al.* 2010b, 2012a and 2012b):

- No significant changes in the groundwater level in the soil or bedrock.
- Significant decreases of pressure head in the bedrock, in particular for modelled zones (HZ19, HZ20 and HZ056) (Figure 4-25).
- Both long-term and short-term changes in pressure head have been effectively measured and interpreted.
- Clear changes have been observed in the direction of groundwater flows because of connections to ONKALO.
- A minor decrease in hydraulic conductivity, probably caused by grouting, has been observed in drillholes located near ONKALO.

- Indications of possible changes in the electrical conductivity of groundwater (salinity) have been observed in connection with flow measurements.

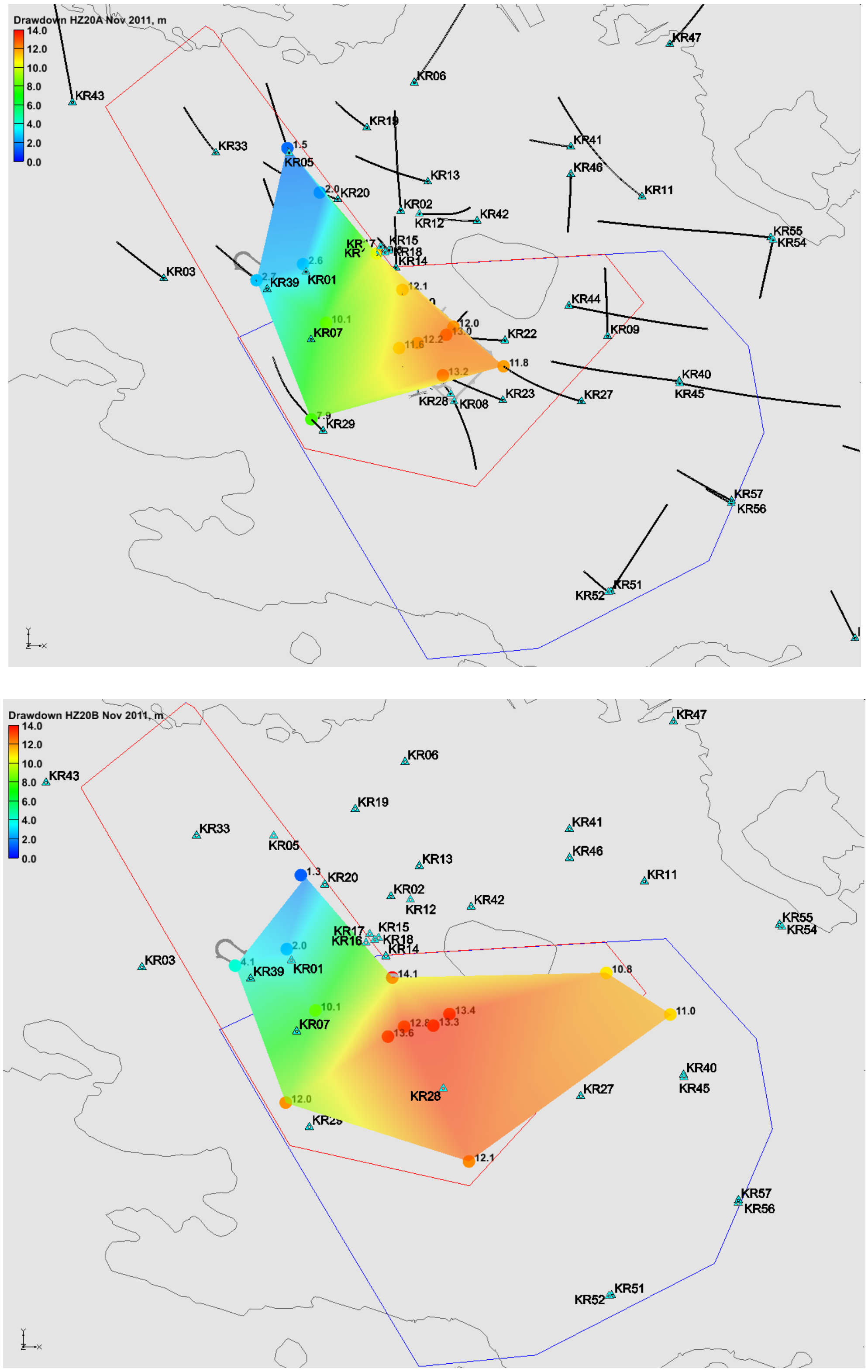

Figure 4-25. *Illustration of observed drawdown, interpreted to be associated with structures HZ20A (red, top figure) and HZ20B (blue, bottom figure).*

4.2.4.3 Hydrogeochemistry

During 2009–2011, the hydrogeochemical monitoring programme was implemented according to plan. The groundwater monitoring programme is divided between investigations of the soil sand top layers of bedrock, and investigations of deep bedrock groundwaters. The main focus of investigations was on studying the deep bedrock groundwaters, and in particular on studies concerning significant hydrogeological structures (HZ19, HZ20 and HZ21) and deep saline groundwater.

Changes have been observed in the groundwater chemistry in the Olkiluoto region; these include the observation that bicarbonate-containing water from the top layers of bedrock have migrated deeper down to the monitoring points as a result of the hydraulic gradient created by ONKALO (Penttinen *et al.* 2012). Hydrological structures HZ20A and B are conveying groundwater towards ONKALO, which either causes dilution or increased salinity depending on whether the monitored drillhole is open or packed-off (Vaittinen *et al.* 2012b). Dilution usually takes place in zone HZ20A, which has a connection to the ground level. Instead, the monitored objects in zone HZ20B have been found to become diluted if the drillhole is open and to sometimes increase in salinity if the drillhole is packed-off. (Vaittinen *et al.* 2012b). Furthermore, the failure of the plugging in hole OL-KR22 in summer 2009 has enhanced the flow on bicarbonate-containing water to zone HZ20, something that was only detected in sampling during 2010 and 2011 (Penttinen *et al.* 2012a and 2012b). The failure of the plugging has resulted in the clear dilution of groundwaters in structures HZ20A and B in drillhole OL-KR22, and it has also possibly contributed to the minor decrease in the salinity of groundwater in structure HZ20A observed in drillholes OL-KR25 and OL-KR27. Dilution of groundwater has also been observed in connection with HZ19 structures (in drillhole OL-KR37). The observation has been made of the water samples taken from the HZ21 structure that the high hydraulic gradient caused by ONKALO has not yet had any marked effect on deep saline groundwaters (Penttinen *et al.* 2012b).

The diluting effect of the Korvensuo basin on groundwater has been observed in particular in the groundwater observation tubes and shallow drillholes in its vicinity (Penttinen *et al.* 2012a).

Groundwater samples have been taken in ONKALO according to the programme, primarily from groundwater stations. Both groundwater chemistry studies and microbiological studies have been conducted in these holes, and the results have corresponded very well with the natural state of groundwater with only a few exceptions. Of these exceptions, the increasing sulphate content that was detected during 2011 in sampling from a groundwater station (ONK-PVA9) located at the disposal depth might be mentioned (Penttinen et al. 2012b). This change is probably also caused by the hydraulic gradient created by ONKALO.

The studies on the impacts of ONKALO construction work continued with water sampling from fractures and structures leaking water and from waters pumped from ONKALO. The construction of ONKALO, particularly shotcreting, causes from time to time considerably high pH values (10–12) in waters pumped from ONKALO. However, the values are rapidly neutralised in the drain ditch, and no harmful effects on the environment have been observed.

4.2.4.4 Surface environment

The results of the environmental monitoring programme are presented in annual working reports (Haapanen 2005–2012), the results regarding the surrounding forests being presented in separate working reports (Aro *et al.* 2010, 2011). The annual working reports also compile the environmental investigations performed by external parties, such as TVO, in the Olkiluoto area. The monitoring programme has mainly been implemented in line with the original monitoring plan (Posiva 2003b), and the deviations have been primarily related to schedules or to closer specification of the focal points of monitoring as more research data has been accumulated.

The biggest changes in the environment being monitored are related to land use. Provisions are made in the research work for changes in the land use by, for example, establishing new test plots as required to replace plots that have either been destroyed or are under threat to areas which according to known plans will remain outside future construction operations. The construction activities taking place in Olkiluoto, including ONKALO and the OL3 power plant site, release dust releases into the neighbouring environment. However, these releases are not expected to cause long-term changes in the environment. The impacts of human activity can also be seen in noise readings that are particularly increased by traffic and construction work in different parts of the island. The impacts of activities of different parties on dust and noise releases can in practice not be differentiated.

4.2.4.5 Foreign materials

The monitoring and control of foreign materials is part of the monitoring programme. Foreign materials refer to all those materials and substances used for constructing ONKALO that are not part of the disposal system. In 2009, 2010 and 2011, a total of 12, 21 and 51 applications, respectively, related to foreign materials or proposals for changing their earlier area of application were processed. The number of different foreign materials is on the increase, because the number of different activities and studies in ONKALO has also kept increasing.

The quantities of construction materials used in ONKALO have been monitored over the years. The records submitted by contractors allow calculating the usage of cement both for grouting and for shotcreting. The quantities of explosives, paints and different metal bolts used in construction work are also monitored. Systematic electronic accounting of the use of fuels, oils and lubricants began in 2010.

Development work on the methods used for analysing explosive residuals left on the rock surfaces of ONKALO after excavation began in 2011 using two techniques. During the first phase of the study, swab samples were taken from the rock walls of ONKALO. The second technique involved taking rock samples that were crushed and then, water-soluble nitrogen containing compounds were extracted from them for analysis. The solubility study of the Densiphalt cladding intended for paving the access route of ONKALO was initiated at the end of 2011 with the intention of producing more information on any factors possibly affecting the long-term safety of the material. The analysis results regarding explosive residues and Densiphalt investigations will be reported during 2012.

4.3 Development of Underground Openings construction

TKS-2009 defined the disposal system, and the Underground Openings production line was described as one of its parts. Underground Openings refer to all facilities excavated in the bedrock that are necessary for the disposal facility. The development work of underground construction activities carried out in connection with constructing ONKALO has been part of the TKS work concerning or related to Underground Openings during the TKS-2009 period now ending.

In addition to controlling the excavation operations, the construction of ONKALO and later the repository is associated with particular requirements concerning the grouting and reinforcement of bedrock, necessary for producing safe facilities. One essential part of the construction of ONKALO and accumulation of experience has been the excavation of tunnels demonstrating the deposition tunnel and the boring of test deposition holes. The experience gained from these has been utilised for producing a description of the initial state of the disposal system.

4.3.1 Planning and design of underground openings

Experience in the design of underground openings has been accumulated over a long period of time, involving various bedrock conditions. The design procedures have become established as ONKALO has been implemented. In the requirements concerning design work, particular emphasis has been placed on taking the safety-critical functions into account when planning the grouting, excavation and reinforcement work.

The procedures applied in ONKALO's implementation planning that were applied during 2010–2012, as the excavation of ONKALO continued at the disposal depth, are presented below. They will also be applied later when planning the construction of the repository.

Initial data

The initial data used for planning and designing the underground facilities is compiled from the following materials:
- bedrock model (interpreted structures and their properties, bedrock quality, state of stress, strength of rock),
- information obtained from pilot holes of the properties of bedrock to be excavated,
- information obtained from probe hole investigations of the properties of bedrock to be excavated,
- observations of the fracture and weakness zones (fracture orientation and density, weakness zones and their orientation, fracture fillings and fracture openings) made in geological mapping, and
- details of water inflow quantities entering the tunnel (measuring weirs).

A three-dimensional, detailed model will be produced of the bedrock sections covered by pilot holes to be used for RSC classification.

Grouting planning

Type plans have been produced on the basis of pilot hole observations and other available information, and these plans have been further specified on the basis of probe hole observations, tunnel mapping and water inflow measurements. For the sections covered by pilot holes, the zone model, water inflow forecast and assessment of suitability for grouting produced for the zone concerned have been utilised.

Excavation planning

Excavation planning has been done in cooperation between the rock-mechanical designer and the excavation site. The rock-mechanical designer has produced excavation designs on the basis of architectural drawings and modified the plans, when required, to accommodate the requirements set by the excavation equipment. The method descriptions related to the blast design and excavation were produced by the ONKALO contractor. The method descriptions and work plans produced by the contractor were inspected by Posiva before implementing them in order to ensure that the site personnel and the contractor are also taking into account the quality and safety requirements set by Posiva.

The excavation damage zone (EDZ) produced was also taken into account in planning the excavation work. The controllability of excavation work has been improved, and the results and conclusions of the earlier implemented project EDZ09 (Mustonen *et al.* 2010) have also been taken into account in planning work. In addition, development work performed in connection with excavating the demonstration tunnels has continued. New procedures have been introduced for the cut, spacing of contour holes and ways to use explosive types for the contour holes. This empirical experience has been used to determine the drilling patterns, explosives, detonators and charging principles to be used. All experience gained from excavation and its control has been applied to ONKALO and will later be applied to the repository.

The verification method for EDZs has also been developed on the basis of results from the above projects. The methods investigated include the observation of hole halves, ground-penetrating radar scanning, seismic measurement methods and ultrasonic methods, of which ground-penetrating radar scanning is the most appropriate one.

Rock reinforcement design

Rock reinforcements are divided into reinforcements during work (temporary) and final reinforcements. The initial data for planning reinforcement during work include the observations from probe holes, possible pilot hole observations, inspection by the shift supervisor before loading the round and the first phase of tunnel mapping, the so-called round mapping, as well as observations made during the work. The planning has been based on a reinforcement planning diagram called Q classification and on loose blocks observed in the tunnel. The preliminary planning of final reinforcement has been done on the basis of the rock models. The final reinforcement has been shown in reinforcement designs determining the probable reinforcement types for the design area and in type reinforcement designs containing the expected reinforcement alternatives for the planned tunnel section. The reinforcement design has sought to have reinforcement during work done directly to the final standard in sections where reinforcement is found to be necessary. The missing final reinforcement has been done for unreinforced parts and parts with temporary reinforcement after mapping.

The work phases of reinforcement during work were changed in 2011 so that each round is reinforced before blasting the next round. The earlier reinforcements during work have been inspected in connection with final reinforcement, including them as part of the final reinforcement where acceptable.

4.3.2 Grouting

The grouting materials are determined on the basis of long-term safety aspects forming part of the requirements as well as on the basis of the technical properties of materials. The material must be separately assessed, approved and instructions on its use given in order to assess its possible impacts on the disposal system with sufficient certainty.

The materials are selected when preparing for grouting work on the basis of technical properties and the fracture openings in the bedrock to be grouted. The approved materials include cement mortars with a low pH value and colloidal silica. Approved acceleration agents and additives required for controlling the gel formation time have been used in the grouting mixes.

The criteria for starting grouting have been established as a result of water loss measurements and Posiva flow-log measurements in probe holes. The designer uses the given limit values to be used as the criteria for starting grouting and for the selection of the grouting material. The instructions for and specification of the accectable water inflow quantities and their control were obtained from experts in long-term safety (Water Inflow Team WARVI).

For shaft grouting, the number and locations of required grouting holes and the phases of grouting work for different levels have been determined on the basis of investigation hole observations. The observations have been used as the basis for deciding the depth to which grouting has been extended in each phase. The leaking waters in tunnels have been primarily controlled by pre-grouting, and there has been no need for post-grouting. The information and experience available indicates that successful post-grouting is a more challenging task than pre-grouting.

Grouting work, tunnels and underground openings

Grouting work consists of the following work phases:
- drilling of probe holes,
- water inflow measurements,
- water sampling,
- water loss measurements, and
- Posiva flow-log measurements.

If the grouting criteria are met and grouting work is started, the work phases are
- boring of the grouting fan, drilling in the shafts,

- grouting,
- drilling of control holes, and
- water loss measurements in the control holes.

In ONKALO, the bedrock has been grouted in all locations where the measured water inflow quantities and rock quality have shown it to be necessary. The ONKALO facilities will be grouted, but grouting will be used sparingly, after due consideration, in the repository. Methods based on the use of cement mixes with a low pH value and colloidal silica have been developed for use in pre- and post-grouting. The necessity for grouting the repository will be re-assessed later from the point of view of design requirements and technical feasibility of the disposal system.

Alternative procedures, methods and materials for grouting the tunnels and shafts were tested during 2011–2012 at the disposal level and in the technical rooms. The suitability and functionality of the tested methods and materials have been verified for the purpose of ensuring that the capabilities required for grouting the repository are in place. The demonstrated capability includes experience of, among other things, the equipment to be used, the pressure conditions, implementation arrangements, materials and recipes, as well as inspecting the results of grouting. The grouting results have been compliant with the set targets, and water inflow volumes in ONKALO have been below the accectable limits.

4.3.3 Excavation

The access tunnel of ONKALO and its associated facilities have been excavated by drill and blast method. The shafts have been implemented using a down reaming method, by first boring a pilot hole in the middle of the shaft and then enlarging the shaft to its final size. The plan is to implement also the central tunnels leading to the repository and the actual deposition tunnels using the drill and blast method.

The drill and blast method is a well-known excavation method, commonly used in normal rock construction work above ground and under water as well as in tunnel excavation operations. During the TKS period now ending, particular attention has been paid in excavation work to controlling the excavation damage zone and the excavation accuracy. Posiva has found tried and tested solutions for excavation that can also be applied to excavating the central and deposition tunnels. The requirements set and the design solutions found determine the selection of equipment and the final application of the final implementation solution of each area to each set of bedrock conditions.

It has been found that in addition to deploying technology and equipment suitable for the requirements, the personnel must also be experienced, well-informed and motivated. All work methods to be applied must be described and tested, and all personnel must have uniform operational routines. Demonstration of the validity of work (testing and inspection plans, quality records) must be comprehensively documented and all information (plans and as built-details) stored in a manner that allows them to be traced later.

Methods for controlling the excavation-induced damage zone have been developed in order to reduce the size of the EDZ and its impact. The following matters have been further tested when applying the knowledge gained from development projects:

- produced damage zone in relation to the requirements,
- measuring the damage zone,
- drilling accuracy and its management,
- equipment-induced restrictions (e.g. with regard to look-out angle),
- comparisons regarding the use of emulsion explosives and cartridge-packed explosives,
- testing electronic detonators, and
- a practical and verified testing method for verifying the properties and impacts of excavation damage.

The experience gained from excavating ONKALO and the information gathered from other sources, such as the Äspö HRL, have shown that there have been no problems with the boring and charging method at any stage, and it does not have any significant adverse effects on long-term safety that would prevent the use of the drill and blast method for excavating the deposition tunnels.

4.3.4 Demonstration tunnels

The implementation extent of ONKALO includes testing and demonstration facilities (Figure 4-26), mainly designed using the dimensions and requirements applicable to deposition tunnels. The tunnel profile has been slightly altered from that of the deposition tunnel (the wall is higher and the ceiling arc lower) in order to accommodate the deposition hole boring device in these tunnels. At this stage of the hole boring device development work, the additional height at the top corners of the tunnels was deemed necessary. The plans for the two demonstration tunnels were produced during 2010, and the tunnels were excavated during 2011 and 2012. The RSC method was also tested in the design, layout and excavation of the tunnels.

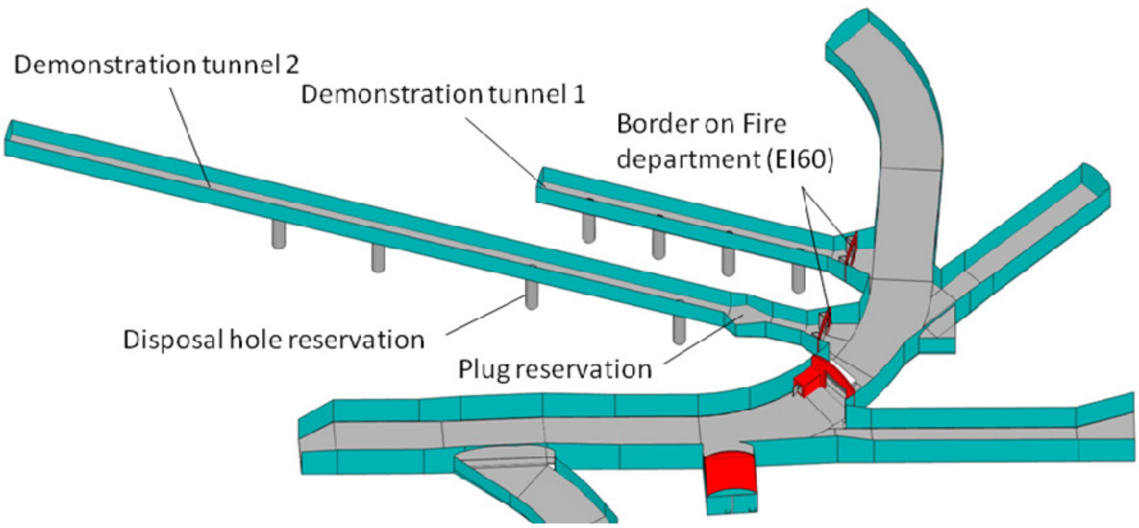

Figure 4-26. *Test and demonstration tunnels in ONKALO at the approximate level of -420 m.*

The demonstration tunnels had a design length of 80 metres. When demonstration tunnel 1 was being excavated, penetration of the water-conducting fracture zone identified in investigation drilling was to be avoided. The tunnel was implemented at a length of 52 metres, and four test deposition holes had been bored in it by spring 2012. The holes were bored using a purpose-built boring device that will be further developed into a deposition hole boring device (Figure 6-12). The holes can be used for subsequent tests and studies.

The other demonstration tunnel was implemented at a length of 105 metres, allowing the sealing of a water-conductive zone to be tested during the excavation work using colloidal silica for grouting. The use of silica for grouting has some scope for further development work, but the results of trial grouting were so promising that silica grouting has subsequently also been successfully used for pre-grouting of the access tunnel.

Steel mesh and bolting were used for reinforcement in the demonstration tunnels. This also allows subsequent visual inspections of the bedrock surface and closer monitoring of any deformations taking place in the bedrock. In addition, this method can be used to further reduce the amount of concrete used in the repository. The used reinforced method can also be applied to other underground openings.

4.3.5 Boring of deposition holes

Both SKB and Posiva have previously tested the boring of deposition holes. The first test was carried out during 1994–1995 in a research tunnel in Olkiluoto's VLJ repository where three 7.5-metre long holes with a nominal diameter of 1,527 mm were bored (Autio & Kirkkomäki 1996). The technique used was the Down Reaming Method (DRM) (Figure 4-27). During 2010–2012, the deposition hole boring technology was developed by designing and procuring a hole boring device. The boring device was used for boring four full-scale deposition holes (for OL1-2 fuel canisters) in the demonstration tunnel. The work was based on the results of the boring operation commissioned by TVO in the VLJ repository, on the test boring operations carried out in the Äspö laboratory and on the preliminary investigations commissioned by SKB. The requirements set by the buffer on the hole were determined and taken into account when developing the equipment and when practising the hole boring operation. The requirements concern the straightness of the hole, the smoothness and integrity of its surface, as well as the shape, evenness and straightness of the bottom.

After the tunnel sections suitable for holes had been selected (the RSC method) and the suitability assessment was given to designer who designed the hole places, an investigation hole was bored and a validation assessment was issued regarding the suitability of the location. After the successful investigation hole phase, the actual pilot hole was drilled and the canister hole was enlarged to its final size by down reaming. The rock material crushed by the cutters and the rinsing water used for the boring were removed from the borehole by suction through the bore pipe as the work advanced.

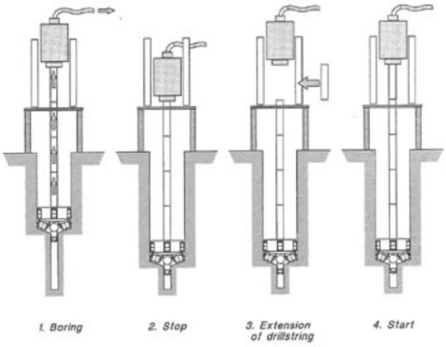

Figure 4-27. *Test boring of deposition holes in Olkiluoto using the DRM technique (Autio & Kirkkomäki 1996).*

The accuracy requirements of the boring operation regarding the straightness of the hole and variation of its diameter, etc., were met, but the boring speed was slower than expected. The boring speed was not found to be a critical factor during the testing phase, so the decision was taken to continue the related development work later. Meeting the requirements set for the deposition hole is very important, because the shape and dimensions of the hole are important for implementing a buffer compliant with the requirements (Figure 4-28). While the efficiency of equipment is improving, compliance with the requirements set for the deposition hole will also be ensured.

The project concerning the hole boring device and the boring operation (KapRe) analysed and developed the following matters:

- Optimisation of the drilling slurry rinsing system.
- Design of the reaming head and the number, layout, shape, etc., of cutters for ensuring that the desired shape of the hole bottom is achieved and other geometrical requirements of the hole are met.
- The rock suitability classification is in close interaction with the deposition hole boring operation.
- Construction of the boring device prototype.
- Tests outside ONKALO and in the test facilities in ONKALO.

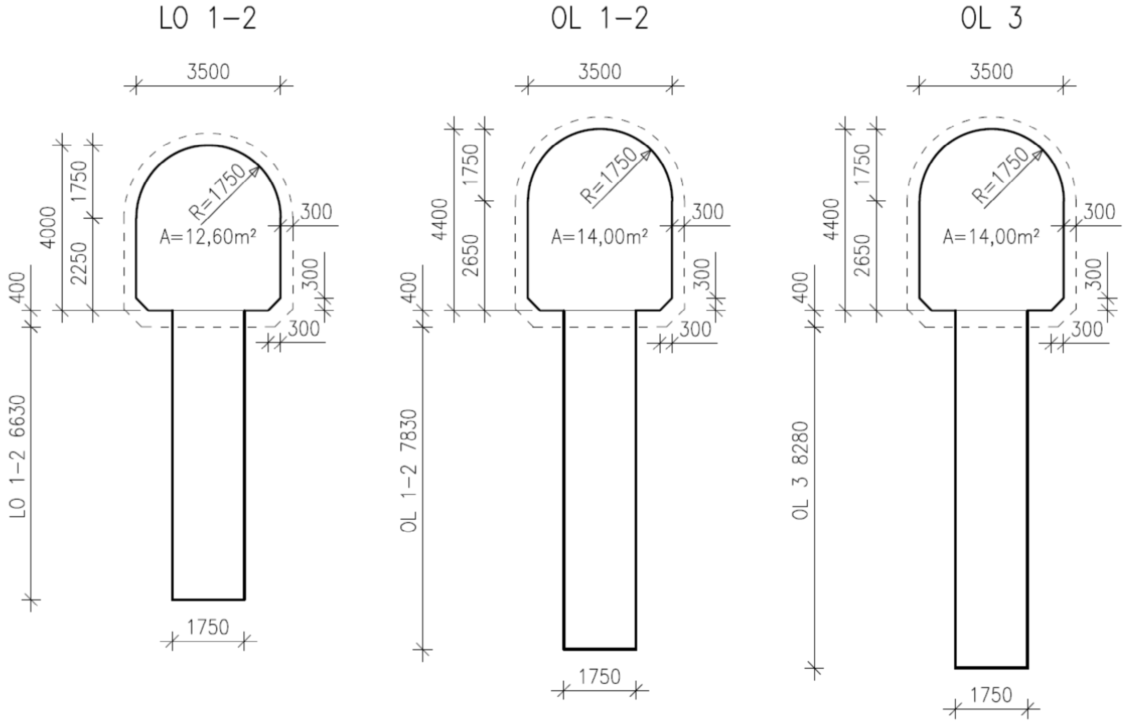

Figure 4-28. *Main dimensions of the deposition tunnels and holes (without chamfers) for different canister types (Saanio et al. 2012).*

4.3.6 Rock reinforcement

Rock reinforcements are made, as required, in all repository facilities. When making reinforcements in ONKALO, the practices and requirements regarding reinforcement were further specified, with particular focus on so-called temporary shotcreting and the relationship between immediate and final reinforcement and their implementation by better matching their pace with that of the blasting work.

Immediate and final reinforcement

The bolt type previously used for immediate reinforcement in ONKALO was a CT bolt shown in Figure 4-29, made of stainless or galvanised steel. In the bolt types used in ONKALO, the plastic tube shown in the figure has been replaced with a steel tube. After grouting, the stainless steel CT bolt serves as final reinforcement. Stainless steel bolts have been and will be installed in connection with final reinforcement next to the galvanised CT bolts previously used. Like other final reinforcement bolts, these are strain bolts of the wedge type with bolt plates or ribbed bar bolts without bolt plates. Following the development work undertaken during 2010–2011, a new type of expanding bolt (Fin-Bolt) has been introduced for reinforcement use. These bolts are also made of stainless steel.

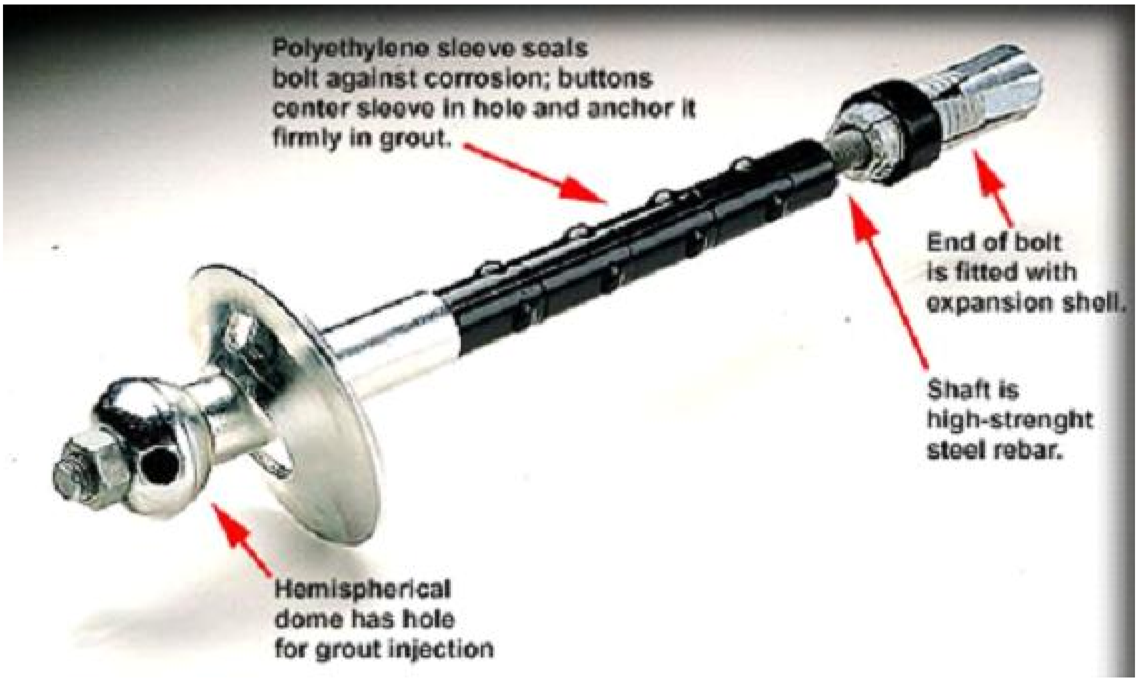

Figure 4-29. *CT bolt.*

When required, shotcreting with or without steel fibres has been used, as well as wire mesh reinforcement. When the results of immediate shotcreting have met the validation test requirements, it has been approved as final reinforcement. Otherwise, it has been supplemented with final reinforcement.

Final reinforcement uses either shotcreting or wire mesh reinforcement in case the rock surface must be left visible; for example, due to research-related reasons. The steel fibres in the fibre-reinforced shotcrete are made of stainless steel.

Installation and dismantling of rock reinforcements

Reinforcement of the bedrock using bolts or shotcreting are well-known techniques. On the other hand, the scope for development has been mainly identified in installation techniques and its pacing with other work. Problems related to shotcreting have been encountered at times with regard to how its initial strength develops, which is why Posiva has developed and tested new shotcreting mixes that significantly improve the early development of strength and therefore speed up the process of bringing the facilities to a safe state. The dismantling of reinforcement has not been tested in ONKALO yet.

4.4 Design of the necessary nuclear facilities

4.4.1 Plant complex

Posiva's plant complex consists of two nuclear waste facilities compliant with the relevant Government decree (736/2008). They are the encapsulation plant and the disposal facility. In the encapsulation plant, the spent nuclear fuel is encapsulated into disposal canisters. In line with a decision done by Posiva, the encapsulation plant is to be located above the disposal facility, in an area managed by Posiva. In the current reference design, a canister shaft connects the encapsulation plant and the disposal facility.

The canisters are transferred from the encapsulation plant to the disposal facility that comprises of underground repository facilities, central tunnels connecting them, an access tunnel, a number of shafts and other underground auxiliary and technical rooms. The disposal facility also includes a repository for low-and intermediate-level waste that is mainly generated in the operation and decommissioning of the encapsulation plant. In addition, the disposal facility has auxiliary facilities above ground, such as the ventilation building and hoist building. The current reference design (Palomäki & Ristimäki 2012) is based on the status of design work in 2012.

4.4.2 Design of the encapsulation plant

The encapsulation plant comprises the building built for encapsulating spent fuel. The most recent plan for the encapsulation plant was presented in the plan report of the main drawing phase (Kukkola 2012). Figure 4-30 shows a cross-section of the encapsulation plant along the canister transfer corridor.

In line with a decision made by Posiva in 2010, the encapsulation plant will be connected to the disposal facility in an area managed by Posiva in Olkiluoto. This location has been Posiva's reference design for the location for a long time. According to the current plan, the disposal canisters will be moved from the encapsulation plant to the disposal facility using a canister lift. This decision means that the entire encapsulation and disposal operations are closely concentrated in one plant area.

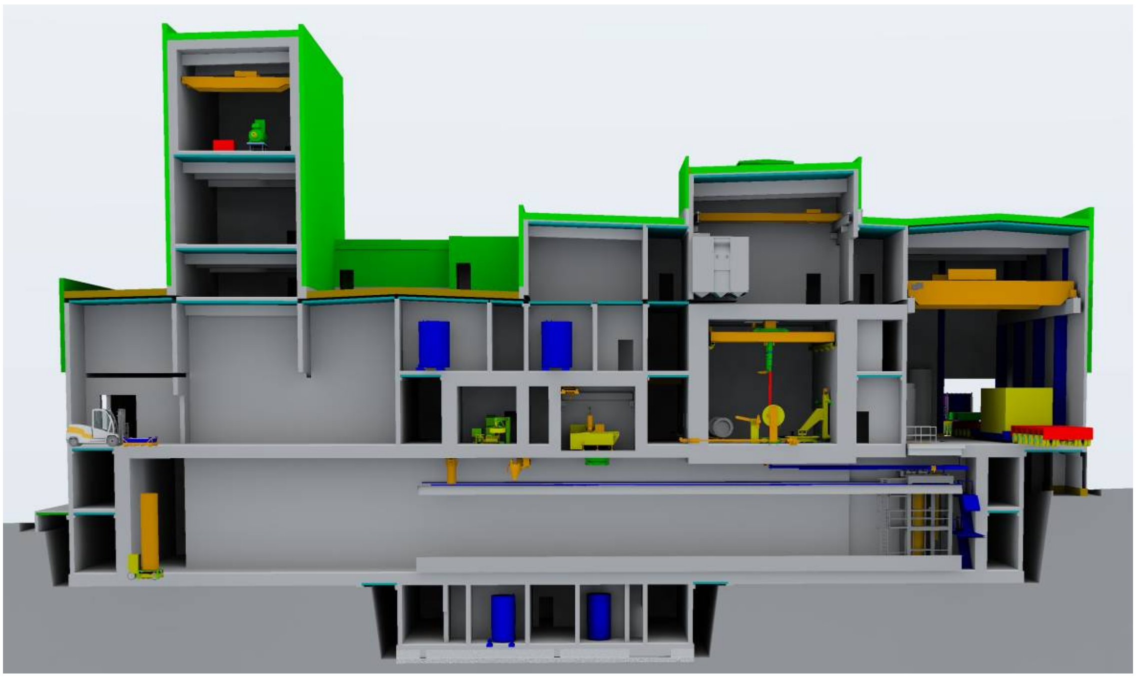

Figure 4-30. *Cross-section of the encapsulation plant.*

The design work for the systems and equipment related to the encapsulation process has advanced as planned, and the more closely specified plans have had some minor impacts on the plant layout. The most significant updates of the system plans have concerned the design of the canister transfer trolley and other equipment in the canister transfer corridor (Suikki 2011), the design of the fuel transfer mechanism and the fuel handling cell (Suikki 2012a), as well as the design of the canister transfer fork-lift truck (previously the AGV) (Suikki 2012b).

In addition, the principal electrical plan for the encapsulation plant (Tuominen 2012) and the principal plan for the ventilation system (Nieminen 2012) have been updated. The updated plans have improved the operation of safety-critical systems (ventilation, removal of decay heat) in any transient situations. The single-failure tolerance of the above systems has been improved by placing the different redundant subsystems of the main systems into different fire compartments. The power supply of the systems has also been designed so that the encapsulation plant has two redundant power supply networks for safety-critical systems. Both subsystems also have their own emergency power generator.

The design work for equipment in the canister transfer corridor has involved development of the plan for the canister transfer trolley, designing the device for measuring and cleaning contamination at the top of the canister and further definition of the plan for the canister top machining station (Suikki 2011).

The design work for the fuel transfer mechanism involved an analysis of the plan for the maintenance manipulator in the mechanism and its operation in different transit situations. Furthermore, particular attention was paid to the ease of service and maintenance of the entire handling cell. A material hatch was designed in the wall of the handling cell, through which spare parts and other accessories can be transferred to the cell when it cannot be entered without a decontamination treatment. Two fuel assembly measurement stations have also been added on the floor of the handling cell. They allow fuel verification measurements to be made, for example, for the purpose of nuclear material safeguards (Suikki 2012a). Figure 4-31 illustrates equipment in the fuel handling cell.

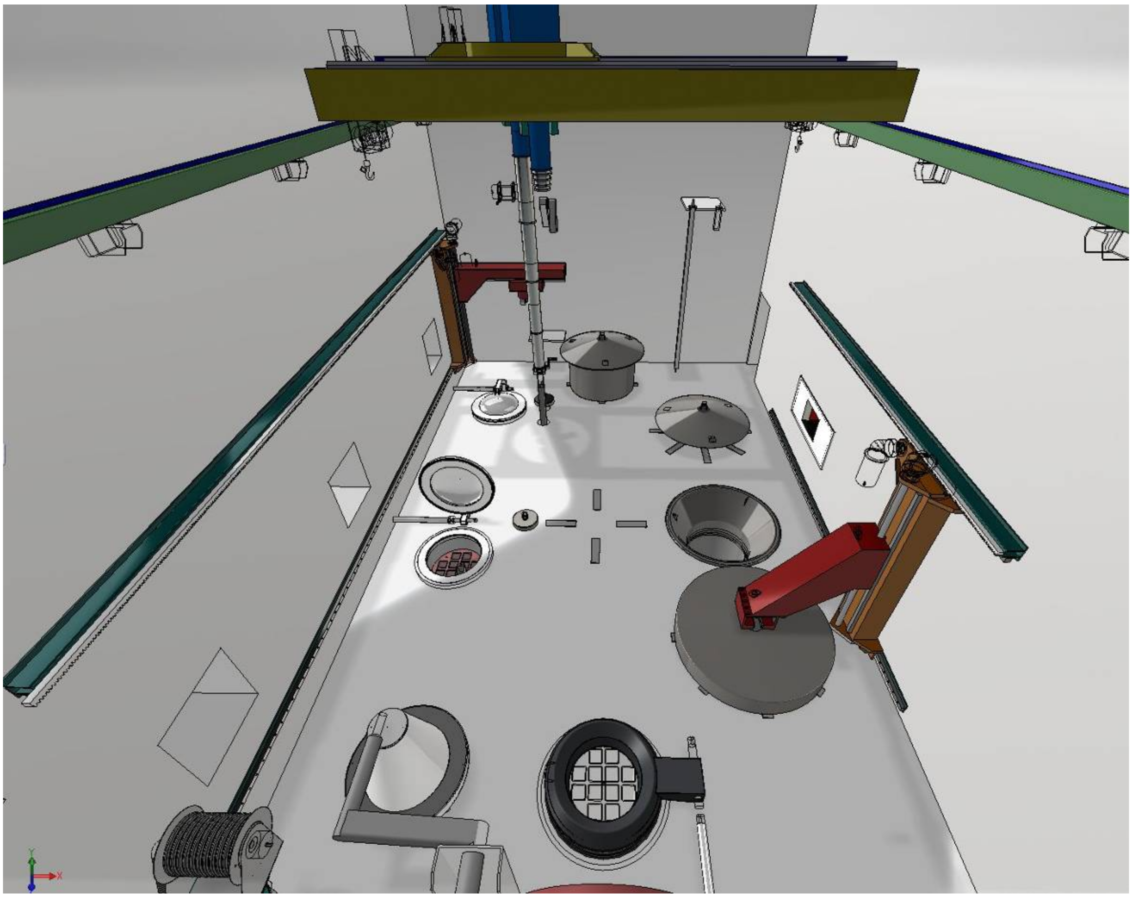

Figure 4-31. *Fuel handling cell.*

The entire transfer concept was re-analysed in connection with updating the plan for the remote controlled mover for disposal canister transfer. The previous plan dates back to 2003. The analysis indicated that the concept of the earlier plan would be very difficult to make large enough for the required lifting and transfer capacity. The updated plan is based on a commercially available mover on wheels. Due to the height of its power unit, the mover in the updated plan can no longer travel under the canister, which is why layout modifications were made to the encapsulation plant in order to make it easier to clear any transient situations.

The construction plans and structural plans of the encapsulation plant have been updated to the standard required for the construction licence application. The construction-technical dimensions and a structural model taking into account the required loads have been produced for the encapsulation plant. A fire plan has also been produced for the plant as part of the licensing material.

4.4.3 Design of the disposal facility

The disposal facility consists of the repository facilities for spent fuel, the central tunnels connecting them, other technical underground facilities, repository for low- and intermediate-level waste, vertical shafts and the access tunnel, as well as the auxiliary facilities above ground directly serving the operation of the disposal facility, such as the building for tunnel technology, the ventilation building and the hoist building. The most recent plan for the disposal facility was presented in the design report of the main drawing phase (Saarnio *et al.* 2012).

4.4.3.1 Repository facilities

The repository facilities consist of deposition tunnels and deposition holes bored in their floors. The intention is to make the deposition tunnels with the smallest cross-section possible in order to keep the amount of backfill material required for them as small as possible, to minimise the disturbance caused by the excavation work, and to have the minimum amount of facilities open at any one time.

The repository facilities can be laid out in the available disposal area in countless different ways. When the information on the bedrock (including the bedrock volume suitable for disposal purposes determined on the basis of RSC, the estimated degree of availability of the bedrock, and orientation of the state of stress) and other design bases of disposal operations, such as temperature-based dimensioning, are taken into account, comparison of the different layout alternatives allows finding the most favourable layout alternative for the entire complex and forming a better understanding of the total volume of all required facilities. The layout will be finally completed in stages as the disposal operations advance and more detailed information on the bedrock becomes available. The facilities will be constructed in phases, and the layout will be reviewed before the implementation of each phase using the most recent available information. The current layout of the facilities and their implementation in stages are presented in a separate plan (Kirkkomäki 2012). Figure 4-32 shows the layout plan for the repository facilities at the disposal depth, based on current research data. The plan takes into account the current confirmed local plan that permits final disposal in the area shown.

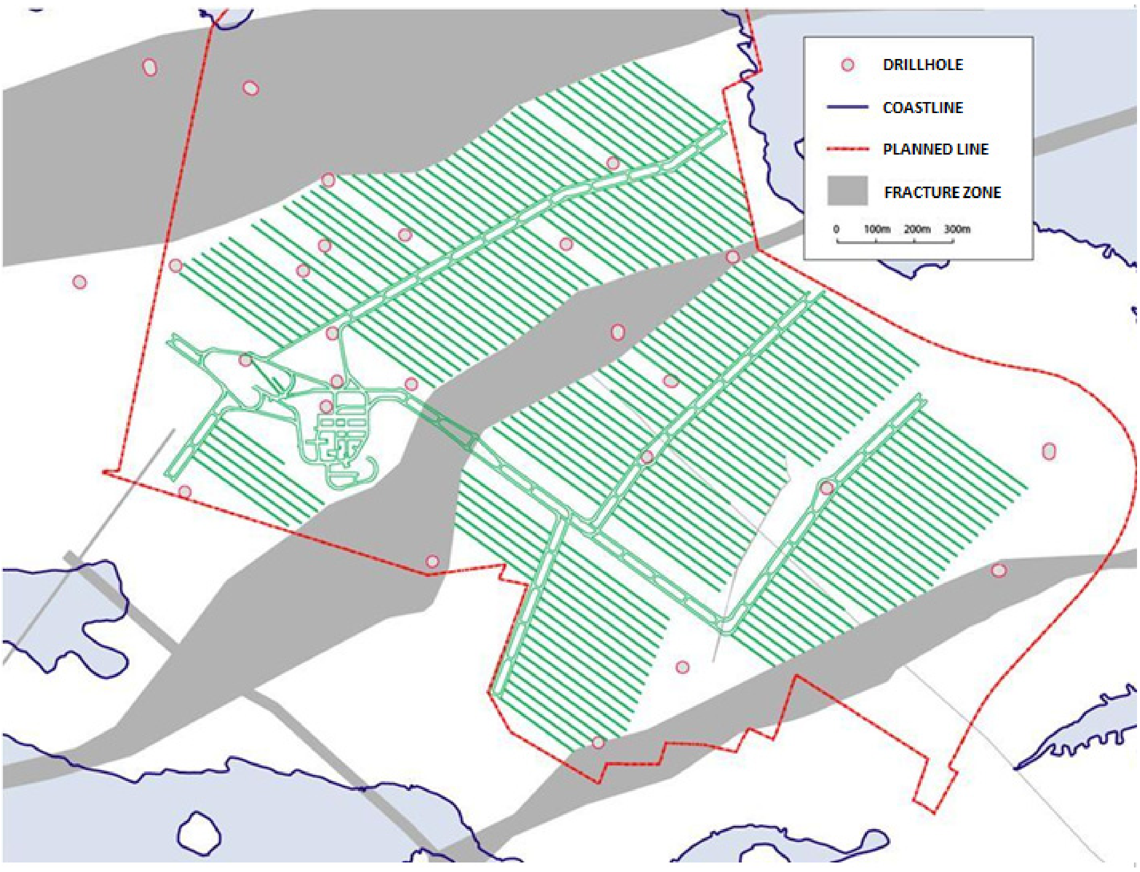

Figure 4-32. *The figure shows the layout plan, based on currently available bedrock information, for the fuel quantity to be shown in the construction licence application (9,000 tU) in the currently valid local area plan.*

The following systems will be constructed, installed and used in the disposal facility: the ventilation system, heating system, water supply system, water inflow system, electrical systems, monitoring measurement systems, as well as the transfer and transport systems. The plan regarding the systems has been compiled in the design for the disposal facility (Saanio et al. 2012).

Due to the long operating period of the disposal facility, the repository facilities will be constructed and closed in phases. During the operating phase of the disposal facility, deposition tunnels will be excavated, canisters disposed of and deposition tunnels backfilled, partly simultaneously. During the operating phase, the disposal facility is for radiation protection purposes divided into a controlled area and an uncontrolled area in order to control the movements of personnel and to measure the external radiation doses absorbed by employees. It is assumed that the disposal facility will be free of any contamination. The separation of the controlled area will also make nuclear non-proliferation control easier and simpler. In the central tunnels, the boundary between these areas is also the same as the boundary between fire compartments. The air conditioning system of the controlled area will be separated from that of the uncontrolled area to prevent any dust and explosion gases generated in the excavation area from entering the controlled area. The boundary of the controlled area will be moved with the progress of the disposal process. During tunnel excavation work, the deposition tunnels are part of the uncontrolled area. The tunnels are annexed to the controlled area before canister installations begin. When canisters have been inserted in the deposition holes and the holes have been packed with bentonite buffer blocks, the tunnel is again annexed to the uncontrolled area for backfilling the tunnel. The tunnels can also be backfilled in stages, such as in sections containing one or four canisters at a time. In such a case, the boundary of the controlled area will also be moved more frequently.

4.4.3.2 Other underground facilities

In addition to the repository facilities described above, the disposal facility also includes other underground facilities. They include the central tunnels, auxiliary and technical rooms as well as the access tunnel and shafts providing connections to above ground.

The research facility ONKALO has been designed and implemented in such a manner that it can later be used as part of the disposal facility. The connections from ONKALO to above ground have been dimensioned so that they will also serve the disposal facility. The dimensions of the access tunnel will also allow different transport operations to be carried out in a flexible manner during the operating phase. The work methods and materials employed in the construction of ONKALO have been selected so as to ensure compliance with the requirements set out for the disposal facility.

After the construction licence has been granted for the disposal facility, ONKALO can be expanded into a full-scale disposal facility by constructing a canister shaft, exhaust air shaft 2 and the central tunnel and deposition tunnel sections required for the first phase. Part of the auxiliary and technical rooms of the controlled area have already been excavated in connection with ONKALO excavations, but the construction work and system installations will be carried out during the construction phase of the disposal facility.

In the 2012 facility design, a canister storage for completed disposal canisters has been added in connection with the technical rooms, near the bottom of the canister shaft. (Figure 4-33). The facility can accommodate 30 canisters. This canister storage is required so that the installation of canisters in the deposition tunnels and closure of the tunnel could be carried out as quickly as possible, thus reducing the impact of water seeping in the bentonite contained in the tunnel before its closure. The canisters for one whole deposition tunnel can be completed and stored in the storage facilities above ground and underground before starting their installation, thus eliminating the impact of any transients in the encapsulating process on the disposal operation.

The repository for low- and intermediate-level waste generated in the encapsulation plant is currently planned at the approximate level of -180 m by the access tunnel (Saanio *et al.* 2012). The safety of this facility and its impacts on the spent fuel repository have been investigated (Nummi et al. 2012), and the results of these investigations will be appended to the construction licence application material.

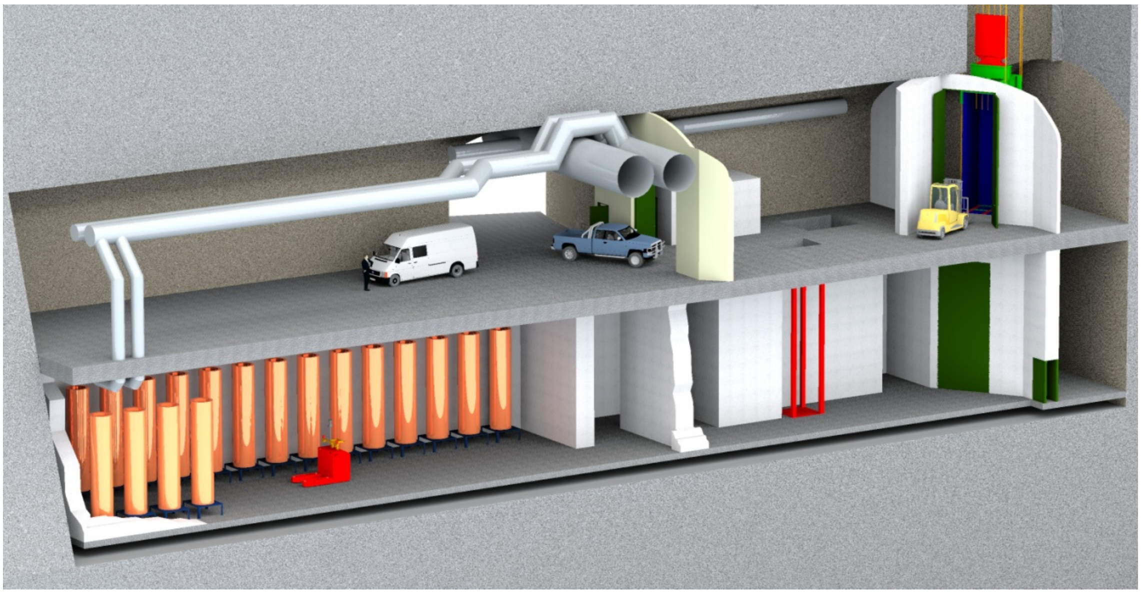

__Figure 4-33.__ Underground canister storage for disposal canisters.

4.4.3.3 Parts of the disposal facility located above ground

The disposal facility also includes parts above ground. They support the operation of the underground disposal facility. The most important building above ground is the ventilation building that will be used to ventilate the entire underground part of the disposal facility. The inlet and exhaust air units are located in the ventilation building. The first phase of the ventilation building was implemented as part of the implementation phase of ONKALO so that it can already be utilised during the operating phase of ONKALO when its ventilation installations intended for the excavation phase are dismantled. The second phase of the ventilation building will be implemented after the construction licence for the disposal facility has been granted. The second exhaust air shaft will also be implemented at that stage.

Other disposal facility parts above ground include the hoist building and the building for tunnel technology. The hoist building is located above the personnel shaft and houses the personnel hoist. The hoist building will be the entrance building to the Posiva's entire facility complex.

The building for tunnel technology has already been implemented and commissioned. It is used as the equipment and control room of systems already implemented in ONKALO. Later on, the final equipment and control facilities for the disposal facility systems will be fitted in the hoist building. At that time, the building for tunnel technology will become the backup control and monitoring facility for these systems. The intention is to concentrate the entire monitoring function of Posiva's plant complex in the hoist building, so that the operations of both the disposal facility and the encapsulation plant can be monitored from there. In addition, access control will be centralised in the hoist building. The systems related to nuclear facilities (the encapsulation plant and the disposal facility) will only be installed in the hoist building once the construction licence has been granted.

4.4.4 Installation and transfer techniques

4.4.4.1 Canister lift

According to the reference design, the disposal canister is transferred from the encapsulation plant to the disposal facility in a canister lift. The canister lift drive is a friction hoist equipped with a counterweight. The lift will be dimensioned for a payload of 30 000 kg, and its speed will be 3 m/s. According to the preliminary plans, the lift cage will be supported by six steel cables with a diameter of 35 mm each. The lift cage moves along rope guides, one in each corner. In addition, there will be two wire guides for the counterweight.

The canister will travel in the lift without any radiation shields. Direct radiation from the canister in the lift will be prevented by labyrinth structures placed at the access openings to the lift shaft. The load-bearing parts of the lift must have doubled mechanical backup arrangements up to the wire rope reel shaft. This means the chances of a canister falling into the shaft as a result of a single failure are insignificant. Furthermore, the shaft bottom has a shock absorber for the eventuality of an accident where the canister falls down. During the preceding TKS period, analyses and small-scale tests using VTT's Impact equipment were performed regarding the shock absorber solution (Kuutti *et al.* 2012). The LECA gravel foreseen as shock absorber material has been modelled, and the collision of the canister with the shock absorber has been simulated using the models. The modelling results could be compared with the test results of the Impact device, thus allowing the model to be verified. The results of the analysis indicate that the planned shock absorber can be implemented and that there is a sufficient certainty that the load exerted on the canister at impact will not exceed the design basis parameters of the canister. In further planning work, the effect of the type of LECA gravel on its shock absorbing properties will be investigated to allow the detailed design of the shock absorber to be finalised.

4.4.4.2 Buffer installation device

The conceptual development and design work for the buffer installation device prototype has been carried out during 2011–2012 as part of the LUCOEX project under the 7th Framework Programme of the EU. In addition to Posiva, SKB, Andra and Nagra are also participating in the project. Each participant is developing its own disposal solution in the project.

An alternative with separate devices for installation and transport of the blocks was chosen as the subject for further development work. The buffer block installation begins with placing the installation device above the deposition hole. The buffer blocks are transported to the installation device by a separate transport device in a closed transport container. The plans for manufacturing the prototype were completed in early 2012, and the manufacturing began in the summer of 2012. The prototype device (Figure 4-34) will be ready for tests in early 2013. After the manufacturing phase, the first trial operation tests will be conducted at the manufacturer's premises. Adjustments to the operation of the device and the first actual tests will commence in early 2013. The tests will first be conducted using blocks made of concrete, to be followed by tests with full-scale bentonite blocks during 2013.

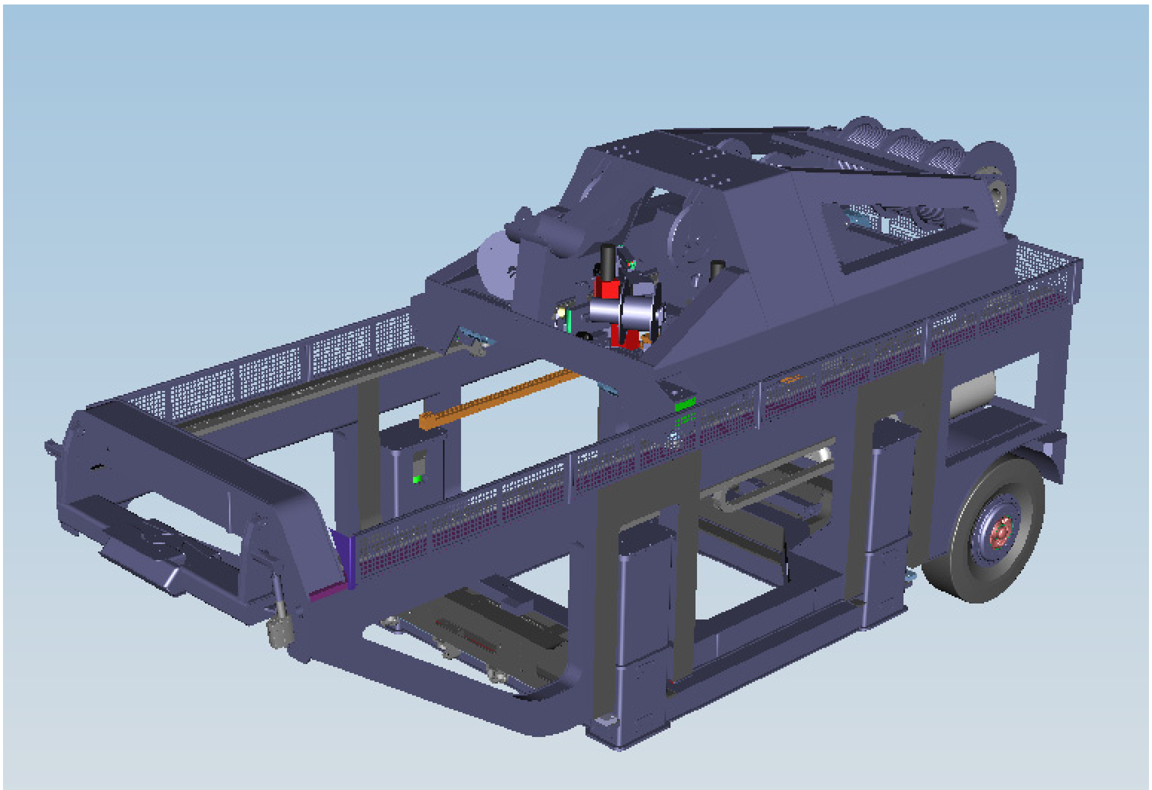

Figure 4-34. *Prototype of the buffer block installation device.*

4.4.4.3 Canister transfer and installation device

Implementation plans have been produced for the canister transfer and installation device prototype (Figure 4-35), and manufacture of the device was begun in 2012. The plan is to start testing the device in spring 2013. The development and design work as well as manufacture of the prototype is divided into two phases so that the first phase will concentrate on ensuring the operability of devices critical to nuclear safety. These include the canister handling equipment and the adjustment mechanisms related to the process of lowering the canister into the hole, aimed at achieving tight installation tolerances between the canister and buffer bentonite. The items to be developed during the second phase include the running gear solutions for the device.

The installation device concept has evolved from an installation vehicle prototype to an installation cart. The starting position is that a dedicated installation device will be developed for each canister type, optimised for the length of the canister, and that all these devices can be moved about using the same tractor. The concept is similar to the transport cask transfer systems currently used at power plants. The prototype now developed was dimensioned with the OL1-2 disposal canisters in mind. Most of the canister handling mechanisms are hydraulically activated.

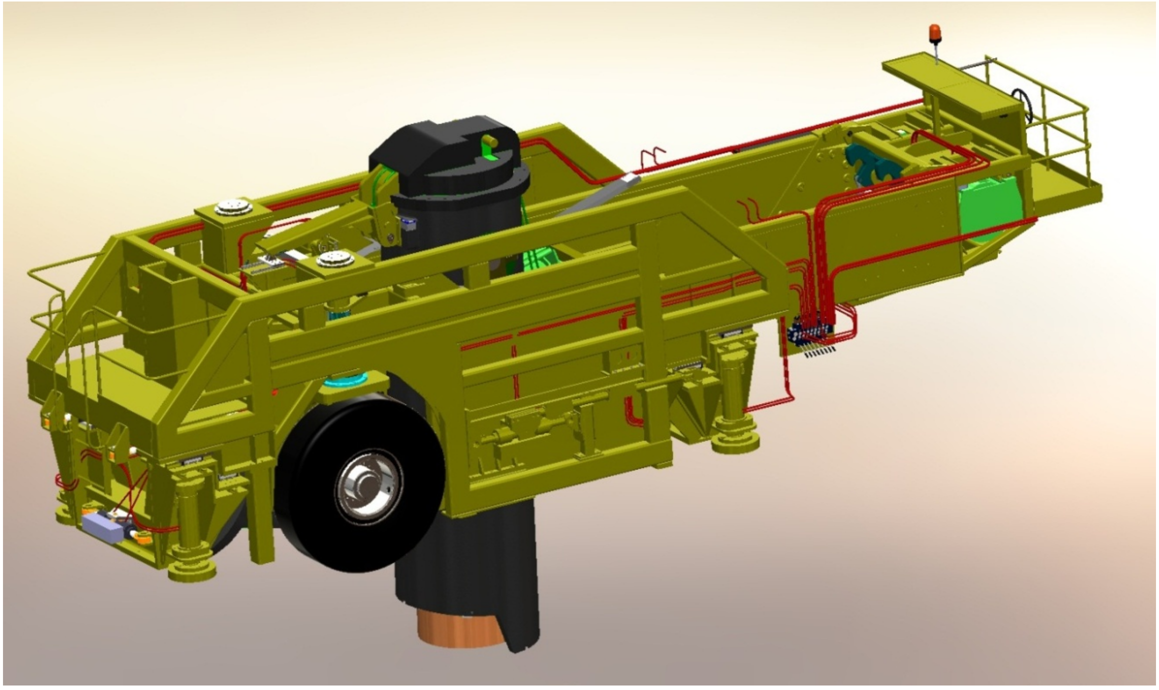

Figure 4-35. *Prototype of the canister installation device.*

4.4.5 Nuclear waste management at the encapsulation plant

4.4.5.1 Technical solutions

A description of the plans for the technical rooms of the disposal facility and the repository for low- and intermediate-level operational waste (Kirkkomäki 2009) and an estimate of waste volumes generated in the encapsulation plant (Kukkola & Eurajoki 2009) were both produced in 2009. The nuclear waste management solutions of the encapsulating plant and the solutions related to the disposal of low- and intermediate-level operational waste have been further defined during the TKS-2009 period. An investigation into decommissioning of the encapsulation plant was also initiated.

Solidification into concrete had been preliminarily agreed as the method for treating liquid waste, and the intention was to dispose of the concrete packages in a concrete tub in a manner similar to that used in the solidified waste facility of the Loviisa NPP (Kukkola & Eurajoki 2009). According to preliminary plans, the repository for nuclear waste generated in the encapsulation plant will be located by the access tunnel, at an approximate depth of -180 metres. The layout planned for the repository facility is shown in Figure 4-36.

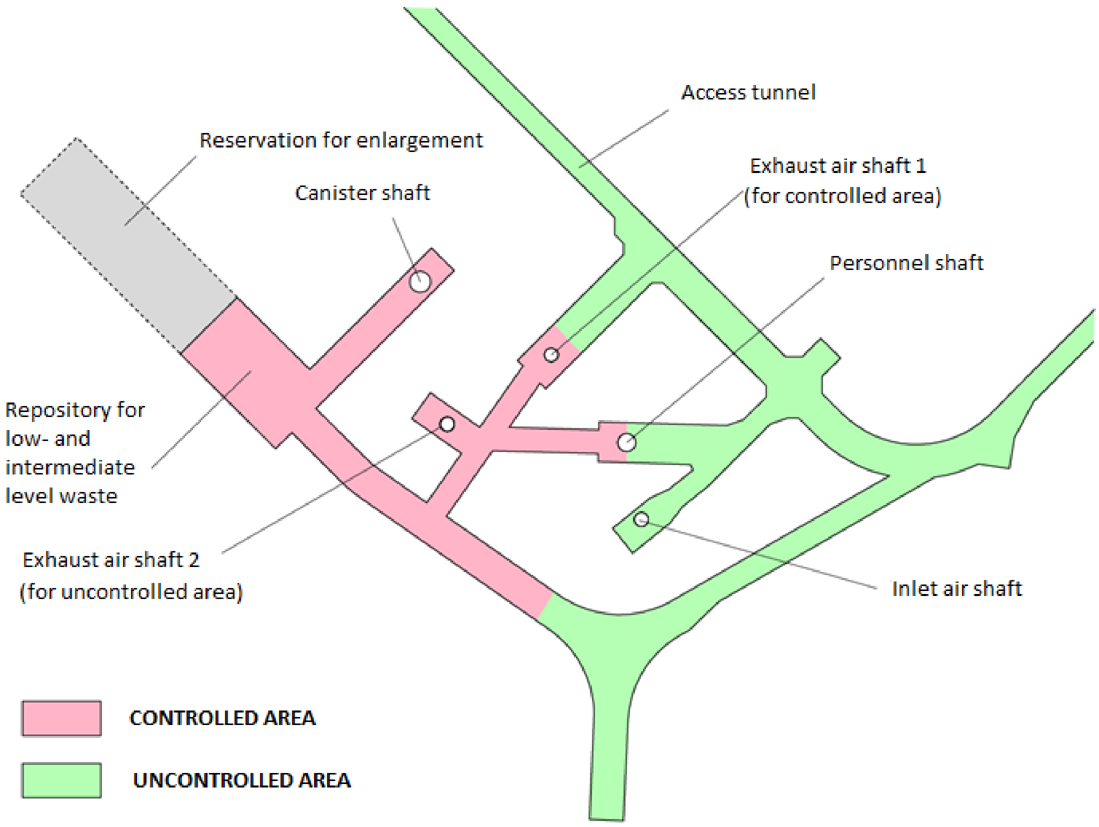

Figure 4-36. *Layout of the repository facility for low- and intermediate-level operational waste (Saanio et al. 2012).*

The use of concrete in ONKALO has been found to be problematic, because the elution waters from cement may interact, with adverse results, with the bentonite buffer in the repository and with the clay-based tunnel backfill materials (*Performance Assessment*). This is why investigations were initiated for finding alternative solidification methods for the accumulating nuclear waste as well as an alternative solution that uses less concrete. At the same time, the estimate regarding the total amount of waste to be disposed of in the facility and the inventory of radioactive substances were further defined (Paunonen *et al.* 2012). Drying of liquid waste in barrels was chosen as the alternative waste processing method. A smaller concrete trough was designed for the intermediate-level waste barrels; it will be sealed by casting when the repository facility for low- and intermediate-level waste is closed down. This allows the amount of concrete in the facility to be significantly reduced, which will also reduce the risk of adverse interactions with the final disposal of spent nuclear fuel.

The space reservation for the facility will still allow the operational waste during independent commissioning phase and decommissioning waste coming from TVO's KPA storage to be finally disposed of here. However, it has been decided that the concrete waste generated in connection with decommissioning the low- and intermediate-level waste will not be finally disposed of in Posiva's underground facilities.

4.4.5.2 Long-term safety

The first safety analysis regarding the low- and intermediate-level waste accumulating during the operation of the encapsulation plant was produced in 2012 (Nummi et al. 2012). The main purpose of the analysis was to show that the radioactive waste accumulating during the operation of the encapsulation plant can be finally disposed of in accordance with the solution suggested by Paunonen et al. (2012) in the planned location along the access tunnel so that the requirements of authorities are complied with. The analysis results indicate that the low- and intermediate-level waste accumulating during the operation of the encapsulation plant can be disposed of adjacent to the repository for spent nuclear fuel.

4.5 Research, development and planning work regarding the engineered barrier system

The engineered barrier system includes the disposal canister, the bentonite buffer surrounding the canister, the backfill and the deposition tunnel end plug, as well as the backfill and end plugs of other underground facilities, i.e. the central tunnels, access tunnel, shafts, underground auxiliary facilities and investigation boreholes.

During the preceding TKS period, the research, development and planning work regarding the engineered barrier system has been aimed at defining the requirements for the engineered barrier system, at producing detailed plans compliant with the plans, for demonstrating compliance and for planning the implementation by defining a production line for each barrier. This work is described in the production line reports issued separately for each barrier, and a so-called initial state has been defined for each barrier on the basis of this work. The initial state has been used in the safety case documentation as the presumed initial state of the barrier in the base scenario.

During the preceding TKS period, the bentonite buffer has been the focus of both technical development work and performance investigations regarding the disposal system. The buffer development work has concentrated on the detailed planning and design of the solution to be implemented as well as on the development and testing of buffer block manufacturing and installation techniques. The research, development and planning work for the buffer has been coordinated within the framework of the BENTO programme during the preceding TKS period. After Posiva defined during the preceding TKS period the main tasks included in the disposal project as activities to be coordinated in a process, coordination of the TKS work for the buffer and the backfill was transferred to the Engineered Barrier System process. Since then, the research work related to the long-term behaviour of the buffer and backfill materials has been defined as belonging to the Safety Case process, and they are described in section 4.6.

4.5.1 Disposal canister and the related production line

In terms of safety, the canister is the most important engineered barrier of the KBS-3 disposal concept. The safety function of the canister is to ensure the long-term isolation of spent fuel by containing it, packed inside a leak-tight container, and to limit the spreading of radioactive substances outside the canister even in possible transient or exceptional conditions. The setting of requirements for the canister, design of the canister and manufacturing demonstrations have already been subjects of development and testing work for a long time, which is why there are very few open issues left concerning the canister design and the production line.

Canister requirements and design

The requirements concerning disposal and the canister, aimed at ensuring long-term safety, are presented in the *Design Basis* report. The requirements have been taken into account in the canister design report (Raiko 2012) and in the *Canister Production Line report*. In addition to long-term safety, many other factors are also taken into account in the design, such as requirements related to manufacture, sealing, inspection and installation. All requirements have been taken into account and matched with each other in the above design report, which also presents the results of analyses demonstrating compliance with the requirements.

In terms of dimensions and shape, the disposal canister must be such that the spent nuclear fuel assemblies, with their possibly slightly altered dimensions and shapes due to use, fit inside it and can be easily inserted.

The canister design report was supplemented during 2012 so that it does not contain any significant deficiencies after the construction licence application has been submitted. The latest extensive supplements to the reports have concerned the investigations regarding residual stresses caused by the manufacture of the canister insert (*Canister Production Line report*) and an analysis of the creep deformation and strength of the copper overpack of the canister using numerical methods (Holmström *et al.* 2012a). Positive outcomes were achieved in 2012 for both: the level of residual stresses in the cast iron insert is very low, and the maximal creep deformation of the copper overpack, including its sealing weld, is very low (maximum strain less than 5 %), so the additional investigations regarding the mechanical requirements of the manufacture and materials of the canister have for this part been concluded. The remaining needs for additional investigations are discussed later in section 5.4.1.

Figure 4-37 shows the main components of the canister. The figure shows the copper overpack, cast iron insert, inner steel lid and lid of the copper overpack slightly detached from each other.

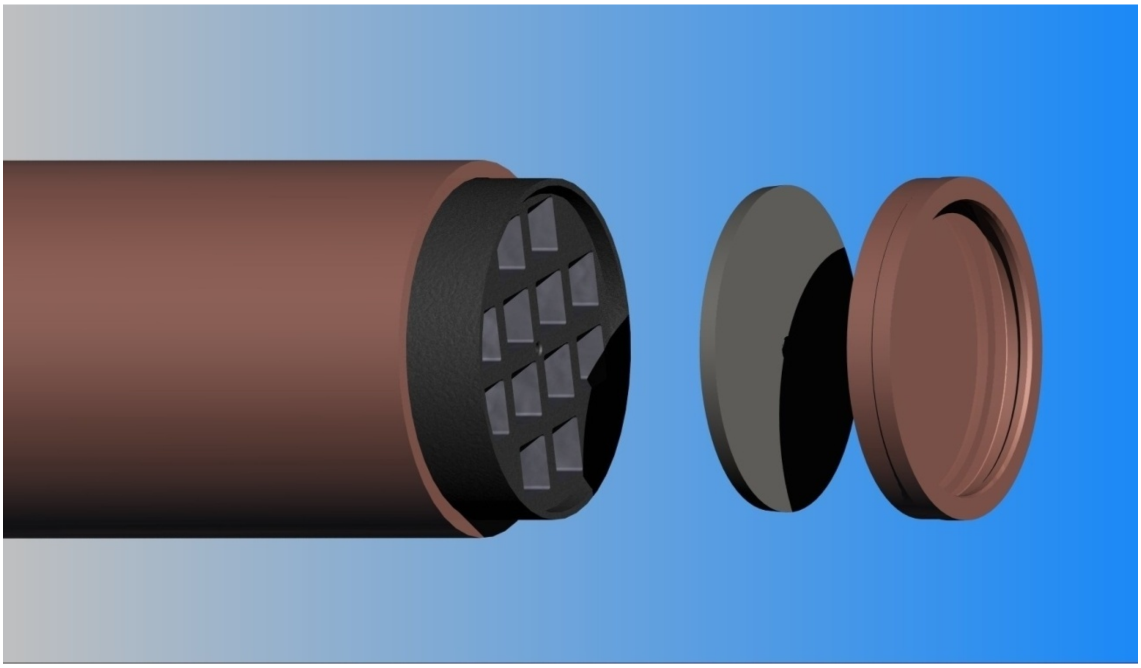

Figure 4-37. *Main components of the disposal canister: the copper overpack, cast iron insert, inner steel lid and copper overpack lid.*

Matching the canister overpack and insert requires sufficient clearances in the external and internal dimensions of components so that the components can be installed inside each other and the covers can be inserted into place. During 2011–2012, the dimensions and their tolerances were adjusted so that the canister can be assembled and the required accuracy requirements during manufacture can be met. At the same time, the clearances inside the assembled canister structure were minimised; they determine the maximal deformations that the copper overpack is subjected to during the external pressure loading stage. These deformations cause both plastic and creep strains in the copper material, and limiting them in the long run is vitally important for maintaining the integrity of the copper material.

Manufacture of canister components

The canister will be manufactured so that the requirements set in the design requirements are met, and the conformity of manufacture with the requirements will be verified by an inspection programme compliant with the quality assurance programme. The details for the end product are so important that they must be verified by separate inspections during production and are defined in the design requirements. Similarly, acceptance limits are specified in the design analyses for these inspections for determining whether the product is acceptable or not. Various inspection techniques and procedures are then designed on the basis of these inspection requirements for performing the required inspections with the required resolution and reliability. Inspection methods and procedures have been developed for manufacturing the canister components (Pitkänen 2012) and for inspecting the canister sealing weld (Pitkänen 2010). In connection with developing the methods, special equipment and manipulators required in various inspections have also been developed and procured. They allow the inspections to be tested in realistic conditions using full-scale canister components produced in the manufacturing tests. After development work on technology and equipment, the focus of inspection technology has been shifted to preparing validation of the inspection methods.

The development work for canister manufacturing techniques has continued in co-operation with SKB. The casting tests of inserts for different canister types have been continued, and several full-scale insert components have been cast every year in order to develop the casting methods and to demonstrate the manufacturing process. The manufacturing techniques and tests for canister components are described in a manufacturing technology report (Nolvi 2009). Significant progress has been achieved with regard to the mechanical properties of material in insert manufacturing tests conducted in Finland, and even as a whole, the castings are now totally on a par with the products of best foreign foundries. So far, inserts suitable for nuclear fuel assemblies of the OL1-2 and LO1-2 types have been cast in Finland. Development work for OL3-type inserts has involved monitoring development work carried out by SKB. The inserts cast in SKB work are similar to those required for OL3 fuel in terms of the number and layout of fuel channels, but they are shorter. In Finland, the need to produce OL3-canisters will only become actual around 2070. Residual stress measurements have been carried out in Bristol on the previously manufactured OL1-2 insert using deep-hole drilling techniques. No significant residual stresses were found in any part of the cast iron insert. Measurements were taken of several cross-sections, all the way to the centre of the insert.

Copper overpack manufacturing tests have also been continued in cooperation with SKB. The raw material billets for the shell have been manufactured in Finland, and further processing of the shell structure by hot working has been done using several alternative methods in Germany, Scotland or Sweden. The different hot working methods have had scope for development regarding the achievement of a homogenous grain size for the material as well as dimensional accuracy, but the continued development work and demonstration manufacture have seen the hot working processes progress so that they are ready for production. No manufacturing problems have been encountered at any stage with regard to the integrity of copper overpacks, which means that the current manufacturing capabilities for copper overpacks can be considered good. The manufacturing process for the separate copper lid for the shell has also been developed so that it is ready for production, allowing lids compliant with the requirements to be produced in normal serial production.

The encapsulation of spent nuclear fuel as well as handling and sealing of the canister have been planned as part of the encapsulation plant planning process. The entire encapsulation process is presented in the encapsulation plant design report (Kukkola 2012). The further processing, interim storage and transfers of sealed and inspected canisters as well as their installation in deposition holes are described in the disposal facility design report (Saanio et al. 2012). The system and equipment design of the encapsulation plant as well as the design of systems for the disposal facility and the design of the canister installation vehicle have also progressed far enough so that a description of the operations required for the construction licence application can be produced. The manufacture of a prototype installation vehicle is in progress. These tasks are described in section 4.4.

Sealing the canister

Development work on the canister sealing process using the electron beam welding (EBW) method has continued. Meanwhile, the alternative method developed by SKB, friction stir welding (FSW), has also been investigated. In the welding tests conducted by Posiva, welding parameters have been optimised, the residual stresses generated in the weld and with the possibilities for reducing them have been studied, and the creation and prevention of different welding defects have been investigated. The canister overpack will withstand corrosion longer if there are fewer weld defects and they are smaller. In turn, low residual stresses in the weld reduce the risk of stress corrosion cracking in the copper overpack, thus also reducing the probability of an early failure of the shell. The long-term safety of final disposal is to a large extent based on the long-term isolation of spent nuclear fuel from the biosphere, achieved by the canister. It is therefore important that the reliability of the canister sealing weld is developed to make it as effective as possible. The reliability of the weld has also been improved by means of design by choosing the location of the weld in the canister shell so that the mechanical stresses to be exerted on it in the repository have been minimised. The sealing weld procedure has been described in the EBW method development report (Meuronen & Salonen 2010) and in the *Canister Production Line report*.

The intention is to make the choice between EBW and FSW as the canister sealing method during the early part of the next programme period. The validity of these methods will have to be compared at that time with regard to several factors concerning the end result and implementation.

Inspection of the canister

Regarding canister inspection methods, inspection instructions covering ultrasonic and visual inspections have been produced for qualifying the canister insert. In addition, reliability studies have been performed regarding the ultra-sonic (US) methods used, mainly in the Reliability IV-V project that was extended to the end of 2012. Technical grounds have been presented for the inspections of canister inserts and copper components for validation purposes. Metallographic verifications are made regarding the indications observed in component inspections. The metallographic verifications of welds will be mainly completed by the end of 2012. Measurements for determining the size of defects will be performed during 2012–2014. The inspections have involved development of the optimal measurement accuracy for detecting the defects as required in the acceptance criteria.

The combined reliability of inspections of the welding process and the weld joint was investigated by calculating the probability of producing and detecting a defect using the Bayesian method. In this case, reliability means that the canister lid weld that has been approved in the inspection does not contain any defects exceeding the acceptance criteria limits. The preliminary results of the assessment lead to the conclusion that, for example, in a case where the weld was assumed to contain several types of defects, the probability of four defective canisters out of a total of 4,000 ending up in the repository is about 0.00057 (Holmberg & Kuusela 2011).

The first NDT measurements of (three) inserts of the VVER type were performed during 2010–2012. Similar preparations for qualifications have begun with regard to copper component (tube, cover, billet) inspections and copper weld inspections. In addition, human factors in the inspections of canister inserts and copper components have been investigated, and this project is ongoing. Determination of the sizes of defects in copper components using eddy current testing and the development of the associated techniques has begun. NDT instructions, similar to those for the inserts, have been produced for inspecting the copper components and welds.

4.5.2 Buffer and the related production line

The buffer surrounds the canister and fills the gap between the canister and the bedrock in the deposition hole. The purpose of the buffer is to protect the canister from adverse thermal, hydraulic, chemical and microbiological processes that might jeopardise the safety function of complete isolation, to maintain favourable conditions for the canister and to slow down the migration of foreign substances to the canister surface and migration of radionuclides from the canister in case it starts to leak. The buffer material must also be compatible with the canister, the bedrock and the tunnel backfill material from the point of view of their performance.

Buffer design

The design basis and requirements regarding the long-term safety of the buffer, together with their rationale, are presented in Posiva's *Design Basis* report. The report presents the requirements of VAHA database levels 1−4. The design specifications for the buffer are presented at level 5 of the database and in the relevant report (*Buffer Production Line report*).

The focus of buffer development work has been on buffer design and development of the buffer component manufacturing and installation processes.

The buffer consists of bentonite clay. The swelling mineral in bentonite clay is usually montmorillonite. The montmorillonite content of commercially available bentonite grades of high quality is usually higher than 80 %. The buffer reference material is bentonite containing 75–90 % of montmorillonite. Minimum and maximum limits have been set for the montmorillonite content, because it affects some very important properties required of the buffer, such as its swelling pressure and water conductivity.

A plan has been produced as the main task of buffer design work that meets the buffer performance requirements and basic technical requirements under specific ambient conditions as defined in the buffer design basis. The deposition hole diameter required by the buffer reference design is 1,750 mm. The outer diameter of bentonite blocks is 1,650 mm. The gap between the bentonite blocks and the bedrock face in the deposition hole is 50 mm, and its acceptable tolerance is ±25 mm. The nominal depths of deposition holes are 6.60 m for LO1-2 canisters, 7.80 m for OL1-2 canisters and 8.25 m for OL3 canisters. The maximum acceptable inclination of the deposition hole bottom is 1/1,750. Figure 4-38 is a schematic illustration of the buffers for canisters of different power plants.

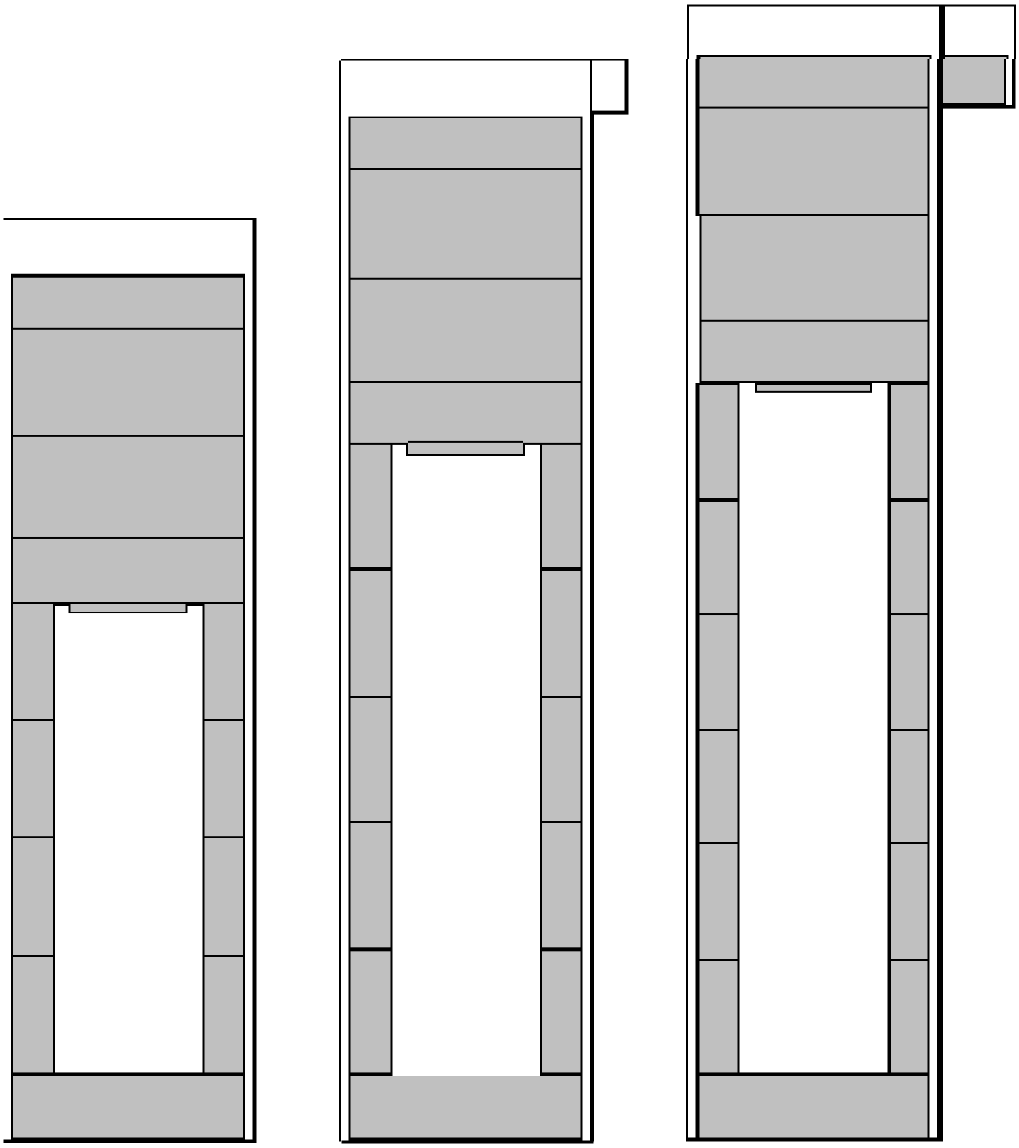

Figure 4-38. *Schematic illustration of the deposition holes, canisters and buffers for spent nuclear fuel from the LO1-2, OL1-2 and OL3 nuclear power plants.*

The detailed drawings of the LO1-2, OL1-2 and OL3 canisters are presented in the relevant report (*Buffer Production Line report*). Figure 4-39 shows the buffer for OL3 canisters, while Table 4-2 shows the dimensions of other buffers.

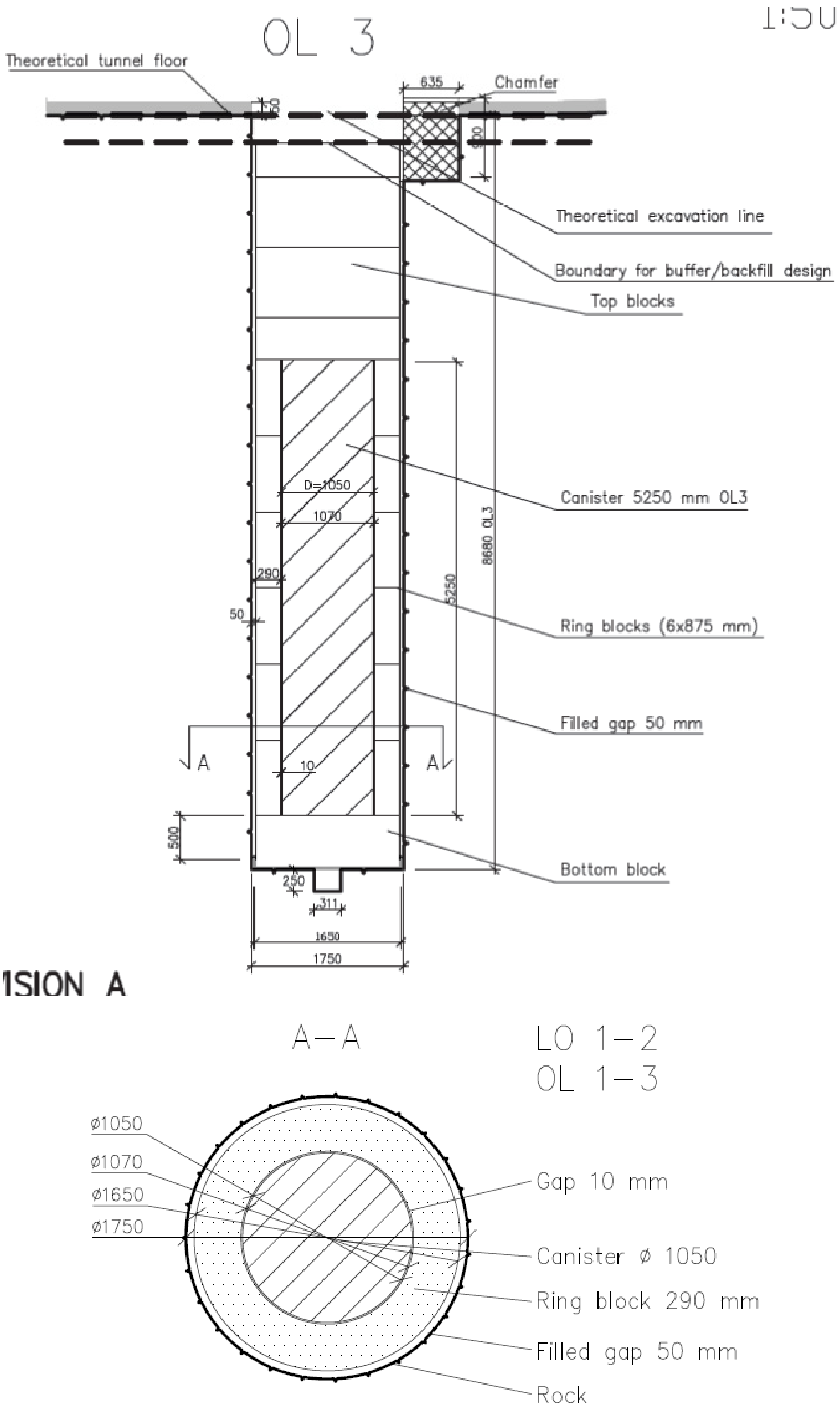

Figure 4-39. *Buffer for OL3 canisters and its dimensions (Buffer Production Line report).*

Table 4-2. *Nominal dimensions of buffer blocks.*

	LO1-2	OL1-2	OL3
Height above the canister (mm)	400 + 2*800 + 500 = 2,500	400 + 2*800 + 500 = 2,500	400 + 2*800 + 500 = 2,500
Height along the canister (mm)	4*900 = 3,600	5*960 = 4,800	6*875 = 5,250
Height below the canister (mm)	500	500	500
Total height of the buffer (mm)	6,600	7,800	8,250
Outside diameter of the block (mm)	1,650	1,650	1,650
Wall thickness of the ring block adjacent to the canister (mm)	290	290	290
Diameter of the canister hole in the ring blocks (mm)	1,070	1,070	1,070

The main changes in the current reference design (Juvankoski 2012) compared to the previous plan (Juvankoski 2009) are:

- the reference design now includes moisture protection for the bentonite blocks,
- the reference design for the bottom of the deposition hole now deploys a copper plate instead of the earlier plan in which the bottom is levelled using cement mortar with a low pH value,
- the gap between the bentonite blocks and the bedrock has been increased from 25 mm to 50 mm,
- the diameter of bentonite blocks has been decreased from 1,700 mm to 1,650 mm to correspond to the increased gap,
- the gap between the bentonite blocks and the bedrock is filled with pellets during the installation phase,
- the heights of bentonite blocks have been changed from even heights to canister-specific heights,
- the height of the bentonite block under the canister has been changed from 800 mm to 500 mm,
- the total height of the blocks to be placed above the canister has been changed from 2,200 mm to 2,500 mm,
- the depth of the deposition hole has been increased by the sum total of the excavation tolerance and the thickness of the copper plate to be placed at the bottom of the hole,
- the water content of buffer blocks has been changed from 16% to 17%,
- the installation bulk densities of buffer blocks are now canister-specific,
- the shape of the chamfer required for OL1-2 and OL3 canisters has been changed, and
- a maximum limit of 90% has been set for the montmorillonite content of the buffer material.

The reliable installation, use and removal of moisture protection for the buffer blocks have necessitated the increase of the gap between the bentonite blocks and the bedrock face in the deposiotion hole to 50 mm (Ritola & Peura 2012). The gap has been increased by decreasing the diameter of the bentonite blocks. The gap will be filled with bentonite pellets made of the same material as the bentonite blocks. The process of filling the gap with pellets has been investigated in laboratory tests of different scales (Kivikoski & Marjavaara 2011). Filling the gap with pellets will improve the supporting action of the buffer against the deposition hole walls, and it will also improve the conduction of heat emanating from the canister to the bedrock even during the early stages of buffer saturation when compared to a mere air gap. The buffer temperature has been calculated to reach the maximum value of about 85 °C (*Performance Assessment*) in a situation where the gap is filled with water or bentonite. The earlier temperature analyses regarding the buffer (Ikonen 2009) are currently in the process of being updated. The work for optimising the pellets best suited for filling the gap and assessment of the results is also nearing their completion (Marjavaara & Holt 2012).

A ⅓-scale buffer test was also constructed in ONKALO during 2011, see Figure 4-40. The purpose of the test was to gather information and experience of the installation, behaviour and durability of the buffer and the monitoring instrumentation for the test in realistic disposal conditions. For the test, two holes with a diameter of 800 mm and a depth of 3 metres were bored in Investigation niche 1 (chainage 1475) in ONKALO. The buffer blocks for the test were made of MX-80 bentonite using isostatic compression. The canisters used in the test can be heated. When the buffer blocks and the canister had been installed, the holes were closed using steel covers anchored to the bedrock, and one hole was artificial wetted using the artificial wetting system installed for the purpose. This has speeded up the process of wetting the buffer. The behaviour of the buffer and the test system will be monitored for several years. The development of pressure, moisture and temperature is measured using sensors of different types from a total of 114 measurement points. The results and experience from the test will be utilised for the planning and construction of a full-scale buffer test and underground joint operating test.

Figure 4-40. *Installation of the buffer test in ONKALO's Investigation niche 1 (chainage 1475).*

Buffer manufacture

Posiva is developing isostatic compression techniques for the manufacture of buffer blocks. The changes to the height of bentonite blocks were made as a result of experience gained in the development work for the manufacturing and machining technology of bentonite blocks (Ritola & Pyy 2011). The blocks can now be made in the desired height, which will reduce the number of blocks and speed up the installation process.

The height of the deposition hole has been changed to match the tunnel bottom excavation tolerance (*Underground Openings Production Line report*). The depth of the deposition hole allows a moisture protection of standard length to be used for the buffer.

The water content of the buffer blocks has been increased by one percentage unit. The cylindrical and ring-shaped bentonite blocks now have different installation bulk density values. These changes are based on the changes in deposition hole and block thickness dimensions made in the buffer design as well as on the goal of having equal bulk densities for the saturated buffer material in different parts of the buffer (Juvankoski 2012).

The rationale behind setting a maximum value for montmorillonite content is the goal of limiting the swelling pressure of bentonite to a level (Juvankoski 2012) that corresponds to the swelling pressure used for dimensioning the canister (Raiko 2012).

A total of around 50,000 bentonite blocks will be manufactured for the deposition holes (4,500 canisters for the spent nuclear fuel from the LO1-2 and OL1-4 NPP units) (*Buffer Production Line report*). A total of around 140,000 tonnes of bentonite will be used for the blocks and pellets. The fuel type has not yet been chosen for the planned OL4 NPP unit, which is why the canisters and buffer components required for its spent nuclear fuel have not yet been designed. For the above estimate, the nuclear fuel, canisters and buffers of the OL4 plant unit have been assumed to be similar to those of the OL3 plant unit. Figure 4-41 shows a schematic illustration of buffer block production.

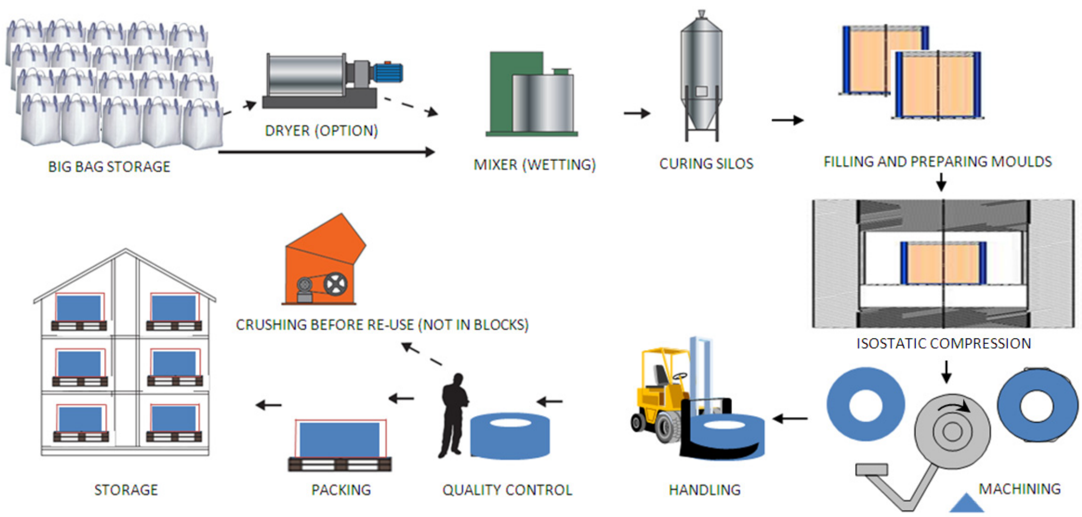

Figure 4-41. *The buffer block production process (Buffer Production Line report).*

Buffer installation

The buffer assembly consists of a copper plate placed at the bottom of the deposition hole during the installation phase, a cylindrical bottom block ring blocks surrounding the canisters (4–6 ring blocks depending on the canister type) as well as four cylindrical covering blocks installed above the canister and pellet filling installed between the blocks and rock surface of the deposition hole.

4.5.3 Deposition tunnel backfill and the related production line

Requirements for the backfill and end plug

The safety functions related to long-term safety, performance targets and the design requirements and values (design specifications) derived from these have been defined for the backfill and end plug of deposition tunnels. The requirements were developed during 2009–2011, and they have been defined in Posiva's requirements management system (VAHA). Most of the current requirements concerning the backfill and plug for deposition tunnels were approved for the VAHA system in 2011, and they are presented in reports *Design Basis***,** *Backfill Production Line report* and Autio *et al.* (2012). The background and rationale of the requirements are presented in the *Design Basis* report together with the requirements of VAHA levels 1−4. The design specifications are presented in the relevant report (*Backfill Production Line report*).

Backfill design

The deposition tunnel backfill design is presented in a report by Hansen *et al.* (2009), and in its updated form in the backfill design report (Autio *et al.* 2012), and in the relevant production line report (*Backfill Production Line report*). The 2009 design report (Hansen et al. 2009) describes a design based on the use of pre-compacted blocks as the main backfill material for tunnels. In addition, the report presents a process for levelling the floor using an *in situ* compaction method and installation of pellets by spraying. In the design updated in 2012 (Autio *et al.* 2012 and the *Backfill Production Line report*), the main backfill components are still the same (see Figures 4-42 and 4-43), but the block size and block installation pattern have been optimised so that a smaller pellet volume is left between the blocks and the tunnel arch than in the 2009 plan. The purpose of this change was to reduce the uncertainties regarding homogenisation of the system. Furthermore, the new design has the blocks interlaced both breadthwise and lengthwise, thus improving the stability and rigidity of the structure. It should also be noted that the backfill design is based on the excavation tolerances of the demonstration tunnels, which has affected the thickness of the foundation layer, among other things.

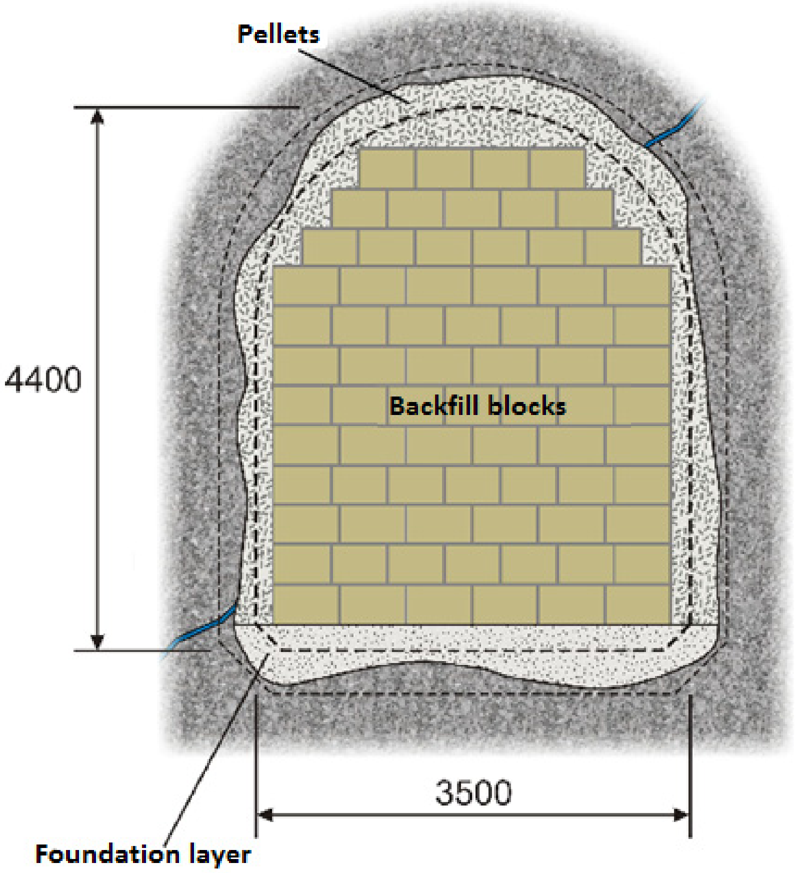

Figure 4-42. *The basic components of deposition tunnel backfill are the foundation layer, backfill blocks and pellets (Autio et al. 2012).*

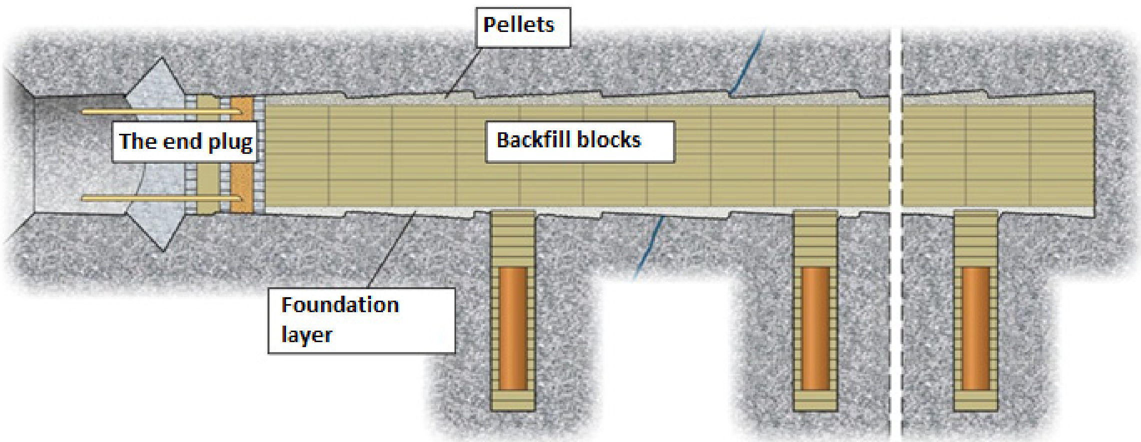

Figure 4-43. *Basic components of deposition tunnel backfill and the end plug. The end plug consists of a concrete part and a sealing and filtering layer (Backfill Production Line report).*

Backfill materials

In the 2009 design (Hansen et al. 2009), Friedland clay was suggested as the reference material for the blocks, with a mixture of bentonite and crushed rock (ratio 40:60) as well as SKB's main material alternative Milos B bentonite (IBECO RWC BF) as alternative materials. The material alternatives for foundation layer were a mixture of bentonite and crushed rock as well as bentonite pellets. The pellet material was specified as high-quality bentonite with a montmorillonite content of > 75%. The updated design (Autio et al. 2012) no longer presents the bentonite-crushed rock mixture (40:60) as an alternative. This is mainly due to the laboratory investigations (Schatz & Martikainen 2012) that raised uncertainties regarding the swelling capacity, hydraulic conductivity and homogenisation of the system under normal circumstances and after the formation of erosion channels.

The mineralogy and chemistry of backfill materials have been discussed and new results published in the source documents by Kumpulainen & Kiviranta (2010, 2011) and Kiviranta & Kumpulainen (2011).

One conclusion regarding the materials was that alternatives (or alternative materials) for the Friedland clay must be assessed for reasons of reliability of supply. They must comply with the requirements set out for backfill in terms of mineralogical composition and quality.

Backfill production line

The different stages and processes of the backfill production line have been defined in the relevant report (*Backfill Production Line report*) (see Figure 4-44). The production line report includes a description of the different production stages starting from procurement of the material and ending in the verification of quality of the installed end product. In addition, the report describes the initial state of the backfill and the end plug as well as their conformity with requirements in the initial state. A preliminary risk investigation has also been performed for the different stages of the production line.

The phases of the procurement chain for backfill raw materials are presented in the production line report. The determination of procurement chains for other backfill component materials, optimisation and investigation of alternative materials will continue during the next three-year period.

The quality control plan and chain for the backfill have been preliminarily specified for each stage of the production line. The development work for the quality control plan and methods will continue on the basis of that work.

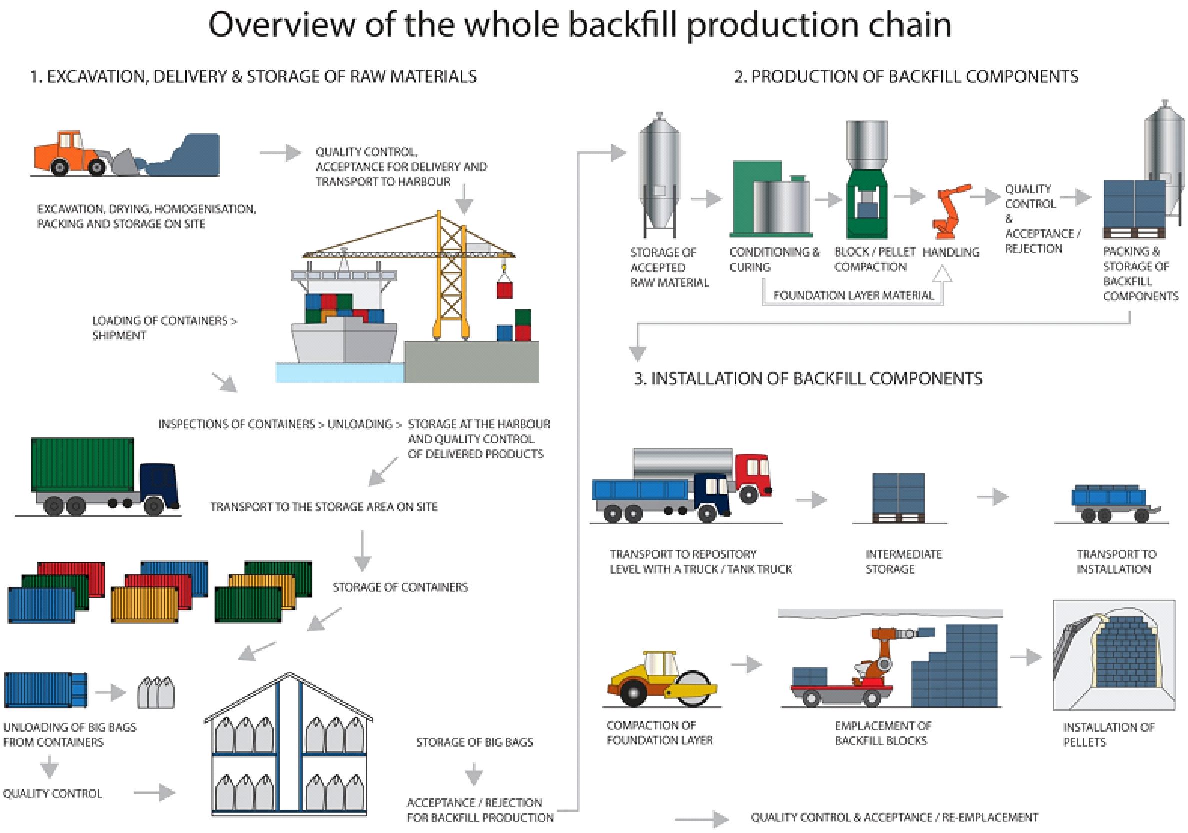

Figure 4-44. *Overview of the production line for backfill components.*

Manufacture of backfill components

The industrial-scale manufacture of backfill components has been tested in Sweden in cooperation with SKB. The backfill blocks are manufactured using a uniaxial compaction method. The small-scale and industrial-scale tests indicate that the current technology is capable of producing backfill blocks of sufficiently stable quality with regard to their water content and density. The development work regarding the compaction of backfill blocks is presented in the relevant report (Koskinen 2011).

Installation of backfill components

The backfill design report of 2009 (Hansen et al. 2009) presented the installation of backfill blocks using a modular method. The updated design (Autio *et al.* 2012, *Backfill Production Line report*) suggests that the backfill blocks are installed automatically, block by block (see Figure 4-45). The automatic installation process has the advantages of precision, efficiency and avoidance of human errors.

The backfill component installation process has been tested in field tests conducted in ¼-tunnel scale (Keski-Kuha et al. 2012). At the same time, the impact of water leaks on the wetting and erosion of the system were tested. In addition, installation tests of foundation layer were conducted in autumn 2011. The result indicates that the installation is a feasible proposition (Autio et al. 2012). However, installation on the scale and at the pace required by the disposal operations will require further development work and testing.

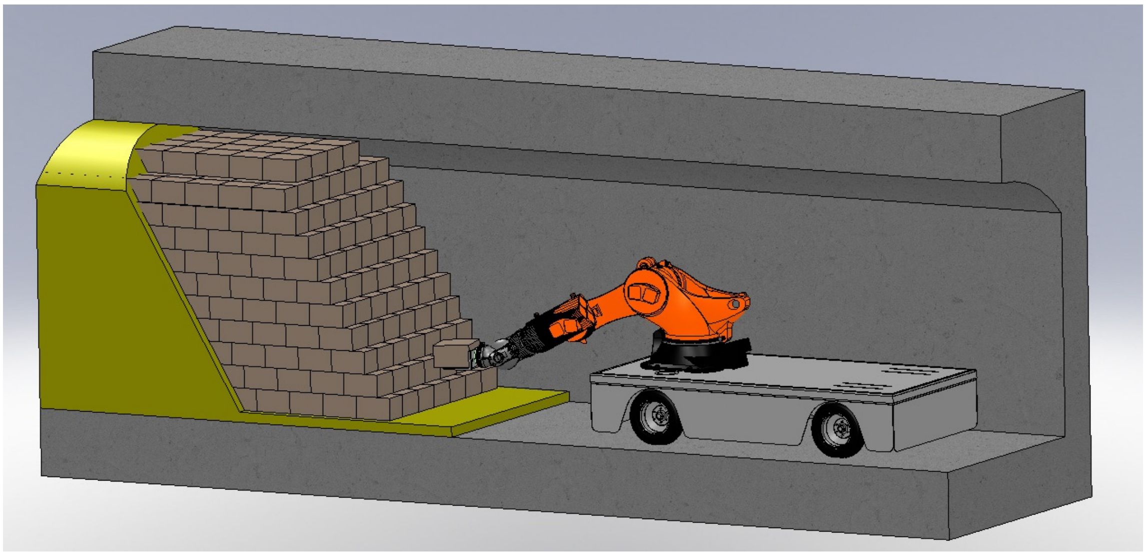

Figure 4-45. *Example illustration of automatic backfill installation device.*

Plan for the deposition tunnel end plug

There are two designs for the deposition tunnel end plugs. The current reference design for the end plug is based on material produced by SKB, and it is presented in the relevant report (*Backfill Production Line report*). In addition to the concrete part, the plan includes sealing and filtering layers on the backfill side of the end plug (see Figure 4-43). An alternative plan for the end plug is presented in a source document by Haaramo & Lehtonen (2009).

4.5.4 Closure of the disposal facility

The closure process includes the backfill and end plugs, or plugs, in all excavated openings outside the deposition tunnels, including access tunnel and shafts as well as investigation holes. The solution forclosure of the disposal facility has been presented during the current TKS period in the relevant production line report (*Closure Production Line report*). Closure of the disposal facility will complete the isolation of the spent nuclear fuel from biosphere and allow for the gradual restoration of natural conditions in the bedrock. The closure of tunnels, shafts and other underground openings will prevent the formation of direct flow and migration paths between the surface and the deposition tunnels and holes. In the long run, the closure will also serve the purpose of maintaining favourable conditions in the bedrock surrounding the disposed spent fuel.

The disposal site and its future evolution have a significant impact on the requirements to be set for the closure of the disposal facility and on the closure design developed on their basis. The requirements and design basis are presented in more detail in the *Design Basis* report for VAHA levels 1–4 and in the Closure Production Line report for level 5.

The closure reference design is based on the geological and hydrogeological conditions of the disposal site (important fracture zones and water conductivity properties of the bedrock) as well as on an estimate of the depth of the eventual permafrost (Figure 4-46) (*Closure Production Line report*).

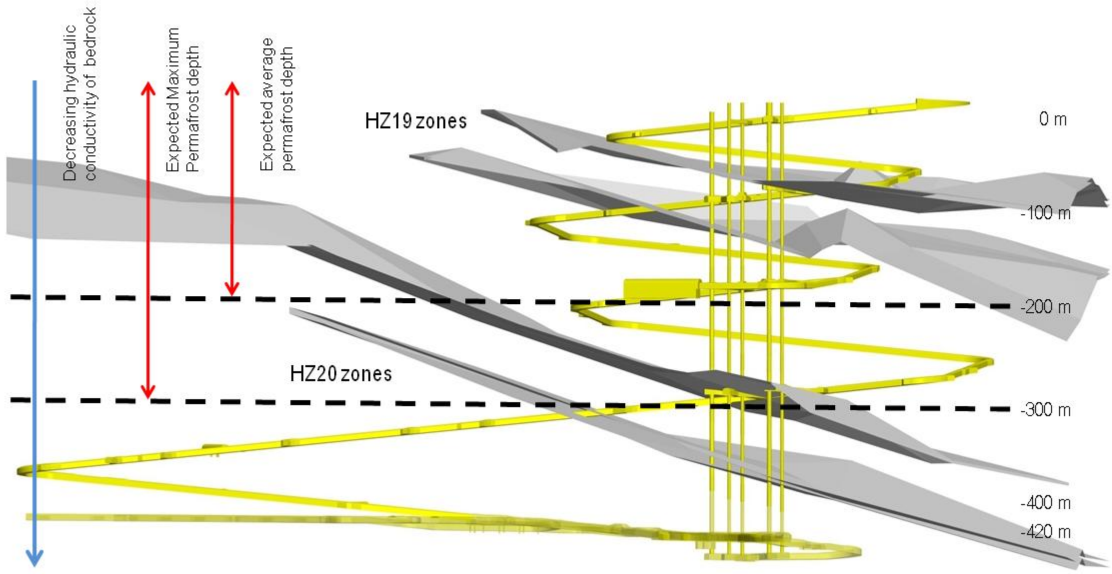

Figure 4-46. *The most important water-conducting zones HZ19 and HZ20 as well as a prediction of the depth of permafrost, which served as the basis for producing the closure solution (Dixon et al. 2012).*

Alternative closure solutions and materials as well as background for the reference design are discussed in the report Underground Disposal Facility Closure Design 2012 (Dixon et al. 2012). A detailed closure design, the backfill materials and methods for closure, as well as principal solutions for the hydraulic, mechanical and intrusion obstructing plugs to be used in the closure process are presented in the Closure Production Line 2012 report.

Closure design

The current view is that closure of the disposal facility will only commence after several decades with the closure of the first central tunnels. Therefore, in certain parts, the current closure plan is still only preliminary.

The Closure Production Line 2012 report contains an outline description of the principles of end plugs, their manufacturing and installation methods as well as matters related to their quality control. The experiences gained from tests and experiments related to the closure of the facility have been compiled in the report Underground Disposal Facility Closure Design 2012 (Dixon et al. 2012). Although the closure design has not been actually tested by Posiva, the deposition tunnel backfill tests and their results, as well as experience from the civil engineering industry will also benefit the development of technology for the final closure of the disposal facility. Furthermore, practical experience related to the closure of the facility has been gained from a shaft sealing project implemented in connection with closing an underground research laboratory in Canada (Martino et al. 2011). The state of clay and concrete componentsafter sealing of the shaft will be monitored. The first monitoring reports are described in a report by Holowick et al. (2011).

According to the current plans, the central tunnels and connecting tunnels will be backfilled in a similar manner as the deposition tunnels. The central tunnels are larger in size than the deposition tunnels, and their excavation tolerances are not as tight, but also their closure requirements are not as strict. Therefore, the same materials and methods can be used.

The technical rooms and the access tunnel to a depth of 420 metres will be backfilled with crushed rock compacted *in situ* or with a mixture of crushed rock and bentonite, depending on the depth and distance from the deposition tunnels. The shafts will be filled in places with clay blocks and in places with a mixture of crushed rock and bentonite by compacting them in the shaft using an *in situ* method. The report by Dixon et al. (2012) describes the properties of mixtures of crushed rock and bentonite, as well as their production and installation methods.

With regard to plugs, the rationale behind choosing the plug locations, and a preliminary plan regarding the number of plugs in different parts of the disposal facility have been presented. In addition, the basis for dimensioning the plugs has been presented, together with a preliminary plan for production methods. Mechanically excavated locations without excavation damage zones are also required for the plugs. The process of choosing a place for a plug, the criteria and the technical implementation have been developed in connection with development work for the deposition tunnel plug, and the information derived from this work can be later applied to the mechanical and hydraulic plugs required for the closure. The durability of end plugs is assessed in a general manner in the *Performance Assessment* report.

So far, no other large-scale tests or demonstrations have been implemented, but a European technology development project for testing plugging and sealing systems for geological disposal facilities started in 2012 (Full-Scale Demonstration Of Plugs And Seals, DOPAS). The project will compile the design basis of plugs and seals, develop new technology for plug and seal materials and for the assembly and construction of plug and seal systems, carry out full or partial design of the systems, and perform five full-scale plug and seal tests. The deposition tunnel plug tests implemented in ONKALO and Äspö are part of the project.

Closure of investigation boreholes

The deep investigation holes drilled for research purposes will also be closed as part of the disposal facility closure process. The investigation holes do not penetrate ONKALO or the disposal facility, but are connected to them via the natural fracture network in the bedrock. These holes form a direct connection from ground surface to the bedrock at the disposal depth near the repository (and below), so their closure is necessary for restoring the natural hydrogeological conditions of the bedrock.

Current alternative for borehole closure is to close sparsely fractured borehole sections with low hydraulic conductivities with borehole backfill material (bentonite clay) and to use low-pH concrete for sections that are fractured and have high hydraulic conductivities.

The current plan entails installing the borehole backfill material made of cylindrical compacted clay blocks from the surface down to a depth of about 500 m so that the backfill material is taken to the desired depth in perforated copper tubes, which are left in the hole together with the backfill material. The backfill material intended for deeper sections of the hole (below 500 m) is taken to the desired depth in a water-tight container from which the backfill material is pushed out. The container is then withdrawn, leaving behind the backfill material and a bottom plate (e.g. of copper). Perforated copper tubes filled with compacted bentonite have been used to close one section in the investigation hole OL-KR24 (Rautio 2006). The risk in using perforated tubes is the clay erosion. Groundwater in the drillholes causes erosion of the backfill material through the perforations during installation, which is why the limiting depth for installation with this method has been set at 500 metres. Erosion can be avoided by using a water-tight container, and this is why it has been chosen as the alternative for backfilling the deeper borehole sections. However, as the container method is still under development, it has not been considered as the only alternative for backfilling all depths in boreholes and is only kept as the alternative for backfilling the deepest sections.

4.6 Safety case

4.6.1 Basis and methodology of the safety case

A safety case (TURVA-2012) will be produced to support the construction licence application. According to the internationally adopted definition, “safety case” refers to all the technical-scientific documentation, analyses, observations, tests and other evidence that are used to demonstrate the safety of disposal and the reliability of the related assessments (IAEA 2006). According to Government Decree VNA 736/2008, *“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.”* It is further stated that *“The safety case comprises a numerical analysis based on experimental studies and complementary considerations insofar as quantitative analyses are not feasible or involve considerable uncertainties.”*

The safety case is part of the material to be submitted to STUK in connection with the construction licence application. The preliminary safety analysis report (PSAR) will be appended with a summary based on the *Synthesis* report of the safety case (see Figure 4-47).

The safety case supporting the licence application is based on a vertical design of the KBS-3 concept (KBS-3V). The safety case was produced for a spent nuclear fuel quantity of 9,000 tU, which corresponds to the estimated total amount of spent nuclear fuel accumulated by TVO's and Fortum's current power plants and their power plants to be constructed (OL1–4 and LO 1–2).

The contents of the safety case to be appended to the construction licence application were described in the TKS-2009 programme in the manner that they were defined in the safety case plan produced in 2008. After 2009, the contents of the safety case have been revised to take into account the official feedback from the first draft version and changes in the official regulations (YVL Guides). The contents of the report portfolio included in the new safety case TURVA-2012 are shown in Figure 4-47.

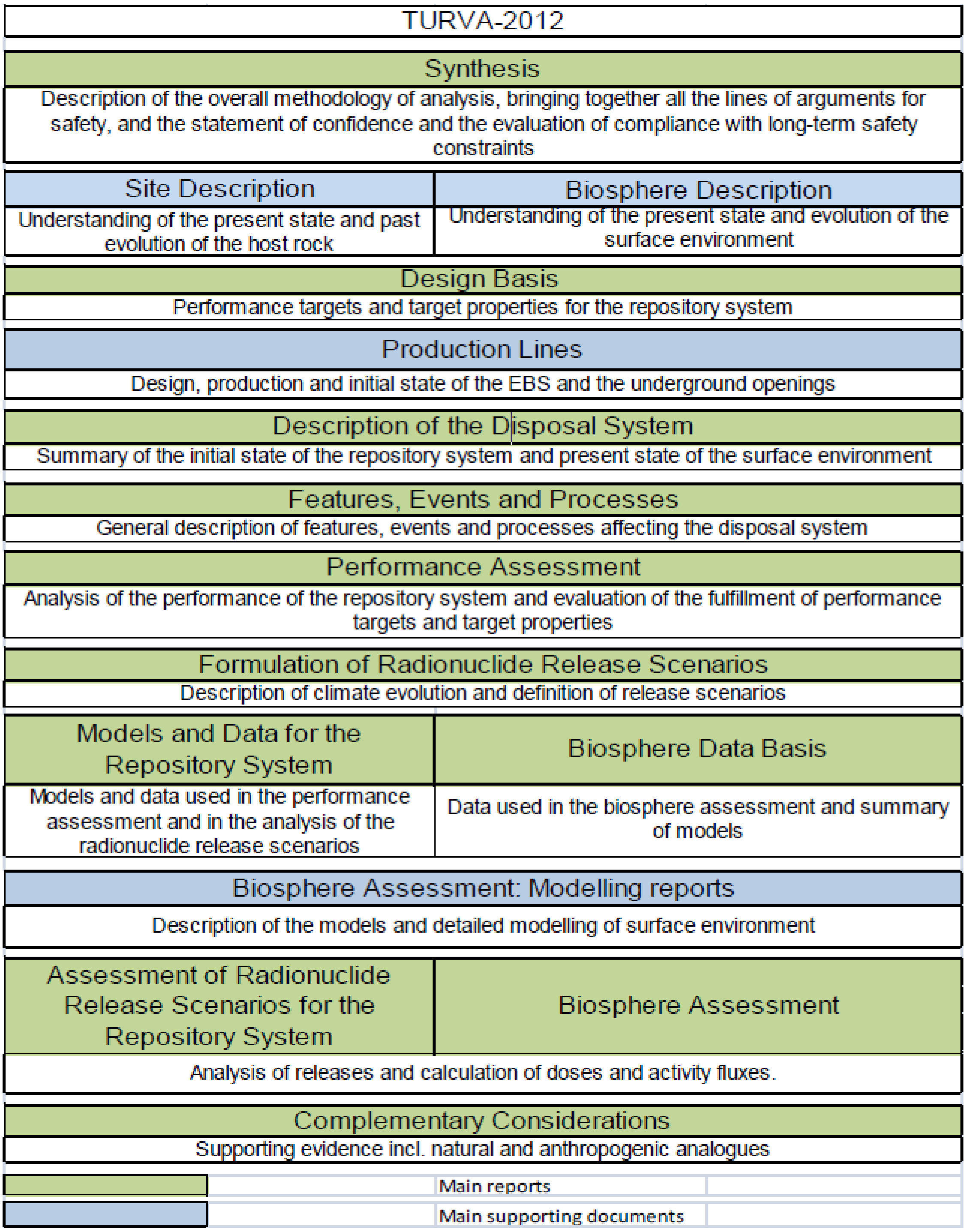

Figure 4-47. *Report portfolio of safety case TURVA-2012. The reports are shown on a coloured background with their contents described briefly on a white background.*

The revised plan includes, among other things, the following changes:

- The portfolio of TURVA-2012 (Figure 4-47) is considerably more extensive than the portfolio of Safety Case 2008 (Posiva 2008c). *Design Basis* and *Performance*

Assessment are totally new main reports, produced in response to the requirements of YVL Guide D.5. The *Design Basis* report presents the performance targets / target properties specified in VAHA and their rationale. The performance targets and target properties were defined to take into account the goal of disposal operations to isolate the radionuclides from the environment for hundreds of thousands of years, as well as the conditions and loads that may be present in development scenarios assessed to be reasonably probable for the disposal system (design basis scenarios).
- The *Performance Assessment* report demonstrates the compliance with performance targets and target properties during the likely evolution scenarios for the repository. The scenarios leading to the release of radionuclides are considered separately in the *Formulation of Radionuclide Release Scenarios 2012* report.
- In the new portfolio, the process report has been re-named *Features, Events and Processes* (FEP), and its contents have been extended, particularly with regard to the environment above ground (biosphere).
- The radionuclide release and migration analysis, including dose calculations and activity releases, are included in the reports *Assessment of Radionuclide Release Scenarios* and *Biosphere Assessment*.
- The assessment of safety spanning over one million years, regarding particularly the performance of the disposal system, is primarily based on *Complementary Considerations*, including, *inter alia*, comparisons with natural analogues and observations regarding the geological history of the disposal site (STUK, YVL Guide D.5, A09).
- The descriptions of the bedrock and the environment above ground (biosphere) (*Site Description* and *Biosphere Description*) as well as the production line reports concerning the engineered barrier system and design of the underground openings (*Production Lines*) have been given a more prominent role in the TURVA-2012 portfolio as documents supporting the main reports.

Independent experts have been used for reviewing the main reports of the safety case before their publication. The significant background reports have also been reviewed in a similar manner. In addition, the climatic evolution related to the disposal system scenarios as well as the solubility, sorption and diffusion parameters of the near-field and far-field areas have been assessed in an expert elicitation process. Furthermore, an expert group has been appointed for ensuring consistency; it reviews all the main reports in the safety portfolio of the licence application. The experts have been chosen so that they cover all key aspects of the process of producing the safety case. In addition to actual review activities, the process includes the documentation of the reviews.

The traceability of the entire documentation of the safety analysis related to the safety case and its initial data has been developed by introducing tools with which the whole process has been systematically entered in the initial data and results database. In addition, the initial data required for the safety analysis have undergone an approval (data clearance) process before they have been used.

The elimination of any deficiencies and uncertainties that might significantly compromise the reliability of long-term safety assessments was set as a key RTD task (Table 4-3) in the TKS-2009 programme before submitting the construction licence application. A key RTD task and an objective for the period 2010−2012 was the definition of assumed initial states of the components of the engineered barrier system in the base scenario. According to the updated safety case portfolio, the initial states are defined in the production line reports (canister, buffer, backfill, the underground openings, closure), and the initial state as well as the current state of the bedrock and the environment above ground are defined in the *Description of the Disposal System* report, while the requirements for the disposal system and their fulfilment are discussed in the *Design Basis* and *Performance Assessment* reports.

The purpose of the research undertaken was to either demonstrate that the remaining deficiencies or uncertainties are of no significance to the safety of disposal or that the risks associated with them is in any case very small and can be accepted in compliance with the safety requirements. Otherwise, the deficiencies will be eliminated by further developing the technical designs and plans for disposal.

Table 4-3. *The key R&D subjects listed in the TKS-2009 programme and the documents in which they were handled.*

Subject	**Discussion on the subject**
Applicability and effectiveness of the RSC methodology	• See sections 4.2.3 and 5.3.2.
Foreign materials in the repository	• Karvonen (2011b) • Annual foreign material reports of the monitoring programme • *Underground Openings Production Line report* • *Closure Production Line report* • *Description of the Disposal system*
Migration properties and other key parameters of the buffer and backfill	• *Buffer Production Line report* • *Backfill Production Line report* • *Description of the Disposal System* • *Performance Assessment*
Expected bedrock conditions (hydrogeological, hydrochemical and mechanical)	• *Site Description* • *Performance Assessment*

4.6.2 Safety concept, performance targets and target properties

In Posiva's safety concept, safety is based on isolation and containment of the spent fuel in copper-iron canisters placed deep enough in the bedrock and protected by other release barriers. No safety functions have been set for the biosphere; instead, it is the subject of protection. However, from the point of view of assessing the impacts of possible releases and from the point of view of acceptability of the concept, the biosphere analysis nevertheless remains an essential part of the safety analysis, and therefore the reliability of the biosphere analysis will be assessed in the same way as other parts of the safety analysis.

The safety concept shown in Figure 4-48 is a conceptual illustration of how the safe disposal of spent nuclear fuel is achieved using the KBS-3 concept and taking into account the particular characteristics of Olkiluoto. Because spent nuclear fuel remains harmful for a long time, it also has to be isolated from the surface environment for a long time. Safe disposal is based on long-term isolation and containment. The functions that contribute to the long-term isolation and containment are indicated in the figure with red pillars and bars. The safety concept is based on the multi-barrier principle. It ensures that no individual harmful phenomenon or uncertainty can compromise the safety of the entire system.

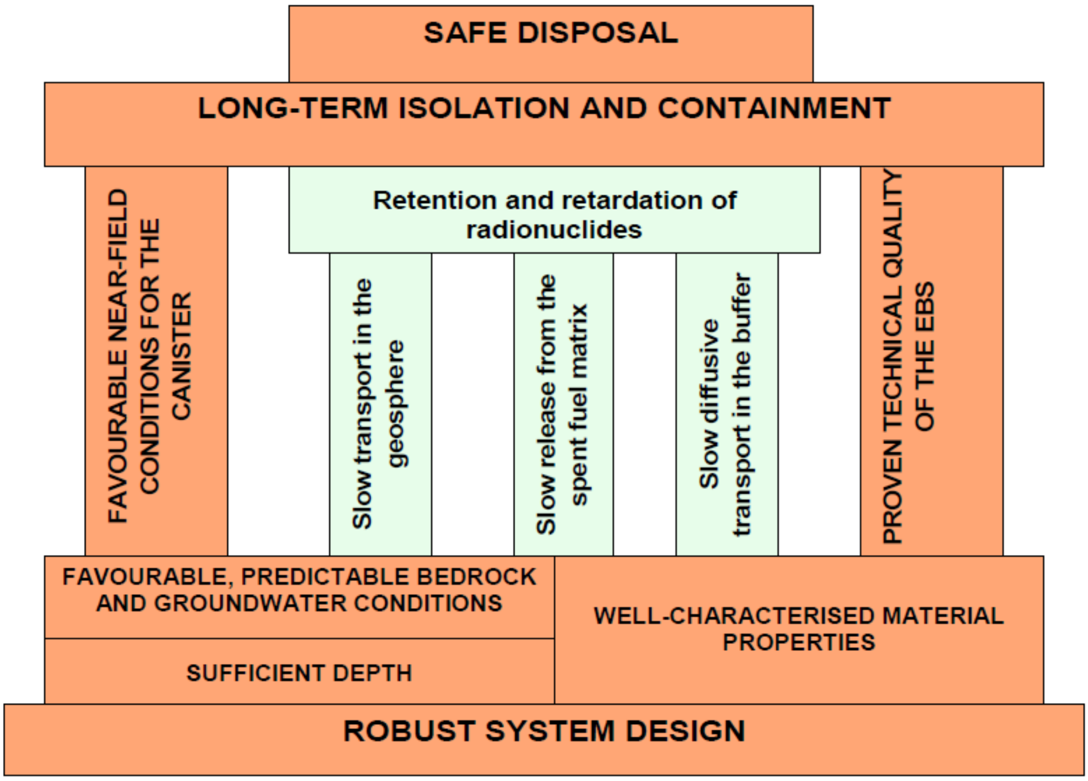

Figure 4-48. *Outline of the safety concept for the disposal of spent fuel inside a crystalline bedrock of the KBS-3 type (adapted, Posiva 2003a). The safety concept is based on a robust design. The red pillars and bars symbolise the primary safety features and characteristics of the disposal system. The blue pillars symbolise the secondary safety factors that are important particularly in a case where radionuclides are released from the canister.*

The safety functions of the release barriers in Posiva's disposal system are shown in Table 4-4. The safety functions, performance targets and target properties are presented in the *Design Basis* report. The classification of the deposition tunnel plug has changed with regard to the safety function definitions of the TKS-2009 report; the plug is now classified as a release barrier together with the deposition tunnel backfill.

The connection between the sequence of developments in the disposal system and the design work has been defined on the basis of unambiguous design requirements and design specifications that contribute to the fulfilment of performance targets and target properties starting from the initial state and during expected development scenarios.

Table 4-4. *Summary of the safety functions of release barriers (the engineered barrier system and the bedrock) in Posiva's KBS-3V disposal solution.*

Barrier	Safety functions
Canister	Ensure a prolonged period of containment of the spent nuclear fuel. This safety function rests first and foremost on the mechanical strength of the canister's cast iron insert and the corrosion resistance of the copper surrounding it.
Buffer	Contribute to mechanical, geochemical and hydrogeological conditions that are predictable and favourable to the canister. Protect canisters from external processes that could compromise the safety function of complete containment of the spent nuclear fuel and associated radionuclides. Limit and retard radionuclide releases in the event of canister failure.
Deposition tunnel backfill	Contribute to favourable and predictable mechanical, geochemical and hydrogeological conditions for the buffer and canisters. Limit and retard radionuclide releases in the possible event of canister failure. Contribute to the mechanical stability of the rock adjacent to the deposition tunnels.
Host rock	Isolate the spent nuclear fuel repository from the surface environment and normal habitats for humans, plants and animals and limit the possibility of human intrusion, and isolate the repository from changing conditions at the ground surface. Provide favourable and predictable mechanical, geochemical and hydrogeological conditions for the engineered barriers. Limit the transport and retard the migration of harmful substances that could be released from the repository.
Closure	Prevent the underground openings from compromising the long-term isolation of the repository from the surface environment and normal habitats for humans, plants and animals. Contribute to favourable and predictable geochemical and hydrogeological conditions for the other engineered barriers by preventing the formation of significant water conductive flow paths through the openings. Limit and retard inflow to and release of harmful substances from the repository.

4.6.3 External conditions

Climate scenarios

The definition of climate scenarios is an essential part of the safety case work, because the climatic conditions determine the initial assumptions and limiting conditions for the development scenarios on the site and therefore also for the developments in the repository. The climatic evolution assumed in the document *Formulation of Radionuclide Release Scenarios* and in the likely evolution scenario set out in the *Performance Assessment* are based on the continuous repetition of the previous ice age cycle (Veiksel) during the next million years. The assumption is a simple one, but it has been used, because Veiksel provides the most reliable set of data from the point of view of climate modelling results. The current warm period is expected to continue for another 50,000 years or so, after which a cold period will start, leading to the initiation of a glacial cycle with a permafrost phase, and later (about 90,000 years from the present) Olkiluoto will be covered by a continental ice. This climate scenario is based on a model (Pimenoff *et al.* 2011) that was found to fairly successfully simulate particularly the final phase of the previous ice age cycle (Veiksel) and the results of which have been supplemented by using geological information (see *Formulation of Radionuclide Release Scenarios,* Appendix 1).

The key work undertaken by the Finnish Meteorological Institute during the TKS-2009 period was the production of climate scenarios for a period of 120,000 years and the formulation of more detailed scenarios in agreement with the above ones for a period of 10,000 years. Furthermore, the possible development scenarios of the climate were made even more specific for the next 100 years, i.e. the operating phase of the repository. The longer-term scenarios and results of ten thousand year-scenarios are shown in a report by Pimenoff *et al.* (2011). Final reporting of the medium-term (10,000 years) scenarios will be completed by the end of 2012, while the report covering the operating phase will be completed by 2014.

Ice formation and the glacier

Further information regarding the open questions or uncertainties regarding glaciers and their formation is obtained from the Greenland Analogue Project (GAP), in which Posiva together with SKB of Sweden and NWMO of Canada investigate the Isunnguata Sermia and Russell glacier streams and the sub-glacial hydrological and hydro-geochemical state in Kangerlussuaq, Greenland. The project will produce a holistic and realistic view of how a ice cover can affect the geological disposal of spent nuclear fuel.

The investigations conducted in the GAP project during the TKS-2009 period and their main results were reported in Posiva's working reports Posiva (2011), Harper et al. (2012a) and Harper et al. (2012b). The key tasks were the establishment of a comprehensive GPS and weather observation network plus processing of the data obtained from the network and its adaptation for use in modelling (including modelling of the mass balance of ice). Radar scans were taken in the research area using several different antennas, producing a comprehensive view of the sub-glacial topography and flow velocity of the glacier. The migration and migration rate of supra-glacial melting waters to the sub-glacial environment, as well as the migration of these waters to the front of the glacier, were investigated using tracer substances. The temperature profile of ice and the sub-glacial pressure conditions were investigated by drilling holes through the ice, in addition to which the sub-glacial flow channels and their interconnections were investigated by slug and tracer tests. The front of the glacier without ice cover and particularly the chemistry of meltwaters, lake waters and spring waters as well as groundwaters was extensively monitored. Information on the depth of permafrost in the area was obtained from holes drilled in the bedrock (DH-GAP1, DH-GAP03 and DH-GAP04) and a deep drill hole DH-GAP04 (with a length of 687 metres and an inclination of 70°) was drilled in 2011 for monitoring the groundwaters present under the permafrost.

Geological mapping has been performed in the research area since 2008, and a geological model of the area has been produced on the basis of the results (Engström et al. 2012) for hydrological modelling (Follin et al. 2011). The geological model includes the deformation zones and also reaches below the continental glacier.

With a view to future formation of continental glaciers, it is important to know the conditions prevailing under a continental glacier and its peripheral areas in situations where the edge of the glacier stays in one place or in a balanced situation for several hundred years, so that more far-reaching conclusions can be drawn of the significance of sub-glacial conditions under the continental glacier and of the conditions at its edge. With this in mind, a basic investigation was performed during the TKS-2009 period in the Kylänniemi district of Saimaa of the glacial history of the Lake District Ice Stream that formed part of the paleo-continental glacier of Scandinavia and of the soil and bedrock investigations conducted in the area. In addition, the behaviour and paleo-environments of the Lake District Ice Stream near the edge of the continental glacier during the Younger Dryas epoch (about 12,800–11,700 years ago) were reconstructed during the research work (Lunkka & Erikkilä 2012).

The research work will continue during the programme period now commencing; a more detailed research plan is presented in section 5.6.

Permafrost

During the TKS-2009 period, permafrost modelling was based on modelling the future development of the climate during the next glacial cycle. Several periods of permafrost will occur during this period. The results indicate that permafrost in Olkiluoto will at its deepest reach an approximate depth of 300 metres during the next glacial cycle. The modelling work took into account the flow of groundwater, segregation and migration of salinity due to freezing as well as the variations in conditions above ground both locally and over time. The development of permafrost and freezing of soil, as well as the possible presence of taliks under the water bodies was assessed using two- and three-dimensional models. The results of permafrost modelling will be reported in a Posiva working report by Hartikainen (2012).

Isostatic and eustatic changes

Climatic developments will cause changes in seawater level both in Olkiluoto and elsewhere. An important factor is the sinking of the Earth's crust associated with the formation of glaciers and the land uplift associated with the withdrawal of glaciers that continues for a long time after the ice has retreated. The glaciers also have a significant impact on the state of stress in the bedrock.

Lund & Schmidt (2011) present a description of the impact of the Veiksel ice formation cycle on the state of stress in the Olkiluoto bedrock and further on fault stability. This work found that the pore water pressure had a significant effect on the fault stability.

Therefore, the uncertainties associated with the model can be reduced if more information is available on the pore water pressures under the glacier and by using models where the diffusivity or poroelasticity of groundwater pressure can be taken into account. Valli *et al.* (2011) have also analysed the impact of the glacier as part of modelling the *in situ* state of stress in Olkiluoto. Section 5.6 presents the further studies on this subject.

In addition, the initial data of the semi-empirical model by Påsse (2001) have been revised by continuing and supplementing the work by Vuorela et al. (2009) (among other things buy adding archaeological timing observations) and by shifting to statistical analysis (Pohjola et al. 2012, Ikonen & Lipping 2011) in order to improve the land uplift predictions regarding the biosphere. In June 2010, Posiva and the Signal Processing Laboratory of the Tampere University of Technology organised an international seminar on land uplift modelling (Ikonen & Lipping 2011). The intention is to supplement the initial data for land uplift modelling and to investigate alternative modelling methods, as discussed in section 5.6.

4.6.4 Future evolution of the disposal system

The future evolution of the disposal system has been estimated in the *Performance Assessment* report, while the safety implications of the uncertainties associated with the evolution have been assessed using scenario analysis. The base scenario covers the most likely future evolution of the repository. Although all canisters are expected to remain intact throughout the entire period considered, the base scenario nevertheless takes into account, as an incidental deviation, the possibility that one, or at most a few, canisters disposed of have a penetrating defect that was not originally detected.

The most likely future evolution of the repository has been discussed in a separate *Performance Assessment* that analyses the developments in the repository or part of it in a situation where the performance targets and target properties of the release barriers are achieved. If the results of the *Performance Assessment* indicate that the failure of safety functions in one or more release barriers may lead to the release of radionuclides, the analysis of the future evolution becomes part of the scope of the *Formulation of Radionuclide Release Scenarios* report. The definition of scenarios in the 2012 safety case is based on STUK's YVL Guide D.5 (L4), according to which the future evolution of the repository as well as the migration of radionuclides shall be assessed in the base scenario, variant scenarios and disturbance scenarios (see Figure 4-49).

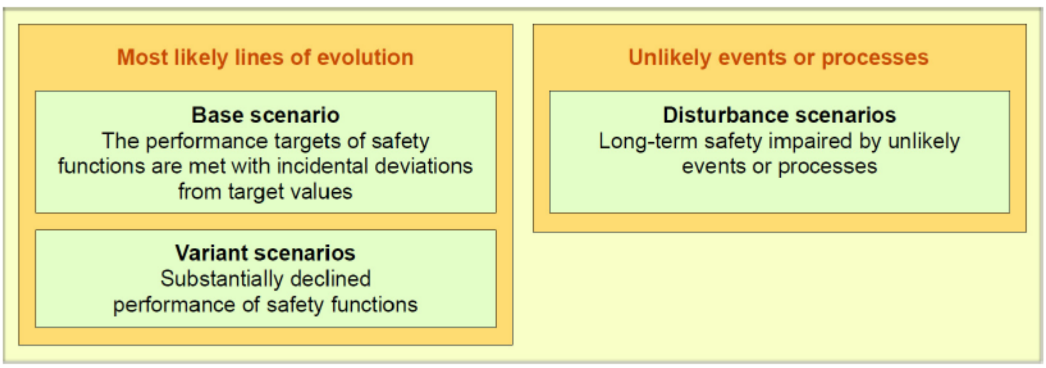

Figure 4-49. *Division of scenarios according to STUK's YVL Guide D.5 (draft).*

As stated above, no performance targets have been set for the fuel or the biosphere, which is why they are not discussed in the Performance Assessment apart from the criticality aspect of fuel.

The environment above ground (biosphere) is an essential part of the safety analysis from the point of view of assessing the impacts of possible release and from the point of view of acceptability of the concept, and that is why the present status of the biosphere and its expected evolution during the next few thousand years are also essential issues.

The initial state of the disposal system components and their likely future evolution are discussed below.

4.6.4.1 Canister

The most important safety function of the canister is to ensure the long-time containment of spent fuel in accordance with Table 4-4. This safety function relies, above all, on the mechanical durability of the cast iron insert and on the corrosion resistance of the copper overpack. The performance targets of the canister are described in the *Design Basis* report, while their attainment is described in the *Performance Assessment* report.

The canister is discussed in the following main reports included in the safety case:
- Description of the Disposal System
    - Initial state
- Design Basis
    - Lists all requirements, including those related to the long-term safety of the canister
    - Performance targets
    - Design specifications
- Features, Events and Processes
    - Processes related to the future evolution regarding the canister
    - Processes related to the migration of radionuclides regarding the canister
- Performance Assessment
- Formulation of Radionuclide Release Scenarios
- Assessment of Radionuclide Release Scenarios for the Repository System
- Models and Data for the Repository System
    - Presence of defects in the canister
    - Corrosion of copper
- Complementary Considerations.

The key tasks regarding the canister during the programme period 2010–2012 now ending are related to the definition of expected initial states of the canister in the base scenario, such as
- the type of manufacturing defects possibly expected in the canister, and their probability at the time of disposal,
- residual stresses remaining in the canister weld, and
- mechanical properties of the insert in its initial state (residual stresses and manufacturing defects).

All the above factors will affect the durability of and the future evolution of the canister.

Initial state of the canister

Most of the canisters are initially intact and will remain so for hundreds of thousands of years (*Design Basis*, *Performance Assessment*). The scenario report describing the possible release of radionuclides (*Formulation of Radionuclide Release Scenarios*) defines the so-called base scenario which, in compliance with YVL Guide D.5, is based on the targets specified for the safety functions so that incidental deviations from the target values are taken into account. Therefore, the base scenario makes the assumption that one, or at most a few, canisters disposed of have a defect that penetrates the copper overpack and has a diameter of 1 mm. The assumption is based on a reliability analysis regarding the intactness of disposal canisters (Holmberg & Kuusela 2011), although penetrating defects with a diameter of 0.5 mm can already be detected. Due to the limited number of test results, the reliability analysis is mainly based on an expert assessment of the welding method (EBW) and of the method for detecting faults (NDT). In practice, further tests can be performed to demonstrate that the probability for more than one canister initially having a penetrating defect is less than 1%. That is why the reference case of the base scenario makes the assumption that one canister in 4,500 initially has a penetrating hole.

The key subjects of research during the TKS-2009 period regarding the initial state of canisters are shown in Table 4-5. The table also shows how and where the research work has been discussed.

Table 4-5. *The key research subjects listed in the TKS-2009 programme regarding the initial state of canisters and the documents in which they are discussed.*

Subject of research	**Discussion on the subject**
Geometry of the canister and its insert	Significance of manufacturing defects, initially defective canisters, maximum limit for the probability of an initially penetrating hole. • Holmberg & Kuusela (2011) • *Performance Assessment* • *Formulation of Radionuclide Release Scenarios* • *Assessment of Radionuclide Release Scenarios*
Temperature inside the canister	Update of the thermal model taking into account possible higher average burnup values. • Ikonen, K. & Raiko, H. (2012).
Mechanical stresses at the time of disposal	Residual stresses in copper welding: • the work is in progress and will be completed in 2013.
Material composition	Material composition of the insert • *Canister Production Line report* Use of different sealing materials required for closing the insert: • discussed in section 5.4.1.1

Processes related to the future evolution

During the previous TKS period, the subjects listed in Table 4-6 were defined as the key areas of research regarding the processes related to the future evolution the canisters. The table also shows how and where the research work has been discussed.

Table 4-6. *The key research subjects listed in the TKS-2009 programme concerning the processes related to the evolution of the canisters and the documents in which they are discussed.*

Subject of research	**Discussion on the subject**
Deformation of the cast iron insert	Ensuring the integrity of the canister with strength dimensioning analyses in case of rapid displacement loading caused by fault movement • discussed in section 5.4.1.1 Creep of the insert: • *Canister Production Line report*
Deformation of the copper overpack due to external pressure	The creep tests on electron beam welded material will continue until 2013. Preliminary results have been reported in a report by Holmström et al. (2012b). Grain boundary enrichment of phosphorus and sulphur will possibly be investigated in connection with the creep tests.
Deformation caused by internal corrosion products	The effects have been taken into account. • in the *Formulation of Radionuclide Release Scenarios* report • in the *Assessment of Radionuclide Release Scenarios* report.
Stress corrosion cracking in the insert	The residual stresses in the insert are discussed in the *Canister Production Line* report.

Subject of research	Discussion on the subject
Corrosion of the copper overpack (excluding stress corrosion fractures)	Current knowledge regarding the corrosion of copper is presented in the report by King et al. (2011). Sulphide corrosion of copper: • *Performance Assessment* • possible consequences: *Formulation of Radionuclide Release Scenarios* The possibility of copper corrosion caused by pure water was investigated in tests that began in 2009. The tests will continue for many more years, with preliminary results published in 2012. • *Performance Assessment* • *Features, events and processes* Oxygen carried to the disposal depth by glacial melting waters: • *Performance Assessment*
Stress corrosion cracking of the copper overpack	Residual stresses in the copper overpack: • Preliminary results regarding the residual stresses in EBW welds have been discussed in Posiva's working reports by Gripenberg (2009), Vainio (2011), Leikko *et al.* (2011), Romppanen & Immonen (2011), Laakkonen (2011a) and (2011b) • Stress corrosion is discussed in the *Features, events and processes* report Dependence of stress corrosion on the redox potential (E_h) values: • Kinnunen & Varis (2011) Impacts of sulphide on stress corrosion cracking in anaerobic conditions: • Investigated in the KYT programme (Arilahti *et al.* (2011))
Presence and development of a canister defect and penetration of water into the canister	The probability of an initial penetrating defect: • Holmberg & Kuusela (2011)
Release of radionuclides from the canister	Conceptual model of the release of radionuclides from a failed canister • *Assessment of Radionuclide Release Scenarios* • *Models and Data for the Repository System*
The probability of a canister failure caused by shear displacement is assessed in the following reports:	• *Performance Assessment* • *Assessment of Radionuclide Release Scenarios*

In addition to the processes identified in the TKS-2009 report, SKB and others have investigated the embrittlement of copper caused by the presence of hydrogen (H_2). Embrittlement of copper was only observed at high partial pressures of hydrogen which are not expected to be present in the repository (Martinsson & Sandström 2012).

Future evolution

During the previous TKS period, the subjects listed in Table 4-7 were defined as the key areas of research related to the future evolution regarding the canisters. The table also shows how and where the research work has been discussed.

Table 4-7. *The key research subjects listed in the TKS-2009 programme regarding the future evolution of the canisters and the documents in which they are discussed.*

Subject of research	Discussion on the subject
Expected future evolution	• *Performance Assessment*
Unlikely but possible future evolution	• *Formulation of Radionuclide Release Scenarios* • *Assessment of Radionuclide Release Scenarios*
Bounding calculations or probabilistic analyses for estimating the consequences of stress corrosion	• Current knowledge regarding stress corrosion is presented in the report by King et al. (2011).
Investigations into associated processes that may damage the canister (e.g. buffer erosion, major flows caused by bedrock movements)	• *Formulation of Radionuclide Release Scenarios* • *Assessment of Radionuclide Release Scenarios*
Failure of multiple canisters	• *Formulation of Radionuclide Release Scenarios* • *Assessment of Radionuclide Release Scenarios*
Conceptual model of defective canister evolution Development of a canister defect	• *Formulation of Radionuclide Release Scenarios* • *Assessment of Radionuclide Release Scenarios*
Behaviour of the water-steam-gas system present in the canister.	• *Models and Data for the Repository System* • *Formulation of Radionuclide Release Scenarios*
The differences due to tolerances of the manufacturing methods and their impact on the mechanical strength of the canister, particularly during future ice age conditions	• *Canister Production Line report*

4.6.4.2 Buffer, backfill and closure

The safety functions of the buffer, backfill and closure solution are described in Table 4-4. The performance of the buffer, backfill and closure solution in compliance with safety functions is assessed with regard to whether the set performance targets and the target properties indicating them are achieved in the expected scenarios and in alternative or limiting conditions. The performance targets of the buffer, backfill and closure solution as well as the design requirements and specifications derived from them are described in the *Design Basis* report, while their attainment is described in the *Performance Assessment* report.

The expected future evolution is described taking into account the geochemistry, hydrogeology and prevailing temperature, and it is presented in the *Performance Assessment* report. By assessing performance in greater detail in these conditions, it is also possible to present sufficiently reliable assessments of the performance in conditions that deviate from them but may be present in the underground disposal system locally or at certain times.

The buffer, backfill and closure are discussed in the following reports included in the safety case:

- Description of the Disposal System
    - Initial state
- Design Basis
    - All requirements, including those concerning the long-term safety of the buffer, backfill and closure
    - Performance targets
    - Design specifications
- Features, Events and Processes
    - Processes related to the future evolution of the buffer as well as the backfill and closure
    - Processes related to the migration of radionuclides regarding the buffer, backfill and closure
- Performance Assessment
- Formulation of Radionuclide Release Scenarios
- Assessment of Radionuclide Release Scenarios for the Repository System
- Models and Data for the Repository System
    - Empirical data
    - Models
- Complementary Considerations
    - Natural analogies

Key factors affecting the performance are described in the table below.

Table 4-8. *Factors affecting the performance of the buffer, backfill and closure*

Subject of research	**Discussion on the subject**
<u>Mechanical erosion</u> The mechanical erosion of clay materials caused by channelled flowing water in the buffer and backfill material may cause local decrease of density in them and thus reduce their ability to meet the performance targets. Mechanical erosion may take place during the early saturation stage as water	A summary of and conclusions regarding the achievement of performance targets regarding mechanical erosion of the buffer and backfill are presented in the *Performance Assessment* report. Erosion was also taken into account in the design work for the closure concept (*Closure Production Line report*) and Dixon *et al.* (2012).

Subject of research	Discussion on the subject
possibly flows in the deposition holes and tunnels from the fractures intersecting them. No significant mechanical erosion can take place in the buffer, backfill or closure.	
<u>Homogenisation</u> Sufficient homogenisation will prevent the formation of permanent flow paths caused by heterogeneity. Homogenisation is an important process for the buffer and backfill.	Homogenisation occurs both between materials that are in contact with each other but have different initial states (such as the compressed blocks and pellets and the buffer-backfill interface) and in conditions such as transient states caused by mechanical erosion. The assessments presented in the *Performance Assessment* report indicate that the target values for material density will be achieved under totally saturated conditions. However, there are still uncertainties regarding the significance of some material parameters and conditions for the resulting degree of homogeneity, and investigations into them will continue.
Mineralogical alteration of clay	The performance of the buffer, backfill and closure in a totally saturated state depends on the development of their geochemical state throughout their entire life spans. In turn, this geochemical state will depend on the conditions in the surrounding bedrock. Consequently, the biggest uncertainties are related to the changes taking place in groundwater flows and geochemistry. The most important parameter affecting the performance of the engineered barrier system is the effective montmorillonite dry density (EMDD). The EMDD will decrease if: • montmorillonite is dissolved in pore water and the dissolved substances migrate to the fracture network in the bedrock, • the mineralogy of montmorillonite is altered, or • montomorillonite is cemented as salts or silicates precipitate on the montmorillonite surfaces. These alterations, deemed possible, are discussed in this table under "Interaction between montmorillonite and groundwater", "Mineralogical alteration of montmorillonite", "Cementation" and "Interaction of substances dissolved from cement with the clay materials".
<u>Interaction between</u>	In this connection, changes in the EMDD are assessed

Subject of research	Discussion on the subject
<u>montmorillonite and groundwater</u> This phenomenon is of significance primarily in the buffer and backfill. This factor will be assessed in relation to the closure on a material-specific basis.	with regard to the dissolution of montmorillonite, and particularly with regard to the silica contained in it. These assessments are presented in the *Performance Assessment* report.
<u>Mineralogical alteration of montmorillonite</u> This phenomenon is of significance primarily in the buffer.	According to certain studies (Inoue 1983, Inoue 1995, Eberl et al. 1993, Tsutomu et al. 1995, Batchelder et al. 1996, Cuadros & Linares 1996, Roaldset et al. 1998), the montmorillonite in the buffer may be altered in certain chemical conditions, weakening the swelling properties of the bentonite. The *Performance Assessment* report presents the conclusion that no significant alteration will take place in the Olkiluoto conditions. In order to verify the conclusions, tests have been started regarding the effects of elevated temperature (270 ºC), in addition to which Posiva has participated in the exchange of information regarding the long-term test at a lower temperature (80 ºC) initiated by SKB and Nagra.
<u>Cementation:</u> This phenomenon is of significance primarily in the buffer.	The buffer may become cemented as a result of the (dissolution and re-)precipitation of salts and accessory minerals. The temperature-induced precipitation of accessory minerals in bentonite and the associated uncertainties have been investigated by computational analyses in the *Performance Assessment* report. In addition, a set of equipment has been developed for longer-term tests. According to current knowledge, amorphous silica is dissolved in the warmest spots of bentonite and precipitated on its cold spots, whereas the gypsum minerals behave in the opposite way, although in insignificant quantities.
<u>Interaction of substances dissolved from cement or colloidal silica (silica sol) with clay materials.</u> This phenomenon is of significance primarily in the buffer and backfill.	There are currently uncertainties associated with the release of substances dissolved from cement and their migration to the deposition holes and tunnels. In order to gain further certainty, Posiva participates in the international Cyprus Natural Analogue Project (CNAP) that investigates the interaction between bentonite and water with a high pH value. The preliminary results of mass balance-based analyses indicate that there is less interaction than expected, even over the long term. The most significant risks are associated with the use

Subject of research	**Discussion on the subject**
	of grouting materials that significantly increase the pH of groundwater locally and with the use of other cement-based materials in the deposition holes. For these reasons, low-pH cement and colloidal silica are now used in ONKALO below the HZ20 structure, and the use of cement-based materials in deposition holes is prohibited. The international long-term cement studies (LCS) project has found that three years is too short a period for detecting bedrock-cement interactions under *in situ* conditions. Modelling results have been published in Nagra's report series. There is still insufficient information on the possible aggregation of colloidal silica (silica sol) and bentonite which directly depends on the gel formation of colloidal silica (*Performance Assessment*).
<u>Iron-bentonite interaction</u> The disposal system includes iron-containing materials, such as bolts, deposition tunnel plugs and canister inserts. Iron may weaken the performance of bentonite, such as its swelling capacity, and therefore the interaction between iron and bentonite has to be investigated.	An investigation into the long-term interaction between iron and bentonite was carried out (Kumpulainen *et al.* 2010), where bentonite samples that had been in contact with iron under reducing conditions for several years (8−10 years) were analysed. The tests indicated that interaction between iron and bentonite slightly reduced the swelling pressure of bentonite, while water conductivity remained the same. Posiva has participated in the large-scale FEBEX test carried out by the Grimsel rock laboratory involving an iron heater surrounded by bentonite. Once the test has been dismantled (2015), the effects that iron has had on bentonite can be investigated. The sorption of Fe(II) in bentonite has also been investigated empirically and by modelling. Tests and modelling of the diffusion of Fe(II) in bentonite are currently in progress. Once they are completed, their results will be reported together with the results of sorption tests in 2013.
Microbial activity in the buffer and backfill	The possible microbiological reduction of sulphates in the buffer and backfill would produce sulphides that are corrosion-inducing compounds and therefore a threat to the durability of canisters. The microbes need a source of energy, usually dissolved organic carbon, for reducing the sulphates. The formation of sulphides in the buffer and backfill as a result of microbial activity and its impact on, among other things, the

Subject of research	Discussion on the subject
	corrosion of canisters has been discussed in the *Performance Assessment* report.
Chemical erosion This phenomenon is of significance primarily in the buffer and backfill as well as in the clay-containing components of the closure solution.	Estimates have been made of the erosion of clay into the water-conducting fractures intersecting the repository as a result of the interaction between dilute waters and clay. These estimates take into account: • the changes in flow rates in the fractures intersecting the repository space under post-glacial conditions, • the durations of these post-glacial conditions, • fracture openings that act as mass transfer interfaces, and • the migration speed of clay mass into flowing water in the fractures intersecting the repository. These factors have been estimated in the *Performance Assessment* report. Small-scale tests as well as model development and modelling related to the phenomenon have been carried out in order to investigate chemical erosion. In addition, Posiva participates in the EU's BELBaR project and the CFM (Colloid Formation and Migration) project of the Grimsel rock laboratory where in situ tests and theoretical analyses are performed to investigate the colloids originating from bentonite and their migration.
Freezing and thawing	If permafrost penetrates the repository, it is claimed to have an adverse effect on the properties of bentonite or backfill materials. The effects of clay materials (buffer and backfill) as a result of freezing and thawing have been investigated empirically (Schatz & Martikainen 2011). The tests indicate that the freezing-thawing cycles do not have an adverse effect on the performance of clay materials (including their swelling pressure). Besides, the current permafrost calculations show that permafrost is not expected to reach the disposal depth.
Mechanical behaviour of the buffer in rock displacements.	The task is to find out how the buffer conveys the impulse caused by a rock displacement to the canister. If the density of buffer is too high, the impulse is conveyed almost without any dampening to the canister, potentially resulting in canister failure. The mechanical behaviour of the buffer in case of the bedrock displacement discussed in the *Performance Assessment* report. The locations of deposition holes will be chosen so

Subject of research	Discussion on the subject
	that the probability of a bedrock displacement resulting in canister failure is small. The determination of criteria for choosing the location is partly based on the measurements performed for the purpose of determining the parameters of the material model of clay. These clay-related measurements will be repeated in order to verify the material model. If required, the other steps of the analysis will also be repeated.
Migration of gas in the buffer	Regarding the migration of gas in the buffer, the general assumption has been made that as a gas inclusion travels through bentonite, the swelling pressure causes its path to close after it has passed and the solids content will homogenis thus allowing the gas to travel along the path of least resistance without leaving any traces. Similar observations have been made in laboratory and field tests, such as that of the formation of most favourable flow paths. In the Lasgit test in progress in the Äspö HRL, the flow paths in partially saturated bentonite were formed in the least saturated points and the so far poorly sealed interfaces as water moved in them from the path of the gas inclusion more readily than in other areas (Cuss *et al.* 2010). On this basis, it can be assumed that the buffer will allow gases to pass without causing any damage to the canister or the buffer. Therefore, there is no need to reduce the risk possibly caused by gas inclusions by technical means. The processes associated with gas migration cannot be accurately predicted yet (e.g. either the pressure at which the inclusion starts moving or the quantity of gas travelling in the inclusion can be predicted, but not both at the same time). In addition, there are uncertainties associated with the full-scale empirical test data, as there is too little data for it to be statistically reliable.
Formation of colloids (related to chemical erosion)	The formation of colloids has been discussed, *inter alia*, in • the *Performance Assessment* report • the *Complementary Considerations* report • for migration, see item "Colloid migration" in Table 4-9 below

4.6.4.3 Bedrock

The safety functions of the bedrock are described in Table 4-4. The target properties of the bedrock were derived from the safety functions. If the properties of the bedrock surrounding the repository are compliant with the target properties, the safety functions of the bedrock will most likely be achieved. The target properties of the bedrock are presented in the *Design Basis* report, while their achievement is presented in the *Performance Assessment* report. The *Performance Assessment* report presents both the expected bedrock conditions around the deposition holes (reference conditions) and an assessment of the probability of deviations (alternative conditions).

The bedrock is discussed in the following reports included in the safety case:

- Description of the Disposal System
    - Initial state
- Design Basis
    - Lists all requirements, including those related to the long-term safety of the bedrock
    - Target properties
    - The design specifications (and requirements) for the underground openings, including the rock suitability criteria (RSC) that provide limit values for the properties of the surrounding bedrock.
- Features, Events and Processes
    - Processes related to the future evolution in the bedrock
    - Processes related to the migration of radionuclides in the bedrock
- Performance Assessment
- Formulation of Radionuclide Release Scenarios
- Assessment of Radionuclide Release Scenarios for the Repository System
- Models and Data for the Repository System
    - Initial data and models used for preparing the safety case
- Complementary Considerations
    - Natural analogies and other evidence of the favourable conditions in deep bedrock and particularly in Olkiluoto.

In addition to these reports included in the safety case portfolio, the properties of the disposal site have been extensively discussed in the *Site Description*, while the suitability of the disposal site has been discussed in the RSC report (McEwen *et al.* 2012).

According to the TKS-2009 programme, the key research subjects regarding long-term safety and the bedrock during 2010–2012 were the initial state of the bedrock taking into account the rock suitability classification, as well as the presence of foreign materials and the expected hydrogeological, hydro-geochemical and rock-mechanical conditions:

- The flow conditions and salinity of groundwater, particularly near the deposition holes, during different review periods.
- Buffering capacity of the bedrock (pH and reductive potential).
- The maximum amount of sulphides reduced from sulphates in microbial reactions and the rate of formation taking into account the methane gas present in the bedrock.

- Long-time impacts of the repository on the bedrock conditions (temperature, excavation, grouting, changes in the stress field).
- Rock-mechanical loads.

Table 4-9 shows the research subjects related to the bedrock and their implementation. The table contains a compilation of all research subjects related to the assessment of long-term safety of the bedrock presented in the TKS-2009 report, some of which are discussed in the chapter discussing the suitability of the disposal site. This chapter focuses on the investigations performed for describing the long-term developments in the bedrock and for radionuclide migration calculations.

Table 4-9. *The key research subjects listed in the TKS-2009 programme regarding the bedrock and the documents in which they are discussed.*

Subject of research	**Discussion on the subject**
Initial state	
Development work for the rock suitability criteria	see section 4.2.2
Characterisation of the state of stress and strength properties of the bedrock	see section 4.2.1
Characterisation and assessment of the mechanical, hydrological and geochemical impacts of ONKALO excavation work	see sections 4.2.1 and 5.3.3.1
Monitoring the use of foreign materials	Karvonen (2011b), see also section 5.3.3.1
Characterisation of the extent and properties of the excavation damage zone and the spalling phenomenon	Mustonen *et al.* (2010), see also section 4.4.3.4
Assessment of the water leaks entering the deposition holes and tunnels by modelling	The *Performance Assessment* report
Assessment of the extent of stress damage by modelling	see section 4.2.1
Assessment of the impacts of stress damage on water leaks and flow paths by modelling	The *Performance Assessment* report
Assessment of changes in groundwater composition by modelling	The *Performance Assessment* report
The effects of earlier excavated facilities and the decay heat produced by disposed of fuel on the initial state of canisters disposed of later.	Stress damage caused by temperature: the work will be undertaken during the next programme period (section 5.3.1.4). Water leaks: Hartley *at el* (2012c)
Processes affecting the evolution in the bedrock	
Convection of heat	The investigations related to the determination of thermal properties have continued; see section

Subject of research	Discussion on the subject
	4.2.1. The thermal model of the bedrock was produced as part of the rock-mechanical model; see section 4.2.1.
Re-activation of fractures and rock displacement	The mapping of fractures and fracture zones both in drill holes and in ONKALO has continued; see section 4.2.1. A model has been produced of the *in situ* state of stress in the Olkiluoto bedrock; see section 4.2.1. Assessment of re-activation and possible displacements under future conditions: • The displacements possibly caused by earthquakes have been assessed by modelling (Fälth & Hökmark 2011, 2012). • In other respects, the re-activation and displacements of fractures have been assessed to be minor on the basis of observations made in ONKALO and the modelling results presented by Hökmark *et al.* (2010), and Olkiluoto-specific modelling has not been deemed necessary.
Bedrock spalling (breaking)	The mapping of stress damage and bedrock response measurements have continued in ONKALO; see sections 4.2.1.1 and 5.3.1.4. The first results of the POSE test investigating the spalling strength of the bedrock have been obtained; the entire interpretation work will be completed in 2013; see section 5.3.1.4. The assessment of bedrock damage and spalling will be updated when the final results of the POSE test are available.
Long-term deformation of the bedrock (creep)	Bedrock displacement measurements have been made as part of rock-mechanical monitoring; see section 5.5.
Water-bedrock interaction	The site-specific investigations (including the filtration test, the test on microbiological reduction of sulphates (SURE)) carried out for obtaining information on water-mineral interactions are presented in section 4.2.1 together with details of the associated modelling work. Assessment of the ion exchange capacity of fracture minerals (particularly K, Ca and Mg tests

Subject of research	Discussion on the subject
	and modelling): the work is currently being planned with SKB. The future evolution in groundwater chemistry and changes in the buffering capacity of the bedrock have been assessed using reactive transport modelling as described in the *Performance Assessment* report based on the work undertaken by Trinchero *et al.* (2012a, 2012b). Interaction between alkaline water and the bedrock has been investigated by • groundwater chemistry monitoring studies; see section 5.5, • reactive transport modelling: see the *Performance Assessment* report (Appendix D), Soler (2010), Soler (2011), • participation in the tests of phase II of LCS in the Grimsel test site (2009−2013).
Formation of methane hydrates	The physical-chemical condition of the methane-groundwater system and the possibilities of methane hydrate formation in the hydro-geochemical conditions of Olkiluoto have been discussed in the reports by Keto (2010) and Tohidi et al. (2010). These studies indicate that formation of methane hydrates in conditions such as those in Olkiluoto is not likely.
Separation of salt	Groundwater samples were taken under permafrost in connection with the Greenland project, and no saline water was found in them. The results will be reported during 2012. In addition, new samples were taken in 2012.
Microbial populations and processes	The reduction of sulphates as a result of microbial reactions has been investigated in the SURE test performed in ONKALO; see section 4.2.1. The development of sulphide content in groundwater has been modelled using reactive migration modelling (*Performance Assessment*) based on the work undertaken by Trinchero *et al.* (2012b). However, microbial reactions were not taken into account in this modelling work. Microbial samples have been taken near the ground level in the Greenland project, and the results will be reported in 2014.

Subject of research	Discussion on the subject
Migration-related processes	
Flow of groundwater	The flow of groundwater during different phases of the glacial cycle has been modelled using both the porous medium model and the fracture network model (Löfman & Karvonen 2012 and Hartley et al. 2012b). The flow modelling work has been based both on the updated hydrogeological models (see section 4.2.1) and on the updated layout of repository facilities (see section 4.4). As part of flow modelling, the development of groundwater salinity both during the operating phase of the repository and at different phases of the glacial cycle have been analysed (Löfman et al. 2010, Löfman & Karvonen 2012). The upconing of saline water during the operating phase has also been analysed using fracture network modelling (Hartley et al. 2012c). The channelling of flows has also been analysed as part of fracture network modelling (Hartley *et al.* 2012b). The flow modelling of paleo-hydrological developments in Olkiluoto is described in section 4.2.1. The natural analogy studies forming part of the GAP project are described in section 4.6.1. Conceptual and numerical models have been developed as part of the GAP project (Jaquet et al. 2010), and the development work will continue during 2013−2014. The impact of the excavation damage zone and stress damage on the flow and migration of groundwater have been analysed in flow modelling (Hartley *et al.* 2012b, 2012c). The link between the bedrock flow models and the surface hydrological model has been developed, particularly with respect to the definition of the surface limiting condition and discharge areas (Löfman & Karvonen 2012, *Assessment of Radionuclide Release Scenarios*).
Matrix diffusion	The work for defining the site-specific migration properties has been described in section 4.2.1.

Subject of research	Discussion on the subject
Dispersion	Mechanical dispersion is taken into account directly in the fracture network models. In the porous medium models, the impact of dispersion on the migration of salts has been analysed with the help of sensitivity analyses (Löfman *et al.* 2010).
Formation of gases and two-phase flow	The quantity, origin and migration of evolving methane as well as the possibility of a two-phase flow have been investigated in a joint project with SKB (Delos et al. 2010 and Tohidi et al. 2010). A summary of the results is presented in the *Site Description* report.
sorption, solubility and precipitation of radionuclides	The speciation and solubility of radionuclides at the buffer-bedrock interface has been discussed in a report by Wersin et al. (2012a). The report takes into account different groundwater conditions. On the basis of results obtained by Wersin *et al.* (2012a), the reduction of sulphates into sulphides does not increase the solubility of radionuclides (Sr and Ra). The sorption properties of the bedrock have been determined on the basis of laboratory tests and a study of literature. The work also included the assessment of uncertainties, and the results will be reported in 2012 (Hakanen et al. 2012).
Colloid migration	The formation of colloids from the disposal materials has in the *Performance Assessment* and *Complementary considerations* reports been assessed to be limited due to the high ion concentration of water. The *Complementary considerations* report contains a compilation of information available in literature regarding the formation of colloids and their migration. The analysis indicates that the retention of colloids may be efficient, but sufficient information is not available for fully understanding the process mechanism. The formation of colloids as a result of post-glacial erosion of bentonite has been analysed separately in the *Performance Assessment* report. An analysis has been made of the impact of colloids on the migration of radionuclides; it will be published in the *Models and Data for the Repository System* report.

Subject of research	Discussion on the subject
	In the radionuclide migration calculations, colloid migration is analysed as sensitivity cases by altering the migration parameters.
Future evolution in the bedrock	
Development of the flow conditions and salinity of groundwater	A summary of the development of flow conditions and salinity of groundwater has been presented in the *Performance Assessment* reports, based mainly on the work by Hartley *et al.* (2012b, 2012c) and Löfman & Karvonen (2012); see also the section entitled 'Migration-related processes' above.
Buffering capacity of the bedrock (pH and reductive potential)	A summary of the development of groundwater chemistry taking into account the water-mineral interaction is presented in the *Performance Assessment* report based on the development of groundwater chemistry in Olkiluoto (*Site Description*) and on reactive transport modelling (Trinchero *et al.* 2012a); see also the section entitled 'Migration-related processes' above.
The maximum amount of sulphides reduced from sulphates in microbial reactions and the rate of formation taking into account the methane gas present in the bedrock	The *Performance Assessment* report and Wersin *et al.* (2012b); see also the section entitled 'Processes affecting the future evolution in the bedrock' above.
Long-term impacts of the repository on the bedrock conditions	In groundwater flow modelling, the impacts of decay heat from spent fuel, open facilities, grouting and excavation damage (EDZ, spalling) on flows, migration routes and the transfer of material between the bedrock and the buffer have been analysed (Löfman & Karvonen 2012 and Hartley *et al.* 2012b, 2012c). A summary of the results is presented in the *Performance Assessment* report.
Rock-mechanical loads	Assessment of bedrock spalling; see the section entitled 'Processes affecting the future evolution in the bedrock' above. The impacts of excavation damage and spalling on groundwater flows; see above. An estimate of the probability of bedrock displacements that could break the canister is presented in the *Performance Assessment* report based on the probability of earthquakes (Saari 2012), on an assessment of potentially unstable

Subject of research	Discussion on the subject
	zones (Lund & Schmidt 2011) and of the number of canister holes where a displacement could occur (Hartley *et al.* 2012c).
Migration properties of the bedrock	In a project initiated in 2008, site-specific migration parameters (solubility, sorption and diffusion) have been updated for the nuclides deemed relevant for the safety analysis. Reporting is currently in progress and will be completed during 2012.

4.6.5 Biosphere

As stated above, no safety functions have been set for the biosphere. However, from the point of assessing the impacts and from the point of acceptability of the concept, the biosphere analysis nevertheless remains an essential part of the safety analysis.

Investigations of the current state of biosphere are conducted as investigations related to the monitoring of state of the environment as part of the Olkiluoto monitoring programme and as investigations producing initial data required for the safety case. These research activities extend outside Olkiluoto and its near-fields, because all ecosystems important for the safety case or their different development phases evolving with land uplift are currently not present in Olkiluoto. In the area of Satakunta and Varsinais-Suomi, seven reference lakes and three reference swamps have been specified (Haapanen et al. 2010, Haapanen et al. 2011). The work of characterising them has already begun, and it will continue in the next few years (section 5.6).

The results of investigations conducted as part of the Olkiluoto monitoring programme have been compiled in annual environmental monitoring reports (Aro et al. 2010, 2011, Haapanen 2005–2012). The environmental monitoring programme is discussed in section 5.5. Table 4-10 shows the major investigations conducted outside the monitoring programme during 2010–2012 whose results are utilised as initial data for biosphere analysis and for developing the models.

Table 4-10. *Biosphere investigations conducted during the period 2010–2012.*

Subject of research	Discussion on the subject
Terrestrial ecosystem	
Investigation of root systems in the intensive test plots in forests.	Helmisaari *et al.* 2009, Aro *et al.* 2010
Inventory of the terrestrial part of investigation lines extending from land out to the sea	Haapanen & Lahdenperä 2011
Initiation of the monitoring programme for berries and mushrooms	To be reported in 2012

Subject of research	Discussion on the subject
The investigation of vegetation in and sampling of peat (surface peat and peat profile) from two reference swamps, physical and chemical properties of the samples	To be reported in 2012
Aquatic ecosystem	
Flow and sedimentation modelling of the Eurajoensalmi straits	Mykkänen *et al.* 2012
Element concentrations in the neighbouring waters of Olkiluoto and in the reference lakes	To be reported in 2012
Investigation of aquatic vegetation in Olkiluoto and two reference lakes, including sediment sampling as well as the physical and chemical properties of plant and sediment samples	Kangasniemi *et al.* 2011
Investigation of vegetation in Eurajoki (the "Jokivarressa" project, Pyhäjärvi Institute)	Kirkkala & Ryömä 2011
The fauna	
Continuous accumulation of the animal sample archive (game, animals found dead), the physical and chemical properties of samples	To be reported in 2012
Physical and chemical properties of fish in the neighbouring waters of Olkiluoto	To be reported in 2012
The soil	
Acoustic-seismic mapping and sediment drilling of the seabed, physical and chemical properties of the sediment samples	Rantataro & Kaskela 2009, Lahdenperä & Keskinen 2011
Digital models of the thickness and layer structure of soil	Mönkkönen 2012
Three excavator-produced pits, in which interpretation of the layer texture of soil and sampling of soil, physical and chemical properties of soil samples	To be reported in 2012
Characterisation and sorption investigations of the soil samples	Lusa *et al.* 2009, Söderlund *et al.* 2011, Virtanen 2011, Söderlund & Lehto 2012, a summary of the sorption investigations on Olkiluoto soil samples will be completed in 2012; the research programme will continue during the next period

Subject of research	Discussion on the subject
Land use	
Aerial photography in Olkiluoto and in western part of the Municipality of Eurajoki in 2009	Non-public material
Interpretation of changes in land use from maps dated 1840–2007	Koistinen & Käyhkö 2011

The key subjects of research during the previous TKS period regarding the actual assessment of biosphere are shown in Table 4-11. The feedback received from authorities after producing the programme for this period was as expected, and the biosphere assessment has been developed in line with the earlier identified needs, particularly

- by using a systematic scenario analysis covering several dozens of cases instead of the earlier method of only using one thoroughly analysed scenario,
- by supplementing the initial data for migration modelling both by site investigations and by increasing the amount of literature material checked from original sources,
- by taking into account the soil and short bore wells in the modelling of surface and soil hydrology as well as in migration modelling (as before, the deep bore wells are processed as separate cases on the basis of the disposal site properties),
- by taking into account different models of nutritional habits as alternative calculation cases,
- by paying particular attention to the illustrativeness of radiation dose calculation methods, particularly with respect to a group larger that the exposed group, and
- by re-organising part of the reporting so that the reports included in the biosphere assessment reporting portfolio (Figure 4-50) can definitely be produced before the deadline.

Table 4-11. *The key research subjects listed in the TKS-2009 programme regarding biosphere-related part of the safety case and the documents in which they are discussed.*

Subject of research	**Discussion on the subject**
Transparency, traceability and robustness	The subject has been a cross-cutting theme in biosphere-related work, and the goals have particularly been pursued • by revising the structure of the biosphere analysis report portfolio (Figure 4-50) and parts of its contents and role (particularly the *Biosphere Description* and initial data report (*Data basis for the Biosphere Assessment*)), • by specifying further the details and interfaces of the modelling chain, and • by tracking the actual origin of literature-based information and by adopting more systematic reference practices. The actual processing of the subject is shown in the safety case material to be submitted in connection with applying for the construction licence.
Sensitivity analyses, assessment of uncertainties and the degree of pessimism	The subject has been a cross-cutting theme in biosphere-related work, and the goals have particularly been pursued • by analysing several calculation cases made at all levels of modelling (scenario analysis), • by performing sensitivity analyses on an ecosystem-specific basis, both in connection with preparing for the actual modelling work and for the models used in the safety case, and • by processing the initial data as well as their uncertainties and degree of pessimism in an uniform manner in one compilation report (*Data basis for the Biosphere Assessment*). The actual processing of the subject is shown in the biosphere section of safety case material to be submitted in connection with applying for the construction licence.
Human intrusion to the repository	Posiva has actively participated in the international BIOPROTA project dealing with the subject (to be reported separately during 2012). The modelling results of the project will be applied to the disposal of spent fuel in Olkiluoto, and this work will be reported as part of the safety case to be submitted in connection with applying for the construction licence.

Topic (role in the biosphere assessment)	Report title
Main biosphere assessment reports	
Scientific basis: site understanding; description of the surface environment at the disposal site; features, events and processes; conceptual models	**Olkiluoto Biosphere Description** BSD-2012
Analysis of scenarios: biosphere synthesis (terrain development, geo-/biosphere interface, radionuclide transport, dose assessment)	**Biosphere Assessment** BSA-2012
Input data to biosphere assessment modelling and summary of the assessment models	Biosphere Assessment BSA-2012: **Data basis**
Supporting biosphere assessment reports	
Models and results on the evolution of the biosphere	Biosphere assessment BSA-2012: **Terrain and ecosystems development modelling**
Models and results on the geosphere-to-biosphere interface	Biosphere assessment BSA-2012: **Surface and near-surface hydrological modelling**
Models and results on the radionuclide transport modelling and dose assessment for humans	Biosphere assessment BSA-2012: **Radionuclide transport and dose assessment modelling**
Models and results on the dose assessment for the other biota	Biosphere assessment BSA-2012: **Dose assessment for the other biota**

Figure 4-50. *Report portfolio of the biosphere analysis, also included in the safety case report portfolio shown in Figure 4-47.*

4.6.6 Scenarios leading to the release of radionuclides

The climatic conditions and their development are deciding factors regarding the development of the entire disposal system, the underground repository and the biosphere.

Although the base, variant and disturbance scenarios cover the entire disposal system, the underground repository and the biosphere are treated separately for the purposes of scenario analysis. This is because they only share a few features, events and processes, (such as land uplift and its impacts on surface hydrology and developments in groundwater). In addition, Paragraph 360 of YVL Guide D.5 prescribes that the evolution of biosphere shall only be analysed for the period during which radiation can be estimated with sufficient reliability and which covers at least thousands of years (GD 735/2008), and in longer periods the activity releases at the bedrock-biosphere interface must be analysed (YVL Guide D.5, 312 and 311). Furthermore, is it not possible to apply exactly the same procedure to the underground repository and the biosphere, because no safety function has been prescribed for the biosphere.

The scenarios concerning the biosphere also deal with the base, variant and disturbance scenarios. The results obtained from scenario analysis regarding the disposal system cover releases during a few thousand years. In other words, the activity of radionuclides is dealt with in the biosphere scenario, with dose rates as the final outcome.

As discussed above (section 4.6.4.1), the great majority of canisters meet the requirements, i.e. are originally without defects. In compliance with YVL Guide D.5, the scenario analyses related to the release of radionuclides are based on the targets defined for the safety functions so that incidental deviations from the target values are taken into account. Therefore, the base scenario makes the assumption that one canister finally disposed of has a defect that penetrates the copper overpack and has a diameter of 1 mm, based on the analysis by VTT (Holmberg & Kuusela 2011).

In compliance with STUK's YVL Guide D.5 (draft 4, 22 September 2010), the safety case discusses in addition to the base scenario

- variant scenarios with which the impact of a significant deterioration of one safety function is assessed or, in case there are linkages between the safety functions, the joint impact of deterioration of more than one safety function, and
- disturbance scenarios dealing with the impacts of unlikely events that may impair long-term safety.

The performance analysis indicates that sulphide-induced corrosion is the most likely long-term process leading to the loss of safety function and performance of several canisters. In the variant scenario of TURVA-2012, the loss of the canister's safety function is combined with a deterioration of buffer performance. In other words, glacial water causes buffer erosion during the period after the glacier has retreated, and as a result, several canisters fail due to corrosion. Sevaral canisters may also fail as a result of an earthquake, classified as a disturbance scenario. The intrusion of people to the repository has also been treated as a disturbance scenario.

The modelling process regarding radionuclide migration has been developed, and new modelling software suites have been introduced. GoldSim software has been introduced for modelling the migration of radionuclides in the near-field. A Connect-flow MARFA package has been introduced for modelling the migration of radionuclides in the bedrock. The MARFA program has been supplemented with an analysis method for migration in transient flow fields. The migration of radionuclides in the biosphere is discussed in section 4.6.5. The results regarding bedrock migration have been better integrated as initial data for biosphere analysis. A database with acceptance procedures has been developed for recording and approving the initial data and results of different phases of modelling work. In addition to the deterministic calculation cases, a probabilistic analysis has also been performed using GoldSim software for modelling migration both in near-field and far-field.

The scenarios and results will be reported by the end of 2012 (*Formulation of Radionuclide Release Scenarios, Assessment of Radionuclide Release Scenarios* and *Biosphere Assessment*).

The work for modelling the migration of radionuclides using probabilistic methods is in progress, and the results will be reported by the end of 2012.

4.6.7 Matters to be elaborated further during the next YJH period

During the next programme period, the investigations supporting the safety assessment for the safety case work performed for the purpose of the operating licence application will continue. They include:

- empirical research into the dissolution mechanisms of fuel,
- development of models used in the climate scenario,
- research into the hydrogeological and geochemical conditions during an ice age,

- investigations and research related to the target properties of and future evolution in the bedrock,
- determination of radionuclide migration parameters, and
- acquisition of initial data and development of partial models for biosphere assessment.

In addition, the *Models and Data for the Repository System* report will be compiled as part of the TURVA-2012 portfolio in 2013.

4.7 Horizontal design KBS-3H

In the KBS-3H design, the canisters are placed in long horizontal deposition drifts (Figure 4-51). Unlike the KBS-3V design (reference design), the KBS-3H variant utilises a prefabricated installation package called a Supercontainer that is assembled in an industrial process at the canister reloading station before disposal, thus reducing the possibility of human error. The Supercontainer consists of a perforated protective shell made of titanium with a bentonite buffer and copper canister installed inside it. Several Supercontainers are installed into each deposition drift. The drifts are almost horizontal, and their maximum length is 300 metres. The drifts have a diameter of 1,850 mm, and they have a slight upward inclination (of about 2^o), which is why water is removed from the drifts by gravity along the bottom of the deposition drift during installation. The Supercontainers and the bentonite blocks installed in the drift stand on feet between which the inflow water can flow out of the drift. The gap between the Supercontainer and the drift wall is 44.5–48 mm.

The authorities have imposed the same requirements for both KBS-3H and KBS-3V, and both designs were presented as solutions in the decision-in-principle. In both designs, the multiple-barrier system is based on favourable and predictable mechanical, geochemical and hydrological bedrock conditions, on a canister having a long service life and a buffer that together ensure long-term protection against mechanical, hydraulic and chemical impacts. The transport of radionuclides released as a consequence of the possible failure of the canister will be slowed down by both the buffer and the bedrock. The factors limiting the release of radionuclides also include the stable fuel matrix and the low solubility of many radionuclides in the chemical conditions expected to prevail inside the damaged canister.

The results for the KBS-3H variant in the work undertaken during the project phase entitled "Complementary studies 2008–2010" now ended, are presented in greater detail in (SKB 2012). The main changes compared to the previous design (Autio et al. 2008) are as follows:

- The DAWE (Drainage, Artificial Watering and air Evacuation) alternative chosen as the reference design for KBS-3H.
- The drift end plug of concrete construction / compartment plug combination has in the new design been replaced with a drift plug made of titanium.
- The risk related to the removal of wetting pipes used for artificial water filling of the compartment has been considerably reduced on the basis of the bentonite erosion studies conducted by replacing the long wetting pipes with short ones.

- Titanium has been selected as the material for the protective Supercontainer shell as well as for the compartment and drift plugs, thus minimising the generation of hydrogen in the deposition drift.
- Design solutions have been produced for the filling components.
- Conceptual designs are in place for the reloading station and the process of transferring the Supercontainer from the reloading station to the deposition area.
- The layout adaptation of the repository has been updated, largely on the basis of the 3V layout.
- Interactions between bentonite and the materials considered for Supercontainer shell (Fe, Cu and Ti) have been investigated. Following the investigations, the decision was taken to use titanium as the material for the Supercontainer shells.
- Full-scale compartment plug tests have been carried out.
- Post-grouting was already tested using Mega-Packer equipment during an earlier project phase.

4.7.1 KBS-3H specific characteristics

In spite of their similarities, there are still differences in the assembly and function of the KBS-3V and KBS-3H designs. From the design perspective, the main difference is that the rock volume excavated for KBS-3H is smaller, which also means that less backfill material is required. The differences in canister installation operations are also considerable. A comparison analysis of the KBS-3V and KBS-3H designs (Gribi et al. 2007) has indicated that from the long-term safety point of view, the main differences are related to KBS-3H specific characteristics variant, such as the Supercontainer and other drift components, as well as to the changes they cause in the hydraulic conditions of the long deposition drift and its immediate vicinity. Empty gap will be left in the installation around the Supercontainers and distance blocks, and this gap will be filled as water causes the bentonite to swell (saturation of the buffer). However, the time taken by this process may vary in different parts of the long deposition drift due to the heterogeneity of the bedrock and the variable flow conditions of groundwater. As long as there are spaces that are only filled with water, it is possible that erosion and the resulting formation of water channels (piping) in the bentonite may cause the redistribution of buffer material in the deposition drift. Taking the heterogenic flow conditions in the deposition drifts into account and finding a solution for them so that the performance of the buffer is not compromised has been the subject of development in the technical design work for KBS-3H.

4.7.2 Description of the selected DAWE reference design

The DAWE (Drainage, Artificial Watering and air Evacuation) design alternative has been chosen as the reference design for the KBS-3H variant. Consequently, the deposition drift is divided into two compartments with an approximate length of 150 m each. The Supercontainers and other components are installed in the deposition drift through the deposition niche, one compartment at a time starting from the rear (Figures 4-51 and 4-52). In special cases, the deposition drift may be divided into more than two compartments when required. A compartment plug will be constructed between the compartments in order to facilitate the artificial water filling of the inner compartment. The gap between the components installed in the drift and the drift wall is filled by artificial water pumped through three short tubes installed in the throughputs in the plug. The fourth tube, also installed in a throughput in the plug, extends all the way to the upper corner at the bottom of the drift where the air pocket is formed during artificial water filling. After this, all tubes are removed and the plug throughputs are sealed. Artificial water filling will accelerate the swelling of bentonite and make it happen simultaneously throughout the drift compartment. The development of swelling pressure is important for limiting the spalling of the bedrock. Installation of the Supercontainers and other components in the next compartment begins immediately when the compartment plug throughputs have been sealed off. The deposition drift is finally closed using a drift plug made of titanium, after which artificial water filling of the compartment is performed in the same manner as for the compartment sealed with the compartment plug (Figure 4-51).

The distance blocks made of bentonite isolate the Supercontainers from each other in the deposition drift. Together, the bentonite contained inside the Supercontainers and in the distance blocks constitute a release barrier called the buffer. For those parts of the deposition drift that do not meet long-term safety requirements and design requirements (e.g. too large inflow of groundwater to the deposition drift; the criterion being 0.1 litres/min per Supercontainer + distance block) and cannot be used as a disposal position for a Supercontainer or distance block, filling blocks made of compressed bentonite are used. In addition to the filling blocks installed in these leakage points, other filling components are also installed in the deposition drift, such as for filling the empty spaces left on both sides of the compartment plug and inside the drift plug. The design of the filling for the drift section between the drift plug and the central tunnel will be solved during the current project phase.

The short bottom section of the pilot hole at the end of the drift and the curved end wall created by the reamer head used for excavating the deposition drift will also have to be taken into account by installing filling components in them, also made of compressed bentonite. The underlying reason for these solutions is the requirement regarding the density of buffer bentonite (after saturation). The gap between the bentonite blocks (distance blocks, filling components) and the drift wall is 42.5 mm.

Figure 4-51 shows a principal illustration of the KBS-3H deposition drift and the components installed in it through the deposition niche. The deposition niche is located between two parallel central tunnels. Another deposition drift can be excavated from the deposition niche in the opposite direction. The compartment plug (made of Ti) divides the drift into two compartments. The drift is closed with a drift plug (Ti). The canister is located inside a Supercontainer, surrounded by bentonite blocks and a perforated protective shell made of titanium. The distance blocks isolate the Supercontainers from each other. Filling components made of bentonite are used in places where inflow water exceeds the positioning criterion. Filling components, transition blocks and pellet filling section, all made of bentonite, are used in connection with the drift plugs and compartment plugs between them and the nearest distance block. This section of the drift is called the transition zone. Its purpose is to prevent changes in the density of the nearest distance block.

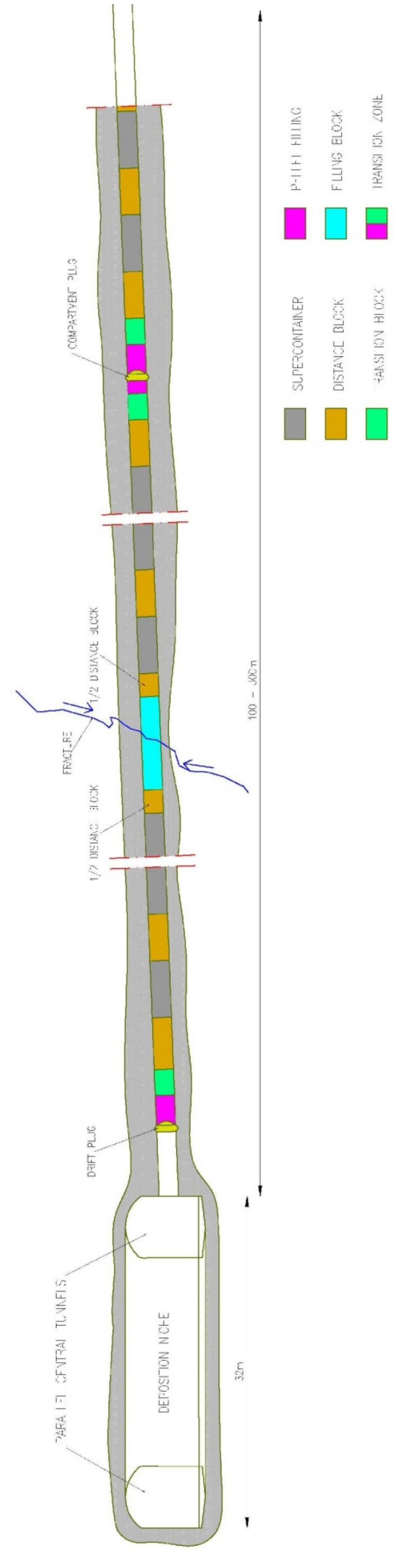

Figure 4-51. *Principal illustration of the KBS-3H deposition drift and the components installed in it through the deposition niche.*

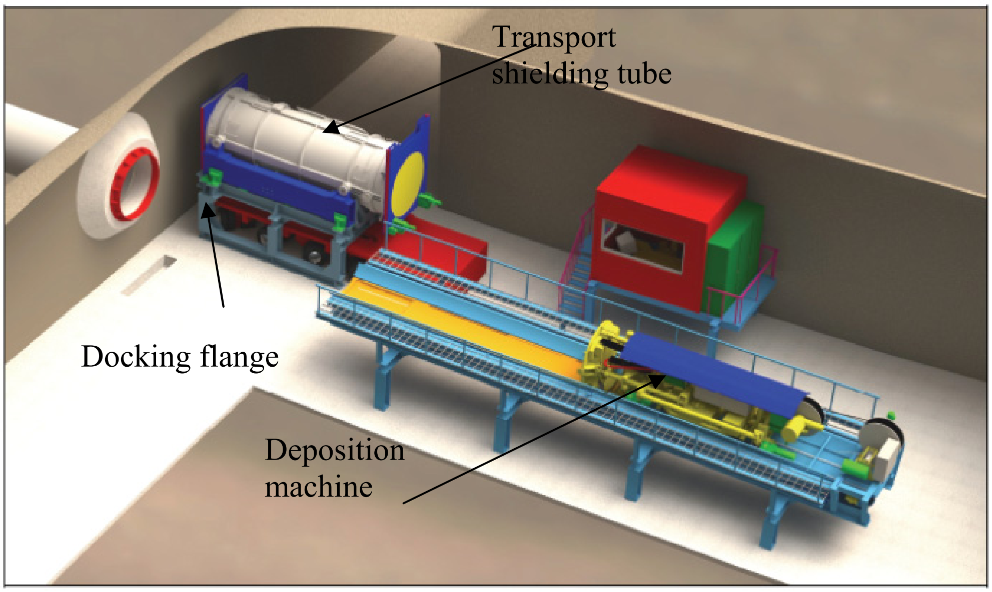

Figure 4-52. *The canister transport vehicle carrying a transport shielding tube (containing a Supercontainer) on the support has been driven to the deposition niche and turned parallel to the deposition drift. Next, the transport vehicle moves the transport shielding tube sideways between the docking flange at the drift opening and the deposition machine (modified, Kirkkomäki & Rönnqvist 2011).*

Before commencing the installation phase, the drift sections unsuitable for the positioning of Supercontainers or distance blocks due to the fact that the inflow water criterion is exceeded will be post-grouted using colloidal silica and Mega-Packed equipment designed and tested earlier during the project. Grouting of the bedrock makes the conditions favourable for installation work and reduces the erosion of bentonite during installation work.

4.8 Nuclear material safeguards

4.8.1 National and international control

The national nuclear materials control is based on the Nuclear Energy Act and Decree and regulations issued pursuant to them. One of the purposes of the nuclear material safeguards system maintained by STUK is to ensure that the obligations of international treaties are fulfilled. With its membership in the EU, Finland is bound by the Euratom Treaty establishing atomic energy cooperation in the community. In its control system, STUK takes into account the obligations pursuant to Regulation No. 302/2005 of the European Commission (European Commission 2005). The controls set by the IAEA are based on the Nuclear Non-proliferation Treaty (NPT) and the control agreement concluded between the nuclear weapon-free EU Member States, Euratom and the IAEA (INFCIRC/193), and its additional protocol (INFCIRC/193/Add.8). The IAEA and the Commission are jointly implementing the Integrated Safeguards model. The IAEA has produced integrated safeguards models for the encapsulation plant and the disposal facility.

The construction of the Underground Rock Characterisation Facility ONKALO began in 2004. The nuclear non-proliferation controls implemented during the construction of ONKALO facilitate the integration of ONKALO as part of the future repository. An application for the construction licence prescribed in the Nuclear Energy Act will be submitted regarding both the encapsulation plant and the disposal facility in 2012. Once Posiva has submitted the construction licence application, it will deliver an update of the basic technical characteristics regarding the encapsulation plant and disposal facility to the Commission for the purpose of organisation and planning of international controls. Pursuant to the additional protocol, a site declaration is submitted to STUK on an annual basis.

4.8.2 Nuclear non-proliferation control regarding ONKALO

The purpose of Posiva's nuclear non-proliferation control is to ensure compliance with the relevant legislation and international treaties governing the matter during the construction phase of ONKALO. Posiva has produced a nuclear non-proliferation control manual that describes the control during the construction phase of ONKALO. The manual is updated as required. The manual defines the design information, as-built and monitoring data concerning ONKALO that is reported three times a year to STUK. In addition, STUK carries out inspections, including the inspections of the ONKALO rock facilities and periodic inspections of the entire nuclear non-proliferation control system. Every year, STUK performs three periodic inspections of the control measures, one of them typically as a joint inspection with the IAEA and European Commission. No objections concerning nuclear non-proliferation control have been raised in these inspections.

The control and monitoring of excavation work in underground rock facilities is based on the requirement to demonstrate that ONKALO does not include any facilities which are not indicated in the design data. The control produces as-built images describing all excavation and construction work carried out in four-month periods. The as-built images are supplemented by laser scanning images showing all of ONKALO contours with an accuracy of a few millimetres. The laser scanning images are produced in 300-metre sections. Monitoring utilizes the micro-seismic network built in Olkiluoto; the surveillance data of the network provides up-to-date information about blasting in Olkiluoto and in the nearby area. This system has proven to be a good method for monitoring the excavation operations from the outside.

The construction licence application will contain a plan of the nuclear material safeguards organised during the construction and operation of the encapsulation plant and disposal facility. The plan covers the transfer chain of spent nuclear fuel from the interim storage facilities via encapsulation to final disposal. Nuclear material safeguards require that nuclear material is constantly under control. During the operation of the repository, the control is based on the verified recording of all nuclear material entering the facility during different phases of the disposal operation and on ensuring that no nuclear materials leave the disposal facility.

4.8.3 Organisation of nuclear non-proliferation control

Posiva's nuclear non-proliferation control manual provides instructions for producing the required reports, and for the preparations for inspections. A person in charge of the construction of ONKALO has been appointed by Posiva and approved by STUK. The nuclear-non-proliferation controls in ONKALO are the responsibility of a designated person and his/her deputy, both approved by STUK.

During the processing phase of the construction licence application, Posiva will appoint the persons required in the Nuclear Energy Decree and have them approved. They are the director in charge of the nuclear facility and the persons looking after the nuclear material control as well as the security and emergency response arrangements. The nuclear non-proliferation controls, later the nuclear material safeguards, will be implemented in Posiva's Safety Unit.

4.9 Licensing

Posiva's primary target is to submit the construction licence application during 2012. During the preparatory work for the application, the dialogue with authorities (the Ministry of Employment and the Economy and STUK) has been intense and open. The cooperation has been based on the principle that the authorities shall have a correct picture of the progress of the project and the challenges it faces.

The requirements regarding the contents of the construction licence application are set out in sections 31 and 32 of the Nuclear Energy Decree. The reports to be sent to STUK at the same time are listed in section 35 of the Nuclear Energy Decree. Pursuant to this section, STUK has in its YVL Guides required several separate reports to be submitted to it in this connection.

The construction licence application is based on the licensing phases described in section 4.1 and on the reports produced and feedback required during them. The received feedback has been analysed systematically by Posiva, and the conclusions have been included in the preparatory work for the construction licence application. Examples of taking the feedback into account include the attention paid in the actual application to fuel transports and their risks, retrievability of the fuel, up-to-dateness of the EIA report, as well as to the other licences, permits and decisions required. The statement issued by STUK regarding the pre-licencing material submitted in 2009 listed several areas of development. They have been and will be taken into account in the further development of the material referred to in section 35 of the Nuclear Energy Decree.

Extensive practical preparations are being made by Posiva and the expert organisations it employs. The application material will be inspected by Posiva in compliance with the principles applicable in the nuclear industry, while its main parts will also be inspected by Posiva's owner organisations. High-level statements of expert opinion, independent of the designers, will be sought regarding the plant design documentation and the safety analyses. Most of the conceptual design work for the plant will be completed by the end of 2012. However, the concept will at that stage also include alternative implementation models in addition to the reference designs, and the choice between them will only be made during the construction process. These alternatives will also be included in the application at this stage. The implementation plans and the resulting updated system descriptions as well as the equipment- and structure-specific construction plans will be completed before the procurement of the subject equipment or structure starts. The preliminary versions of operational safety analyses (deterministic and probabilistic) will be completed during 2012. The safety analyses will be updated at least once before the operating licence phase. The majority of reports on long-term safety will be completed during 2012. The expected delays have been discussed with STUK. The reports on long-term safety will also be updated at least once before the operating licence phase. The expected progress of the project during 2013–2018 is discussed in Chapters 5 and 6 of this nuclear waste management programme.

The intention is to integrate the underground research facility ONKALO as part of the future disposal facility during the construction licence phase. This is possible because the construction of ONKALO has been carried out using the procedures prescribed in nuclear facility legislation and under the regulatory oversight of STUK. In addition to the empirical information and experience gained in the construction process, the construction of ONKALO has also provided useful experience for Posiva and authorities regarding the application of regulations and oversight procedures, primarily developed with the nuclear power plant environment in mind, to Posiva's field of activity. In its present state, ONKALO consists of investigation niches and an access tunnel leading to them, as well as of structures and systems located both underground and above ground for supporting the safe working conditions in the investigation niches. The adjustments made over the years to the extent of ONKALO have been discussed in advance with STUK. At present, ONKALO does not include any systems, equipment or structures classified according to the three-level safety classification system.

The design and validation of safety-classified systems is done using the procedures described in STUK's future YVL Guides B.1 "Design of safety systems" and B.2 "Safety classification". The maturity of system design is demonstrated with the system descriptions included in the safety report. The conformity of the systems is checked by system-specific trial runs and joint operating tests of the systems. The validation of safety-classified equipment and structures is carried out in accordance with the instructions shown in the E series of YVL Guides. Due to the fact that the YVL Guide reform process is still in progress, STUK has decided that Posiva may use draft guides (L4) and STUK will make guide-specific application decisions regarding Posiva. The definition of requirements for equipment and structures and the design data based on them, including quality control plans for procurement, will be presented as part of the construction plans. Each piece of equipment and structure will be subjected to a structural inspection. The party carrying out this inspection will be determined on the basis of the applicable safety class. The validation of systems and equipment will be described in Posiva's quality system.

The information and rationale regarding the KBS-3H concept will be presented in their entirety in the subject-specific report related to the PSAR and submitted to STUK.

5 RESEARCH AND DEVELOPMENT REGARDING THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL DURING 2013–2018

5.1 Basic premises

TVO and Fortum, the companies with the nuclear waste management obligation, have commissioned Posiva to make the preparations for the disposal of spent nuclear fuel. The work has been done adhering to the objectives set out for it already during the 1980s, according to which it must be possible to commence disposal operations around 2020. The research and development programme initiated in 1983 with the aim of constructing a disposal facility for spent nuclear fuel is about to achieve one of its important milestones as the last, verifying phase of the investigations aimed at selecting the site is completed with the construction licence application in 2012.

The schedule for the final disposal of spent nuclear fuel is based on the decisions by the Government and the Ministry of Trade and Industry, according to which the planning of disposal in Finland shall be based on the premise that spent nuclear fuel will be kept in interim storage until its final disposal can commence around 2020. The most recent decision by authorities setting out the target schedule (KTM 9/815/2003) states that the parties under the nuclear waste management obligation shall, either together, separately, or through Posiva, "*prepare to present all reports and plans required for obtaining a construction licence for a disposal facility for spent nuclear fuel as referred to in section 32 of the Nuclear Energy Decree by the end of 2012, on the basis of which the disposal facility can be constructed so that disposal operations can commence in 2020.*"

Posiva's work is aimed at facilitating the commencement of disposal in line with the ministry's decision. However, there are many factors affecting the schedule, such as the time taken by the authorities to process the construction licence application, or the duration of the construction phase. The schedule will be defined further in connection with the construction licence process and in the YJH programme document to be submitted in September 2015. The objective of *"disposal operations can commence around 2020"* allows a few years' tolerance regarding the exact date of commencement.

In order to meet the target schedule, the construction of the nuclear waste facilities, i.e., the encapsulation plant above ground and the underground disposal facility, must commence around 2015 provided that the construction licence application takes a few years to process. The underground construction work will involve supplementing the connections to the ground level by vertical shafts and the excavation of the actual central and deposition tunnels from the facilities constructed in ONKALO; these tunnels will be required for commencing the disposal operations. The operating licence prescribed in the Nuclear Energy Act for commencing disposal operations will be applied for from the Government in good time before the planned commencement. The time for submitting the operating licence application can be estimated more accurately in connection with the YJH programme to be produced in 2015.

The focal areas of the research and development work presented in this programme report are, as illustrated in Figure 5-1, the production of materials required for the construction licence application, facilitation of the commencement of licensed operation, and the creation of capabilities for the functions required in final disposal.

Once the construction licence application has been submitted, during the period 2013–2015, the work will concentrate on testing and demonstrating the practical implementation of the disposal system. The intention is to test the equipment and components required for operating the facility. In practice, this means testing the practical equipment construction work in full-scale installation tests. These tests will be conducted in the tunnels constructed in ONKALO for the purpose. The system-specific tests are carried out for verifying the operability of the plans presented in the construction licence application and for making further adjustments to the plans, as required, on the basis of the experience gained. Adjustments to the plans will also be made on the basis of feedback received from the construction licence application process.

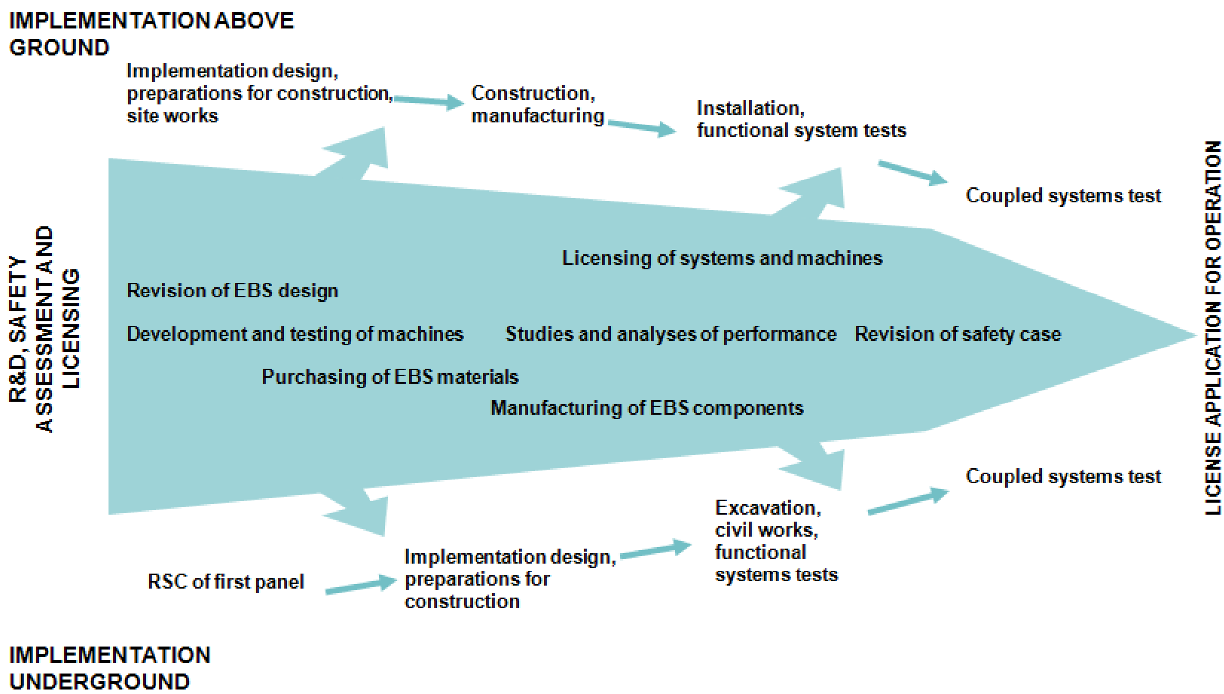

Figure 5-1. *Research and development work, safety assessment and the licensing process are the key tasks to be undertaken during the period 2013–2018 for achieving the readiness to submit the operating licence application.*

A separate implementation plan will be produced for these tests to be conducted in ONKALO. Its purpose is to ensure that these demanding tests are performed in a controlled manner and that the results are representative. Each test will be planned, its location characterised and the limiting conditions of the surroundings determined. Model forecasts will be utilised for planning the tests and for monitoring the results during the tests. Once the tests have been completed, the information gained when dismantling them will be used for revising the plans for the engineered barrier system and for planning future joint operation tests.

The development of the horizontal disposal solution KBS-3H will continue with full-scale tests in cooperation with SKB provided that the work carried out so far has produced positive results regarding further development and the solution meets the safety requirements. The goal is to supplement the documents presented for this solution in the construction licence application so that it could be included in the operating licence application alongside the vertical solution.

In order to meet the target schedule set for final disposal, the operations aimed at constructing the disposal facility should begin in 2015. For this purpose, a sufficiently extensive bedrock volume must be characterised so that the suitability of the bedrock can be assessed using the set criteria. With this in mind, the rock suitability classification (RSC) scheme will be developed to the required standard so that the overseeing authority can approve the proposed procedure and give permission to commence excavation work on the basis of the plans based on it.

Resources will be invested in the solutions for the engineered barrier system and in demonstrating their conformance. STUK has expressed its views on safety issues in its statements regarding the pre-licencing material submitted by Posiva in 2009, in the feedback it has given for the reports submitted after that as well as in its statement regarding Posiva's TKS-2009 programme. They are related to various matters including the gasket solution for the canister insert lid, moisture protection of the buffer during installation, the optimisation of buffer pellets, the solutions related to backfill materials and backfill operations, as well as to the foundation layer solution for the deposition tunnel, the plug solution and the closure solutions for the shafts. The development work regarding these issues is aimed at solving most of them during the programme period so that construction plans can be produced for the canister, the buffer, the backfill solution and plug for deposition tunnels as well as the closure solutions for all other facilities. Production of the construction plans requires that the sufficient performance of all factors important to safety can be reliably demonstrated. The same requirement applies to producing the safety case required for the operating licence application.

In order to achieve the preparedness to apply for the operating licence, it must be possible to use components planned and manufactured for the disposal operations in the operational tests. That is why their procurement and manufacturing procedures will be developed to such a state that they allow for ensuring the usability of each component for disposal purposes in a nuclear facility. The objective is to develop the procedures and obtain an official approval for the product compliant with them. The intention is to utilise the cooperation with SKB of Sweden in the procurement and manufacture of components for the engineered barrier system.

The results of development work for the engineered barrier system and the experience gained in the testing of its installation will be combined in the joint operating test. That refers to a tunnel built in compliance with the requirements applicable to the deposition tunnels of the repository and to an installation of the KBS-3V solution carried out in it, albeit without spent fuel. The joint operating test will be set up by using equipment and components developed and procured for final disposal purposes and licensed for their intended use. The joint operating test is intended for demonstrating in practice that the initial state required for long-term safety can be verifiably achieved. This will demonstrate that final disposal operations can begin.

The purpose of the joint operating tests conducted above ground is to demonstrate the degree of preparedness of these plants and functions. However, the intention is to conduct the joint operating tests underground and above ground as separate tests independent of each other.

The following sections will discuss in detail the objectives of research and development for the period 2013–2015 and in an outline fashion for the period 2016–2018.

5.2 Nuclear fuel characteristics, information management and long-term safety research

5.2.1 Nuclear fuel characteristics

Spent nuclear fuel and its characteristics will be described in the system descriptions produced during 2012. The descriptions will be produced based on a plant type (OL1/OL2, OL3 and LO1/LO2) so that nuclear fuel type specific data sheets will be attached to each of the system descriptions thus produced. The system descriptions will be based on the system descriptions of fresh nuclear fuel produced by the owners, supplemented with information regarding the changes due to reactor use and storage in interim storage. In particular, the system descriptions will contain information that is relevant to the technical arrangements and safety analyses for final disposal. System descriptions will be specified based on further information received from analysis, research results and operation experience as well as feedback received related to the construction licence application throughout period 2013–2018. However, the system descriptions will not cover estimates of the long-term behaviour of nuclear fuel under disposal conditions (among others solubility and oxidation). The system descriptions will be attached to the preliminary safety analysis report (PSAR) to be submitted to STUK in connection with the construction licence application.

The nuclide-specific activity inventories are the basis for all radiation and nuclear safety analysis (including long-term safety and criticality safety). The nuclear fuel data presented in the construction licence application is based on a report by Anttila (2005a) combined with the owners' estimates of the accumulation of spent nuclear fuel. The intention is to update the above-mentioned report before 2018 for the purpose to produce required reports for the operating licence application. The activity inventory of the constructional parts and of impurities in the nuclear fuel will particularly need updating. The development of nuclear fuel and computer models has also brought up the need to update the report. During the operating phase, it makes sense to perform the analyses and calculations using actual nuclear fuel data.

The demonstration of criticality safety, both with regard to operational safety and long-term safety, is a prerequisite for obtaining the construction licence. The current understanding of criticality safety is based on a report by Anttila (2005b). Based on the above mentioned report criticality safety could be shown by plant technical design solutions, selection of fuel assemblies and burnup credit. From the perspective of long-term safety, the use of burnup credit will require further analyses which are presently performed and results will be available and attached to application documentation. It could be presumed that investigation will continue in a working group with representatives from the owners, Posiva, VTT and STUK, particularly with respect to high enriched nuclear fuel of OL3 unit, also after 2012. International cooperation relevant to the issue is also taking place; among others in order to harmonize criteria.

5.2.2 Management of nuclear fuel data

The data of spent nuclear fuel to be disposed will be collected and managed in a nuclear fuel data base maintained by Posiva. The data base will include mechanical and nuclear design data of each fuel assembly, operation history relevant for final disposal as well as required data for nuclear waste and nuclear material accountancy. The intention is to also include in this data base information related to handling of nuclear fuel (transports, measurements, encapsulation, interim storage, inspections, verifications) as well as the required calculation tools to the extent required by Posiva. The development of the fuel data base will continue in cooperation between TVO, Fortum and Posiva. The system will be implemented by 2018.

Discussions have taken place with the owners regarding the need to investigate the reliability of data related to the fuel assemblies removed from reactor use and the impact of errors on the selections to be made. In particular, the computational method used for residual heat calculations of the nuclear fuel used in Loviisa will need empirical and/or computational verifications. A calorimetric project, carried out as a thesis work, is being initiated at Fortum in this connection. Additional empirical investigations will be conducted on the basis of the thesis work as required, and they will form the basis of conclusions regarding the reliability of calculations for the residual heat of Loviisa fuel and regarding any routine verification measurements.

The new guideline concerning nuclear material safeguards being prepared at STUK, YVL Guide D.1, includes the requirement that the integrity of fuel assemblies has to be verified (for the purpose of nuclear material safeguards) by measurements. According to STUK's interpretation, these measurements by authorities (STUK, IAEA) must be performed at the encapsulation plant. For Posiva, preparing for the safeguards measurements will require space reservations in the handling cell of the encapsulation plant. The measurement method, still under development, will also carry significant risks regarding the passing time of the whole disposal process.

5.2.3 Long term safety research of spent nuclear fuel

During the period 2013−2018, the fuel research related to long-term safety will concentrate on accumulating additional information (or on confirming the current assumptions) on the initial state of fuel as well as on the development of knowledge of the input term used in the calculations regarding the release and migration of radionuclides (RN). A subject of particular interest is the release of radionuclides from high burnup fuel, given the latest international trends on the use of fuel in the reactors.

The most important parameters related to the initial state of spent fuel and its role as the source term for the radionuclide release and migration calculations are the radionuclide inventory and how it is divided into the four fuel components (pores, fuel matrix, structural components made from Zirconium alloys and other metals). In 2011 re-assessment of the RN inventory presented by Anttila (2005a) it was found that the used inventory is still valid because it covers fuel with a maximum burnup 60 MWd/kgU, and no major changes have been made to the fuel construction or materials. This burnup level could be considered conservative for the purpose of the safety assessment. The need for updating the RN inventory for the FSAR will be reconsidered in the light of the permitted burnup levels and the latest research results of fuel designs.

The most important issues for the course of development regarding the fuel and the model used in the radionuclide release and migration calculations are the early release of radionuclides, particularly from high burnup fuel, as well as the dissolution process of UO_2, which is one of the most important parameters regulating the long-term releases.

High burnup fuel solubility investigation will continue until 2015 in the FIRST Nuclides project initiated in 2012 under the EU's framework programme. "First-Nuclides Fast / Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel" is a Euratom project (FP 7) aimed at obtaining further information on the fast IRF (instant release fraction) radionuclides released from disposed high burnup UO_2 fuel (about 55 MWd/kgU). The project started in January 2012 and will run for three years. Two OL1 fuel rods are stored in Studsvik, where they have been subjected to a post-irradiation examination (PIE). Fission gas release measurements has been performed 2010 for these rods using a pucture method.

The fuel solubility investigations in natural groundwater and research of the impact of the fuel surface properties on solubility will also continue in a REDUPP project initiated in 2011 under the EU's framework programme. REDUPP is a three-year (April 2011 − April 2014) cooperation project under the Seventh Framework Programme of Euratom (European Atomic Energy Community). The project will investigate how the surfaces of solid materials with fluorite structure – UO_2, ThO_2, CeO_2 and CaF_2 – change over time with dissolution and how these changes affect the dissolution rate. Both estimate calculations and laboratory tests are performed in parallel in the project for monitoring the dissolution of crushed synthetic material. Empirical data will guide the calculations and vice versa, thus resulting in a computational model to describe the development of surfaces with a fluorite structure during the dissolution process. The ultimate goal of the REDUPP project is to reduce uncertainties regarding the dissolution rates of spent nuclear fuel used for release and migration calculations.

Posiva is planning to qualify other assumptions regarding source term (such as distribution of radionuclides, fluctuation range of fission gas releases, crud (corrosion product deposit on fuel surface, Chalk River Unidentified Deposit) as source term, the release rates from components made from Zirconium alloys or other metals) with the help of an assessment performed by Fortum and TVO based on actual data on the material composition and quantities. Fortum and TVO are currently in the process of creating a database of spent fuel together with Posiva.

A probabilistic sensitivity analysis (see section 4.6) is currently being performed for the purpose of testing the effect of certain parameter values on the release and migration of radionuclides. The parameters tested for the fuel are the IRF values, the inventory and distribution of stabile elements, the crud inventory and the solubility limits. The results will be published by the end of 2012, and they will show the parameter uncertainties that have the biggest effect on the radionuclide release and migration calculations. The results will also guide the work for collecting fuel data during the period 2013−2018.

The work for developing the long-term criticality scenario(s) will continue in compliance with STUK's requirements (draft YVL Guide D.3). The cooperation between Posiva, Nagra and SKB initiated in 2010 will continue in the form of periodic workshops discussing this issue. The subjects for investigation are: identification of those FEPs that might lead to a critical situation (such as corrosion, dissolution of fuel), the types of situations as well as the critical situations inside and outside the canister, their geometrical prerequisites and probability, the consequences of critical situations and possible modelling of the radioactive release.

In the safety case for KBS-3H, the fuel, i.e., the source term for analyses, is taken into account in the same manner as in the safety case compiled regarding the KBS-3V alternative for the construction licence application.

5.3 Properties of the disposal site

5.3.1 Characterisation and modelling of the disposal site

The main objective of characterising and modelling the disposal site is to produce, by the end of 2016, an updated site description report (Olkiluoto Site Description 2016). The report is part of the background material related to the operating licence application for the disposal facility. It will be used for producing the safety assessment (FSAR) and for updating plant plans. The report will contain updated model descriptions of each area of the site investigation work. Among other things, they contain all available information on the investigations conducted in the eastern area and in ONKALO.

During 2013–2015, the investigations will concentrate on the open issues discovered in connection with the 2011 site report and on matters raised in official assessments. The key issues requiring further investigations and studies during the next research period are the uncertainty factors related to the Olkiluoto site model 2011 (section 4.2.1):
- Characterisation of the disposal planning area and particularly its eastern part for the purpose of improving the reliability of the geological and hydrogeological structure model.
- More in-depth understanding of the state of stress and strength of the bedrock, particularly in disposal depth conditions.
- Description of hydro-geochemical processes (such as the formation of sulphides, the origin of methane and redox conditions).
- Determination of the matrix properties of the bedrock (porosity, thickness, diffusivity...) at the disposal depth.

When planning the research programme, the key findings in STUK's statement regarding the TKS-2009 programme (STUK 5/H48112/2009, 5 October 2009) were taken into account. The main comments raised by STUK are consistent with the open issues discovered during the process or producing the site model:

- The eastern area has not necessarily been sufficiently characterised and modelled.
- There are uncertainties related to the differences in salinity in pore waters and groundwaters.
- The total buffering capacity has not been sufficiently investigated.
- The state of stress in the bedrock has not been sufficiently investigated. In particular, the plans for bedrock stability investigations at the disposal depth have scope for improvement.

5.3.1.1 Surface hydrology

The surface hydrological model is used for describing the water flows in the soil and the movements of groundwater in the top sections of the bedrock. The surface hydrological model can be used to calculate the components of the water balance of Olkiluoto island and to predict the impacts of ONKALO construction work and the Korvensuo basin on the water balance. During 2013−2018, the current surface hydrological model will be maintained and developed by, for example, introducing new features in order to improve the applicability of the model to different calculation cases.

Maintenance of the surface hydrological model

The production of a short-term prediction system for the hydrogeological impacts of ONKALO construction work is an important part of the surface hydrological modelling work undertaken during 2013−2018. The prediction system and the model associated with it facilitate responses to exceptional decreases in groundwater level caused by different types of leaks and investigations into the possible root causes of these decreases. They may take place in the bedrock fracture zones or the matrix. The model can be supplemented with local zones not included in the hydrogeological structure model on the construction site scale. This allows investigating whether the local zone can explain the exceptional behaviour of groundwater.

The work for modelling the infiltration experiment will be continued by specifying further the zone model of the test area bedrock and by adding the local zones concerned to the surface hydrological model. The analysis of water flow paths will be continued in the test, and the objective is to obtain confirmation for the modelling results from the measurement data produced by the monitoring programme (e.g. the geochemical measurement data).

Addition of new features to the model

In connection with the short-term prediction system, the surface hydrological model will be supplemented with a new section that allows assessing the origin of the water inflows in ONKALO's access tunnel and shafts and the water entering the zones (soil layers, the Korvensuo basin, sea water). The particular objective of the prediction system is to calculate/predict any changes in the migration routes. Such an update is performed two or three times a year. In connection with the prediction system, the modelling of impacts of the Korvensuo basin will continue in line with the plans outlined in the TKS-2009 programme (calculation of particle migration routes and the age of water).

Forecasts of the development of salinity, both for the structures and the bedrock matrix, will be added to the model prediction system. In the first instance, the model will be recalibrated by using both pressure measurements and observed changes in salinity as the benchmark for functionality. The calibration material for the model includes the dynamic changes in pressure head and salinity in the zones and in the bedrock matrix during the period when the construction of ONKALO has been in progress (i.e., since 2004). The prediction system will be developed so that the model is capable of producing both short-term (less than 1 year) and long-term (100 years) estimates of the impacts of permanent and temporary leakages on the development of salinity in the zones and in the bedrock matrix. The short-term predictions for salinity are updated two or three times a year, while the long-term prediction is computed once a year. Investigations into the probability distribution of the main parameters of the model will continue in connection with recalibrating the model.

During 2015−2018, the possibilities for adding a geochemical partial model to the surface hydrological model will be investigated. That would allow assessing the impacts of ONKALO's leaks and the Korvensuo basin on the chemical behaviour of bedrock groundwaters in the structures.

The reporting plan regarding surface hydrology for 2013−2018 is as follows:
- Development of the salinity model and reporting the tests in a 2012 working report.
- Posiva report on the surface hydrological model (2014/2015).
- Reports associated with the Olkiluoto site description for the surface hydrological model in 2016.
- Working report on the possibilities for appending the geochemical partial model as part of the surface hydrological model (2016/2017).

5.3.1.2 Geology

The drilling operations in the eastern area were completed in early 2012, and the geological and geophysical results obtained from them will help to specify further the geological model of the eastern area in the coming years. The geological model of Olkiluoto will be updated during 2012 and 2013 (version 3.0), and it will be published during 2013 in a Posiva report entitled *Geology of Olkiluoto*. In addition to the investigation results of the eastern area, the initial data used for the new geological model includes supplementary mapping of exposed bedrock areas and structural interpretations, new lineament interpretations and research results from ONKALO.

Version 3.0 of the geological model will use a similar internal structure as was used for version 2.0 (Aaltonen et al. 2010), but the intention is to achieve more advanced integration. As the intention is to produce a comprehensive overall picture in the model report and to present in a compiled and traceable manner the interpretations made of the geology of Olkiluoto, the model presents, among other things, a more detailed migmatite classification. The previous rock type categories will remain in use, but, for example, the internal structure and properties of veined gneiss and diatextitic gneiss units will be described using migmatite categories. Mapping material and photographs from exposed bedrock areas and the tunnel have been used for the new migmatite interpretations. The TGG rock type categorisation (tonalitic-granitic-granodioritic gneiss) will continue to be used, but, for example, in maps these rocks can also be divided into the following three categories: supra-crustic rock, mafic magmatic rock and felsic magmatic rock. The results of alteration investigations will be reported as a separate Posiva report, and a summary of the subject will be presented in connection with version 3.0 of the geological model. The chemical properties of altered rocks will be further investigated, and the alteration index will also be further developed to correspond better with the processes that have taken place in Olkiluoto.

The detailed-scale modelling described in section 4.2.2.2 will continue in stages as new research data becomes available, primarily for the purposes of Rock Suitability Classification (RSC). In addition to RSC, the model is used directly for the needs of design and construction, as well as for specifying further some local results. During 2013–2015, the detailed-scale modelling work will concentrate on brittle and hydrogeological characteristics, as well as on rock types and the characteristics of ductile deformation. Although the rock types and the characteristics of ductile deformation have no direct impact on the classification done using the RSC method, they may, for example, provide information on the impact of rock orientation on the characteristics of fracture formation. As far as possible, the rock alteration phenomena are also taken into account in connection with small-scale modelling. The first detailed-scale model covering the extended area, and the methods used for producing it, are described in the *Geology of Olkiluoto* report. The model is being actively updated, and its interim versions are given to the end users as memorandums and as 3D files, as required.

The geological discrete fracture network modelling (GeoDFN) is also developed further in parallel with deterministic geological modelling. The GeoDFN model will be updated into version 3.0 and reported during 2014. In this work, geological and geophysical materials and interpretations are used as background material, particularly fracture mapping material from the deepest parts of ONKALO. The fracture mapping, important for DFN modelling, will be supplemented, for example, with the systematic mapping of some extensive floor surfaces with the intention of acquiring further information on the size distribution of fractures.

Version 3.0 of the geological model will serve as background material for other areas of the site description work. Once the model is published, the 3D descriptions will be maintained by taking into account any new material. In addition, the compatibility of the site-scale model and the detailed-scale model is ensured by updating them as required. The geological model can be updated to version 3.1 if required for the 2016 site description report.

The results of tunnel mapping have previously been reported as so-called outcome reports in the working report series. A compilation of all geological mapping work regarding ONKALO will be reported during 2014 as a Posiva report.

5.3.1.3 Geophysics

In 2012, mise-a-la-masse measurements will be carried out in the eastern part of the planning area in drill holes OL-KR54–57. The results will be processed and reported in 2013. The measurements will provide additional information on the continuity of structures for use in geological and hydrogeological structure modelling.

A significant part of the geophysical studies during the programme period is related to the demonstrations performed in ONKALO. The mise-a-la-masse measurements and reflection seismic measurements to be performed in the demonstration tunnels and investigation holes will be planned in 2012. They will be carried out during 2013 and reported in early 2014. In addition, low frequency scanning with ground-penetrating radar will be performed in the demonstration tunnels and investigation holes in order to investigate the continuity of fractures and damage zones in the bedrock. High frequency scanning with ground-penetrating radar as well as GPR-assisted EDZ measurements will be performed in the new investigation niches possibly excavated in the demonstration area. The results of the above measurements will be used in particular for updating the detailed-scale model required for rock suitability classification.

The methods of down-hole geophysics established in research carried out in ONKALO and at ground level and the parameters observed in them are optical and acoustic imaging, hole scanning, caliper, density, magnetic susceptibility, natural gamma radiation, resistivity, acoustic full wave form as well as temperature and resistivity of bedrock groundwater. Down-hole geophysical measurements will be carried out according to the established practice in all pilot holes drilled in the underground facilities particularly for the needs of the detailed model. In addition, seismic scanning and low frequency scanning with ground-penetrating radar are performed in the central tunnel area for the purpose of characterising the bedrock properties in the disposal panel area. Seismic and electronic geophysical measurements between the holes will also be carried out if deemed necessary for testing and developing the rock suitability classification process.

Part of the investigations support rock-mechanical research. The main objective is to make observations of the correlation between the mechanical properties of the bedrock with the parameters measured using geophysical methods. The geophysical measurement methods most suitable for this purpose are the electrical and seismic applications as well as the ground-penetrating radar method. In addition, the attenuation of seismic wave as a function of depth is investigated. The need for updating the wide-area lineament interpretation for the summary report of seismic research in Olkiluoto to be produced in 2015 (see Chapter 5) will be investigated.

5.3.1.4 Rock mechanics

The POSE test investigating the spalling strength of bedrock will be continued in ONKALO until the end of 2013. During the third phase of the test, investigation hole ONK-EH3 in Investigation niche 3 at level -345 m was fitted with instruments. Heating of the hole began in summer 2012. Four monitoring holes were drilled around investigation hole ONK-EH3, and they were fitted with dozens of temperature sensors for monitoring the temperature of the bedrock mass. In addition, possible spalling of the bedrock is measured using acoustic emission instruments installed in the holes. The spalling damage is expected to concentrate symmetrically on the hole walls in the directions with the largest tangential stress field. The orientation of the damage allows making interpretations of the direction of the main stress and the spalling strength of the bedrock. Rock-mechanical and elastic predictions are produced for the test and compared with the actual results using backward calculation. The empirical part will be completed by the end of 2012, and the results of the test will be reported by the end of 2013.

If the third phase of the POSE test is found to be a useful research method, a similar test can be carried out in veined gneiss at the disposal depth. The decision regarding that test will be taken when the previous phases have been completely carried out, interpreted and reported.

A summary report of the results of spalling investigations will be compiled for the Site Description 2016 report, and the results will also be utilised for preparing a thermo-mechanical spalling prediction in the areas of the 1st and 2nd panels and the central tunnels.

The thermal properties of rock largely determine the thermal load of deposition holes and set limits on the distances left between them. Therefore, the work for determining the thermal properties of rock will be continued with both *in situ* and laboratory measurements. The main focus of measurements is on more detailed characterisation of the conditions at the disposal depth. In addition to the laboratory studies on samples, the scale-dependency of thermal properties will be investigated by carrying out a separate thermal conductivity test *in situ,* at the back wall of Investigation niche 3, for the purpose of investigating the thermal properties of an extensive mass of bedrock. The thermal conductivity test will involve drilling a heating hole of about 10 metres and several monitoring holes in the bedrock. The purpose of the test is to investigate the thermal conductivity and other thermal parameters on a scale larger than what is possible in a laboratory or using TERO76 test equipment, in an actual bedrock mass where foliation and rock type variations affect the thermal properties. In addition, the TERO76 measurement instrument will be tested in connection with the POSE test and the *in situ* thermal conductivity test in conditions corresponding to actual disposal. TERO76 measurements will also be made selectively in the drill holes of the eastern investigation area. The results will be utilised for updating the calculations of the POSE test and the thermal model for the area.

The work for determining the mechanical properties of brittle deformation zones will continue by taking samples of the zones for laboratory studies. In addition to laboratory studies, the long-term deformation monitoring of BFZ019c and BFZ045b zones will be started using measurements at convergence bolts. The results will be used for backward calculations in order to determine the properties of these zones both for the rock-mechanical model and the state of stress model for the area, Rock sampling for the purpose of determining the strength properties by laboratory studies will concentrate on the disposal depth and Investigation niche 3.

The rock-mechanical model (RMM) will be updated gradually as new information is accumulated. The model will be developed in order to improve its suitability for use and updating. The intention is to later use the model as an implementation tool for the designers and builders of the disposal facility. The update of the rock-mechanical model (RMM v. 3.0) will be completed by the end of 2014.

The work for determining the state of stress in the area will continue in ONKALO using LVDT stress measurement instruments and in investigation hole OL-KR56 using a method based on hydraulic rock stress measurements. The factors caused by the state of stress in bedrock will be investigated, among others, by interpreting borehole breakouts and core discing in connection with geological reporting as well as by interpreting spalling and the occurrences of rock falls off the tunnel roof. A compiling interpretation of state of stress (*semi-integration*) will be produced on the basis of information from different sources. It will be used as the basis for updating the 2015 state of stress model for the area. The state of stress model for the area will also take into account the impact of brittle deformation zones on the stress field, both locally and as a function of depth.

5.3.1.5 Hydrogeology

During the programme period, the hydrogeological studies will particularly concentrate on investigating the hydrogeological properties of the eastern part of the planning area and on assessing the groundwater effects of ONKALO. The progress in excavating the access tunnel of ONKALO has made it possible to analyse the bedrock sections describing the disposal conditions in greater detail. From the hydrogeological perspective, it has therefore been possible to shift the focus of analysis to the surrounding area scale for describing the fracture networks and flow properties in the bedrock. Field investigations will be performed both above ground and in ONKALO. The field investigation, interpretation and modelling work is aimed at the next site model report to be published in 2016.

Field investigations

The investigations above ground include single-hole measurements and interaction tests. Posiva flow-log measurements (PFL) will be continued as required as repeat measurements in deep drill holes. In connection with these measurements, information will also be obtained on the temperature of water in the holes and on the *in situ* electrical conductivity.

In addition to the flow measurements, HTU (Hydraulic Testing Unit) measurements will also be performed. The focus of these measurements will be on the hydraulic properties of bedrock sections representing the disposal depth (at the depth range of 300–700 metres). The objective is to determine the locations of water-conducting fractures and their transmissivity in a drill hole. The advantage of HTU measurements is the fact that they can be used for measuring lower water conductivity values than Posiva flow-log measurements. The HTU measurements performed by the end of the TKS-2009 period covered rather comprehensively the central investigation area and also parts of the eastern area. During the programme period now commencing, the focus will be on collecting measurement data from the eastern investigation area.

The larger-scale pumping tests planed in the TKS-2009 programme for the purpose of investigating the hydrogeological connections in the eastern investigation area did not materialise due to delays in the drilling operations and hole investigations (section 4.2.2). More extensive pumping tests will begin in the eastern investigation area during 2013. The purpose of pumping tests performed in drill holes is to monitor the interaction it causes in the form of a pressure response in the surrounding plugged drill holes. Such preliminary interaction tests aimed at investigating the hydraulic connections were performed in 2011 in connection with the drilling of the hole OL-KR56 by measuring flow responses in separately selected drill holes located nearby (see section 4.2.2). The work of analysing the test results is still in progress, but if the results are promising, further preliminary tests may still be undertaken in 2012 using a similar method in connection with pumping operations performed during the investigations into holes OL-KR56 and OL-KR57.

The transverse flow measurements began during the TKS-2009 period in selected drill holes and at selected depths for the purpose of investigating the flow rate and average direction of water travelling in the fractures. Their purpose has been to make observations on the impacts of ONKALO construction work on groundwater and to produce further information on the hydrogeological properties for investigating the migration properties. During the next few years, the main focus will be on the bedrock sections with the highest water conductivity values. The hole sections to be measured will be selected on the basis of Posiva flow-log measurement results on a case by case basis. The measurements performed for the infiltration experiment will continue using both difference flow and transverse flow meters; the extent of these measurements will be separately agreed.

The hydrogeological measurements will continue in ONKALO applying the same principles and to the same extent as in previous years. Systematic Posiva flow-log measurements are performed in the pilot, characterisation, probing and grouting holes drilled in the tunnel for the purpose of investigating the locations of water-conducting fractures and their properties. The water inflow measurements will continue as part of the Olkiluoto monitoring programme (section 4.2.4).

The field investigations of the research programme regarding small-scale water conductivity (HYDCO) will continue with single-hole and cross-hole interaction tests conducted in the holes to be drilled in the investigation niche. HYDCO is an extensive research programme. The field investigations are conducted in order to collect hydrogeological, geochemical, geological and geophysical data from the investigation holes in order to investigate the connections of small-scale (10−50 m) fractures of poor water conductivity ($T < 10^{-7}$ m^2/s). The progress of the field investigations is monitored and guided by an expert group established for the research programme. The final scope and contents of the HYDCO research programme will be determined on the basis of the research results obtained from the drill holes and their interpretations. The empirical part is expected to be completed in 2013, and the report will be produced during 2014.

Interpretation and modelling

The update of the hydrogeological structure model will be completed in 2014. This update will be based on the update of the geological site model to version 3.0 in 2013, together with the new hydrogeological field observations made in the investigation area (particularly in its eastern part). The key objective of the model update is to produce a more reliable hydrogeological description of the eastern part of the investigation area while also basing it on all research material accumulated by the end of 2013.

The hydrogeological fracture network model (GeoDFN) will be updated during 2013–2015 on the basis of the geological fracture network model (GeoDFN) and all fracture-specific data, particularly that obtained from ONKALO and characterisation holes. The HydroDFN model will have closer interaction with the GeoDFN model and the hydrogeological structure model on investigation site scale for producing the most consistent site description possible. The closer integration of the model with GeoDFN will produce a description based on geological data of the channelling of flows inside the bedrock fractures, and this will further lead to more realistic estimates when analysing the migration of radionuclides.

The past history of conditions in Olkiluoto will be updated by the end of 2016 using numerical flow modelling. Until now, the initial state has been fixed to a situation prevailing some 8,000 years ago when the salinity of the Littorina Sea was at its highest. The coming model update will re-assess the current groundwater situation by, among other things, analysing the significance of the glacier melting phase to groundwater conditions. The model update will take into account the hydrogeological structure model on the investigation site scale and the update of the salinity model where in particular the interdependency between matrix pore water and fracture groundwater has been defined further. With the model update, the area covered by the flow model will be extended to reach several kilometres towards the current mainland. In this connection, the information produced by the surface hydrological model of the distribution of groundwater level values and its historical development will be appended to the model.

In relation to site modelling, the detailed analysis and prediction modelling of ONKALO's groundwater impacts will continue using numerical flow modelling methods. The modelling-related method and developments in computer capacity allow more detailed modelling where the observations regarding groundwater impacts can be taken into account comprehensively. The so-called VINTAGE algorithm allows the efficient processing of fracture networks, while the Ensemble Kalman Filtering technique finds the model parameters with which the calculated hydrogeological parameters (pressure and salinity) best match the observations. In addition, groundwater flow modelling will be used to describe the development of groundwater conditions as part of the investigations regarding the demonstration facilities and the joint operating test.

In support of the complex of hydrogeological modelling work, the analyses of hydrogeological observation material will continue with the same partial entities and principles as in the previous TKS-2009 period. The objectives of different task entities are briefly described in section 4.2.2 .

The work of analysing hydraulic pressure responses is aimed at analysing the entire material collected by the end of 2012 by the time the site model is updated. The work of analysing the representativeness of water conductivity and transmissivity values measured at different times and using different methods was initiated during 2009. During the YJH-2012 period, the material will be supplemented, as required, for the parts of the observations that were not included in the analyses performed during the TKS-2009 period. The work of analysing the flow responses observed in the flow measurements will continue using the same principles as have been used so far in the work initiated during the TKS-2009 period. The work of identifying water-conducting fractures and of defining their properties will continue so that a comprehensive database covering all holes drilled from above ground and all pilot holes drilled in ONKALO will be available by the end of the YJH period.

5.3.1.6 Hydro-geochemistry

The themes of hydro-geochemical research during the coming programme period will be linked with the total chemical buffering capacity of the groundwater system, the sulphide circulation as well as with the distribution and paleo-hydrogeological development of salinity. The key subjects requiring further investigations are the reduction of aerobic water, i.e., the mechanisms that consume the oxygen present in bedrock fractures and the soil, the energy sources used in the microbiological generation of sulphides (DOC, H_2) as well as the availability of iron related to the precipitation of sulphides and the mechanisms controlling the diffusion of salinity in matrix pore water and fracture groundwater. Information is mainly acquired using targeted test arrangements and sampling associated with them, but also by targeting characterisation work (groundwater, pore water, pore structure and mineralogical studies) particularly to deep bedrock conditions, to the interface between sulphate- and methane-containing water and to the filtration zone. The supplementary hydro-geochemical characterisation work will continue in the eastern area. The sampling techniques will be developed, particularly with respect to the reliability of gas samples. Another key objective of the site investigations is to develop and apply reactive migration modelling to simulating the hydro-geochemical phenomena in Olkiluoto. Calibration of the models in systems with known boundary conditions is also important for the reliability of evolution simulations included in the safety case. Modelling is used to assess the stability of the hydro-geochemical system.

Buffering capacity

The current knowledge regarding the total chemical buffering capacity of the groundwater system in Olkiluoto is based on several elements: mapping of the buffering potential and its functionality (groundwater and mineralogy) as well as on its testing (field tests and modelling), as well as on evolution modelling work regarding the sufficiency of buffering capacity. The last of these issues is discussed in section 5.6 dealing with the safety case.

Regarding the groundwater and fracture mineralogy of Olkiluoto, the buffer potential has so far been mapped comprehensively in the central area as part of the earlier research programmes, but the supplementary work will continue in the eastern part of the planning area where mapping of the latest drill holes (OL-KR54–KR57) has not been completed yet. The statistical analysis (drill core sample material) of potential buffer fracture minerals (calcite, sulphides, clay minerals), where the mineral material quantities available for the buffer mechanism at the fracture surfaces and the distributions in different hydrogeological structures of the bedrock (structures, transmissivity of fractures, etc., are differentiated, started in 2012. The supplementary mineral analyses of moraine material regarding the carbonate and sulphide minerals are also being planned.

Comprehensive paleo-hydrogeochemical studies regarding the evolution of fracture calcite and fracture pyrite (structural description, chemical and isotope analyses) have been performed in the central area, particularly in the potential groundwater filtration zones in the areas of structures HZ19 and HZ20. Supplementary investigations are still in progress in the eastern area regarding structure HZ146 and regarding the conditions in deep bedrock in drill hole OL-KR56. A summary report of the fracture sample investigations as well as of the results concerning the unbalance of uranium decay series at the fracture surfaces will be produced during the early part of the research period. Both investigations will produce information regarding the long-term changes in redox conditions in relation to depth, all the way from Precambrian Time to the present day.

The hydro-geochemical sampling in the eastern investigation area will continue until sufficiently comprehensive hydro-geochemical data have been obtained for each hole drilled there. In addition to the chemical and physical-chemical parameters of the samples, the isotopes and microbes in the samples as well as the gases dissolved in groundwater are characterised. The investigations regarding hole OL-KR56 drilled in the eastern investigation area concentrate particularly on characterising saline groundwaters in the depth range of 600–1,200 metres. Control samples and additional samples will still be taken from other investigation holes during 2012–2014 for the next model update, particularly in the northern side of ONKALO. The sampling locations will be selected annually on the basis of needs detected while interpreting the groundwater material.

Dissolved gases constitute a significant chemical buffer in Olkiluoto. The PAVE technique (e.g. Rouhiainen 1994, Ruotsalainen *et al.* 1996) has been developed for gas sampling from drill holes. It involves collecting the sample into containers under *in situ* pressure. In the laboratory, the samples are released from the containers and analysed. However, the pumping of samples always results in a pressure drop which has been found to cause uncertainties in the results as the gas composition becomes fractioned (Gascoyne 2005, Pitkänen & Partamies 2007). A gas sampling method where the pressure of the groundwater sample can be kept at a level corresponding to the natural conditions has been developed for sampling from ONKALO. The results have been encouraging, which is why the tests with this new sampling method will continue in ONKALO. Furthermore, the analysis of gases in pore water under deep bedrock conditions will be tested as part of matrix pore water sampling (OL-KR56) so that the impact or pressure drop caused by pumping on the behaviour of gases is avoided unlike in groundwater sampling.

Microbiological sampling will be performed in shallow groundwaters in the soil and top layers of the bedrock (0–10 m) during 2013–2015. The sampling will supplement the microbiological material acquired in previous sampling campaigns particularly from the eastern investigation area and help investigate whether the microbiological population has changed as a result of work in the area.

A filtration test aimed at investigating the buffering capacity of the hydro-biochemical system present in the bedrock fractures against acidic and oxygen-containing water filtrating from above ground has been in progress around investigation hole OL-KR14 at the bedrock-soil interface since the end of 2008 (Käpyaho et al. 2012). Numerical models will be calibrated on the basis of the results of this test, and these models will be used to simulate the sufficiency of the total buffering capacity in the climatic conditions of the future. The modelling projects related to the safety case are described in section 5.3.1 . Until now, it has been possible to assess the behaviour of the pH front and calcite buffer of the system, but no redox front has been detected. The reducing conditions have been maintained throughout the test due to the buffering effect of the soil. Therefore, the test has not produced any new information on the sufficiency of the redox properties and the redox capacity. The test results obtained so far will be reported in early 2013. The decision has been taken to develop the test arrangement so that the migration of oxygen can be monitored and numerically assessed. This can be achieved by feeding oxygen-containing water with a tracer to the fracture zone pumped in the test, i.e., by bypassing the impact of the soil. The alterations for the test arrangement are being planned and test simulated, and the change will be implemented during 2012. The hydrogeological, chemical and microbiological monitoring of the test will continue to the extent required by the new test arrangement. The progress of the test will be simulated using both hydrological filtration modelling and reactive migration modelling (Karvonen 2011a, Trinchero et al. 2012b). The target is to complete the test at the latest in 2015 and have the site-specific data available for buffering capacity modelling.

Sulphides dissolved in groundwater

The sulphides dissolved in groundwater represent one of the key factors causing corrosion in copper. Usually, the concentrations in Olkiluoto are insignificantly small regarding long-term safety, but relatively high, potentially harmful concentrations (> 1 mg/l) have been observed occasionally. The high concentrations are related to the interface between sulphate- and methane-containing waters, which is why it has been thought that the high sulphide concentrations result from the joint action of anaerobic methane oxidisers and sulphate reducers. The microbes would use methane (CH_4) as the source of energy in this thermodynamically advantageous process. However, the carbon isotope balance, for example, does not support the hypothesis on a large scale. The isotopic data suggests that the microbes are utilising some other dissolved organic compound (DOC) available in the CH_4-containing groundwater. A series of tests regarding the reduction of sulphates (SURE) was initiated in ONKALO in 2010, aimed to investigating the importance of methane in the reduction of sulphides.

The groundwater data suggests that high sulphide concentrations develop as a consequence of the investigations mixing the groundwater types under conditions where microbes will readily initiate the reduction of sulphates into sulphides. The bedrock groundwater monitoring results indicate that the sulphide concentrations decrease once the hydrogeological system has stabilised (e.g. once the drill hole has been plugged), which may be due to the fact that the process peters out when the source of energy is exhausted and/or the FeS phase is precipitated. The iron sulphide phases control the solubility of sulphides thermodynamically, but the release of iron from the source phase (probably silicates) is a slow process, which delays the decrease of sulphide concentration (Wersin et al. 2012b). The main tasks during the research period are related to the continuation of the SURE test, i.e., to more detailed characterisation of groundwater regarding the availability of potential sources of energy for the microbes (DOCs) and iron. In addition, monitoring will be intensified in those sampling points where high sulphide concentrations have been observed at some stage. The microbiological and chemical processes will be integrated as part of the reactive migration modelling process.

The first phase of the sulphate reduction test investigating the reduction rate of sulphates and the factors affecting it in both methane- and sulphate-containing waters will be completed by the end of 2012. The first results of the investigations carried out in sulphate-containing waters seem to indicate that as a sole source of energy, methane cannot initiate the microbial activity related to the reduction of sulphates or, consequently, any significant production of sulphides (Pedersen *et al.* 2012). Instead, it activated iron-reducing agents, with the result that ferrous iron was produced in the test, apparently originating from the Olkiluoto rock materials taken from the drill holes and used in the reaction vessels. When hydrogen was added to the sulphate-containing groundwater, the production of sulphides began. The results obtained so far require that the investigations into the microbiological processes are continued during 2013–2015. The investigations performed in sulphate-containing water will be repeated in order to verify the above results. The particular objective is to investigate the creation mechanism, origin and availability of iron(II) ions, because the iron sulphide phases control the solubility of sulphides. In addition, the primary DOC utilised by the microbes as a source of energy should be specified further; it seems to be available in methane-containing groundwater in spite of the internal microbiological processes (e.g. methanogenesis) present when different groundwater types are mixed. Depending on the results of investigations performed in methane-containing water, repeating them may also have to be considered. The test arrangements can be modified for the repeat tests. This would, for example, allow testing the potential of longer-chained carbohydrates to act as an energy source for microbes in sulphate reduction. The tests now carried out will provide the basis for first estimates of the rate of sulphide formation under the tested groundwater conditions. The detailed plans regarding further investigations into the microbiological processes will be completed in spring 2013 at the latest.

In addition to the SURE test, chemical and microbiological material related to the reduction of sulphides will be further collected from ONKALO and from deep drill holes. These sampling campaigns will, for example, help investigate the time the elevated sulphide concentrations prevail in water and the reasons for the decrease of concentrations. The molecule-biological studies regarding sulphate-reducing agents and methanogens have revealed that both physiological groups display a rather wide diversity. The significance of different types of microbes for the solubility of sulphides is to be investigated in closer detail.

Salinity distribution and paleo-hydrogeology

The groundwater chemistry in Olkiluoto is dominated by a considerably wide variation in salinity and composition, particularly in relation to depth. It has been further found that the micro-pore water of the rock matrix is significantly more dilute than fracture groundwater in the deep bedrock. The underlying reason for the varying composition of groundwater present in the fractures can be explained fairly reliably (*Site Description*, Stotler *et al.* 2012). The difference in compositions between matrix water and fracture water is not known, which results in an uncertainty regarding the paleo-hydrogeological understanding of factors affecting the chemical composition of groundwater. It has been suggested in matrix pore water characterisation reports (Eichinger et al. 2006, 2010a, 2012; the University of Bern), on the basis of laboratory determinations of the diffusion coefficients, salinity differences between waters and a simple diffusion model, that methane-containing saline groundwater would only have influenced the matrix pore waters for a short time in geological terms, perhaps only since the Weichsel ice age. On the other hand, the geochemical characteristics of groundwater indicate that it is very old and that the "parent water" was probably formed hundreds of millions of years ago. According to the paleo-hydrogeological model description (*Site Description*), the ambiguity of interpretation may be caused by anionic exclusion combined with complex micropore structure and/or by the slow rising of saline water in the bedrock. In the micropores of rock, the negative surface charges of minerals restrict the diffusion of anions particularly when the free space is of the order of a few nanometres or a few tens of nanometres only. In such a case, the pore space available for the anions is smaller than that for the water molecules, for example. Open porosity on this scale may be typical of the Olkiluoto rock types where retrogressive metamorphosis has caused alteration of the main minerals (e.g. sericite formation) inside the minerals and in micro-fractures at the grain boundaries, i.e. they are filled. Anion exclusion and the complex and strict micro-pore texture of the bedrock slow down the processes and possibly maintain salinity differences (apparent unbalance) between the bedrock fracture and matrix. Such salinity differences can also develop if saline water raises in the area. There have been earlier observations of anion exclusion (Valkiainen et al. 1995, Kaukonen et al. 1997), but no hydrological measurement data supporting the theory of raising saline water have been obtained. The phenomena are of significance to the safety case, because they affect the long-term flows of groundwater and matrix diffusion. In the presence of anion exclusion, groundwater can actually be in balance regarding salinity in the available pore space, and that shows that the methane-containing groundwater zone has been very stable for millions of years. On the other hand, anion exclusion must be taken into account in migration analyses as a factor restricting matrix diffusion. A matrix water investigation performed in pilot hole ONK-PH9 (Eichinger et al. 2012) revealed that waters were approaching a state of equilibrium in areas of greater porosity near a water-conducting fracture zone (HZ20B). This will require a more detailed definition of diffusion porosity and salinity profiles around the fractures.

So far, it has been impossible to explain beyond dispute the salinity differences between bedrock groundwaters and matrix pore waters with anion exclusion any more than with the rise of more saline groundwater levels that began recently, less than 100,000 years ago. (See section 4.2.2.2 , Hydro-geochemistry). Settling the matter will still require accurate hydrogeological and chemical observations from deep bedrock under as disturbance-free conditions as possible. In particular, the determination of matrix leaking waters around a water-conducting fracture would produce important information in case saline groundwater has entered the upper layers of the bedrock only recently; deeper down, this should have happened much earlier. In that case, there would have been much more time for matrix diffusion to equalise the water salinity differences. On the other hand, if the state is caused by anion exclusion, the salinity differences should be permanent even deep down.

In order to investigate the matter, the plan is to drill an investigation hole, as vertical as possible and hundreds of metres deep, on a low islet near Olkiluoto. Such a location will provide hydrogeological conditions which are disturbed as little as possible by the local groundwater processes present in the Olkiluoto bedrock. That would allow accurate observations to be made of the pressure and salinity of water inside the deep bedrock, and this would produce information on the strength of the regional gradient that could be used to estimate the movements of saline groundwater in front of Olkiluoto and elsewhere along the coastline. Samples for matrix pore water investigations would be taken systematically from this drill hole. If anion exclusion is not the deciding factor causing the observed differences in salinity, the salinity of matrix pore water will increase with increasing depth, finally reaching the general salinity level of groundwaters. At the planning stage, before starting drilling, a detailed programme will be produced for the investigations to be carried out. This programme will be published as a Posiva working report. The feasibility of implementing the project will be investigated in this connection. As the work will be performed under rather exceptional practical conditions, careful planning of the implementation will also take time. The implementation of this work will probably not start until 2015.

In addition to the above, the pore water studies will continue with many different tests. The studies already in progress involve investigating the impact of drilling water (OL-KR55) and performing the first laboratory comparison with the samples from the REPRO test (salinity, diffusion coefficient, matrix porosity, permeability) in order to verify the reliability of earlier results. The results will be reported at the turn of the year 2012–2013. Towards the end of 2011, pore water samples were taken from the bottom section of deep drill hole OL-KR56 (from the depth of 700–1,200 metres). They will be used to investigate whether the salinity differences even out when moving to a hydrogeologically more stable bedrock environment. The results will be available in 2013. Pore water sampling for profiling the HZ20B structure was also planned in connection with deep drill hole OL-KR56, but the structure could not be identified in spite of continuous hydrological monitoring during the drilling operation. The intention is to perform this profile sampling, possibly already during 2012, in a pilot hole to be drilled in ONKALO, and detailed measurements and descriptions of micro-porosity and permeability will also be produced in that connection. After that, a summary report of the pore water investigation results will be produced in 2014.

Detailed fracture mineral investigations (calcite, pyrite, uranium series) required for paleo-hydrogeological modelling have been performed for several years. A summary report on fracture minerals will be produced in 2013. These summary reports and other groundwater material will be used as the basis for updating the paleo-hydrogeological model in 2014.

The salinity model of fracture groundwater will be published in 2012. It is based on groundwater samples and fracture-specific electrical conductivity (EC) measurements. The results included some obvious deviations from the general distribution of salinity, and a detailed sampling campaign with respect to them is being planned for 2013–2014. The report assessing the representativeness of the electrical conductivity data of groundwater will be updated during 2014 for use in the update of the salinity model. The intention is to update the salinity model during 2014 with the data from the eastern area.

Supplementary reporting

An overall assessment of the representativeness of groundwater data was performed in 2007 (Pitkänen et al. 2007). The amount of groundwater data has increased substantially since the representativeness report was published, and it will be updated by the end of 2014. In that connection, the representativeness of isotopic data and gas data of the groundwater samples will be particularly assessed. Uncertainties have been found to be associated particularly with the sampling technique used for gases dissolved in groundwater, and these uncertainties have to be assessed before the next modelling report is released. The modelling work based on representative gas data, preformed for the purpose of investigating the formation of gases and their accumulation in groundwater as well as the solubility of gases in different thermodynamic conditions, will continue. Gas samples will be taken from fracture and matrix waters for investigating the rate at which gases accumulate in the groundwater system. In this connection, the origin of helium is verified by isotope analysis, for example.

The verifying research data obtained from hydro-geochemical investigations will be utilised for the site description report and its background modelling work. Mass balance modelling will be applied to interpreting the post-glacial geochemical evolution, and the reactive migration model will be used to test the performance of buffer reactions and capacity during that period. The initial data for the models will be developed by investigating the cation exchange properties of fracture-filling materials in the bedrock with a series of laboratory tests. The plan is to perform this investigation in cooperation with SKB.

The pumping test involving hole OL-KR6, initiated in 2001, still continues. The work for assessing and reporting the results of the test is still in progress. The annual monitoring of the test with regard to groundwater chemistry will continue until the hydrogeological and chemical summary report is completed and decisions can be taken regarding continuation of the test. The goal is to have the summary plan completed during 2013.

5.3.1.7 Migration properties and modelling

REPRO (Rock Matrix REtention PROperties), the matrix diffusion test which started in ONKALO's Investigation niche 5 in 2011, will be completed during the coming programme period. The purpose of the REPRO test is to produce site-specific data of the retention capability of bedrock at the disposal depth to be used for migration modelling. The results of the test will help assess the retention of radionuclides caused by to matrix diffusion in a situation where the engineered barrier system is assumed to have lost its functional capability. In addition, the information produced by the test will help gain a wider understanding of the significance of matrix porosity as a storage of saline water.

The auxiliary and supporting laboratory studies of the REPRO test will be completed in 2013. The tracer tests in the water phase, particularly the associated through-diffusion test, are expected to continue until 2015. The second phase of the water phase diffusion test will be initiated in late 2012 using a flow rate of 10 µL/min. The monitoring of tracer throughput associated with the test will continue for several months into 2013, after which the current plan entails starting the last phase of the test using a flow rate of 5 µL/min. The water vapour / gas phase diffusion tests performed in the REPRO investigation niche will be completed in 2014 at the latest. As with the first phase, the detailed plan for the continuation programme of tests will be based on detailed model calculations performed in advance. The preliminary plan is to publish an interim report of the results of the REPRO test in 2013. The final report for the test will be produced in 2015.

Reduction of the migration properties of the Olkiluoto bedrock into four fracture - fracture filling - matrix systems (see Figure 4-20) will be revised, and this concept may be supplemented on the basis of laboratory studies and geological mapping data accumulated by the end of 2012. The description of bedrock migration properties will be appended with a description, based on geological mapping data, of the degree of heterogeneity between bedrock fractures, associated with the detailed-scale channelling of groundwater flows.

5.3.1.8 Investigations required for the design of underground openings

In addition to the vertical shafts bored for ONKALO, two additional shafts have been planned for the disposal facility, the canister shaft and the second exhaust air shaft. Of these, the necessity of having the the second exhaust air shaft will be reconsidered as the implementation planning work advances. The shaft grouting and reinforcement planning requires detailed information on the bedrock which, as a rule, has to be acquired by drilling operations in the planned shaft locations and by investigations in investigation holes.

Both of the planned shafts will be located in an area for which very comprehensive bedrock information is already available. Three shafts have already been opened in the immediate vicinity of the area, and the information obtained from them is available for use as initial data for planning these new shafts. The designers will be provided with predictions regarding the quality of bedrock based on the available research data and models. The more detailed bedrock information required as initial data for grouting planning will be acquired with the investigations of drilling samples from probe hole s and with the measurements performed for each shaft section before grouting.

5.3.2 Rock suitability classification

5.3.2.1 Extension of the rock suitability classification demonstration

The decision was taken during the past programme period in 2011 to expand the area of research and demonstration facilities in ONKALO at level -420 m. The starting point was to demonstrate the functionality of the Rock Suitability Classification (RSC) system and the associated detailed bedrock modelling work. The drilling operations required for the extension of the RSC demonstration began in 2012, and the single-hole investigations compliant with the principles of pilot hole investigations were performed in the drill holes, together with supplementary investigations. The drilling operations and hole investigations performed for the purpose of testing and demonstrating the RSC will continue during the programme period now commencing. The plan is to enlarge at least two of the holes into tunnels at a later stage. They are the eastern vehicle connection to the original facilities, ONK-TYT-4399-21, and the southern central tunnel ONK-TYT-4512. The planning work also includes investigating the possibilities for excavating additional demonstration tunnels in a place where two drill holes are located east of the demonstration facilities. The RSC work in the extended demonstration facilities will continue during the programme period now commencing and include in 2013 mise-a-la-masse measurements between holes and seismic investigations. The extended RSC demonstration will be used as a basis for the assessment and development of the RSC-II criteria, the development of research methods (including down-hole seismics) and demonstration of the functionality of the RSC method.

5.3.2.2 Assessment of functionality and further development of the rock suitability criteria

During the coming programme period in 2013 and 2014, the developed suitability criteria (the RSC-II criteria) and the practical application of classification based on them will be tested and demonstrated in ONKALO. During 2013, a Posiva report will be published on the RSC demonstration, the functionality of the criteria will be assessed and the entire classification criteria will be finalised and submitted for approval so that it can be implemented in the construction work. The goal is to have the method proven and put into use by 2015. The experience gained in applying the system will be used as the basis of further development work, if required, for enhancing the classification process. To this end, development work of the observation and research methods required for suitability classification will be carried out in parallel with the RSC demonstration. A Posiva report containing a comprehensive account of the experience gained from applying the RSC, the development work carried out and possibly an updated classification procedure will be published in 2017, before submitting the operating licence application. Rock suitability criteria for the 3H solution will also be determined during 2013–2014 (see section 5.8).

5.3.2.3 RSC work for the joint operating test

The plans include organising a joint operating test in the underground facilities before Posiva is ready to submit the operating licence application. The RSC work associated with this "KBS-3V prototype" will commence during years 2013–2015 of the coming programme period with preliminary investigations and selection of the location required for it and continue during 2016–2018 by participation in the planning and implementation work. The RSC procedure will be applied to the planning and construction of the joint operating test. The RSC will affect the test arrangement regarding the layout of tunnels and the selection of deposition hole locations. An RSC-compliant suitability assessment will be performed for all classification scales: for the central and deposition holes and for the deposition holes (section 4.2.3). The experience from the joint operating test will, as far as possible, be taken into account in RSC 2017 reporting.

5.3.2.4 The first deposition panel

During years 2014–2015 of the coming programme period, an RSC manual describing the suitability classification method will be produced. It will be used during the construction of the first disposal panel. Rock classification compliant with the manual will be applied in design and planning work as well as in construction during the years following the issuance of the construction licence. According to the plant plans, the first disposal panel will comprise a central tunnel and six deposition tunnels with an approximate length of 300 metres each. The area has been indicated to the designers as suitable for disposal use on the basis of the current models of investigation site scale, i.e., there are no layout-defining features (LDFs) in the area. In order to define further the suitability assessment regarding the area and in order to update the plans for the repository facilities, further information will be required of smaller structures and fractures in the area and of their continuity. For this reason, a characterisation hole (central tunnel pilot hole) will be drilled in the planned location of the central tunnel. The detailed-scale model (see Figure 4-10) can be updated on the basis of information obtained from that hole. The decisions on any other characterisation holes will be taken on the basis of the detailed needs of the RSC process. Any drilling operations will be planned so that sufficient protective distances to the planned repository facilities are taken into account. The layout-defining features based on the geological and hydrogeological structure model will be next updated in 2014.

The location of the first central tunnel will be determined on the basis of the suitability assessment and bedrock modelling performed for the first planned deposition panel. A pilot hole will be first drilled in this location, and investigations compliant with the pilot hole programme will be performed in it and the results interpreted. Following excavation of the central tunnel and the investigations performed in it, pilot holes will be drilled from the tunnel to the first section of each of the six planned deposition tunnels for suitability assessment purposes. When excavation of the deposition tunnels has begun, tunnel investigations and drilling of pilot holes for the next tunnel sections will be performed at the same time.

The tunnel investigations, selection of deposition hole locations and drilling of deposition hole pilots for other deposition tunnels will progress in parallel with drilling and investigating the deposition hole pilots and the actual deposition holes in the first deposition tunnel. The drilling, investigation and approval of deposition holes will progress by interlacing the different work phases so that the waiting times at different stages are minimised.

The volume of the detailed-scale modelling initiated in 2010 for the purpose of describing the demonstration facilities was extended in 2012 to cover the planned area of the first panel (section 4.2.2.1). The detailed-scale model will be updated during the coming programme period on the basis of new research data, and the model will be used as initial data for the RSC procedure concerning the first disposal panel.

5.4 Research, development and testing of the engineered barrier system

5.4.1 Development and testing of the disposal system

5.4.1.1 Disposal canister

Canister design work

A few issues related to demonstrating the performance of canisters still warrant further investigations to be continued during the next programme period. A summary of canister design work is presented in a design report (Raiko 2012). The investigations that are related to canister design and which are to be completed during the programme period are presented below.

- The method for closing the copper lid will be selected.

- Gasket solutions will be re-designed for the inner lid of the canister.
- Justification will be presented for the use of a burnup credit in demonstrating the criticality safety of the new fuel types even in long term.
- Acceptance criteria will be established for those properties of the canister components and sealed canisters that are important for the safety of final disposal.
- A quality control programme will be produced for the manufacture of canister components and for the processing and sealing of the canister, consisting of the inspection plans implemented at different stages of the operation.
- Manufacturing drawings will be produced as part of the construction plan, and they will be maintained with the help of a formal approval procedure and version management.

The inner lid of the canister was planned to be sealed using an O ring made of nitrile rubber. The solution cannot be accepted because it would leave about 250 grams of organic material inside each canister, and this is thought to be problematic for the long-term processes inside the canister. Therefore the sealing solution for the inner lid will be re-designed and re-tested. One possible solution being considered is to use soft metals as a flat gasket, both between the lid and the edge of the insert and between the fixing bolt collar in the middle of the lid and the steel lid. The outer gasket faces the cast material of the insert, which makes the solution rather challenging due to the high quality surface required of the sealing face. A particular level of leak-tightness of the lid is required if the canister is to be closed using the EBW method. When the EBW method is used, the shield gas present under normal pressure in the void of the insert must not be allowed to leak into the vacuum in the surrounding space. Maintaining the vacuum is vitally important for the success of the welding operation. When the FSW method is used, instead, the gas tightness of the lid is not necessary; it is sufficient to ensure that the shield gas is not replaced by ambient air. The gas tightness of the rest of the cast iron insert is also investigated when testing the lid gasket tightness.

Nuclear fuels have developed during the operation period of the plants. Consequently, it has also been possible to increase the discharge burnup; last year, the discharge burnup values of fuel were increased at both the LO1-2 and OL1-2 plant units (sections 7.1 and 8.1). Increasing the burnup rate improves fuel efficiency in electricity generation. The increase of burnup rates causes changes to the criticality safety assessments regarding the management of spent fuel. The increase requires a higher degree of enrichment for the uranium, and this will cause a considerable increase of reactivity, particularly for fuel that has only been in the reactor for a short time. If such nuclear fuel assemblies have to be disposed of, for whatever reason, there is a risk that the sub-criticality of water-filled canisters in a transient situation cannot be shown without canister-specific analyses. Therefore, the fuel-element-specific selection criteria for nuclear fuel to be encapsulated should also take into account the degree of enrichment and the burnup in addition to the production of decay heat in order to ensure sub-criticality. Particularly in the case of the larger EPR/PWR fuel elements, spent fuel lots require that burnup credit is also used in their sub-criticality analyses. That is why the criticality safety assessments will be updated particularly due to the development of fuel types used and changes in the burnup rates of nuclear fuel to be disposed of, but also due to the expected deformations in fuel elements assumed in the long-term analyses regarding canister structures.

Preliminary acceptance criteria have been presented in the design documentation for the canister components and the sealing weld. Before starting the operating phase, the preliminary inspection documentation of canister structures will be submitted for approval. The construction plan setting out the acceptance criteria for all parts and manufacturing phases constitutes an essential part of this documentation. These criteria will in turn be used as a measure of acceptability in the inspections included in the quality control programme. The preliminary acceptance criteria will be presented in the construction plan as justified and systematic entities. Likewise, the preliminary inspection plans have already been presented in the inspection technique development reports (Pitkänen 2010 and 2012), but in the construction plan, the inspection plans will now be presented as detailed and systematic inspection plan documents. The third set of documentation required in the construction plan phase consists of manufacturing drawings that will be produced on the basis of the existing preliminary drawings as well as dimensional and tolerance details.

The construction of the canister must be inspected before starting the manufacture of the canister intended for actual disposal use, in practice at the latest when the operating licence is being applied for. Similarly, the final plans for the canisters must be presented in the final safety analysis report (FSAR) included in the operating licence application documentation that will also include the descriptions of all systems. In practice, the canister design must be frozen even before that, around 2015, to allow enough time for performance assessment of the entire disposal system and documenting it as part of the operating licence application material. The canister structure plan must be approved before the canister components required for the joint operating test performed above ground can be manufactured. The frozen detailed plans of canisters will also be required for plant design work around that time.

In addition to the tasks outlined above, the canister-related rock-shear analysis will be revised in order to demonstrate the performance of the canisters (in addition to the previous deterministic method) as a probabilistic risk analysis (PRA) to obtain a more realistic picture of the risk level and the requirements of canister material ductility and integrity.

Canister tests

Before starting the operating phase of disposal activities, the planned canisters must be tested both in different functions of the encapsulation plant and in the transfers and the actual installation in the deposition hole with the surrounding bentonite buffer. The tests or demonstrations required for the manufacture of canister components or the canister sealing weld are not discussed in this connection; instead, this section concentrates on the processing steps of the encapsulation and disposal processes of the canister to be approved.

The testing requirements regarding the canister are listed below as bullet points. Most of these tests will be performed as part of the trial operation of the encapsulation plant and disposal facility and as part of the testing of handling and processing equipment or transfer vehicles.

- Transport of the canister components from the factory, including the lifting and transfer frame
- Acceptance inspection of the canister components at the encapsulation plant
- Installation of the canister to the canister transfer trolley
- Docking of the canister into the handling cell
- Fuel assembly insertion tests
- Canister atmosphere exchange tests and the related verifications
- Inner lid installation tests and checking of leak tightness
- Docking release tests
- Lifting of the copper lid into the welding chamber
- Docking of the canister into the welding station
- Vacuum pumping, checking of leak tightness (only with the EBW alternative)
- Copper lid installation tests
- Sealing weld tests (EBW or FSW)
- Docking release from the welding station
- Final machining of the canister top section (for both the EBW and the FSW alternatives)
- Docking of the canister into the inspection station
- Inspections of the sealing weld using different NDT methods
- Docking release from the inspection station and transfer to the canister support device
- Release of the canister from the transfer trolley and driving it aside
- Driving the remote controlled mover under the canister and loading the canister onto the mover
- Transport of the canister into the buffer store at the encapsulation plant and/or to the canister lift
- Transport of the canister in the lift, up or down
- Moving the canister into the underground buffer store
- Transfer of the canister from the buffer store to the installation vehicle loading station
- Loading of the canister into the installation vehicle
- Transfer of the canister to its installation location in the deposition tunnel of the repository
- Positioning of the installation vehicle above the deposition hole
- Installation of the canister into the deposition hole while inspecting the canister surface for any transport damage using a visual inspection device
- Installation of a buffer block on top of the canister
- Canister retrieval tests for all processing stages back to the fuel handling cell
- Verification of the possibility to continue processing the canister in case of different fault situations occurring in the processing and handling equipment.

The operational tests listed above will be performed during the trial operation phase of the plant, before starting the processing of real nuclear fuel, in other words, before the actual operating licence. Canister installation tests into a deposition hole, buffer installation tests on top of a canister as well as sealing weld tests and inspections of sealing welds will already be performed using prototype equipment during the next three-year period. During the trial operation phase, the tests can still be monitored physically at close range. At the beginning of the actual operating phase, certain verification tests or measurements still have to be performed near a canister filled with real nuclear fuel; for example, the verifying the prevailing radiation level and the decay heat on the canister during different phases of the encapsulation process and storage.

Development work for canister component manufacturing techniques

The development work for canister component manufacturing techniques will continue during the forthcoming programme period. The manufacturing tests will continue with respect to the remaining areas of development in preparation of validations of manufacturing technology and for the purpose of maintaining the required skills. The goal is that Posiva should in the future have access to several component suppliers who are able to manufacture approved canister components in the series required for disposal operations. In the manufacture of copper canisters, the primary focus is on the pierce and draw method, as the intention is to use that method for the first canisters to be used for disposal. Several manufacturing tests have shown that the pierce and draw method can be used to manufacture canisters that comply with the requirements, complete with a bottom. The trial manufacturing series will be used to demonstrate that manufacturing is of industrial scale and capable of producing verifiably acceptable canisters. The trial manufacturing series using the alternative extrusion method will also be continued, and the plan is to qualify this manufacturing method when SKB is about to start its disposal operations. Canister insert casting tests will be performed in order to develop an industrial process and in order to prepare for validations. The manufacturing instructions for canister components will be supplemented as the manufacturing tests, the requirements derived from design analyses and the inspection techniques develop. The assembly method and assembly site of copper canisters and canister inserts have to be established during the forthcoming period.

The canister component manufacturing processes will be described and the manufacturing instructions, quality control programmes and drawings will be supplemented and finalised. The manufacturing and quality control instructions to be produced for the canister components regarding the manufacturing methods to be used for the canisters disposed of during the first few years will be submitted to STUK for approval. The plan is to start the validation of canister component manufacturers and manufacturing techniques during the coming three-year period and continue it during the following period after that. The plan is to start the validation of canister component manufacturing methods gradually, first for the copper components and then for the inserts.

The feasibility of canister component manufacturing techniques and quality control programmes will be demonstrated by the method tests to be performed in connection with the validations.

Development of canister sealing techniques

The method of sealing the copper overpack will be chosen during the early part of the first three-year period; the alternatives are electron beam welding (EBW) and friction stir welding (FSW). Both methods have been developed with the same goal in mind, but the choice has to be made by assessing several relevant factors. The welding method will also affect the residual stresses in the weld and the creep ductility of the weld material. The residual stresses in the weld may affect the corrosion susceptibility of copper, which is why the welding method or the possible method for treating the weld afterwards will be developed in order to minimise the phenomenon. The creep strength of the copper weld has proven to be slightly lower than that of base copper, particularly when the EBW method is used, but the simulations of creep deformations in copper overpacks preformed in 2012 gave results that indicate that a rather low creep strength of the copper overpack weld material is sufficient, so the creep strength of the welds can be considered sufficient with a reasonable safety margin. In addition, the construction of the copper-iron canister is such that the largest creep strain of the shell material is effectively limited by the geometrical boundary conditions of the structure, i.e., the creep strains cannot increase even over a longer period after the copper overpack has come into contact with the iron insert.

A compilation report on the development of the welding process will be published in 2013 for the purpose of choosing the sealing method. It will present the results of research and development work regarding the sealing methods. A statistical assessment will be made of the electron beam welding (EBW) method for choosing the welding method and for the safety case. In that connection, the probability of a weld defect penetrating the canister wall will be assessed, for example. These reports are part of the documentation that will be compiled for the purpose of assessing and choosing the sealing methods. The decision on the sealing method will be made on the basis of assessing the selection documentation.

Once the method has been chosen, a welding qualification plan of a general nature will be produced. A construction plan for the welding equipment will be produced.

Development work of the welding process will continue using the chosen method. Once the choice has been made, the areas for development and any details related to the weld requiring further investigations will be defined. The aim of the development work is to resolve any outstanding open issues regarding the welding process. Further definition of the performance of the sealing process and of the ability to produce acceptable quality will also be part of the development work. Among other things, performance refers to the probability of a penetrating weld defect and to the largest probable defect in the welds of canisters to be disposed of.

The development of quality control of the welding process will be continued so that the quality assurance materials and measures related to the welding equipment and process can be specified by the time they must be procured.

Tender invitation documentation will be produced for procuring the welding equipment. It will include the following:

- specification of the welding equipment,
- the quality assurance plan used during the construction of the welding equipment, and
- a plan of factory tests and training during the construction process.

A preliminary Welding Procedure Specification (pWPS) will also be produced as part of the weld-related development work for the factory tests and acceptance tests of the welding equipment. The pWPS will be developed further and used for validating the welding method. The quality assurance and inspection methods will be developed for the welds with the future operation of the facility in mind. They include statistical process control and processing of the monitoring data regarding the welding process.

Approval will be applied for the pWPS with a pre-production method test using equipment to be constructed in the encapsulation plant.

The canister bottom welding process will be developed in the same manner as the sealing welding process, and it will be qualified as one of the canister manufacturing processes.

The initial state of the weld will be investigated, and the aim is to improve the properties of the weld by developing the welding process. The initial state refers to the different properties of the canister sealing weld, such as its chemical contents and mechanical properties, residual stresses as well as its creep strength and corrosion resistance. The details of the initial state of the weld will be required for the canister structure plan to be produced around 2015.

The training and qualification plan for the welding operators and the welding coordinator will be produced so that the welding operators and the welding coordinator can be trained in connection with equipment manufacture and qualified before or during the qualification of the welding method. A training programme will be produced for the welding operators and the welding coordinator as part of the development work. At the same time, a plan for equipment training will be produced jointly with the welding equipment manufacturer. Part of the equipment training can be done using the supplier's equipment. The final equipment training will be done at the equipment manufacturer's premises as well as at the encapsulation plant using the actual canister sealing equipment.

An inspection and approval plan for the welding equipment, of a standard ready for implementation, will be produced for commissioning by 2018. The requirements for the welding equipment will be set out in the welding standards. They will depend on the method to be chosen: the requirements for the EBW method are defined in five standards (SFS-EN ISO 14744 incl. five parts), while those for the FSW method are defined in ISO DIS 25239-5. In addition, the encapsulation plant sets additional requirements not covered by the above standards, and they must be taken into account in the inspection and approval plan.

Development work for canister inspection techniques

The development work for different NDT methods can be divided into four stages:
- development of basic NDT methods,
- investigations of the detectability of defects,
- development of the method for determining the size of defects and assessment of its reliability, and
- development of approval and rejection procedures for the inspected components.

During the first three-year period, the primary focus will be on the last two items.

Currently, the focus is on applying the determination of defect sizes in all components. The work for determining the size of defects mainly concentrates on analysing and assessing three methods of different types. These assessed methods are:
- basic determination of defect size on the basis of measurement data,
- determination of the size using the SAFT (Synthetic Aperture Focusing Technique) method and phased ultrasonic sensors (PA-SAFT, Phased Array Synthetic Aperture Focusing Technique), and
- determination of defect size by using a sampling phased US array.

The reliability of defect size determination is one of the most important subjects of evaluation during the first three-year period.

The approval and rejection of components and welds will be done using the agreed acceptance limits that may, for example, be based on the applicable loads and the strength of the subject material (insert) or on the smallest accectable remaining wall thickness (copper). This, in turn, depends on the defects in the material. In the approval process, the inspection results are converted so that they are commensurable regarding the acceptance limits so that they can be evaluated and an unambiguous decision to approve or reject can be made.

The development work for the inspections included in the methods will be continued so that the focus of method development work is on combining the inspection results of different methods and on developing the resulting approval and rejection process. Combining the inspection results obtained using several different NDT methods and investigating the reliability of the result thus arrived at will be one of the challenges of the next few years in the development work for disposal canister inspection techniques. Metallographic verification based on the NDT measurement results from different components will be used as an aide for investigating the reliability of NDT methods.

In addition to developing the NDT methods and procedures, the reliability of inspections will be assessed using statistical methods. The goal is to be able to show that the canisters are unlikely to have defects that can be detected by technical means. Another objective is to show that the detection limits of defects are sufficiently low to meet the qualification requirements.

Furthermore, bringing the inspection methods to an "industrial" level will be a key task throughout the programme period. The goal based on the investigations carried out is to use the developed NDT methods as the basis and to optimise all methods to the form to be used in the encapsulation plant. The same development goal will also be applied to components inspections. Certain specific assessments, such as investigating the impacts of radiation on the inspections, will be performed before 2018. The next development subjects among NDT methods are the testing of GaAs direct conversion detector in radiography and the use of camera inspections in the visual inspection of components (copper tubes, copper lids and inserts). The surface inspection process of the cast iron insert will be developed by testing the suitability of the developed eddy current sensors for the detection of deep surface defects. In ultrasonic techniques, the matrix-phased sensor will be tested, together with its use for detecting weld defects and determining their size. Other US sensor types will also be tested. The software development work for eddy current testing will continue, concentrating on analysing defects and on determining their size.

The inspection instructions will be optimised and improved continuously by performing inspections on trial production components and welds of actual size. Another objective is to meet the requirements regarding the detection of defects and determination of their size, and to achieve the related standard required for validation. The statistical deviations in inspections will be investigated during the inspections on the manufacturing programme of the components to be inspected, information on the variation of inspection parameters will be collected and their effects will be taken into account in the inspection instructions in order to ensure that they reflect the reality as well as possible.

In a qualification process for the main components of the disposal canister compliant with the Finnish qualification practices and the recommendations of ENIQ (the European Network for Inspection and Qualification), the inspection instructions are analysed by the qualification body. In addition, the impact of human factors on the inspection instructions and decision-making in the approval and rejection process of canister components and disposal canisters will be investigated. The purpose of investigating the impact of human factors is to identify weak spots in the inspection instructions which can then be eliminated by developing the instructions. The instructions for all inspections of disposal canister components will be produced, as will the instructions for component acceptance instructions (Pitkänen 2012).

The qualification process includes the compilation of demanding documentation, such as the production of qualification documentation and the qualification plan, analysis of the technical rationale for different methods, and finishing touches on the instructions. The documentation will include the descriptions of inspection subjects, definition of the objectives of inspections, the defects being looked for, the detection targets and the qualification level, the technical justification documentation as well as the inspection instructions. The goal is to reach the qualification readiness compliant with STUK YVL Guide 3.8 for the inspection methods used for sealing welds and canister components.

The inspection equipment and systems foreseen for the encapsulation plant will be specified on the basis of results produced by the developed methods. The tender invitation materials will also be produced during the first three-year period. The operating and qualification targets for the equipment will set the requirements for training the inspectors and for accumulating experience from the inspections. The selection of equipment suppliers will become topical after the construction licence has been obtained, when the quality control for the construction process is defined and the equipment is tested in different conditions. The final test will be conducted in actual plant conditions at the encapsulation plant when the equipment has been installed.

5.4.1.2 Buffer

The bentonite buffer design report (Juvankoski 2012) describes the current reference design. The buffer design will be revised on the basis of modelling and studies related to operational capability described in section 5.4.2 , on the basis of the planning/design and development work described below and on the basis of full-scale tests performed in ONKALO. During the first three-year period, the objective of planning/design and development work is to produce the material required for the construction plan of the buffer. The acceptance criteria for all buffer components and their manufacturing steps will be presented in the construction plan.

The construction plan must be approved before commencing the production of buffer components intended for actual disposal use, i.e., at the latest when the operating licence application is submitted. The final plan for the buffer will also be presented as part of the final safety analysis report (FSAR) included in the operating licence application documentation that will also include the descriptions of all systems. When aiming at the commencement of disposal operations in 2020, the buffer design must in practice be fixed around 2015, to allow enough time for assessing the performance of the entire disposal system and documenting it as part of the operating licence application material. The buffer construction plan must be approved before the buffer components required for the underground joint operating test can be manufactured.

Evenness of the deposition hole bottom

According to the reference design (Juvankoski 2012), the gap left between the bentonite buffer blocks and the installed canister is 10 mm. The wall of the canister hole must be vertical. The accectable range of the gap between the buffer blocks and the rock wall of the deposition hole has been specified as 25−75 mm to keep the density of the buffer within the permitted limits. This means that the maximum accectable inclination of the deposition hole bottom is 1/1,750. As foreign materials are to be avoided in the disposal facility, machining of the deposition hole bottom to the required straightness is planned as an alternative to the use of different fillers and mortars. A device will be designed and manufactured during 2013–2015 with which the bottom of the deposition hole can be machined to the required straightness and roughness.

Moisture protection of the buffer

The current opinion is that it must be possible to protect the installed buffer temporarily against water leaks in the deposition hole, and possibly also against the humidity of air before installing the tunnel backfill. The reference design describes one possible method for protecting the buffer temporarily from moisture. The work for producing and testing the prototype of this protection has begun. The compatibility and functionality of the different protection components will first be tested in laboratory conditions, after which testing will continue in the demonstration tunnel of ONKALO. The compatibility of the moisture protection with other components and equipment will also be verified in the installation tests.

The need for protecting the buffer against moisture will be determined in greater detail by investigating the impact of water leaks and humidity of air on the buffer as a function of time and seepage volumes. The results of these investigations may allow restricting the use of moisture protection to water leaks of a certain magnitude. The disposal sequence can also be modified from the current reference design so that accectable water leaks will not disturb the installation process.

Gap filling with bentonite pellets

The plan is to fill the gap between the buffer blocks and the deposition hole wall with bentonite pellets. The pellets are made of the same raw material as the buffer blocks. Since the suitable pellets are not available on the market, the method for producing them will be investigated. Pressing and extrusion are possible methods for producing the pellets. The pressing method can also be used to influence the size and particularly the shape of pellets, which will affect the density and thermal conductivity of the backfill, the penetration of water inside the pellets and their ease of installation.

The pellet development work will involve investigating the properties of pellets produced using different methods, in particular the progress in the early phase of their wetting process. The effect of the shape of pellets on their ease of installation will also be investigated.

Full-scale buffer demonstration

A full-scale buffer demonstration compliant with the reference design (Juvankoski 2012) will be installed in the demonstration tunnel excavated in ONKALO. The purpose of the test is to demonstrate the feasibility of the reference design and to monitor the early behaviour of the buffer. The work is a continuation of the ⅓-scale buffer test installed in Investigation niche 1 of ONKALO in 2011.

The test involves the installation of a full-scale buffer (blocks and pellets). The installations will be mainly preformed using the prototype installation device manufactured for the purpose (see section 4.4). If blocks pre-fitted with instrumentation are used in the test, they cannot be installed by the prototype installation machine; instead, they will be installed using special arrangements. Before starting the installation, the need for moisture protection during installation will be assessed and preparations for its use made, as required.

The test will also deploy a full-scale copper canister and cast iron insert. The copper canister will not be sealed by welding; instead, it will be fixed with bolts. The canister will be fitted with (electrical) heaters with a power equivalent to the heating power of spent nuclear fuel. The insert will be modified as required for the installation while keeping the weight of the canister as close as possible to the correct figure. The canister will be installed using a prototype installation machine manufactured for the purpose (see section 4.4).

The buffer test will be closed with a counterweight cover that allows the buffer to rise within certain limits. The compressibility of the tunnel backfill over the deposition hole has been defined as the accectable heaving of the buffer. The buffer cannot swell freely, only after a certain threshold pressure has been exceeded.

The test environment will be equipped with different sensors for monitoring the test. The purpose of monitoring is to follow the behaviour or the buffer and to ensure that it performs as expected during the early stage of the test. At the same time, experience will be gained of the performance of the monitoring instrumentation. This can also be utilised in longer-term monitoring. The parameters monitored during the test include the temperature and moisture gradient of the buffer as well as the radial and axial forces created by the bentonite buffer as it swells. The results and experience from the test will be utilised for planning the underground joint operating test.

Development of buffer manufacture

During the first three-year period, the development work for buffer block manufacturing involves the manufacture of full-scale buffer blocks using isostatic compression. The objective of full-scale tests is to ensure that the results obtained in the previous smaller-scale tests are comparable and scalable to full scale. The effect of various factors, such as the moisture content, compression pressure and raw material properties of bentonite, will be investigated to establish how readily they affect the properties of the pressed block. When required, the manufacturing process will be modified to better take into account the effect of significant factors. This will provide information on factors affecting the manufacturing process and their accectable variation ranges, required for producing instructions for the manufacturing process.

The manufacturing steps also include machining the block blanks produced in the pressing process. Machining equipment suitable for the buffer materials will be developed for this operation during the first three-year period. The aim is to develop equipment that would allow machining the block blanks with the required efficiency and accuracy.

The achieved results will be used as the basis for assessing the suitability of the isostatic method for producing buffer blocks and for comparing it to the uniaxial method used by SKB in its buffer block production. The purpose of this assessment work is verify during the first three-year period that the isostatic method can be used for producing buffer blocks compliant with the requirements.

The potential manufacturers and manufacturing locations of buffer blocks for disposal operations will also be investigated during the first three-year period. The alternatives are producing the blocks in house or outsourcing the work to external manufacturers. The location can be in Olkiluoto or elsewhere. At the same time, the best alternative will also be investigated for producing the pellets used to fill the gaps between the buffer blocks and the bedrock.

During the second three-year period, the plant's own buffer component production facility will be built, or alternatively, the production will be outsourced to an external producer. The decision to build the in-house facility must be taken during the first three-year period to allow time to complete the facility and the production method and to test the production and obtain STUK's approval for it before starting the underground joint operating test.

Development of the buffer installation technique

The buffer block installation technique will be developed in the LUCOEX project during 2011−2014. On the basis of the results of the project, the installation equipment development work (Figure 5-2) will towards the end of the first three-year period move to the next phase intended for testing the installation process from the point of view of a production process, using bigger installation series and more repetitions. The purpose of the tests is to check that the equipment works and is capable of installing the buffer blocks with the planned accuracy and speed so that the target quality requirements are met. This may require modifications to the installation equipment constructed in the LUCOEX project, or the construction of totally new equipment.

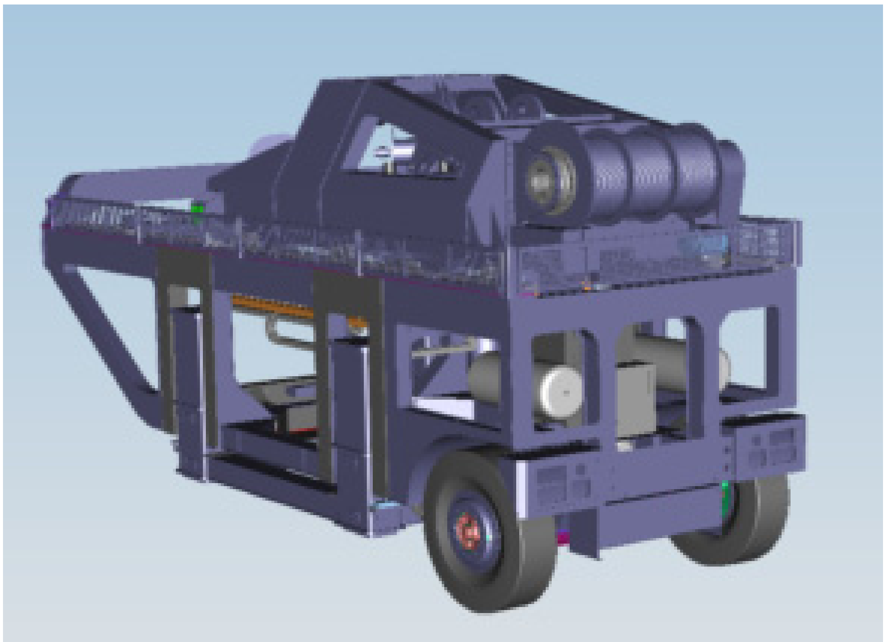

Figure 5-2. *Prototype of the buffer block installation machine, developed as part of the LUCOEX project.*

The final installation equipment to be used in disposal operations will be manufactured during the second three-year period. The equipment built during the earlier phases will be utilised as far as possible.

In addition to installation, another goal for the first three-year period is to develop the transport logistics of buffer blocks from the storage facility to the disposal facility and the handling process taking place there before the installation.

Management of installation transients

The installation tests performed during the first three-year period may provide a better understanding of the factors that may cause delays in the installation and even damage to the blocks during the installation process. The reasons being analysed are those that may cause the installation to be suspended for rectifying actions. Suitable methods and equipment will be developed in the LUCOEX project for solving these situations. When required, these devices will be tested and developed further towards the end of the first three-year period.

The final equipment suitable for disposal operations will be tested during the latter three-year period.

Development of buffer QA

The quality assurance of buffers covers the procurement of material and the manufacture, storage, transport and installation of the blocks. Experience of larger-scale material procurement as well as of buffer manufacture and storage will be gained in conjunction with buffer block manufacture during the first three-year period. This experience can be used for assessing the quality assurance plans produced so far and for making any changes to them when necessary.

The functionality of quality assurance methods can be tested during the latter three-year period.

The quality of installations and the quality assurance measures required will be investigated during the first three-year period in connection with the development work regarding installation techniques. The results will be used as the basis for assessing the functionality of the planned quality assurance methods. The buffer quality manual will be developed on the basis of these results.

The functionality of quality assurance methods will be tested during the latter three-year period.

5.4.1.3 Deposition tunnel backfill and end plug

During the first three-year period, research and development work regarding the deposition tunnel backfill and end plug will be carried out for the purpose of producing construction plans. This work will include determining the requirements and acceptance criteria for both the backfill and the end plugs of tunnels. The requirements will be used as the basis for updating the existing reference designs and for producing the detailed designs with tolerances. The final system descriptions of the backfill and end plug will be produced during the latter three-year period.

The backfill design issues to be resolved during the first three-year period include choosing the materials for the main backfill components (the block backfill, pellet backfill and foundation layer) on the basis of the above requirements. This work includes a investigation of the suitable materials and material suppliers, investigation of alternative materials as well as verification of the conformance of materials with the requirements. The need for a foundation layer and its thickness according to the final design will be assessed by taking into account the requirements but also the evenness of the rock face produced by excavation and subsequent machining.

Solutions for controlling the groundwater inflow during the backfill operation will be sought during the first three-year period so that backfilling can be performed in spite of any water possibly entering the tunnels. Different alternatives for controlling the water inflow will be investigated, such as distributing the water inflow evenly to a wider area at the backfill-bedrock interface, as well as different weir solutions. Alternative solutions for controlling the inflowing waters will be presented, and one or more of them will be selected for testing in connection with the backfill tests.

The detailed design of the deposition tunnel end plug, including development of the concrete recipe, will be performed during the first three-year period. Following the design work, detailed drawings as well as construction and work plans can be produced for the plug.

A quality manual will be produced for the backfill and the end plug during the first three-year period, containing separate quality plans for all components. In addition, the quality documents will include the specifications, drawings, method descriptions and quality control plans for each component. The quality control methods will be developed and tested in connection with testing the components. The quality manual, quality plans and quality documents will be required for construction plans, and they will be adhered to, as applicable, when performing the backfill tests and the joint operating tests. The final quality manual will be produced during the latter three-year period with documents to be adhered to when the disposal operations begin.

The backfill components will be tested in the demonstration tunnels of ONKALO during the first and latter three-year periods. In the first instance, the tests will be related to the implementation and installation of components in compliance with the requirements. The tests will be planned and most of them also carried out during the first three-year period when the test plans and quality control plans for the tests are produced. Component-specific tests will be performed for all backfill components: the foundation layer, block and pellet backfill and the end plug. After these tests, a full-scale backfill test will be performed in which all backfill components are installed together and the end plug is constructed.

The backfill installation equipment prototypes will be designed and manufactured during the first three-year period (see section 6.4.5.4). For the installation of blocks, the choice will be made regarding the installation concept to be used; the possible concepts include installation of the blocks one by one or as bigger units. The manufacture and factory tests of the block installation device will take place during the first three-year period, and the prototype equipment will be both tested and operated in tunnel conditions in connection with the component-specific backfill tests in ONKALO. The prototype of the pellet installation device will be designed and manufactured in parallel with the block installation device. The equipment required for installing the foundation layer and the end plug will be identified in connection with producing the test plans, taking into account any development needs related to new equipment. Experience of the installation equipment prototypes will be gained in connection with the component-specific tests, and any development needs will be taken into account in the design/planning of installation equipment to be procured for disposal operations during the latter three-year period.

The installation of the foundation layer will be tested during the first three-year period. The purpose of these tests is to demonstrate the feasibility of the reference design regarding the foundation layer. The suitability of installation devices, work methods and quality control methods for the conditions prevailing in ONKALO will be tested. In addition, the density, evenness and load-bearing capacity achieved for the foundation layer will be tested. The impact of water inflow on the behaviour of the layer will be tested after the actual installation test.

The installation of blocks using the installation device prototype will be tested during the first three-year period. The purpose of these tests is to demonstrate the feasibility of the reference design regarding the block backfill and to test the suitability of the quality control methods. The installation of blocks without the foundation layer will be tested first in facilities above ground. The purpose of this test is to develop working methods and to investigate the block installation tolerances on an even floor. In the second phase, the block installation tests will be repeated in ONKALO. In this case, the test is performed on top of a foundation layer, and its purpose is to investigate the working methods, installation tolerances and the impact of the foundation layer on the installation process.

The installation of pellets will be tested using the installation device prototype, first on an artificial structure that simulates the space between the blocks and the bedrock. During these tests, the working methods and quality control methods will be developed and the achieved density of the pellet backfill will be measured. Installation tests where the pellets are installed between the blocks and the bedrock will be performed during the above block installation tests performed in ONKALO. The purpose of these tests is to demonstrate the feasibility of the reference design regarding the pellet backfill.

The deposition tunnel end plug will be implemented in ONKALO as a full-scale component-specific test during the first three-year period. The purpose of this test is:

- to test the process of excavating the location of the end plug (as part of the development work for underground openings and bedrock construction work),
- to test the feasibility of constructing the end plug as well as the working and quality control methods,
- to monitor the hardening and shrinking of the concrete part of the end plug,
- to test the mechanical strength of the concrete part of the end plug, and
- to test the water-tightness of the end plug.

The experience gained from the test will be used to update the plug design, and the changes made to the design will be assessed during further development of the end plug. An end plug compliant with the updated design will be constructed in ONKALO in connection with the full-scale backfill test.

After the component-specific tests, a full-scale backfill test will be conducted in ONKALO where in addition to the deposition tunnel backfill components, buffer blocks are also installed to a deposition hole bored in the tunnel floor, and an end plug is installed at the mouth of the test area. The backfill components will be installed using the backfill installation devices. The purpose of this test is to demonstrate the feasibility of the reference design using all backfill components. The test will verify that the components can be installed together and that the quality can be verified during each phase of the work in line with the quality plans. After that, water can be led into the test area and the performance of the backfill and end plug can be monitored with the installed instruments.

The monitoring methods for the deposition tunnel backfill and end plug will be developed and tested in connection with the component-specific tests. The parameters to be monitored on a component-specific basis will be chosen in connection with producing the test plans. The purpose of the component-specific tests of the backfill and the development of monitoring methods is to prepare for the backfill test described above and for the joint operating test to be conducted underground. In addition, the development and testing of monitoring methods is part of the preparations for producing a plan for monitoring the engineered barrier system during the operating phase. The results and experience from the tests conducted in the demonstration facilities will be utilised for planning the underground joint operating test.

The backfill block manufacturing tests will be continued during the next three-year period using the block size specified in the 2012 backfill design (Autio et al. 2012). Blocks will be produced for tests performed in ONKALO, and the manufacturing and quality control processes will be developed and optimised at the same time. In the longer run, preparations will be made for industrial-scale manufacture.

5.4.1.4 Closure of the disposal facility

Requirements have been set for the closure of the disposal facility, and a closure plan has been presented on that basis. In practice, the underground openings will only be sealed off after several decades, starting with the central tunnels, and proceeding to the other openings at a considerably later stage. Closure will not proceed to the connections to ground level until the 2100s. Consequently, no detailed plans will be produced for these systems during this decade. The work related to closure plans will focus on the preparation of documents required for the operating licence application during the next programme period.

The bedrock conditions form the basis of requirements concerning the closure of the underground openings. The closure solution for the facility will be updated, when required, to comply with any new requirements. The mixtures of crushed rock and bentonite and their performance will be investigated because the use of rock material offers advantages, which are related to the erosion of backfill material and to its migration from the tunnel to the fracture network. The current installation methods have not been optimised with relatively large excavated volumes in mind, and the international development work in this area will be followed and tests carried out in Finland if needed. However, the tests will mainly concentrate on ensuring the long-term performance and on verifying the material properties, and the tests will be conducted in laboratory conditions.

International full-scale demonstrations and tests related to the plugging and closure of the disposal facility, tunnels and shafts have been initiated in recent years or are in the process of being initiated. Posiva is participating in the follow-up and monitoring of the shaft sealing test (Enhanced Sealing Project) conducted in connection with the closure of AECL's Underground Rock Laboratory (URL) in Canada. The test has involved isolating a water-conducting zone using a mixture of bentonite and crushed rock and casting concrete plugs above and below it in 2009. Posiva will also be coordinating the European DOPAS research project in 2012–2016 for testing different types of plugs in full-scale experiments (including the deposition tunnel plugs to be implemented in ONKALO and Äspö). The DOPAS project will also produce information for more detailed design of the hydraulic plugs and experience on the use and performance of low-pH concrete in different types of plugs.

Demonstration of the conformance with the requirements of the closure of the investigation boreholes and testing the success of the borehole closure installation methods will be key tasks forming the basis of future development of the current solution. A strategy has been produced for closing the investigation holes, including the requirements, criteria and hole-specific plans (Karvonen 2012). At the same time, testing of the installation methods has become a more topical issue. In addition to testing the methods, the possibilities for dismantling the test installed in ONKALO investigation hole OL-KR24 at the depth of -510...-530 m by overcoring will be investigated. The test consists of a backfill section of MX-80 blocks installed using perforated copper tubes and of plugs cast of low-pH concrete above and below the backfill section. The materials will have been installed in the hole for seven years by 2013, which means that investigating and analysing the samples from it (provided that dismantling by overcoring is possible) will produce valuable information on the performance and properties of the closure materials after installation. At the same time, the success of the initial condition following installation can be verified.

The testing of installation methods for and performance of the borehole closure solution will only be topical objectives for planning and initiating new field tests after the performance of materials used in the OL-KR24 closure test has been verified. The possibility of coating the backfill material for investigation holes in order to make installation easier must also be investigated before testing the methods. The pilot holes drilled at ONKALO can be utilised for the test activities related to the closure of investigation holes.

5.4.2 Performance of the disposal system

5.4.2.1 Disposal canister

The investigations regarding the performance of the canister are closely related to the canister development work described above. The work related to the mechanical properties and corrosion resistance of the canister are also particularly important for the long-term performance of the canister. The initial condition of the canister will also affect its performance, which is why the work related to welding and NDT inspections and their reliability is important for the performance of the canister. Elimination of the defects (penetrating or non-penetrating) initially present in the canister is vitally important for the performance of the canister, because the defects could lead to a loss of the canister's leak-tightness and to the release of radionuclides earlier than expected.

The presence of residual stresses in these welds may cause stress corrosion (depending on ambient conditions), which will affect the corrosion resistance of the copper overpack. Investigations regarding the residual stresses remaining in electron beam-welded canisters will continue during the three-year period now commencing. The work will involve assessing, on the basis of residual stress measurements, the long-term safety implications of the levels of stress remaining in the welds and in particular the question whether the levels of stress will cause a risk of stress corrosion for the canister. The results will be utilised when selecting the copper overpack sealing method in 2013.

The creep tests of electron beam-welded samples initiated in 2007 will continue in order to acquire more information for modelling the service life of canisters. The purpose of these tests is to assess the impact of long-term creeping on the expected service life of the canister. The results will be utilised when selecting the copper overpack sealing method in 2013.

The investigations regarding the canister damage mechanisms will be continued during the next programme period for the purpose of excluding various forms of corrosion. Certain tests carried out in oxygen-free aquatic environments have given indications that copper may react directly with water. The phenomenon cannot be excluded from the possible copper damage mechanisms until sufficient consensus has been achieved regarding interpretation of the tests. Further investigations regarding this subject are in progress in several laboratories (including the investigations commissioned by SKB and the tests in progress as part of the KYT programme). Posiva has also initiated tests running for many years at VTT regarding the corrosion of copper in an oxygen-free aquatic environment. The work will involve repeating some of the tests published by Hultquist et al. (2009). The interim results of these tests will be published in working reports during the next programme period. In addition, all results will be compiled and reported when the test ends. The above results, together with the results possibly obtained from other tests, will be used in the safety assessment to be produced in connection with the operating licence application documentation.

Development work for the combined potential model of copper will continue, and the model will be updated with the empirical results obtained since the previous modelling work (King 2007). The model can be used to predict the development of the corrosion potential of copper (including both the anodic and the cathodic reaction) in compacted bentonite.

The key issues regarding the corrosion of copper are discussed in a report by King et al. (2011).

5.4.2.2 Buffer and backfill

The design work for the buffer, backfill and their different components has made significant progress during the past three years. Performance studies have been conducted on the basis of the updated plans; their results have, among others, been published in the *Performance Assessment* report. For example, achievement of the swelling pressure of the buffer and the backfill in the expected conditions (flow rate, availability and chemistry of water) has been demonstrated both by laboratory tests and by HM (hydraulic-mechanical) modelling.

The mechanical erosion of clay materials due to channelling has been studied, and the results obtained so far will be reported in connection with submitting the construction licence application. The preliminary results indicate that the mass loss caused by erosion does not seem to have a significant impact on the density of the buffer or the backfill required for their performance.

The behaviour of the buffer and the backfill as a function of time has been analysed using T-H-C (thermo-hydro-chemical) modelling. The flow conditions and chemical conditions of Olkiluoto groundwater were used as its boundary conditions. The modelling results indicate that the buffer and the backfill seem to perform as expected and maintain their performance over a long period of time.

During the coming programme period, the work will concentrate on reducing the outstanding uncertainties, thus improving the reliability of the plan solutions to be presented. In addition, it will be investigated if the selection of clay materials can be optimised with the help of factors affecting the swelling pressure and diffusivity (including the use of molecular-dynamic modelling).

Particularly long-term tests in conditions corresponding to the flow and chemistry of the Olkiluoto groundwater have been planned for 2013–2015, together with advance simulations of the demonstrations to be performed in ONKALO. The modelling work performed on their basis will be available in the safety assessment produced for the operating licence application. The investigations regarding clay materials alternative to the current materials will also be initiated in parallel to the modelling work. The subjects of investigations during the coming period will include the geochemical evolution of the buffer and the backfill during the evolution, particularly the evolution of pore water in the buffer and the backfill as well as the production of sulphides due to microbial activity in the buffer and the backfill.

Posiva is also participating in the work of the international engineered barrier system modelling working group (the EBS Task Force), where the objective is to improve the understanding of different processes, such as saturation, homogenisation and the migration of substances dissolved in pore water and equivalent, thus improving the reliability of modelling.

The issues discussed in section 4.6 will still remain as matters to be defined further in the future performance investigations. The key objective of the tasks is to demonstrate that the performance targets of the barriers and the target properties reflecting them will be achieved in the expected course of future developments and in the alternative or limiting conditions. The different areas of performance investigations include:
- development of the conceptual model,
- development of numerical models and simulations,

- if no analytical solution is available due to the nature of the matters being studied, an attempt will be made to simulate them using a computer,
- combined tests representing the expected conditions and the disposal solution,
- tests representing the disposal solution in a limited manner, carried out in expected conditions, and
- tests representing the alternative or limiting conditions.

Mechanical erosion

The development work for the conceptual model will be continued by acquiring more empirical material, particularly from larger-scale tests.

The objectives of developing the conceptual model are:
- to help interpret the test results,
- to present the rationale regarding the possible variation ranges of parameters indicating the status of safety functions, i.e., state the limiting conditions for the presence of mechanical erosion, and
- to present the rationale behind the relevant limiting conditions.

This will allow obtaining better assurance of the impacts of changes in different factors on the measured material.

In order to ensure the representativeness of the small-scale tests, they will be repeated and also conducted on a larger scale (Figure 5-3).

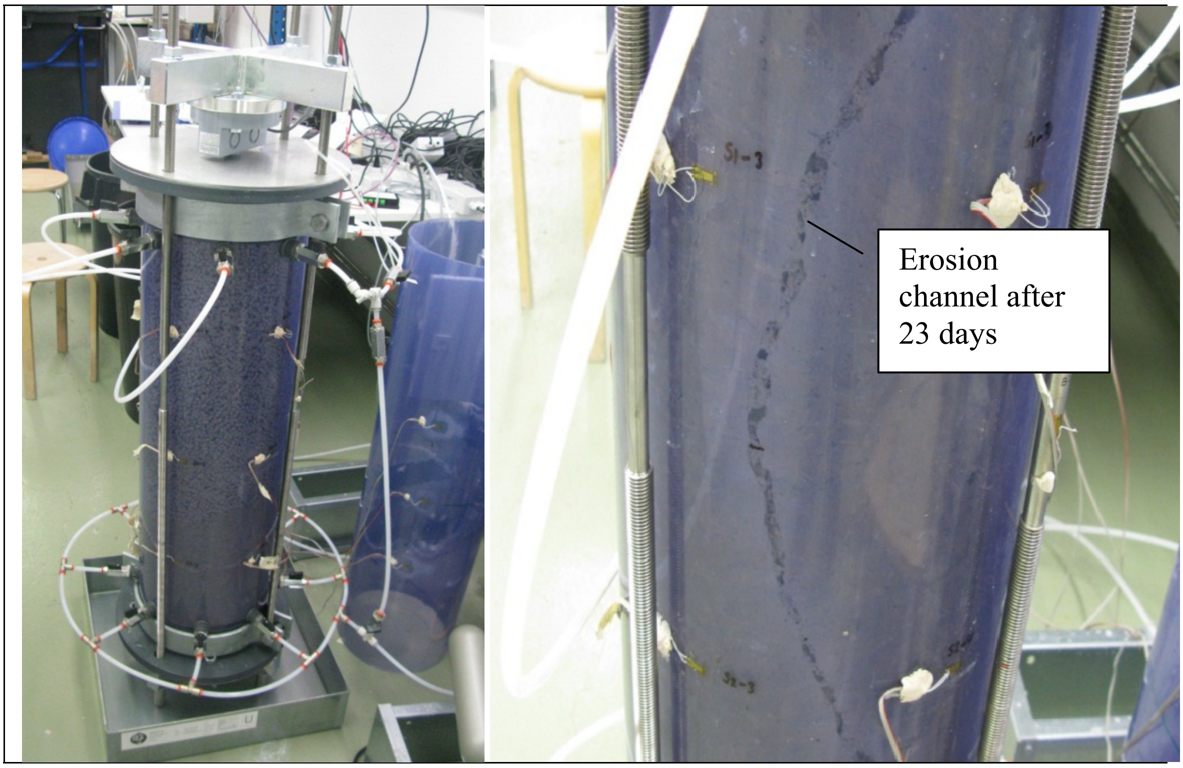

Figure 5-3. *Test arrangement for measuring the erosion rate. The length and width of the channel are also among the parameters measured in the test. In the illustrated test, the water flow rate was 0.1 l/min, while the salinity of the solution was 10 g/l (NaCl).*

Measurement instruments have also been developed for investigating the creation of channels and the penetration of clay into the fractures intersecting the repository facilities (Figure 5-4). Tests will be conducted for different clay materials, varying the parameters relevant to erosion, such as the flow rate and the salinity of water.

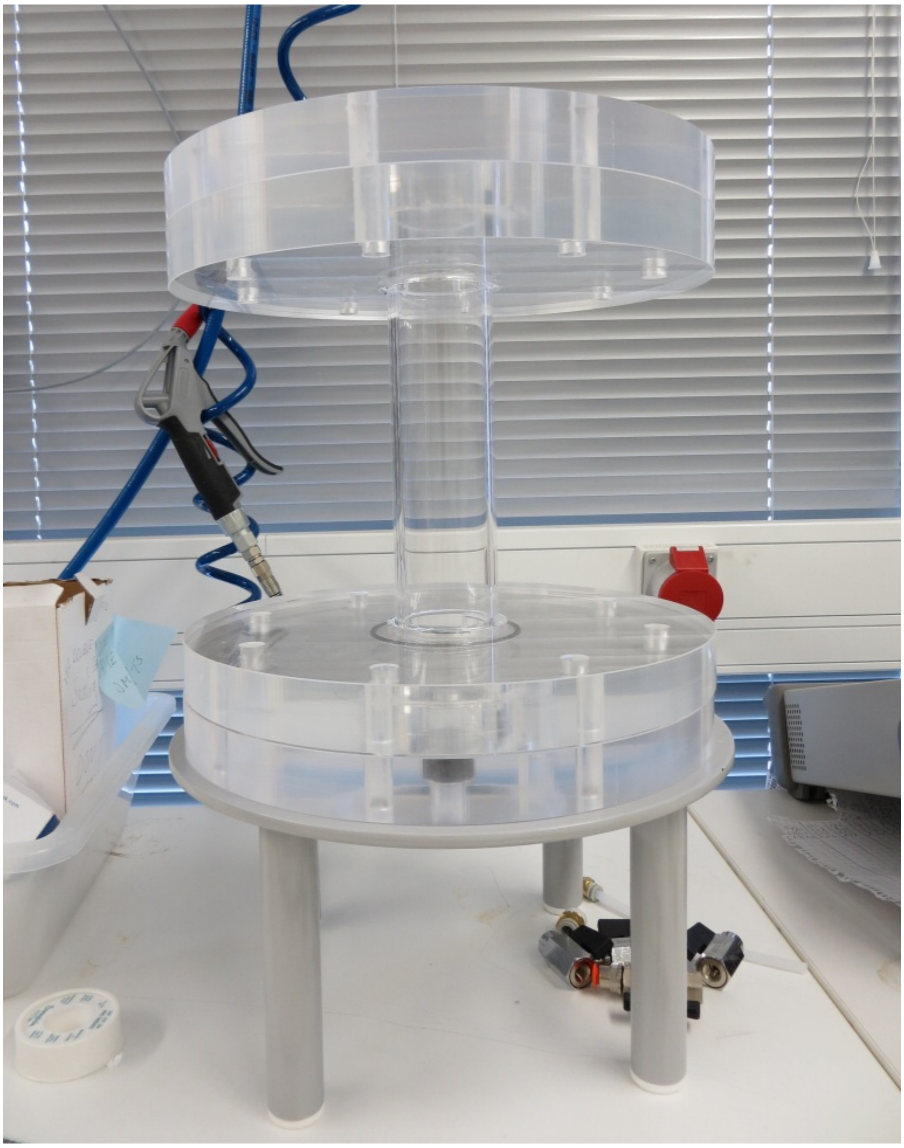

Figure 5-4. *Test arrangement for investigating the ability of bentonite particles carried by water flows to seal fractures in the bedrock.*

The results will be utilised for updating the technical solutions for the buffer, backfill and closure, as well as for the safety assessment performed for the operating licence application.

Homogenisation (and development of the swelling pressure)

The homogenisation tests initiated in 2012 will be continued on different scales in order to improve understanding of the processes affecting the homogenisation of buffer and backfill materials. The most important parameter to be monitored is the bulk density of block, pellet and *in situ* compacted materials (e.g. at an eroded channel).

The process of leaking waters being absorbed in buffer material in the deposition hole (both in buffer blocks and pellet backfill) will be investigated as one homogenisation-related process. The aim of the work is to investigate the impact of different water inflow quantities on the performance of the buffer after its installation and to produce more detailed information particularly on the impact of small water inflow quantities after installation. Figure 5-5 shows the increase in pressure due to the absorbed water and the resulting swelling of bentonite (Y-Displacements).

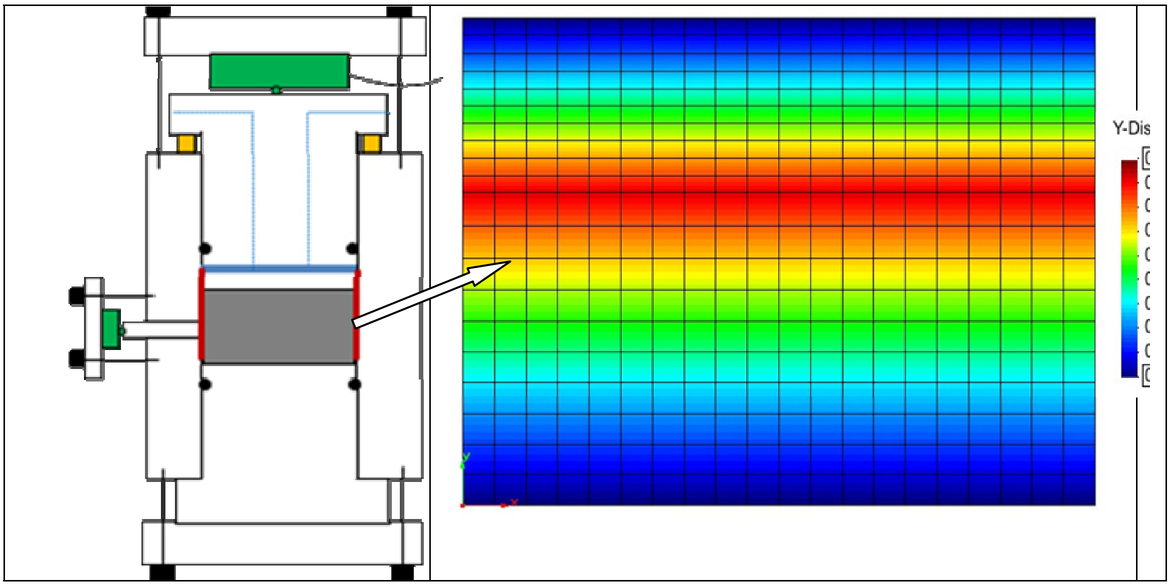

Figure 5-5. *Homogenisation test equipment (left) and the modelling result describing the dislocation after a few weeks of saturation (right). The test is part of international cooperation with the EBS Task Force.*

Another particular process being investigated is that of water being absorbed in the pellet-filled gap between the buffer and the bedrock (Figure 5-6).

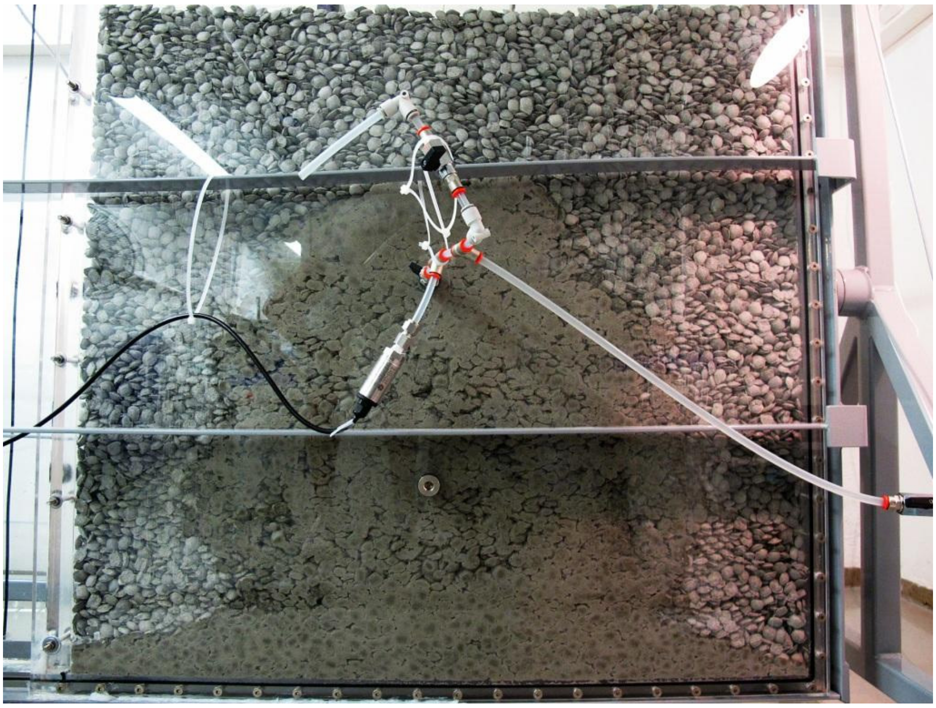

Figure 5-6. *Infiltration test for investigating the process of water being absorbed in the pellet backfill between the buffer and the bedrock.*

Full-scale tests will be conducted in laboratory conditions utilising the symmetries of the engineered barrier system (including the symmetry of the buffer in relation to the tangent and the symmetry of the backfill in relation to the tunnel) in order to reduce the physical size of the test arrangements, In addition, small-scale tests will be performed for a considerably bigger part of the deposition hole and/or tunnel. The buffer test of approximately ⅓-scale in ONKALO will be continued in order to increase the degree of saturation far enough to make observations of the homogenisation process. In addition, full-scale tests will be initiated. In order to model these tests and particularly for further developing the modelling capabilities, the model development work and participation in the activities of the modelling working group of the EBS Task Force will be continued.

Further information on the factors and design parameters affecting the behaviour of the buffer-backfill interface will be sought by numerical sensitivity analyses. They will utilise the modelling method developed by Leon (2012). Laboratory tests will be conducted for the purpose of validating it. In addition, further information on the performance of the buffer-bedrock interface will be obtained from the dismantling operation of the Prototype Repository in the Äspö bedrock laboratory which Posiva will participate in. The results of the tests and modelling work will be utilised for the design solutions of the buffer, backfill and closure, as well as for developing the RSC.

Chemical erosion

There are still uncertainties associated with the phenomenon of chemical erosion caused by the interaction of very dilute groundwater and bentonite – both with respect to empirical data and the models used. The work for developing the conceptual model and its numerical implementation will continue. The reasons for the differences of test and modelling results will be investigated, and therefore the development of the conceptual model will be continued particularly for assessing the dynamic[1] scalability. New conceptual models will be tested by validating their numerical implementation with small-scale tests. Figure 5-7 illustrates the erosion of bentonite in dilute water in test equipment at a scale of approximately 1/90.

Similarly, the small-scale tests will be continued with a particular focus on finding the forces exerted at different parameter values. The work will mainly be done as part of the EU's BELBaR project that will continue until 2016.

Posiva participates in the CFM (Colloid Formation and Migration) project of the Grimsel rock laboratory where *in situ* tests and theoretical analyses are performed to investigate the release of colloids and radionuclides from bentonite and their migration in natural bedrock fractures.

The results of tests and modelling work will be utilised in the safety case, produced in connection with submitting the operating licence application, for assessing the impacts of chemical erosion on the long-term safety of the disposal system.

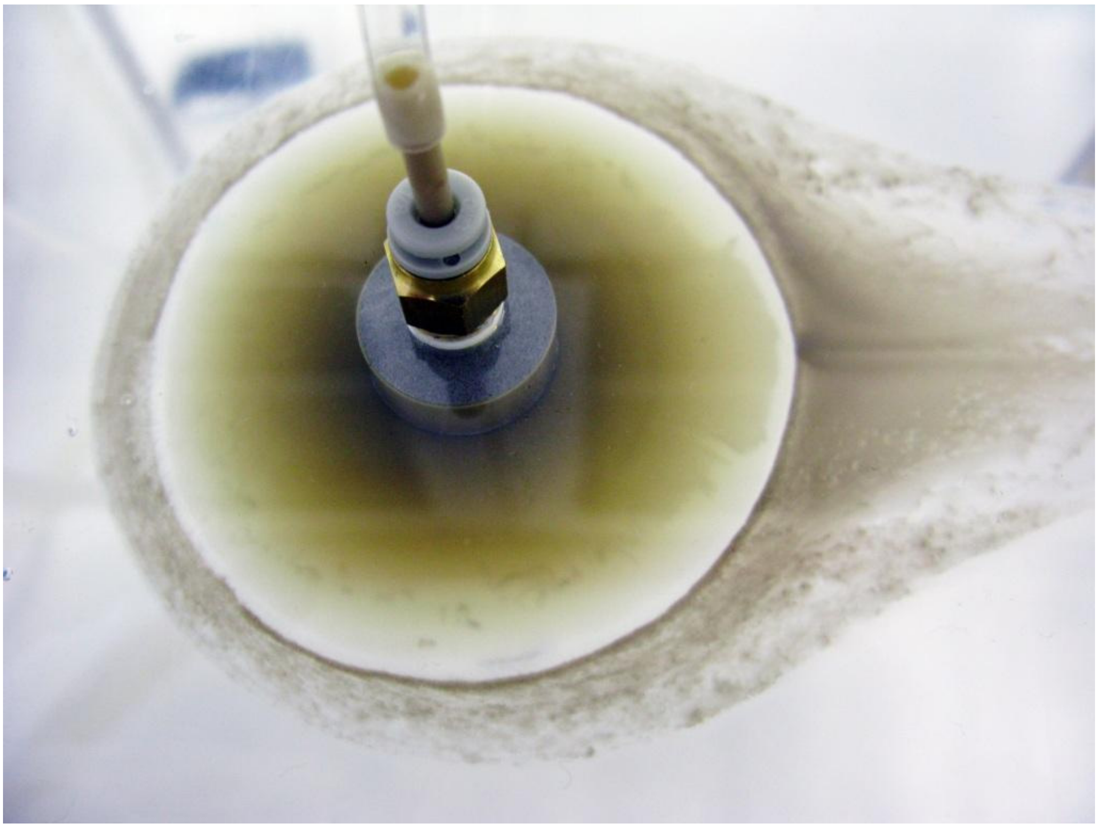

Figure 5-7. *The bentonite sample in the middle of the test device has been chemically eroded in the 1 mm fracture, forming transition zones typical of the phenomenon,*

[1] Dynamic scaling: the different driving forces of phenomena are present in the tests carried out in different scales in the same ratios, so that the relative movements/dislocations of different parts of the flowing/modified systems are of the same size, and the phenomena are scaled correctly from the dynamic point of view.

Interaction of substances dissolved from cement and silica sol with clay materials

There are perticular uncertainties associated with the release of substances dissolved from cement and their migration to the deposition tunnels and holes. However, the analyses based on pessimistic assumptions indicate that the impacts of dissolved substances on the bentonite are insignificantly small (*Performance Assessment*). The cement weathering model (*inter alia* Soler 2010) and the assumptions used in the assessment will be revised and reported in detail during the next programme period.

In order to demonstrate the suitability of the mass balance method used in the Performance Assessment report for assessing the interaction between bentonite and the substances dissolved from cement, Posiva is participating in an international project entitled the Cyprus Natural Analogue Project (CNAP) investigating the interaction between high pH and bentonite. The project will end in 2013, and the results obtained will be used in the next performance assessment. In addition to the above, the *in situ* and laboratory investigations on the interaction between cement and the bedrock will be continued, as is the modelling work in the international LCS (Long-term cement study) project in Grimsel. It has been found in the above investigations that three years is too short a period for observing the bedrock-cement interaction *in situ*, because the reactions are so slow, which is why the investigations will continue during the next programme period. In addition, the monitoring of groundwater for the presence of weathering products of cement-based grouting materials used in ONKALO will continue.

The investigations related to the gelation of colloidal silica will produce basic information on how much non-gelated silica can come into contact with bentonite. If the quantity proves to be significant, the possible aggregation of bentonite and silica will be assessed empirically.

Interaction between montmorillonite and groundwater

The interaction between montmorillonite (the main mineralogical constituent of the clay material used) and groundwater has been assessed to be insignificant from the performance point of view. The groundwater conditions inside the bedrock and any changes in them during the construction work are being monitored as part of the Olkiluoto monitoring programme. The need for further investigations regarding the interaction between montmorillonite and groundwater will be assessed on the basis of the results obtained (e.g. in case changes are observed in the groundwater conditions) The evolution of groundwater conditions and the related future work are described in section 5.6.

Mineralogical alteration of montmorillonite

The tests initiated for the purpose of verifying the conclusions regarding the mineralogical alteration of montmorillonite, lasting several weeks and conducted at a considerably high temperature (270 ºC), will serve as a preparation for the tests lasting several months and conducted at lower temperatures (150−200 ºC). The next, final phase will be the tests planned on the basis of the previous phases. They will last for several years and take place in conditions that are thermally still more demanding than those prevailing during final disposal (T = 90 ºC). The purpose of these tests is to reduce the uncertainties related to critical factors as well as to reinforce the current understanding regarding the behaviour of montmorillonite at the expected temperatures. In addition, the exchange of information on similar investigations will continue with SKB and Nagra.

Cementation

The estimates regarding the possible alteration of the effective montmorillonite dry density (EMDD) in the buffer as a result of the influence of temperature and groundwater are primarily based on computational analyses. They will be supplemented with the necessary tests during the next programme period. Figure 5-8 shows the test equipment developed for this purpose. The results of tests and modelling will be used in developing the technical solutions for the buffer, backfill and closure in connection with their next round of updates.

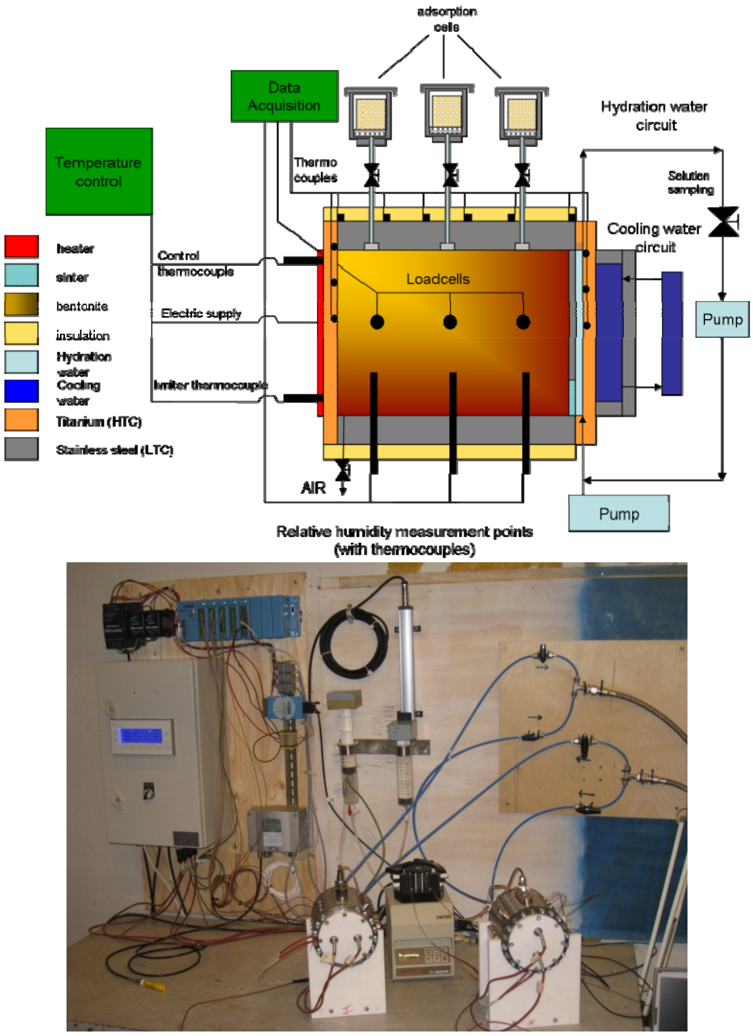

Figure 5-8. *Schematic illustration of the equipment and the test arrangement used for investigating cementation.*

Iron-bentonite interaction

Information on the long-term interaction between iron and bentonite will be obtained when the large-scale FEBEX test in the Grimsel rock laboratory is dismantled in 2015. The test arrangement includes an iron heater surrounded by bentonite. By characterising the bentonite samples taken near the heater, information will be obtained on the possible iron-induced alteration of bentonite and the extent of such alteration. Water conductivity and swelling pressure are among the most important parameters.

The tests and modelling related to the sorption and diffusion of Fe(II) currently in progress will end in 2012, after which the results of sorption and diffusion tests regarding Fe(II) will be reported.

The results of the tests will be utilised in conjunction with the operating licence application when assessing the impacts of the iron-containing materials used in the repository on the long-term safety of the disposal system.

Microbial activity in the buffer and backfill

The activity and survival of microbes in the buffer bentonite and backfill materials have not been fully established yet. Microbial activity needs water, large enough pores (micropore texture) and nutrients. As bentonite saturates, it swells, reducing the pore space as the swelling pressure develops. It is therefore possible that microbial activity reaches its maximum, at least locally, during the saturation process. However, it is still unclear at which stage the activity decreases to an insignificant level.

It was assessed in the *Performance Assessment* that the highest microbial activity would take place in backfill material where enough sulphates are available, and that microbial activity would be possible at the backfill-bedrock interface. There are still uncertainties associated with the quantity and activity of sulphate-reducing bacteria (SRB) possibly present in the backfill material, which is why the amount of sulphides produced by the microbes is not known with full certainty either. However, the *Performance Assessment* report contains the assessment that the precipitation of sulphides with the iron compounds dissolving from the backfill material will limit the amount of sulphides migrating all the way to the canister.

In order to investigate the mechanisms related to microbial activity and to reduce the uncertainties associated with them, a comprehensive study will be performed during the next programme period regarding the current level of knowledge. The study will form the basis for planning possible empirical studies and for developing the modelling work in order to obtain a more detailed picture of the sulphide quantities formed in the backfill and buffer at different times. The results will be utilised in conjunction with the operating licence application when assessing the impacts of microbes remaining in the repository on the long-term safety of the disposal system.

Freezing and melting

Bentonite, the chosen reference material for the buffer and backfill, has been found to endure several freezing-melting cycles (Schatz & Martikainen 2011, Schatz & Martikainen 2012), so further investigations are not required for this subject.

Mechanical behaviour of the buffer in rock displacements

In order to investigate the mechanical behaviour of the buffer, the material parameter tests conducted previously (Börgesson et al. 2010) will be repeated, and small-scale dislocation tests will be conducted as required in order to qualify the material model and the most commonly used modelling methods before possibly repeating the numerical analyses of rock displacement. The results of the tests and possible modelling work will be utilised in the safety case, produced in connection with submitting the operating licence application, for assessing the impacts of rock displacement on the long-term safety of the disposal system.

Migration of gas in the buffer

The investigation into the migration of gas in the buffer will be continued in the Äspo rock laboratory in LAGSIT, a large-scale test running many years, for the purpose of obtaining statistically more reliable data. Posiva has also participated in the EU's FORGE project of many years, ending in spring 2013. The results of the projects will be assessed, and a plan for further investigations will be produced on their basis, if required.

5.4.2.3 Closure of the disposal facility

The final closure of the disposal facility will only become topical decades after the operation has commenced; first for the central tunnels and for the connections to ground level further decades later. A preliminary technical solution has been produced for the closure. It will be defined further by the time the operating licence application is submitted. A more detailed technical description of the closure solution will be produced and its conformity with requirements established and the performance investigations regarding the materials used for the closure will be conducted during the next programme periods (in 2013–2018). The intention is to utilise in the closure the earlier conducted performance investigations of clay and backfill materials as well as cement and concrete investigations. The performance of different plugs, implemented in different conditions, will be assessed as part of the EU's DOPAS project, and the results of the project will be utilised as supporting material when demonstrating the performance of Posiva's plugs for both the deposition tunnels and the other underground openings.

Freezing-thawing tests will be initiated during the next three-year period for the backfill materials to be used for the closure of the disposal facility, particularly above the disposal depth, and the results will be reported by the time the operating licence application is submitted.

5.4.2.4 International large-scale tests

During the coming programme period, Posiva will continue its participation in international projects focussing on the monitoring of full-scale tests describing a disposal solution of the KBS type, as well as in projects (EBS Task Force, etc.) providing, among other things, peer assessments and quality assurance for the tools used in modelling work. Among other things, Posiva is participating in the LOT (Long-term test of buffer material) and ABM (Alternative buffer materials) projects of the Äspö HRL and in the FEBEX (Full-Scale engineered barrier experiment in crystalline host rock) project of the Grimsel laboratory monitoring the development of different parameters with on-line measurements. In addition, samples will be taken in the LOT and ABM tests at 1-, 5- and 20-year intervals. The current project plan involves dismantling the FEBEX test in 2015.

5.4.2.5 Selection of materials and alternative materials

During the coming programme period, Posiva will continue the characterisation of buffer and backfill materials and initiate the survey of and investigations into alternative materials. The objective is to survey the properties affecting the performance of buffer and backfill materials in detail and to determine the possible range of variation of these properties. The results can be used as the basis for assessing the suitability of other possible materials for alternative materials. This will require testing and development of the currently used analysis methods, particularly with regard to mineralogical and physical properties, and these will be focus areas during the coming three-year period.

5.4.2.6 Partial tests on the disposal system

The partial tests on the disposal system include the full-scale buffer demonstration discussed in section 5.4.1.2 and the tests on the foundation layer as well as the buffer and pellet backfill discussed in section 5.4.1.3, and the operating test covering all backfill components. In addition to the purpose discussed in section 5.4.1, these tests will be used for verifying the appropriate performance of the buffer and the backfill before commencing the joint operating tests and for determining the need for and requirements of the long-term monitoring of the joint operating test referred to in section 6.5. Furthermore, an assessment will be made on whether any phenomenon will restrict the operating activities in terms of time.

The dominant phenomena/processes and the significance of parameters with major impacts on them will mainly be assessed in small-scale tests, and with computer simulations, where applicable. The performance-describing measurements, performed in the partial full-scale tests on the disposal system, will primarily be used for assessing the scalability. In addition, the TBT (Temperature buffer tests), CRT (Canister retrieval tests) and Prototype Repository tests performed in the Äspö HRL are among those used for assessing the scalability. The typical dominant processes in this context include the absorption of water in the pellets and blocks, the channelling of water flows particularly in pellet-filled places, the retention of water and the resulting swelling, as well as the increase in temperature. The factors having a significant impact on these processes include the speed of water flow from the bedrock to the excavated facilities as well as the pressure, flow rate and composition of water and the composition and thermal conductivity of different components.

The expected changes in the measurements describing performance are small in places where water inflow volumes are small. The results from such places are not expected to be available in time for planning the joint operating test. Therefore the conditions still acceptable in the rock suitability classification will be simulated artificially, as required. An example of such artificial simulation is the simulation of a water-leaking fracture by feeding synthetically prepared water through a pipe.

The necessity of measuring the factors affecting the evolution after the engineered barrier system has been installed, such as the water conductivity of different parts of the surrounding bedrock, will be assessed at the beginning of the programme period, and these measurements will be undertaken at that time if required. The described tasks include:
- water absorption and retention test using a simplified (laboratory) test arrangement,
- absorption and retention test regarding the water contained in the foundation layer material, conducted in connection with the foundation layer installation test (described in section 5.4.1.3),
- absorption and retention test regarding water contained in the backfill pellets using a simplified (laboratory) test arrangement,
- absorption and retention test regarding the water contained in the backfill pellets, conducted in connection with the pellet installation test (described in section 5.4.1.3),
- absorption and retention test regarding water contained in the backfill pellets and blocks using a simplified (laboratory) test arrangement,
- absorption and retention test regarding the water contained in the backfill pellets and blocks, conducted in connection with the backfill test (described in section 5.4.1.3),
- assessment of the predictability of processes taking place after installation of the buffer and its validation with 1/6-scale and ⅓-scale laboratory tests,
- assessment of the predictability of processes taking place after installation of the buffer and its validation with a full-scale buffer test (described in section 5.4.1.2), and
- determination of the water conductivity and water pressure values in different parts of the bedrock deemed to constitute the near-fields of the demonstration facilities.

5.5 Monitoring programme

The Olkiluoto monitoring programme (OMO) is in progress for the purpose of monitoring the long-term developments in the disposal site and facility. The results of the monitoring programme are reported annually in Posiva's series of working reports. A separate report is produced for each area of monitoring (rock mechanics, hydrology, hydro-geochemistry, surrounding environment above ground and foreign materials), presenting the investigations conducted during the year and comparing the results with those of previous years.

The monitoring programme was updated in 2012 to cover the coming years until the commencement of disposal operations (Posiva 2012a). The programme sets six main objectives for monitoring:

1. To demonstrate that the bedrock properties in the disposal site will remain favourable for long-term safety.

2. To produce information that can be used for developing and testing different models describing the disposal site, thus increasing the knowledge of the properties and evolution of the site.
3. To observe the environmental impacts of the project.
4. To provide the builders and designers of the plant with feedback and information regarding the impacts of construction work on the bedrock and the environment above ground.
5. To observe the performance of the engineered barrier system in order to verify its expected and predicted behaviour.
6. To fulfil the obligation concerning nuclear facilities to monitor the environmental radiation and the releases of radioactive materials.

The first four of these objectives are in line with the 2004 programme, and the research activities related to them has been divided into the areas of rock mechanics, hydrology and hydrogeology, hydro-geochemistry, foreign materials and the surface environment. The fifth and sixth objectives were introduced in 2012. The requirement of monitoring the engineered barrier system will actually only become topical when the disposal operations begin, but the techniques to be possibly used for monitoring the engineered barrier system will already be developed and tested during the coming period 2013–2018. Likewise, the programme for monitoring radiation and releases during operation will be planned, and the basic state will be surveyed.

5.5.1 Rock mechanics

In the research area of rock mechanics, the state of stress in the bedrock, changes taking place in it and the possibly resulting bedrock deformations and spalling will be monitored. The rock-mechanical monitoring work will also cover the temperature of bedrock and any increases in it, the land uplift, as well as the tectonic movements of and seismic phenomena in the bedrock. The intention is to acquire information on the stability of the Olkiluoto bedrock, including possible observations of the re-activation of fractures or the creation of new fractures.

In order to detect the seismic phenomena occurring in the bedrock both naturally and as a result of human activity, such as the construction of ONKALO, a micro-seismic measurement network has been established in Olkiluoto and its near-fields. In 2010, the network included 15 stations: 11 above ground (of these, 3 outside Olkiluoto), one in a drill hole (at the depth of 150 m) and two in ONKALO (at the depths of 280 m and 370 m, respectively). In the coming years, the network will be expanded with the construction of underground facilities to the technical rooms of ONKALO and to the central tunnels to be excavated at a later stage. This will further improve the possibilities of detecting micro-earthquakes caused by excavation work. The development work for the monitoring network will also include an update of the data transfer system to be implemented in 2012–2013.

The bedrock deformations caused by the redistribution of the state of stress following the excavation operations will even in the future be monitored mainly using extensometer and convergence measurements. The extensometer measures variations in the length of a drill hole, while convergence refers to monitoring the deformations in the cross-section of tunnels or shafts by measuring the distances between fixed points at the walls. Extensometer measurements are in progress in ONKALO near Investigation niche 3, and convergence measurements have been performed in Investigation niche 3 itself. The performance of convergence measurements at shaft ends has been found to involve technical difficulties, and, in the future, they will concentrate on monitoring the three major damage zone penetrations in ONKALO and only secondarily on monitoring the tunnels. Measurements are performed twice a year in order to monitor any dislocations associated with the damage zones. The intention is to extend the deployment of both methods to the technical rooms and demonstration tunnels at the disposal depth. The impact of excavation work on the bedrock is also monitored by regular visual inspections of all parts of ONKALO.

The movements of large blocks in the Olkiluoto bedrock and the land uplift following the previous ice age are investigated by monitoring the relative locations of fixed GPS pillars. The pillar network was established in 1994, and since 2010, it has consisted of 18 pillars, 12 of them on the Olkiluoto island and six in its near-fields. Two different methods are used for determining the location of pillars: GPS satellite positioning is used for measuring horizontal movements, while precision levelling is used for measuring vertical movements. The GPS measurements in nine pillars are now automatic, and they will become continuous in 2012. The location of the other nine pillars is still determined by separate measurements performed twice a year. A 511-metre baseline has been also established in Olkiluoto for the purpose of verifying the results. Its length is measured electronically in connection with the GPS measurements. The plan is to perform precision levelling measurements of the GPS pillars at two-year intervals. In addition, the vertical bedrock movements are monitored annually with levelling measurements of the local measuring point networks established in the ONKALO and VLJ repository areas and of the line crossing the Olkiluodonsalmi straits. The elevation measurements for the whole of Olkiluoto island are linked to the nationwide measurement point grid with the help of precision levelling measurements of the line between Lapijoki and Olkiluoto performed at four-year intervals, next in 2015.

5.5.2 Hydrology

Hydrological monitoring provides information on the changes in groundwater level and bedrock groundwater pressure, groundwater flows, hydraulic properties of the soil and the bedrock, the inflow of groundwater into ONKALO, the salinity of groundwater, the impact of the Korvensuo reservoir on groundwater and on any disturbance to the surface hydrology caused by construction of the disposal facility. In addition, the factors important to surface hydrology are monitored. They include the surface water runoff and infiltration to groundwater, seawater level, rainfall, snow cover and the ground frost.

Most of the groundwater monitoring measurements are performed in drillholes of different depths and in groundwater observation pipes, of which there are almost one hundred in Olkiluoto. The groundwater level is measured (usually manually) once a month from the groundwater observation pipes in the overburden and from shallow drillholes (with a depth of a few ten metres). Automatic measurements are taken every hour in a few observation points.

The hydraulic head of deep bedrock groundwater is monitored from holes that are several hundreds of metres deep and divided into monitoring sections with multi-packer equipment. The pressure of bedrock groundwater in each measurement section (of which there is a maximum of eight in one hole) is measured automatically at one-hour intervals. Until now, the monitored sections between packers have mainly been selected from zones with a high hydraulic conductivity, but the programme will be changed so that less conductive bedrock sections are also monitored in order to obtain information on the hydrology of bedrock corresponding to the disposal conditions.

The groundwater flows in bedrock are measured using a Posiva Flow Log (PFL DIFF) equipment lowered in a drillhole and with a transverse flow meter (PFL TRANS). Flow measurements are performed annually, usually in about four open holes, in the assumed excavation impact zone, as well as every time when a drillhole with multi-packers is temporarily opened. Flow measurements can be performed both above ground and in holes drilled in ONKALO. HTU measurements are performed every other year in deep drillholes for investigating any changes in the hydraulic conductivity of the bedrock. Information on the hydraulic properties of top layers of the bedrock and of the soil is acquired by the slug measurements performed in shallow holes and groundwater pipes.

The methods used for monitoring the amount of inflow water into ONKALO include measurement weirs constructed in the access tunnel and the observation of individual leaking fractures and structures. The volume and moisture of ventilation air as well as the quantity of process water used are also monitored for the purpose of determining the total water balance of ONKALO. So far, monitoring of the ventilation air has been based on individual measurements taken once or twice a month, but when the permanent ventilation through the vertical shafts is introduced, the monitoring will be continuous and automatic.

The salinity of bedrock groundwater is monitored in connection with the hydrological PFL measurements by measuring its electrical conductivity. This supplements the results of laboratory analyses of the water samples included in the area of hydrogeochemistry. So far, the electrical conductivity of the entire bedrock mass, where changes may be caused by variations in the composition of groundwater, has also been investigated with a geophysical Gefinex SAMPO scan performed annually from above ground. However, the increasing construction activities above ground may mean that it is impossible to use this electromagnetic method, which is why it was not included in the updated monitoring programme.

As a particular local issue, the impact of the Korvensuo reservoir on bedrock groundwater is monitored. The basin is located in the middle of Olkiluoto, a few hundred metres from the mouth of the ONKALO access tunnel. The water level in the basin is measured weekly, and the level of groundwater in the filtration tubes in the weir surrounding the basin is measured monthly. In addition, water conductivity measurements are carried out every other year in the filtration tubes.

5.5.3 Hydrogeochemistry

The purpose of hydrogeochemical monitoring is to observe any changes in the chemical properties of groundwater and surface water. The most important investigation method is the laboratory analysis of water samples taken regularly from different points. The samples are taken from shallow and deep drill holes using different pumps and sampling devices depending on whether the hole is packed-off or not. Samples are taken in ONKALO and its impact on the surrounding environment is monitored by taking samples after use from the sedimentation pool on ground level and from the ditch via which the water is discharged into the sea. The intended concentration of sodium fluorescein, which is used as a trace compound in process water, is measured and confirmed before water is used in ONKALO.

Samples of shallow groundwater are taken every year in two campaigns, one in spring and the other in autumn, to distinguish the seasonal variation from other changes. The sampling locations are chosen annually on the basis of previous results and other observations.

The sampling programme regarding deep groundwater is also planned annually on the basis of earlier observations and expected changes. In addition to the laboratory analyses of water samples, certain physical-chemical parameters (pH, electrical conductivity, oxygen concentration, redox potential and temperature) can also be measured in situ. The mixing of water from the Korvensuo basin with natural groundwater is investigated by determining the concentrations of heavy hydrogen and oxygen isotopes ^{2}H and ^{18}O in the water samples. The method is based on the fact that these isotopes are more abundant in the water of the Korvensuo basin than in natural groundwater.

The hydrogeochemical measurements and methods are also used to produce information for monitoring foreign materials and different areas of the surface environment. The aim is to detect the impacts of foreign materials used in the construction of ONKALO, particularly those of cements and explosives, in the compositions of the water seeping in the tunnel and the process water. In turn, the chemical environmental impacts of construction work are monitored by investigating the samples taken from the observation holes and the open ditch that are located near the piling area for quarried rock.

5.5.4 Surface environment

Monitoring of the surface environment produces information on factors affecting long-term safety. This is done by investigating the quality and quantity of groundwater infiltrating into the bedrock and by monitoring land uplift. In addition, the migration of radionuclides in the soil and bodies of water, their intake by vegetation and their further migration in different nutrition chains are investigated for the purpose of biosphere modelling. The interaction between the surface environment and bedrock groundwater is investigated in the context of groundwater formation and migration of radionuclides in the bedrock. This interaction is affected by various factors, including the changes in land use, drainage of surface water and climatic conditions. Another purpose of the monitoring is to follow the direct environmental impacts of disposal operations apart from those related to radioactivity. As the planned operating phase of final disposal is approaching, preparations must also be made in 2013–2018 for monitoring any releases by determining the basic state of the environment to the extent that it is not yet known on the basis of the investigations performed by the Olkiluoto NPP.

Of the subjects of surface environment monitoring related to long-term safety, land uplift is also discussed in the area of rock mechanics, while the infiltration of surface water into groundwater is discussed in the area of hydrology and hydro-geochemistry. The aspect of land uplift relevant to the development of surface environment is the retreat of the shoreline and the gradual conversion of shoreline waters from sea into wetlands and further into dry land. This is why the plan is to perform laser scanning of the terrain elevation on two lines crossing over Olkiluoto at 5- to 10-year intervals in addition to the information obtained by precision levelling performed as part of the research area of rock mechanics.

Plenty of local initial data regarding the quantitative description of numerous phenomena in the biosphere is required in the modelling work done for the purpose of assessing the long-term safety of final disposal. Due to the large variation depending on time and location, typical of the properties of biosphere, the acquisition of this initial information requires the measurement of long time series in several locations. This is why it was deemed appropriate to include the research to be performed for modelling purposes in the monitoring programme even though it is not intended for monitoring the changes of any property over time or as a consequence of construction work. The initial information for biosphere modelling, investigated as part of the monitoring programme, includes:

- the sorption ability of loose surface soil and sediments regarding different elements,
- the quantity and growth of the biomass consisting of different plant types and mushrooms in the forests and swamps,
- passive and active intake of substances from the soil into vegetation,
- the accumulation of different elements, particularly in mushrooms and plant parts, such as berries, utilised for human consumption,
- the populations of land animals and birds, particularly of game and small animals,
- transfer of elements into the nutrition network and their intake by agricultural plants,
- the quality of seawater and the sorption capacity of the solids suspended in it,
- the flow rate and water quality of rivers,
- erosion and sedimentation in water bodies,
- the production of biomass by aquatic plants, intake of elements into aquatic vegetation,
- the numbers and biomass of aquatic animal populations,
- catches of fish, and
- the migration of elements into plankton, seabed fauna and fishes.

The interaction between the surface environment and groundwater has also been chosen as a separate subject of surface environmental research. It is of importance to both the development of the chemical properties of groundwater and hence the expected long-term evolution in the disposal facility and to the migration of radionuclides from the bedrock into the atmosphere. The water infiltrating in the soil is investigated by collecting water samples using lysimeters placed in areas with different types of surface environment. In addition, the changes in land use in Olkiluoto are monitored, because, for example, the construction of buildings and roads, clearing of vegetation and the pavement of land areas affect the hydrological balance. The programme also includes the monitoring of surface water drainage, which in Olkiluoto means monitoring the water quantity and quality in the largest ditches, as well as the collection of climate and weather data. Part of the weather information comes from TVO's weather station, but Posiva is also investigating the micro-meteorological parameters included in the research area of the surface environment, the thickness and water content of the snow cover, the depth of ground frost and the isotopic composition of groundwaters.

The environmental impacts of construction activities being monitored include noise, dust, increase in traffic, releases from process waters and quarried materials, the pollution of soil and waters as well as the impacts on flora, fauna and the quality and quantity of water in the wells in Olkiluoto.

When the disposal facility starts operating, it becomes a nuclear facility under the obligation to monitor the releases of radioactive substances and radiation into the environment and to investigate, in advance, their probable methods and routes of spreading for the eventuality of transients or accidents. Even though this obligation does not actually become valid during the programme period now commencing, preparations for it must be initiated by determining the basic radiological state of the environment and by studying the potential release routes of radioactive substances. Since there is no intention to monitor the operation of the disposal facility or the concentrations of radioactive substances inside it in the monitoring programme, but instead as part of the control related to the operation of the facility, the monitoring under the monitoring programme will be limited to investigating the quantities and migration of unstable isotopes in the surface environment of Olkiluoto. Part of the measurements will be made of the samples taken in connection with monitoring the surface environment. The research is divided into investigations of radioactive substances present in water bodies, the atmosphere and nutrition networks, and it will make use of the environmental radioactivity monitoring already being performed by the Olkiluoto NPP. The plan is to initiate the determination of the basic radiological state of the surface environment in 2016 and to carry it out in phases so that all necessary subjects have been investigated by the time the disposal operations begin. Once the basic state has been determined, some of the measurements will be continued as a regular monitoring activity in order to detect any changes.

5.5.5 Foreign materials

The materials foreign to the disposal system may be harmful to the long-term safety or the environment if they end up in the disposal facility or the surface environment. In order to assess and minimise these harmful effects, the monitoring programme has a section for foreign materials, responsible for monitoring, regulating and reporting all use of foreign materials in the construction of the disposal facility. A material handbook is maintained of the foreign materials used in the construction work and other operations. It includes all materials approved for use in ONKALO.

In order to detect the impact of foreign materials, the compositions of natural groundwater and the process water used in ONKALO are monitored. The groundwater is monitored as part of the hydro-geochemical programme. Samples are taken regularly of the process water pumped above ground after its use, both from the sedimentation pool and the outlet ditch leading to the sea. The effect of cements and grouting materials is typically seen as an increase of alkalinity, while that of the explosives used in excavation is seen as an increase in the concentrations of nitrogen oxides.

5.5.6 Engineered barrier system

The monitoring activities for the engineered barrier system are currently being planned and developed. The monitoring methods and the required instruments will be tested and developed in the tests of engineered barrier system to be performed during 2013–2018 in the facilities built for the purpose in ONKALO. The objective is to develop methods that would allow monitoring the evolution of the engineered barrier system in genuine disposal conditions for years or even for decades. This will produce empirical information that will be beneficial for assessing the long-term safety of disposal with analytical models and numerical simulations. Small-scale investigations on the installation and early evolution of the bentonite buffer were initiated in 2011, and the intention is to continue them at least until 2017. The investigations will advance to full-scale buffer tests in 2014 and to the underground joint operating test of the buffer, tunnel backfill and plug towards the end of period 2013–2018. The monitoring methods for the deposition tunnel backfill and end plug will be developed and tested in connection with the backfill tests. The investigations, development work and tests to be undertaken during 2013–2018 regarding the engineered barrier system are described in greater detail in section 5.4.

The behaviour of the engineered barrier system will be monitored both in full-scale system-specific tests implemented during the construction of the disposal facility and in the joint operating test to be built during the operating activities. In addition to the monitoring performed during the joint operating test, separate tests can be initiated to support the fulfilment of the monitoring obligation if for a certain essential process there is no monitoring technology available that would be compatible with the joint operating test monitoring.
. Those processes that can only be investigated after the tests have been dismantled will be investigated, as far as possible, in system-specific tests to be dismantled after a few years of monitoring.

The monitoring during operating activities must be performed in locations that correspond to the actual disposal conditions as closely as possible. The disturbances caused by the monitoring system on the monitored subject must be minimised. The plans must also take into account the fact that the monitoring system must not hamper the attainment of other goals of the joint operating test. For example, the required cabling f may prevent the implementation of the monitoring in connection with the installation tests. The major technical challenges of monitoring include the durability and stability of sensors when measuring very small changes over very long periods, as well as implementation of the cabling required for data transfer and power supply in such a manner that they will not disturb the evolution of the monitored system. The possibilities for wireless data transfer are being investigated, as is the suitability of a system that would not require sensors to be implanted in the subject to be monitored. However, the current starting point involves conventional technologies requiring cables.

The corrosion of the disposal canister copper overpack and the accumulation of deposits on its surface can be investigated by taking samples of the canister after the long-term test has been dismantled.

The key parameters to be measured when monitoring the buffer include the temperature distribution (both in the bentonite and in the hostrock), humidity, swelling pressure in both radial and axial directions of the canister, pore pressure as well as any displacement of the buffer and the canister. Any chemical changes in the bentonite can only be investigated using samples taken after the test has been dismantled, but it may be possible to measure continuously certain pore water parameters, such as the pH and redox potential. As a rule, monitoring of the tunnel backfill is similar to that of the buffer.

According to the current plans, the developments in the plugs to be installed to the mouths of the deposition tunnels can be monitored by observing the leakage of water through them and the surrounding bedrock, and by measuring the displacement of the plug. It is conceivable that the plugs of the actual deposition tunnels can also be monitored from the time the plug is installed until the central tunnel is backfilled.

Posiva is planning to continue the long-term monitoring of the engineered barrier system as long as required during the disposal operations. The locations of deposition holes to be bored for the tests will be chosen using the same rock suitability classification (RSC) scheme as will be used for the actual repository, which means that the holes may stay very dry even for decades. Therefore, the bentonite installed in these holes will not necessarily have time to become wet or its swelling pressure to significantly increase during the time that monitoring at the disposal depth is possible. Therefore, it may also be necessary to conduct long-term monitoring tests in holes that have larger groundwater flows than allowed in the suitability criteria or in holes with artificial wetting in order to speed up the process.

More detailed plans for monitoring the engineered barrier system will be produced on the basis of the progress made in the research and development work during 2013–2018. The monitoring plan for the engineered barrier system will be published in connection with submitting the operating licence application.

5.6 Safety case

5.6.1 General

The main objective of the safety case-related tasks during the coming three-year period is to acquire more information for the needs of the operating licence application. The main tasks regarding the safety case include:
- production of a plan for the next safety case,
- development of the methodology used in safety assessments and verification of the reliability of initial data,
- development of the quality management regarding the safety case, and
- production of a safety assessment regarding the KBS-3H design by the end of 2015.

The safety case for the construction licence application will be supplemented with regard to any missing parts during the first half of 2013 (*Models & Data for the Repository System*). The entire Safety Case Plan will be produced for the FSAR, and the targets for each phase will be presented and a schedule set out for them. The matters to be taken into account when producing the plan include the development work regarding planning and construction, the demonstration work concerning the KBS-3 design and the new information obtained regarding the long-term behaviour of the engineered barrier system, as well as any more detailed information obtained of the properties and suitability of the bedrock.

Knowledge of the bedrock and surface environment in Olkiluoto will continue to increase. Both the long-term tests conducted in ONKALO and the results of hydrogeological and geochemical modelling can be utilised for assessing the performance of the disposal system and for migration modelling. Important additional information on the initial state of the engineered barrier system and its behaviour will be obtained from the demonstration programmes that have begun. The additional information can be used for testing the models required for the safety case.

Regarding the KBS-3H design (section 5.8), the objective for the next few years is to develop the KBS-3H design on the basis of the chosen DAWE (Drainage, Artificial Watering and air Evacuation design alternative) design to a stage where comparison of the 3V and 3H alternatives on the basis of their long-term performance and safety is possible. The performance of the KBS-3H design will be verified and demonstrated in a full-scale test (Multi Purpose Test, MPT) at the Äspö rock laboratory during 2012–2014. Other areas of development include drilling/boring a straight pilot hole and reaming it into a deposition drift in line with the criteria set, development of post-grouting techniques using Mega-Packer equipment, and the development and testing of buffer and backfill components. A safety assessment based on the KBS-3H plan will be produced during 2013−2015. The assessment will take into account the particular characteristics of 3H that differ from the safety case produced for vertical design KBS-3V.

In parallel with the safety assessment regarding KBS-3H, the methodology required for the safety case of the operating licence application (FSAR) will also be developed, taking into account the official feedback received from the review of the construction licence application. Preliminary reviews and scoping analysed will be used to ensure before producing the actual safety case that a disposal system compliant with the design basis will meet the requirements set regarding long-term safety with sufficient reliability margins, and that the system can also be implemented in compliance with the set quality targets. If required, the technical plans will be amended or uncertainty margins reduced by developing the assessment methodology.

The comparison between the safety features and other properties of KBS-3V and KBS-3H will be performed during 2016. It will provide the basis for deciding whether the safety case work should be continued on the basis of the 3V design, or whether it should be re-directed towards the 3H design.

In accordance with section 4.6, the research supporting the safety case that will be produced for the purpose of the operating licence application will continue during the next programme period. They include:

- empirical research into the dissolving mechanisms of fuel,
- development of models used in the climate scenario,
- research into the hydrogeological and geochemical conditions during ice ages,
- investigations and research related to the target properties of and future evolution of the bedrock, and

- acquisition of initial data and development of partial models for biosphere assessment.

In addition to the new and verifying initial data discussed above, the modelling work performed for the safety case will be developed during the coming years with regard to, among others, the following areas:
- development of integration between the disposal facility and the surface environment,
- clearer linkage of groundwater flow modelling and process modelling (e.g. buffer erosion / canister erosion) with radionuclide migration modelling,
- modelling of the groundwater flow conditions during ice formation and the associated groundwater chemistry, and
- extended use of probabilistic modelling in the migration calculations.

The contents of modelling and other elements of the safety case will be presented in the Safety Case Plan to be produced in 2013.

5.6.2 External conditions

Climate scenarios

The main factors affecting the future climate include changes in the Earth's orbit and its axis of rotation that affect the amount of solar radiation energy received (insolation) and the amount of greenhouse gases in the atmosphere. The future development of insolation can be calculated with relative accuracy, because the different factors affecting it and their (cyclic) development over time are well known. However, linking the concentration of greenhouse gasses, particularly of carbon dioxide, as a dynamic factor to long-term modelling has proven to be remarkably difficult due to the unknown and complicated interactions associated with it.

The models used for forming climate scenarios will be developed during 2013−2015. It was observed in the modelling work undertaken during the past programme period that the simulations of the most recent ice age made using CLIMBER modelling did not correspond to geological observations in all respects. Compared to the observations, the model produced too much ice in the Olkiluoto area and too little ice in some other areas. During 2013–2015 (−2018), the climate modelling on a time scale of 100,000 years will be developed in the following respects:
- The CLIMBER-SICOPOLIS model is sensitive regarding the parameterisation of its glacier model and its surface energy and mass balance model (Ganopolski et al. 2010). The treatment of geothermal heat flux and the linkage between the climate glacier model in the CLIMBER-SICOPOLIS model system will be developed in 2013–2015.
- It is still not possible to completely model the changes in the atmosphere's carbon dioxide content occurring during an ice age cycle (of approximately 100,000 years). However, modelling has recently produced promising results (Brovkin et al. 2012), and their suitability for modelling the carbon cycle during the ice age cycle will be assessed in 2013–2015. The starting point for this will be the different scenario assumptions regarding the quantities of man-made greenhouse gases.

Ice formation and the glacier

Three sub-projects (A, B and C) have been in progress in the Greenland Analogue Project, and they have produced information regarding the glacier (Sub-Project A), bottom of the glacier (Sub-Project B) and the bedrock (Sub-Project C). The field work for all three sub-projects will be completed during 2012. The results will be analysed and studied during 2013, and the results will be reported in a two-part final report during 2013 and 2014. The first part of the report will present the key results and their scientific interpretation. The second part of the report will focus on interpreting the results from the long-term safety point of view. The second part of the final report is expected to be completed during 2014. The results will be used to develop the existing models for the analysis of glacier dynamics, hydrology, groundwater flows and chemistry as well as the hydro-mechanical connections of ice ages. In this way, uncertainties can be reduced and the boundary conditions used for modelling can be determined better for the operating licence application. The plan is to continue monitoring in the Greenland research area even after 2012, and its possible results will be utilised for the operating licence application.

Investigations were performed during the past programme period in Lake Saimaa and the Salpausselkä area, and the results were used to reconstruct the behaviour and paleo-environments of the Lake District Ice Stream near the edge of the continental ice. The investigations will continue during 2013–2015 for the purpose of characterising the impacts of the melting waters of the possible glacier on groundwater near the edge of the ice. The objective is to acquire information on the hydrological and geochemical impacts of dilute melting water in the extreme conditions of deglaciation.

During the programme period now commencing, the modelling of glacier area and glacier thickness will be improved further, and the possible impacts of the thickness of the glacier on the canister design basis will be verified.

Permafrost

During the previous programme period, the permafrost assumptions used for scenario modelling were based on the information produced by the climate model regarding the ground-ice interface. However, it turned out that this temperature value produced as a "by-product" of the climate model is often unrealistic. Although of little importance for the actual climate model, the information on ground temperature is essential for reliable permafrost modelling. Therefore, the permafrost modelling will be specified further during the coming programme period by supplementing it with a more detailed treatment of the impact of the ice layer on the transfer of heat by taking into account the advection of heat caused by the flow of ice and the thermal energy caused by internal friction. The results will be utilised for the safety assessment to be performed in connection with the operating licence application.

Land uplift

During the coming years, the land uplift model for the surface environment (biosphere) (Pohjola et al. 2012) will be developed further by assessing the uncertainties associated with the initial data collected from literature, by acquiring new timing data from the near-field of Olkiluoto for reducing the spatial variations, by taking better into account the GPS and precision levelling results of the Olkiluoto and Satakunta areas, and by checking the consistency of the glacier models (see above) and the work already performed (section 4.2.2) and to be performed (section 5.6.3) regarding glacial displacement. The results will be utilised for the safety assessment to be performed in connection with the operating licence application.

5.6.3 Bedrock

A summary of the development of bedrock properties during the operating phase of the disposal facility and during a period covering several ice formation cycles is presented in the *Performance Assessment* report. The report concludes that the bedrock near the canister hole locations chosen on the basis of rock classification meets its target properties apart from any individual deviations. The deviations from target properties are due to the uncertainties associated with long-term developments and their modelling. These uncertainties can be reduced by acquiring supplementary information on the conditions in the disposal facility site and on the performance of the engineered barrier system in these conditions.

The key themes of research for 2013−2018 regarding the evolution of the bedrock and the migration of radionuclides in it include:
- the evolution of groundwater chemistry (the presence of dilute groundwater, reduction of sulphates into sulphides, release of iron and precipitation of sulphides, as well as the buffering capacity of bedrock),
- description of the groundwater flow conditions, particularly during ice ages,
- integration of bedrock groundwater flows and bedrock water chemistry and the interaction between water and bedrock with the objective of providing more accurate information on the relative stability of groundwater chemistry during long periods of time, and
- the possibility of bedrock displacement near the repository facilities.

The goal of the investigations is to respond to the feedback received in the assessment by authorities concerning the safety principles to be observed and an assessment of their implementation (statement dated 30 December 2010 by the Ministry of Employment and the Economy entitled "Käytetyn ydinpolttoaineen loppusijoitushanke - alustavat selvitykset ja suunnitelmat liittyen tulevan rakentamislupahakemuksen valmisteluun") as well as fulfilment of the performance targets (bedrock target properties) and the suitability of the disposal site (STUK: Posiva Oy:n Olkiluodon ydinjätelaitoksen turvallisuusselvitys 6.6.2011). The long-term impacts of the excavation damaged zone (EDZ) and the alteration of bedrock properties and the changes in them during operation, brought up by STUK in its statement dated 6 June 2010, are discussed in the *Performance Assessment* report, and particularly their impacts on groundwater flows are found to be small. The flow conditions, groundwater chemistry and the number of canisters possibly damaged by earthquakes and limiting that number are issues which have attracted the attention of authorities in the context of the performance of the engineered barrier system.

The key areas of research regarding the bedrock are closely associated with characterisation and modelling the disposal site as well as with the development of rock suitability classification. They produce initial information and boundary conditions for assessing the long-term evolution of the bedrock. The field investigations in the surface holes in Olkiluoto and in ONKALO related to the properties of the disposal site, update of the models describing the properties of the disposal site and the tasks related to the development of bedrock classification, to be utilised in safety assessment work, are described in section 5.3.

During 2013−2014, the work regarding the bedrock and aimed at assessing the long-term safety will mainly focus on the acquisition of supplementary initial data and on model development work. The description of bedrock evolution, including the evolution modelling of groundwater flows and chemistry, will be updated, mainly during 2015−2016, for the operating licence application on the basis of the updated site description of Olkiluoto. A summary of the results will be presented in the updated *Performance Assessment* report to be published after that. Most of the work for determining the scenarios and for producing the radionuclide migration models will take place after 2015.

Evolution of bedrock temperature

The evolution of bedrock temperature is described in connection with permafrost modelling (see section 5.6.2), and it is also taken into account in groundwater flow modelling and spalling estimates (see below). The development of temperatures near the deposition holes is presented in the *Performance Assessment* report on the basis of thermo-technical dimensioning presented by Ikonen (2009). The description of temperature developments in the near-field will be updated for the operating licence application as required, if there are changes in the initial data (e.g. in the amount of heat produced by fuel or in the canister design). The updated information on the thermal properties can also be taken into account at that time.

Excavation-induced changes in bedrock (EDZ and spalling)

The preliminary results of the POSE test as well as the information on the properties of the excavation damaged zone obtained from investigations in ONKALO and from literature have been utilised when assessing the significance of the excavation damaged zone from the point of view of long-term safety and particularly from the point of view of groundwater flows. Due to the uncertainties associated with the properties of stress-induced damage (continuity and water conductivity), several alternative assumptions regarding these properties were used in modelling. These assumptions were pessimistic, given the available information. The results (*Performance Assessment*) indicate that the impacts on groundwater flows and long-term safety are minor.

Characterisation of the state of stress and strength properties of the Olkiluoto bedrock and of the excavation damage will continue in ONKALO. The POSE test is used to investigate the effects of the heat produced by spent nuclear fuel on the bedrock properties in the vicinity of deposition holes. The work for characterising the excavation damaged zone (EDZ) will continue with the objective of investigating the hydraulic properties of the EDZ. The new results of POSE and EDZ studies and their interpretation will be taken into account in flow modelling.

Bedrock displacement

Re-activation of fractures and displacement may occur in connection with changes in the state of stress. The most significant of these changes are related to the excavation of underground openings, effects of the heat produced by spent nuclear fuel and to ice ages. The formation of the excavation damaged zone and the creation of stress-induced damage during the excavation and operating phase have been assessed to have a bigger impact than the re-activation of fractures and rock displacements, and the assumptions made in the analyses regarding the EDZ and spalling have also covered the effects of re-activation and placements (*Performance Assessment*).

The rock displacements most significant to the long-term safety of disposal are the possible post-glacial displacements in the fault zones near the repository and the consequent secondary displacements in the bedrock fractures in the repository area. The work for analysing the displacements of deformation zones and fractures in connection with post-glacial displacements will continue. The objective of the work is to investigate the probability and magnitude of displacements, taking the properties of zones and fractures into account more realistically (including the orientation of zones in relation to the state of stress, their continuity and the properties of fracture surfaces). The previous analyses have assumed the zones and fractures to be planar (Fälth & Hökmark 2011, 2012). Furthermore, it will be investigated whether the way in which earthquakes are presented in the modelling can be developed to allow investigating the impacts closer to the zone where the primary dislocation occurs.

The analysis of displacements is closely associated with the development of rock suitability classification where the displacement analyses are utilised for determining the layout-defining features (LDFs) and for specifying the maximum size of fractures that are allowed to intersect the deposition holes. The results of rock classification and fracture network modelling will be used to assess the probability of displacements leading to the failure of canisters in the deposition holes.

The state of stress in the bedrock affects the stability of faults zones. The stability is analysed by taking into account the updated information on the development of the state of stress during an ice age, as well as the updated stress model of Olkiluoto.

A summary report of seismics in Olkiluoto will be produced by the end of 2015. This report will present a summary of studies conducted in Olkiluoto and elsewhere in Finland where possible displacement observations have been surveyed and analysed. The estimate regarding the frequency of earthquakes occurring in Olkiluoto will also be updated. For the update, at least the update of the geological model of Olkiluoto and the new earthquake observations in the FENCAT database will be taken into account and the possibility for using other sources of information (e.g. the Swedish National Seismic Network (SNSN)) will be investigated. In addition, the effect of a larger analysis area on the frequency of earthquakes will be analysed.

Groundwater flow and development of salinity

The groundwater flow modelling work performed for the safety case will be developed during the next programme period so that the salinities of both the fracture groundwater and the matrix pore water can be taken into account in fracture network-based modelling. This will produce a more realistic estimate of the development of groundwater salinity in the host rock and of its variation as a function of place and time. In previous modelling work, these could only be treated dynamically in the so-called continuous porous medium method, so that the results can be deemed to represent the average values of an extensive area.

It has only been possible to take into account the ice-induced stress and its hydro-mechanical impact when modelling the future development of the Olkiluoto area in a two-dimensional case used for a scoping analysis of the significance of the phenomenon. During the next programme period, the impact of the state of stress caused by the weight of ice and its development over time on the flow of bedrock groundwater will be included in the three-dimensional flow model.

The impact of future ice ages and the subsequent interglacials on the groundwater conditions will be modelled in a continuous fashion in connection with the climate scenario modelling to be updated during the following programme period. This is an improvement on the previous scenario modelling where modelling was only performed for the agreed limited periods of time due to limitations on the computer resources available. The flow of groundwater during the different phases of the ice age cycle will also be modelled using regionally more comprehensive models. The modelling will be further supplemented by taking into account the progress of phase changes in the bedrock and its impact on different parameters, including the pressure of water and salinity of groundwater, as the dissolved solids tend to move to the liquid phase as the water freezes.

Migration of gases

High concentrations of dissolved methane have been observed in the groundwater of the Olkiluoto bedrock (other substances present in gaseous form under NTP conditions are also dissolved in groundwater in smaller quantities than methane). The methane present in deep bedrock is thought to be of abiogenic origin; having been created under thermogenic conditions in deep bedrock, it migrates to the top layers of bedrock, mainly by diffusion over long periods of time. Delos *et al.* (2010) estimate the flux of methane from deep layers of the Olkiluoto bedrock to be $1.8 \cdot 10^{-7}$ mol/m^2 per year. During the future periods of permafrost and continental ice, the chemical, pressure and temperature conditions of bedrock groundwater may also be favourable for the formation of methane clathrate.[2] The significance of this phenomenon for the stability of groundwater conditions is not known. The possibility for modelling the behaviour of the gas-water mixture in deep crystalline bedrock conditions both during the long, stable permafrost and glacier phases and during changes in climate conditions will be investigated during

[2] According to Tohidi et al. (2010), the current conditions are not favourable for the formation of methane clathrate in Olkiluoto.

the coming programme period. Processing of the phenomenon using the means of numerical modelling will require development of the physical model and the use of powerful computers. The applied equation of state must allow the modelling of conditions where methane clathrate is formed, among others.

Buffering capacity of the bedrock

The microbial reactions taking place in the soils and bedrock are among the most significant chemical buffering mechanisms in Olkiluoto. The most significant buffer minerals present in the bedrock fractures are calcites, sulphides and clay minerals. Dissolved gases also constitute a significant chemical buffer in Olkiluoto.

The intention is to model the buffering capacity of bedrock by means of reactive transport modelling. The initial data used for the models and the calibration of models are based on the results of previous investigations, field tests and simulations. They will be supplemented during the coming years e.g. by investigating the buffering of oxygen-containing water in the filtration zone (see section 5.3.1). The planned modelling is based on updated climate scenarios. Integration of the water-bedrock interaction and groundwater flow modelling will be developed by appending the description of the evolution of groundwater chemistry and its buffering capacity to the description of flow conditions in Olkiluoto. The modelling will take into account the different phases of the ice age cycle more comprehensively, including the possible infiltration of meteoric water continuing for a longer time. The reactive migration modelling will produce a description of the evolution of groundwater chemistry and an assessment of the sufficiency of buffering capacity.

Development of the sulphide content of groundwater

High sulphide concentrations have been observed in the Olkiluoto groundwater at the interface between sulphate- and methane-containing water where sulphates are reduced to sulphides as a result of microbial activity. The results of groundwater monitoring indicate that the high sulphide concentrations seem to be caused by the fact that groundwater types at different redox states become mixed by the investigation activities, and microbes react readily to this. The sulphide concentrations appear to decrease when the groundwater conditions stabilise. There are investigations, both being planned and in progress, for studying the circulation of dissolved sulphides in groundwater, the microbiological reactions associated with the reduction of sulphates as well as the speed of reactions between sulphides and iron (the SURE test, see section 5.3.1) by analysing various factors including the availability of sulphate-precipitating iron in groundwater and the conversion of the formed iron sulphide into a less soluble form, pyrite.

The results of investigations and the models calibrated on the basis of field studies are used when assessing the long-term developments regarding sulphides dissolved in groundwater using the reactive transport model. The information derived from flow models regarding groundwater flow conditions and paths are also required for the analyses. The modelling work will be performed during 2015–2016.

The results of the investigations will also be utilised for analyses regarding the near-field for assessing, for example, the microbial activity taking place in the buffer and backfill.

Interaction between cement-based materials and bedrock

The natural analogy studies and the studies conducted in different rock laboratories show that the reaction of substances dissolved from cement with the fracture minerals probably affects the hydrology of the bedrock. There are currently still uncertainties associated with the subject, and information required for reducing them, particularly regarding long-term effects, will be obtained from the LCS (Long-term Cement Study) in progress in the Grimsel rock laboratory.

Modelling of radionuclide migration in bedrock

The radionuclide transport modelling involves estimating the activity flows from the bedrock to the surface environment (biosphere). The concept of bedrock migration is the migration of radionuclides with groundwater flows along the fracture network in the bedrock where the total flow is divided into individual flow paths. The laws of flow physics force the flow paths to lower elevation areas which will be connected to water bodies even in the distant future under the climate conditions that maintain them.

According to the migration concept, the migration of radionuclides along the flow path is slowed down by matrix diffusion and sorption. The variation in the bedrock migration properties along the flow path is further reduced to a few basic cases − to four basic cases in the radionuclide migration modelling produced for the 2012 safety case − that are used to describe the thickness, porosity and effective diffusion coefficient of the facture filling material, alteration halo and unaltered bedrock matrix. However, this description will be revised as part of the site model update and updated, as required, using all geological mapping data collected by the end of 2013. However, the description of fracture-specific migration properties will be supplemented with an estimate based on geological mapping of the internal heterogeneity of bedrock fractures which in the migration concept to be developed will be associated with channelling. The modelling will also include limited matrix diffusion which is caused by the structure of anion exclusion, on one hand, and by the structure of linked diffusion porosity, on the other, where the linkage becomes weaker with longer distances. It is still uncertain to some extent how much these phenomena limit the matrix diffusion in the Olkiluoto bedrock, which is why the significance of these uncertainties will be subjected to sensitivity analyses.

In the future, determination of the factors limiting matrix diffusion will be based on the site investigations results obtained during the previous program period. For example, the foliation of bedrock, typical of mica gneiss, the main rock type in Olkiluoto, may affect the intensity of diffusion so that the diffusion is considerably weaker perpendicular to the foliation plane than parallel to it. Quantitative information on the subject is expected within the next few years from studies combining the detailed information regarding the pore structure of rock and the diffusion tests.

Modelling of the impact of sorption as a retention process is based on the values of distribution coefficient K_d in different conditions of groundwater chemistry and rock mineralogy. Its numerical values are based primarily on laboratory tests conducted using reference waters and (crushed) rock samples corresponding to the conditions in Olkiluoto (Hakanen et al. 2012). The site-specific database of sorption parameters will be supplemented taking into account any changes to the migration concept.

The uncertainties regarding the retention of radionuclides in rocks and fracture clays in producing the sorption data for far-field were mainly caused by two factors: firstly, the available sorption data had been determined for so-called site-specific water conditions that were in parts significantly different from the water conditions selected for the descriptions of future evolution regarding the water conditions in Olkiluoto, and secondly, scaling of the sorption values obtained for crushed rock to correspond to intact rock caused uncertainties (Hakanen *et al.* 2012).

In order to estimate the sorption in different geochemical conditions, a thermodynamic sorption model will be required for the nuclides, including calculation of the chemical forms of radionuclides relevant to migration, their sorption reactions on mineral surfaces and any competing sorption processes. This is discussed in detail, for example, in a recently published book entitled *Thermodynamic Sorption Modelling in Support of Radioactive Waste Disposal Safety Cases (NEA Sorption Project Phase III)*, whose production Posiva also has supported. In a report produced for Posiva in 2012, the sorption of cesium in rocks and the sorption of cesium and strontium in illite were the only items or far-field sorption data that could be calculated using the mechanistic sorption model developed for PHREEQC software. Similar models will be developed for all important radionuclides, first for the earth alkaline metals Sr and Ra, then for oxyanions (Se, Mo) and for elements (Eu, Th), from the sorption parameters of which the sorption of other actinides exhibiting valence states of 3 or 4 will be derived. The ultimate goal is to be able to calculate the sorption of all important substances using the thermodynamic model. The use of clay sorption models obtained from literature is being tested during 2012 for calculating the sorption in the water conditions of Olkiluoto.

The sorption values for intact rock were scaled from the sorption estimated for crushed rock making the simple assumption that all mineral surfaces in crushed rock participate in the sorption but in intact rock, sorption only takes place in mica minerals. The sorption values for intact rock can be empirically determined within a reasonable time by using electro-migration to speed up the diffusion. This method can be mainly used for cesium and earth alkali substances for which a prediction of the magnitude of sorption can be calculated using the sorption model. This study continues in 2012 with cesium. The effect of the uncertainties regarding the determined values on migration modelling will be handled by probabilistic estimation.

Together with modelling the biosphere, the modelling of release migration pathways will be revised with the objective of obtaining a more accurate picture of the dispersion of release routes from different deposition holes and also from individual deposition holes for the purpose of supporting the selection of representative release pathways as calculation cases for the safety analysis. Since the release pathways from all deposition holes cannot be processed at the same time due to the computational restrictions in the models, a screening model will be developed for assessing the dose effects of different discharge points more accurately. Here, the route dispersion, the migration times, the retention of typical radionuclides or radionuclides already selected for a specific case, as well as the most significant factors of the biosphere affecting the radiation doses, will be taken into account.

5.6.4 Biosphere

The safety case work regarding the surface environment (biosphere) is aimed at the safety assessment to be performed in connection with the application for the operating licence. The work will continue in much the same way as that performed for the construction licence application. Since the acquisition, analysis and reporting of initial data for the biosphere analysis is an extensive task, a separate plan will be produced for the work, supplementing the 2013 update of the Safety Case Plan (section 5.6.1). During the first three-year period of the programme period, the main focus will be on the acquisition and analysis of initial data as well as on model development work. During the latter period, the focus will be on the modelling and reporting work required for the safety case.

A significant part of the new initial data will be produced as a result of work performed in line with the monitoring programme (section 5.5). However, this will not cover the investigations outside Olkiluoto, including the studies regarding the reference swamps and lakes (Haapanen et al. 2011, Kangasniemi et al. 2011) as well as agricultural products (Helin et al. 2011), which will all continue. In addition, similar investigations will be implemented in the river ecosystem. The empirical sorption study programme (Lusa et al. 2009, Virtanen 2011, Söderlund et al. 2012) will continue to acquire additional information on the swamp environment and the bottom sediments of lakes. The intention is to rectify the deficiencies detected in the *Biosphere Description* report and in the report entitled *Data Basis for the Biosphere Assessment* regarding the material balances of different ecosystems (in particular rivers and the fauna of all ecosystems) and in the input data used for biosphere models so that they will cover the elements important for calculating the radiation doses and the biotopes used for modelling, their internal variation and evolution in the time scale used for dose assessment (10,000 years). The work for collecting samples of flora and fauna will concentrate on the reference species selected in the biosphere description report that cover the nutrition networks of both the natural environment and man.

As a special task during the period 2013–2015, C-14 timing data of ancient shoreline phases will be collected for the land uplift model (see section 5.5) and the abundance and use of wells of different types in the Olkiluoto region will be investigated. During this period, the production of summaries for the site investigations concerning the biosphere will begin so that they are available in good time for safety assessment to be performed in connection with the application for the operating licence during the next period.

The subjects of development during the period 2013–2015 regarding biosphere modelling are the further specification of the soil model and the model regarding migration via release routes and the atmosphere, as well as more extensive utilisation of literature for the acquisition of initial data. In addition, the active participation in the international development work for assessment methods regarding the radiation doses of plants and animals will be continued. If required, the development work will be continued during the period 2016–2018, but the focus will then be on the actual modelling work required for the safety case and on reporting it. In order to improve the soil layer model (Mönkkönen 2012), more observations will be made regarding the thickness of soil layers in the areas where the most essential release routes surface, and the layer surface interpolation methods and tools will be developed. The development work regarding the modelling of migration routes was discussed at the end of the previous section.

The possible gasification of radionuclides from the soil, their mixing with the air in the canopy layer and their migration from there through the nutrient intake of plants will be investigated. The investigation concerns those radionuclides that the vegetation can, on the basis of preliminary data, take in through its foliage (e.g. C-14, I-129, Cl-36, Se-79). The structure and initial data of the migration models will be improved as required. This work will primarily be undertaken in international joint projects. In addition to Posiva's own research, information acquired from literature will also be required as initial data for the biosphere models in order to ensure the comprehensiveness of initial data and in order to compare them with data used in other similar contexts. The goal for the period 2013–2015 is to utilise most of the essential literature material known.

5.6.5 Scenarios and their analysis

As discussed in section 4.6 , the expected future evolution regarding the disposal system has been estimated using the help of performance analyses, while the implications of the uncertainties associated with the future evolution regarding safety and the migration of radionuclides has been assessed using scenario analyses.

The design basis (*Design Basis)* for the disposal system has been specified so that the performance targets will be achieved in the expected circumstances (base scenario) apart from any incidental deviations. The fulfilment of targets is also demonstrated by a performance analysis (*Performance Assessment*) which also identifies the uncertainties and exceptional situations where the performance targets will not be met in all respects. The consequences of such exceptional situations as well as the consequences of the unlikely transients ignored in the design basis are discussed separately in compliance with the scenario report entitled *Formulation of Radionuclide Release Scenarios*.

The scenario analyses have demonstrated that the failure of a safety function of one or more release barrier is of no significance to the safety of disposal or that the risk associated with them is in any case very small and can be accepted in compliance with the safety requirements.

The major uncertainties related to the performance of release barriers and identified on the basis of the performance analysis of 2012 will be investigated during the next programme period (section 5.4.2). In addition, performance analyses will be initiated on the basis of updated design and research data that will also be used as the basis for updating the scenarios used in the safety case presented in the operating licence application.

5.7 Nuclear waste management at the encapsulation plant

5.7.1 Technical solutions

The technical solutions regarding nuclear waste management at the encapsulation plant will be specified further during 2013–2015 with the detailed design of liquid waste processing systems and the repository for low- and intermediate-level waste. The liquid waste solidification system for the encapsulation plant will be chosen before commencing the construction of the plant.

The technical details of the repository for low- and intermediate-level waste will be defined further during 2013–2015 as the plant design work advances. Supplementary analyses regarding the final location of this facility in the repository will be performed in this connection. The plans for backfilling and closing the facility will be revised when the closure plans for the access tunnel and shafts are updated. Due to the diverse nature of the waste to be brought to the facility, it will probably not be possible to bring the average water conductivity of the facility in line with the water conductivity of the original bedrock when the facility is backfilled and closed. This will be taken into account when designing the plug systems for closing the facility. The implementation of this repository is currently planned for the 2020s when operational waste starts accumulating.

5.7.2 Long-term safety

The impacts of the low- and intermediate-level waste on the disposal of spent nuclear fuel will be assessed. The comments of authorities will be taken into account in this work. Since the backfill and closure designs are the focal areas important for long-time safety, the requirements for the facility will be defined further in connection with producing the closure design. No rock suitability criteria have been produced as yet for the low- and intermediate-level waste hall. These RSC criteria will be produced before starting the implementation planning for the facility and its construction.

5.8 KBS-3H variant

5.8.1 On-going research and development work for 2013–2015

This section discusses the research and development work in progress, aimed at developing the KBS-3H variant on the basis of the DAWE reference design so that it would be possible to compare the 3V and 3H designs and produce the PSAR, if required. The comparison of the variants also includes environmental impact, costs and safety issues (long-term, operational and occupational safety). The work will be performed as a joint project between SKB and Posiva. The "System Design Phase" of the joint project will take place during 2011–2015.

5.8.1.1 Full-scale demonstrations

The operation compliant with the design made for the horizontal variant will be verified and demonstrated in a full-scale test (Multi Purpose Test, MPT) at the Äspö Hard Rock Laboratory HRL) at the depth of -220 m in a 95-metre horizontal drift excavated previously during 2004–2005 (Bäckblom & Lindgren 2005) by horizontal push-reaming technique. The MPT has been integrated with the international LUCOEX project that will be in operation during 2011–2014. The installation work for the test will begin during the first half of 2013. The planned duration of the test phase is 400 days.

The MPT will test the manufacturing, transport and installation of main components, as well as the techniques compliant with the chosen DAWE reference design, such as artificial wetting of the deposition drift. The components used in the test are the Supercontainer, two distance blocks, one compartment plug (of steel) and the filling components behind the plug and towards the end of the test section. The components will be fitted with instruments for monitoring their performance during the test (see Figures 5-9 and 5-10 and Table 5-1). The measurement results will be compared to the pre-modeling of the MPT that is planned to be performed before installation of the test. When the components are dismantled after the test phase, samples will be taken of bentonite-containing components for analysis. The analysis results will be used for supplementing the measurement results obtained during the test in order to assess the behaviour of bentonite and other components.

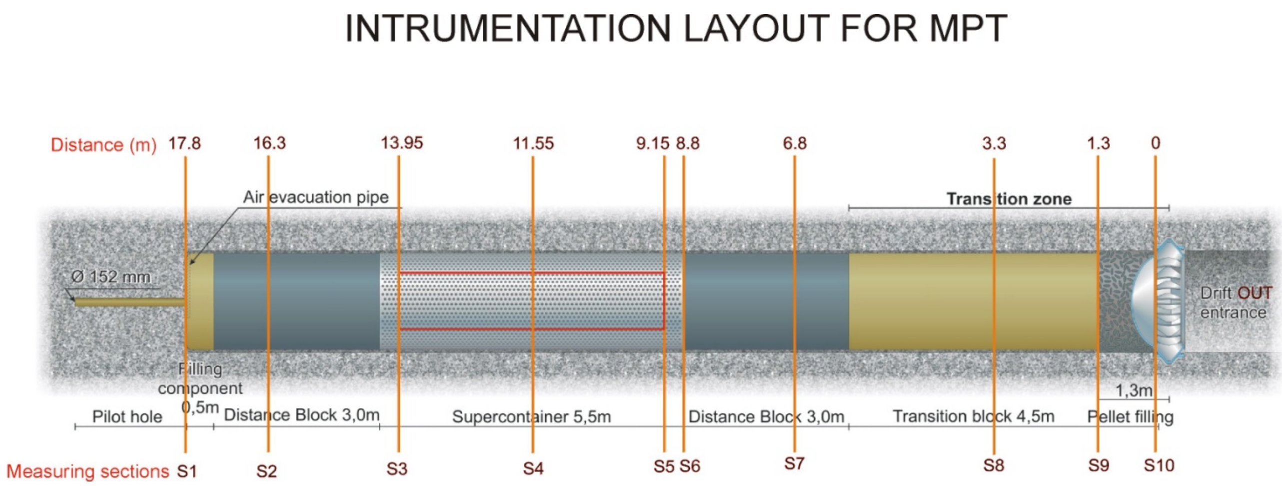

Figure 5-9. *Schematic illustration of the components and preliminary instrumentation plan for the Multi Purpose Test (MPT). The total length of the components is almost 20 metres. The instrumentation of measuring section S4 is shown below; see Figure 5-10.*

Table 5-1. *Distribution of the sensors into different measuring sections. Some of the sensors are wireless, some are connected with cables. The legend for sensor types is shown at the bottom of the table.*

Sensor type	**Measurement profile**											
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**Out-side**	**Total**
TP bedrock/plug	5	4		2			4	4	4	5		28
TP buffer				6	4	5						15
PP bedrock	1	4					4		12			21
PP buffer		4		4	5		4			7		24
WC		6		4	5		6	7	6			34
WP		6		4	5		6	6	6			33
WF	1	2		2	2		2	2	2			13
DS					4	4						8
DB									2			2
DC											3	3
IS				2								2
IB		1					1		2			4
SG supercont.			12	16	12							40
SG dome											20	20
FM											1	1
GP					1	1				1		3
Wireless	0	6	0	0	6	0	6	6	6	6		36
Cabled	7	21	12	40	32	10	21	13	28	7	24	215
Total	7	27	12	40	38	10	27	19	34	13	24	251

S1: one pore pressure sensor will be installed in the pilot hole.
S9: each of the four drill holes drilled in the bedrock at the subject profile will be fitted with three pore pressure sensors.

Legend of the sensor type abbreviations used in Table 5-1.

Abbreviation	**Meaning**	**Abbreviation**	**Meaning**
TP	Total pressure	IS	Inclinometer in the supercontainer
PP	Pore pressure	IB	Inclinometer in bentonite
WC	Water content (capacitive)	GP	Gas pressure
WP	Water content (psychrometric)	SG	Strain gauge
WF	Water content (volumetric)	FM	Flow meter
DS	Dislocation of the supercontainer	DC	Collar for dislocation measurement
DB	Dislocation of bentonite		

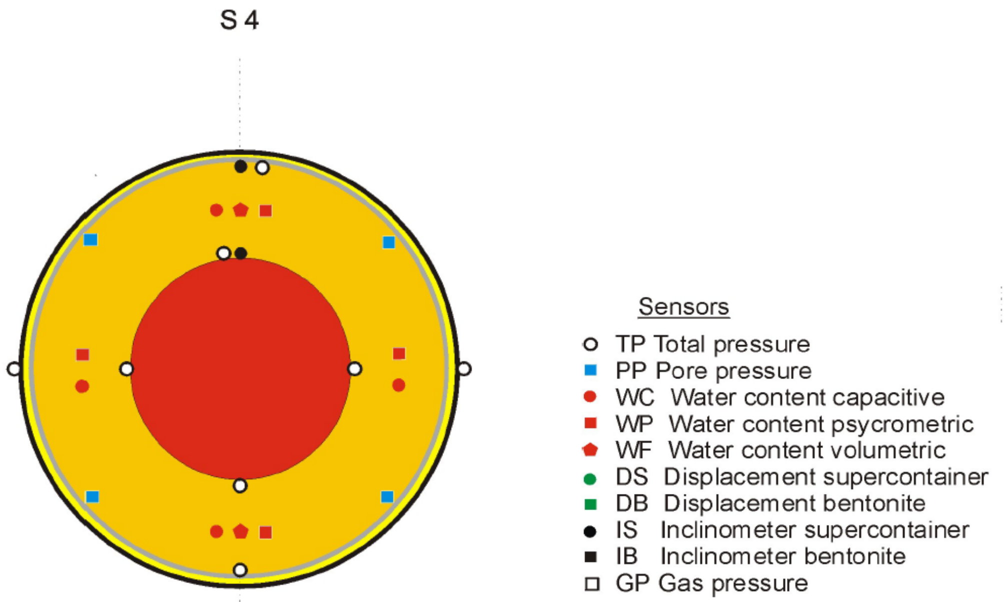

Figure 5-10. *The locations of the sensors in measuring section S4 situated in the middle of the Supercontainer, see Figure 5-9.*

The deposition machine developed during an earlier phase of the project will be used in the installations for the MPT. Test drives totalling about 50 kilometres have been performed with the deposition machine at the Äspö HRL. Technical improvements will be made for the deposition machine before the MPT, both regarding hardware and software.

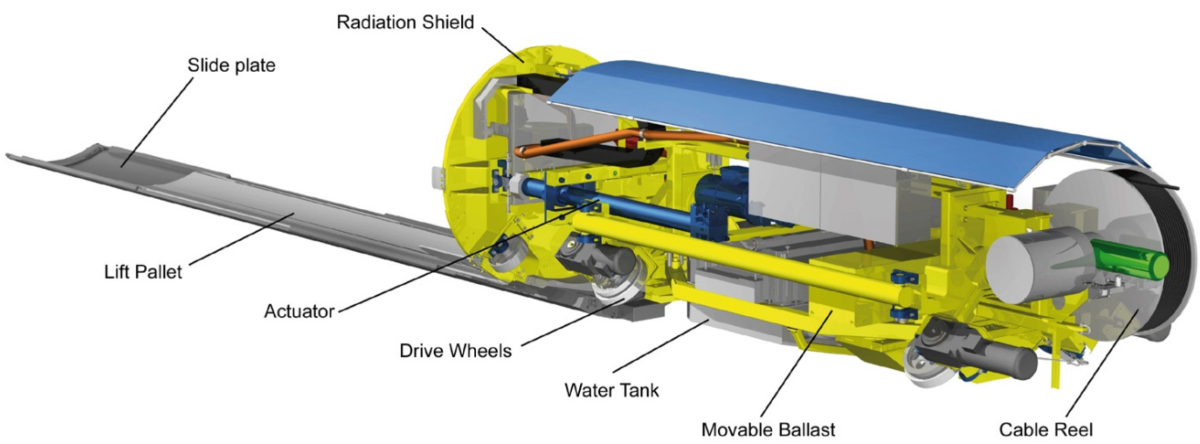

Figure 5-11. *Deposition machine developed for the KBS-3H concept.*

One of the biggest challenges is to accomplish a straight pilot hole that will be reamed into a deposition drift. So far, attempts to demonstrate it have not been totally successful. Two horizontal drifts were excavated earlier, during 2004–2005 (Bäckblom & Lindgren 2005) in the Äspö HRL at a depth of -220 m (diameter 1,850 mm). The pilot hole was bored using a tool based on rotary crushing, and the pilot hole was enlarged using a reaming tool. One of the horizontal drifts is 95 metres long, and the other 15 metres long. The steering device that actively corrects the direction of the hole when it detects that the direction is wrong failed, and the tests had to be implemented with a reduced scope. The demonstration did not show yet that horizontal holes can be bored to their full length of 300 metres so that they meet the relatively strict criteria regarding their straightness and geometry, albeit that the short horizontal holes did meet the criteria.

Tests related to the straightness of the pilot hole will be performed either in Äspö or in Olkiluoto during the current phase of the project. Irrespective of the technique used, directional core drilling or full-face boring, to accomplish a straight pilot hole requires sufficiently accurate deviation tool, so that the direction of the hole can be corrected as early as possible if it deviates from the plan. An artificial "test hole" is being planned above ground near the Äspö HRL; its location will be measured accurately along its entire length. This hole will be used for testing and calibrating alternative measuring instruments.

Directional core drilling has been selected as the technique to be primarily tested in the pilot hole (diameter 76 mm) with reaming in several stages. Initially, the hole will be reamed to the diameter required for pilot holes and then to the full deposition drift diameter of 1,850 mm. The parameters used for determining the final quality of the drift wall are its geometry, straightness, as well as the roughness and waviness. The pilot hole will be bored to its full length of 300 metres, while reaming will only be performed up to 100 metres. The tests conducted on the pilot hole also include its careful characterisation. Their implementation will, in the end, be affected by the selected hole diameter, because the availability of investigation techniques suitable for holes over 76 mm in diameter is limited.

The plan is to excavate a dedicated test site (demonstration drift) for KBS-3H at level -420m in the Äspö HRL after the pilot hole tests (see Figure 5-12). The location and construction of the test site will be affected by the expansion project currently in progress in Äspö HRL. A number of target properties have been set out for the test site. It is hoped that the site will meet these targets, among other things, because the demo drift will also be used for testing Mega-Packer, the post-grouting equipment developed for groundwater control. The equipment has produced good results during an earlier project phase when it was used for grouting a 95-metre horizontal hole at level -220 (Figure 5-13) (Eriksson & Lindström 2009). The purpose of the new test is to investigate the operation of the equipment in pressure conditions corresponding to those at the deposition depth.

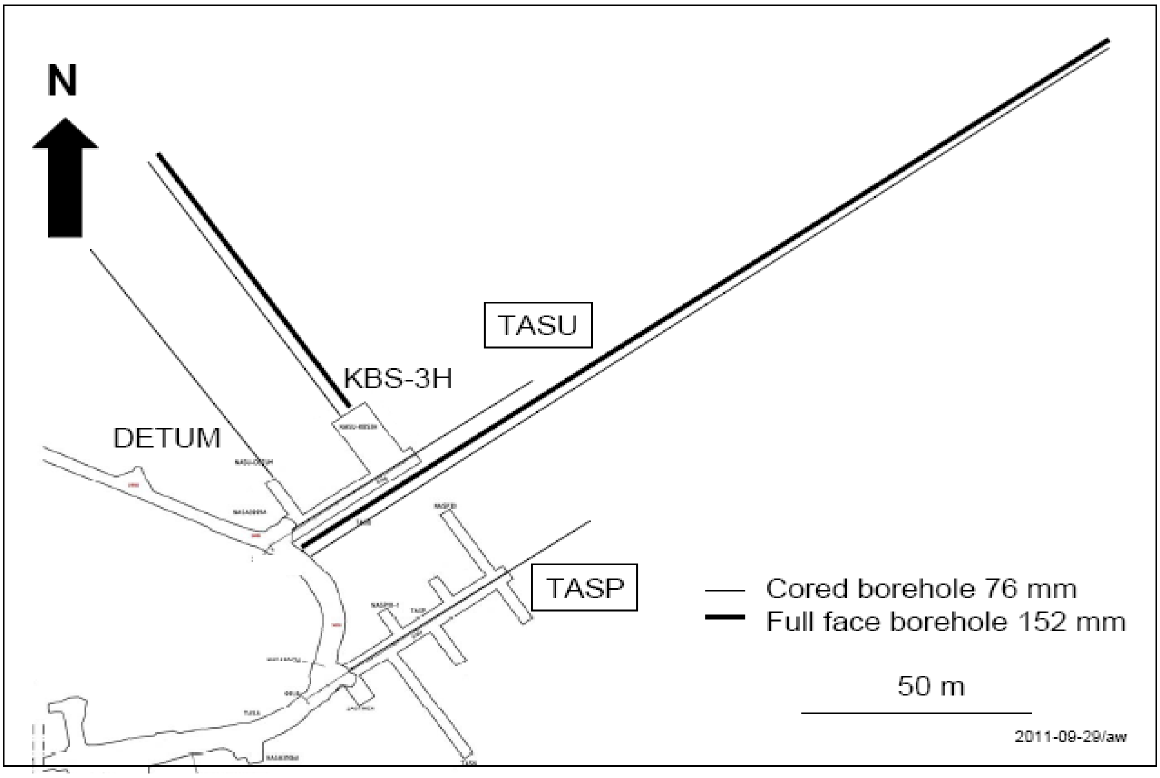

Figure 5-12. *Preliminary location of the planned KBS-3H demonstration drift in the Äspö HRL at level -420.*

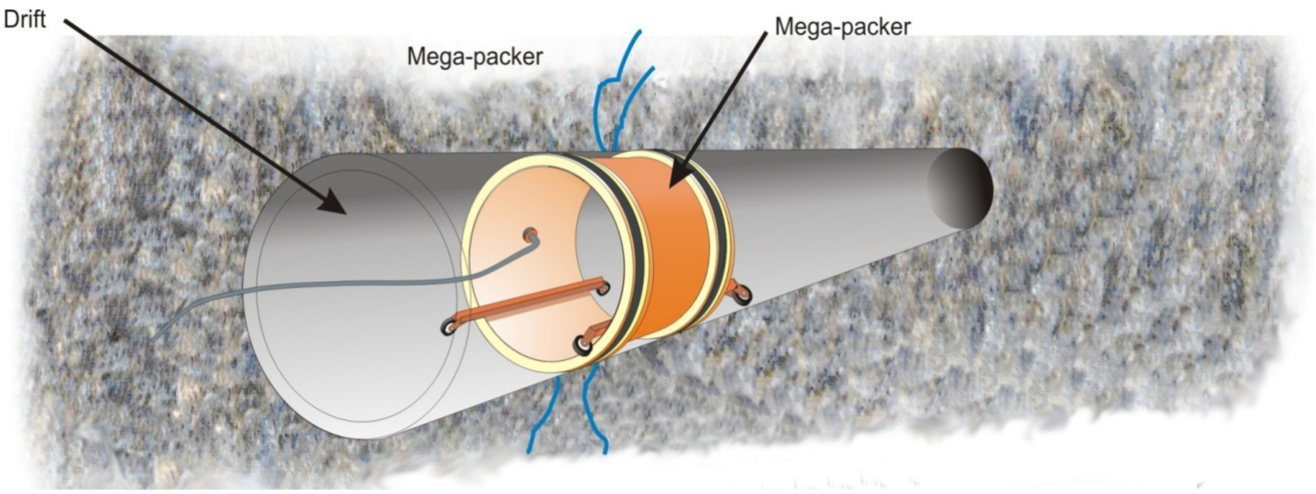

Figure 5-13. *Schematic illustration of the Mega-Packer and its use for post-grouting a leaking fracture in a 3H deposition drift. The grouting material used is colloidal silica (Autio et al. 2008).*

5.8.1.2 Investigations and planning regarding buffer components, including filling components

In the KBS-3H variant, the distance block is also considered part of the buffer in addition to the bentonite contained in the Supercontainer. At the installation phase, their dry density and water content values differ from each other. The development of swelling pressure (its rate of increase and absolute value) of the bentonite blocks included in both components is tested in laboratory conditions using dedicated test equipment called Big Bertha (BB). In the test, the bentonite to be tested is installed in a horizontal hole made of steel, and the development of pressure after artificial water filling is measured (see Figure 5-14). The test conditions can be made "dry" or "wet" by adding water during the test. In dry conditions, water is only added by artificial water filling. The first such test was conducted during the previous project phase entitled "Complementary studies 2008–2010". The test will be modelled, and the results of the work will be utilised for pre-modeling of the MPT.

The holes in the protective Supercontainer shell are also of significance when considering the swelling properties of the bentonite contained in the Supercontainer. About 60 % of the surface of the shell is covered by holes. The bentonite swells into the gap between the Supercontainer shell and the drift wall through these holes. The swelling of bentonite will be tested in a small-scale laboratory test in which the situation has been simplified by reducing it to a case with only one hole. This test will also be modelled, and the result will be utilised for pre-modeling of the MPT. The MPT will also produce plenty of information on the post-installation behaviour of bentonite (thought instrumentation and dismantling of the test at the end).

The swelling properties of the distance block are also important for its performance as a hydraulic plug between two Supercontainers. The rate of increase and absolute value of the swelling pressure are also important for limiting the spalling of the bedrock. The rapid development and large value of the swelling pressure tend to mitigate spalling or even prevent it altogether.

The decisions to increase the diameter to 1,850–1,855 mm (the allowed tolerance) and to reduce the diameter of the Supercontainer by 4 mm affect the gap between the Supercontainer and the drift wall (44.5–48 mm). It will be taken into account in the test arrangements, and it will also have a positive effect on the Supercontainer installation work. The thinner wall thickness of the protective shell became possible when its material was changed to titanium.

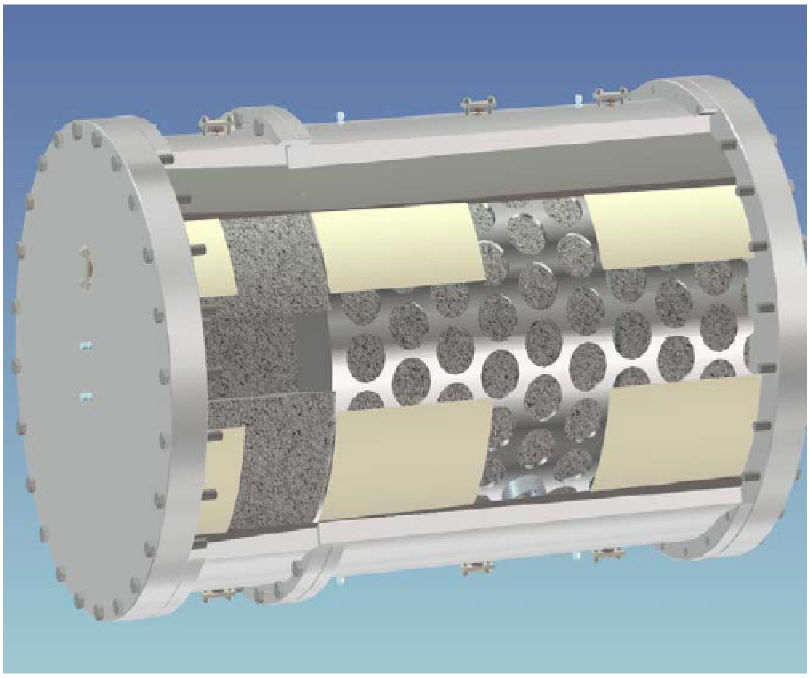

Figure 5-14. *Schematic illustration of the Big Bertha device with an inside diameter of 800 mm and a maximum length of 1,400 mm. The white discs shown in the figure can be used if more water is required during the test (SKB 2012).*

In addition to the swelling properties of bentonite, the other subjects identified in the previous phase of the project included the following:

- The chemical erosion of bentonite caused by glacial waters following an ice age is a common area of research in the development of both the KBS-3V and KBS-3H variants, and it is being investigated in the 3V project. From the erosion point of view, the difference between the 3H and 3V designs is related to the different geometries of the deposition hole and the deposition drift, and for the 3H, it will be investigated on the basis of the results of the common research phase.
- Another bentonite-related subject common to the KBS-3V and KBS-3H variants is the effect of different compaction techniques (isostatic vs. uniaxial) on the properties of bentonite blocks. This subject is being investigated in the 3V project, and the results will also be applicable to the 3H project.
- The water transport process and the swelling of bentonite in a heterogeneous environment.
- The water transport between the Supercontainer bentonite having a lower water content and distance block bentonite having a higher water content.
- The self sealing of fractures / horizontal erosion and homogenisation of the filling blocks in case of a leaking fracture.
- Testing of the filling components (the size of the transition zone has been based on modelling and calculations).

The designs for the buffer and filling components will be taken to a more detailed level during 2013–2015.

A report will be produced of the investigations regarding filling components, their results and the component designs. It will present updated design versions of the components.

5.8.1.3 Other components

The designs for other components (the Supercontainer and the plugs) will be taken to a more detailed level, and they will be presented in a report to be produced during 2013–2015.

5.8.1.4 Plant design-related work

The layout adaptation of the disposal facility will be updated on the basis of the most up-to-date geological model and other bedrock-related information. The updated number of canisters to be disposed of and the results of development work for the KBS-3H variant will be taken into account when revising the earlier layout adaptation. In addition to layout adaptation, the technical solutions for the operating phase of the 3H variant and the stepwise construction of the repository in the Olkiluoto bedrock will also be updated. Among other things, the work will include updating the technical plans for the canister reloading station and designing the necessary underground storage facilities for various items, including completed Supercontainers.

System descriptions and a report on the facility description will be produced during 2013–2015. They will concentrate on the 3H specific features, while the issues common with the 3V variant will be dealt with by making reference to the corresponding 3V report. The system descriptions will be produced in the same format as those for 3V. The work will also include the equipment required for the KBS-3H variant.

5.8.1.5 KBS-3H production line reports

In all, five production line reports will be produced, one of them a overarching report "Repository Production". The four actual production line reports are:

- Buffer and filling components
- Design, Construction and Initial State of the KBS-3H Underground Openings
- Plugs (compartment and drift plugs)
- Supercontainer.

The production line reports will concentrate on the 3H specific features. The reports will be produced jointly with SKB, and they will highlight the organisation-specific differences in the 3H design work. Regarding the common areas (3V/3H), reference will be made to the 3V reports, nevertheless also mentioning the key issues in the 3H reports.

5.8.1.6 Occupational and operational safety

"What if" analyses of both occupational and operational safety were conducted during the previous project phase. The work will continue and concentrate on work phases particular to 3H: excavation of the deposition drift, operation of the reloading station and installation of the components into the deposition drift. The work related to occupational safety will also highlight any differences in the occupational safety legislations of Sweden and Finland.

5.8.1.7 Long-term safety during 2013–2015

The investigations regarding long-term safety of the horizontal variant will be performed in phases during the next few years. In the SKB-Posiva joint project in progress, the work will advance so that the key areas for investigation identified in the preliminary KBS-3H safety analysis in 2008 will be analysed first. The investigation needs are particularly related to cases that could lead to different consequences than in the vertical solution. These are related to the failure of several canisters and concern the erosion of bentonite caused by dilute glacial water after an ice age and the resulting canister corrosion, as well as to canister failures caused by rock shear. The assessment will be performed on the basis of a comparison analysis where the assessment is compared to a similar assessment regarding the KBS-3V variant. The work will be performed regarding the chosen DAWE reference design. The work has begun with an analysis to be performed for Forsmark utilising the SR-Site material to be updated for the needs of the KBS-3H. Posiva will perform the corresponding analysis for Olkiluoto during 2013–2015. When the results of analysis have been assessed, a more detailed plan will be produced for KBS-3H-related safety assessment work, and the results will be utilised when producing a new safety case plan for the coming programme period 2016–2018.

The next goal of the safety assessment performed during the 2013–2015 project phase will be to complete the performance analysis that assesses the fulfilment of safety functions, performance targets and target properties in the KBS-3H deposition drift during the expected evolution, also taking into account uncertainties related to the initial state and evolution. This work will be based on the *Design Basis* report to be produced for KBS-3H, relying on the existing safety functions and performance targets of KBS-3V with regard to most release barriers and on the corresponding report produced for KBS-3V. The work will focus on the 3H-specific features compared with the vertical concept. At the same time, SKB will produce a corresponding Design Premises report for the horizontal variant. These reports will also take into account the latest results of KBS-3V analyses (TURVA-2012 and SR-Site) as well as the results of the preliminary safety assessment regarding KBS-3H performed in 2008.

The work for analysing and assessing the Supercontainer shell materials (Fe, Cu and Ti) has continued during the KBS-3H project. The results of this work indicate that titanium will have the least impact on the buffer and its properties, and it was decided that the Supercontainer shells will be made of titanium. The empirical study on the interaction between titanium and buffer material will continue during the next programme period.

Alongside the performance analyses regarding the deposition drift, production line reports will be produced for the KBS-3H alternative. They will be used as the basis for determining the initial state for the safety assessment. During the next programme period (2013–2015), the target properties of bedrock and the rock suitability criteria (RSC) derived from them will be determined for the KBS-3H alternative. This work will largely rely on the existing target properties and suitability criteria for KBS-3V. Particular attention will be paid in this work to the development of stability criteria regarding water leaks and mechanical properties (the so-called long fracture criteria). The intention is to present these results in a RSC-3H report to be produced during

2013–2015. The earlier layouts will be updated, taking into account also the rock suitability criteria determined for KBS-3H.

The purpose of the safety assessment regarding the 3H variant is to achieve the required level of knowledge that will allow assessing whether the horizontal concept is at least as safe as the vertical concept. The Olkiluoto-specific safety case for KBS-3H will be compiled in a report portfolio in the same manner as the safety case for KBS-3V. The portfolio consists of packages shown in Figure 5-15. As shown in the figure, some of the 3V-related reports in the TURVA-2012 portfolio will be updated to concern 3H, while some of the reports are common to 3V and 3H. The reports shown in yellow are specific to KBS-3H, while the reports shown in green will be those where the analyses made for the 3V solution will be updated to apply to the 3H solution. The reports shown in blue are the same as those in the safety case produced for the KBS-3V solution.

Naturally, the description of and course of development regarding the bedrock and biosphere of the disposal site will be the same as those for the 3V solution, as will the models and data related to the biosphere. The results of safety analyses for the KBS-3H and KBS-3V solutions can be compared on the basis of geo/bio releases. When required, the dose calculations will be run through the reference case to be reported for KBS-3V, and the results will be reported in the KBS-3H Synthesis Report.

In the reports to be updated, the parts specifically concerning the particular features of the KBS-3H alternative will be revised. A comparison analysis of the KBS-3V and KBS-3H alternatives (Gribi *et al.* 2007) has indicated that from the long-term safety point of view, the main differences are related to the particular characteristics of the KBS-3H alternative, such as the Supercontainer and other structural components, as well as to the changes they cause in the hydraulic conditions of the long deposition drift and its immediate vicinity. In other words, the updates will mainly concern the KBS-3H deposition drift with its components and the area surrounding the drift. Therefore, most of the reports to be updated will not be altered.

The following reports will be produced specifically for the KBS-3H:
- Synthesis − KBS-3H
- Design Basis − KBS-3H
- Production Lines − KBS-3H
- Performance Assessment − KBS-3H difference analysis, 3H drift analysis
- Assessment of Radionuclide Release Scenarios for the Repository System - KBS-3H.

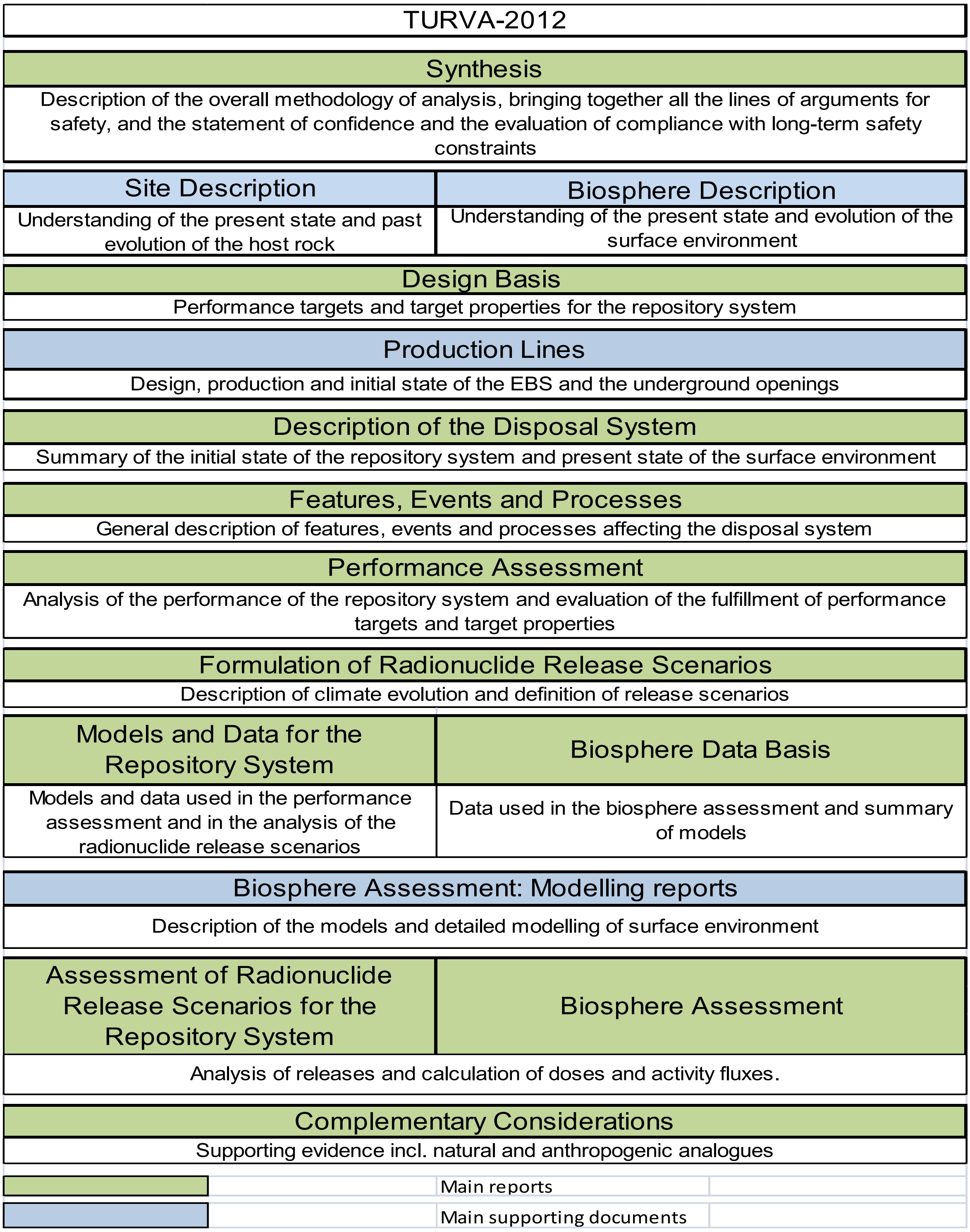

Figure 5-15. *Safety case portfolio for the horizontal disposal solution.*

5.8.2 Plans for the period 2016–2018

When the current project phase is completed and the results of the safety case confirm that the horizontal variant is at least as safe as the vertical variant, an overall assessment covering both variants will be performed. It is expected that the capabilities for this will be in place early in 2016. The assessment will be used as the basis for deciding how to proceed with these variants towards implementation. The assessment will be analysed in detail in the YJH programme to be produced in 2015.

In parallel with the current project phase, preparations will be made for the changes required in the plant design to allow switching to the horizontal concept. In addition, it is ensured that the possibilities for performing large-scale tests and joint operating tests for the KBS-3H solution in ONKALO are maintained. The cooperation with SKB may be continued, performing part of the work in ONKALO and part in Äspö.

6 PLANNING AND IMPLEMENTATION OF THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL DURING 2013–2018

6.1 Basic premises

As provided in nuclear energy legislation, Posiva's plant complex will consist of two separate nuclear facilities, the encapsulation plant and the disposal facility, which will be presented as one entity for licensing purposes.

The objective for the early years of the YJH-2012 programme is to finalise the implementation plans for the encapsulation plant and disposal facility so that the capabilities for commencing the construction work are in place when the necessary licences and permits have been obtained. The key objective of the work to be undertaken during later years is to produce the capabilities required for submitting the operating licence application. The goal is to achieve readiness for the operating licence application so that final disposal operations can begin around 2020.

Commencement of the operations will require that the licensing of all key systems in the plants has been appropriately taken care of and that their operability has been demonstrated in joint operating tests and in trial operation. Before commencing the disposal operations, the production facilities required for producing the different parts of the disposal system will also be built. These include the canister assembly plant and the production plants for the bentonite buffer and backfill material. The availability and procurement chain of raw materials must also be secured for the needs of the disposal process. The preparations for fuel transports will require the procurement and licensing of fuel containers and transport equipment as well as taking care of the safeguards-related details of transports. The practical construction and procurement activities described above will require the systematic development of competencies, human resources and procedures.

Alternative solutions may be considered for the different production plants. They do not necessarily have to be located in Olkiluoto; instead, their locations may be decided on the basis of, for example, lowest costs. They can, when feasible, be joint plants with SKB, or the production of components may be outsourced in its entirety. In such a case, the availability of services must be ensured separately.

The main functions required for implementing final disposal are shown in Figure 6-1. The construction functions will produce the required disposal facilities. These functions include the required bedrock investigations and implementation planning. The procurement functions will produce the engineered barrier system, the canisters as well as the buffer and backfill components. The production will require supply chains for the required components as well as production plants. In the planning alternative shown in Figure 6-1, the clay component production plant is located near the Olkiluoto harbour.

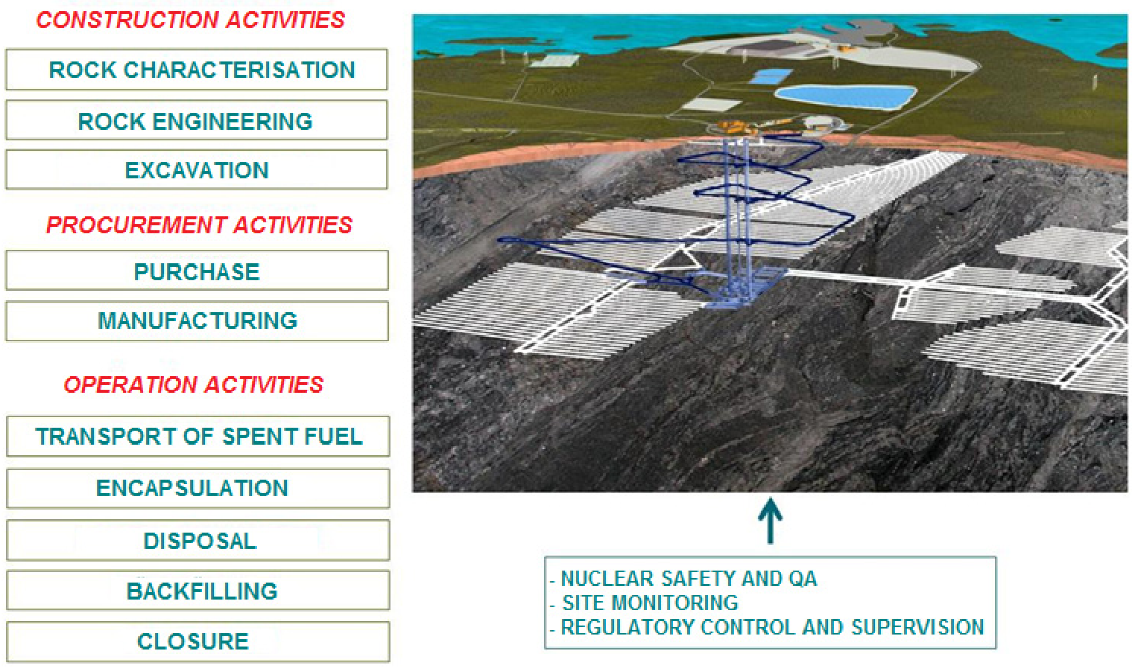

Figure 6-1. *The main functions for implementing final disposal. Quality management and the regulatory oversight by authorities apply to all operations. The possible impacts of implementation on the bedrock will be monitored by specific procedures.*

The purpose of operating activities (Figure 6-1) is to install the KBS-3 solution in the bedrock in a permanent manner. This work is completed when the system components (canister, buffer and backfill) have been installed in the facilities excavated deep inside the bedrock and the requirements regarding the initial state of the system are fulfilled. The intention is to develop these functions to such a level during the programme period now commencing that the implementation of final disposal is possible and that the necessary approvals by authorities and the operating licence can be obtained for it.

Figure 6-2 illustrates the systematics of the research, development and planning work aimed at describing the initial state, pivotal to the long-term safety of the disposal solution, as a basic premise for licensing and implementation.

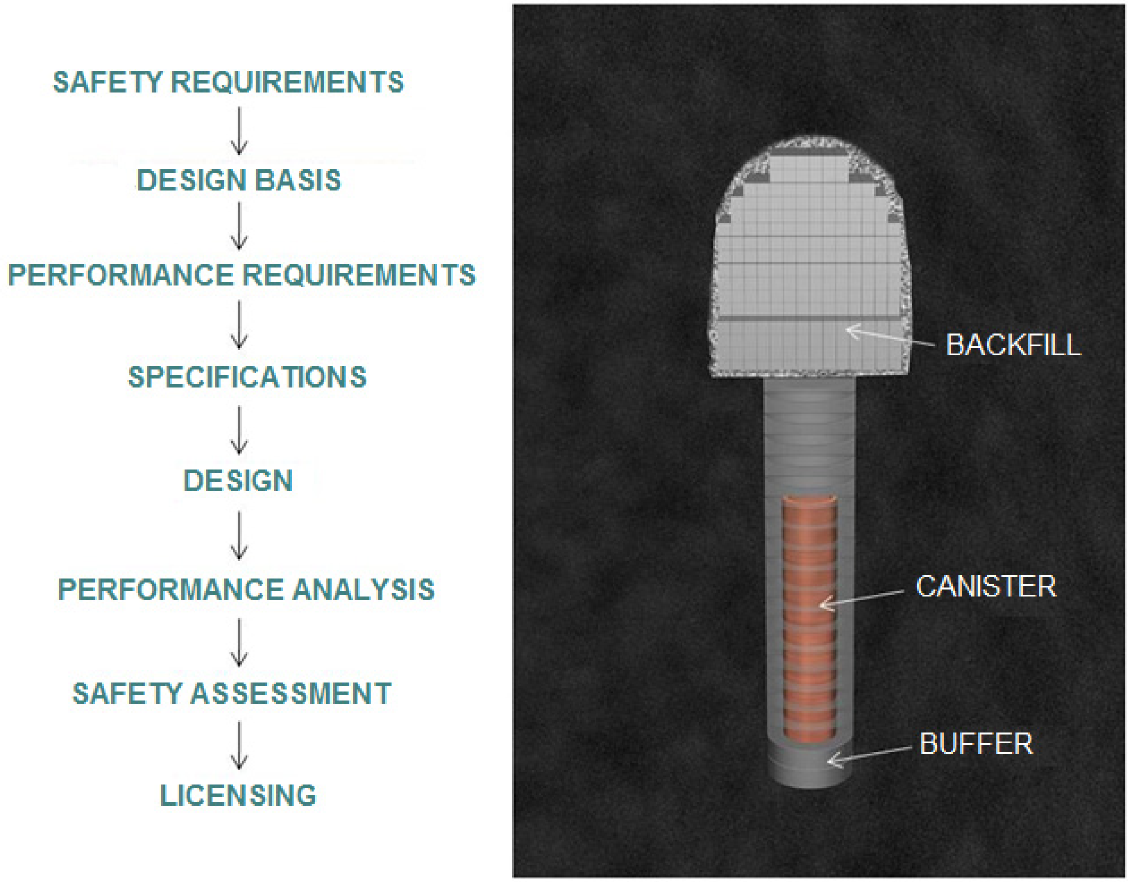

Figure 6-2. *The KBS-3 solution. The figure shows the progress of research, development and planning work performed for the purpose of developing the solution and for demonstrating its safety for the purposes of licensing and implementation.*

The plan is to demonstrate achievement of the initial state compliant with the requirements by performing an underground joint operating test. It refers to a deposition tunnel to be built in the underground disposal facility in compliance with the requirements and to the installation of a disposal solution performed in it without spent fuel. The joint operating test will be set up by using equipment and components developed and procured for final disposal purposes and licensed for their intended use. The joint operating test is intended for demonstrating in practice that the functions required for the implementation have been developed sufficiently ready and that the initial state required for long-term safety can be verifiably achieved, and that the capabilities required for disposal are thus in place.

Figure 6-3 shows the main tasks pivotal to planning and implementation and their linkage to the achievement of readiness for submitting the operating licence application. After the construction licence application has been submitted, during 2013–2015, the goal is to advance with the implementation plans so that construction can begin immediately when the licence is granted. The key issues regarding the initiation of underground construction work are the completion of development work regarding rock suitability classification and the collection of initial data required for planning in order to produce the implementation plans for the first deposition tunnel area.

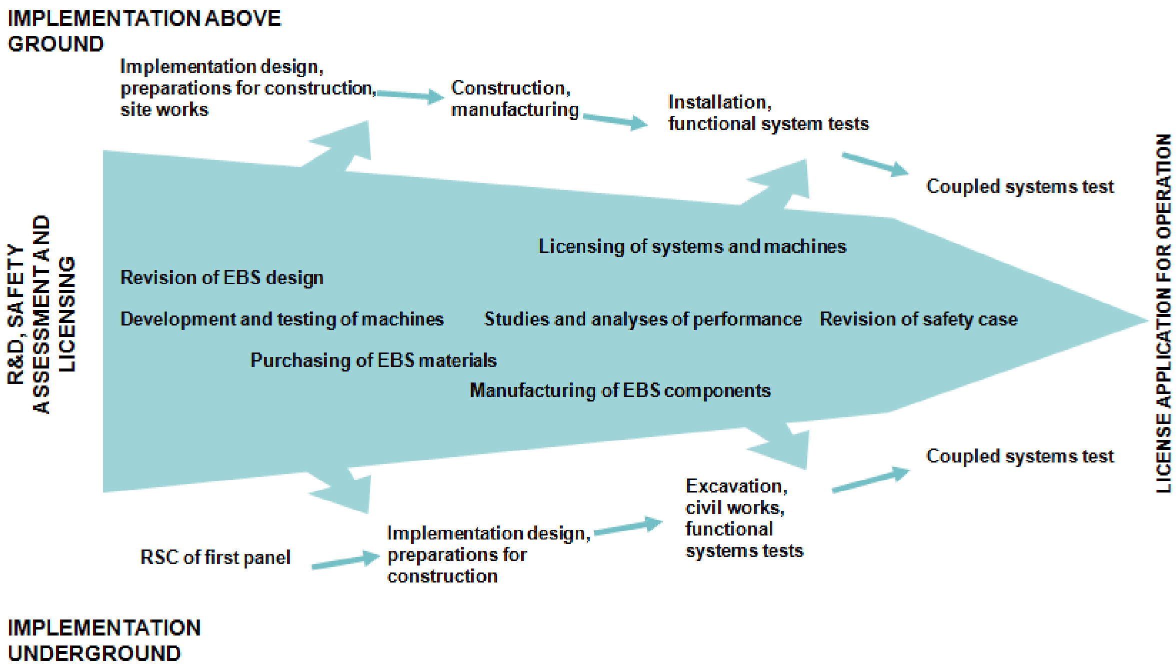

Figure 6-3. *Key task entities for planning and implementation regarding implementation taking place both above ground and underground for the purpose of achieving readiness for the operating licence application.*

Estimates of the implementation schedules are presented in the sections below. They have been produced on the basis that the intention is to start disposal operations around 2020. In order for this to be a realistic basis, the assumption was made when analysing the schedules that the processing of Posiva's construction licence application would take about two years. Accordingly, the company could obtain the licence so that construction and other activities pursuant to it could commence during 2015. If there were delays in this respect, it would postpone the implementation activities set out in this programme. Due to this and other uncertainties associated with producing the schedule, more detailed implementation schedules can only be presented in the nuclear waste management programme to be produced in 2015.

6.2 Land use planning and work in the area

6.2.1 Situation regarding land use planning

Posiva has concluded a long-term lease agreement with TVO regarding possession of the land area required for disposal operations. This agreement covers the area above ground that is required for the disposal of canisters corresponding to 9,000 tU in the disposal facility. According to the plant plans, the disposal operations will begin around 2020 so that the final closure of the facilities would take place about one hundred years from the commencement of disposal operations.

The construction of a disposal facility, even if it is located underground, requires a valid local plan with the necessary entries related to final disposal. The Olkiluoto area has a valid master plan and several valid local plans.

The area administered by Posiva has a local plan that became legally valid in March 2011 (Figure 6-4, the coloured area) that permits the final disposal of spent nuclear fuel at a depth of 400–700 metres. The local plan is based on the master plan that became legally valid in June 2010 pursuant to a decision by the Supreme Administrative Court. The same plan renewed the plan for the Olkiluoto accommodation village and repealed the nature preservation plan of Liiklankari. Liiklankari is part of the Natura 2000 network.

The 9,000 tU of spent fuel can be disposed of in the plan area shown in Figure 6-4. However, the basic premise is that final disposal is implemented in a safe manner, using the most favourable bedrock area. In order to facilitate this, the intention is to have as much as possible of the Olkiluoto disposal site shown in the local plan as an area where disposal is permitted.

The work for producing the local plan for Olkiluoto will continue, and the plans will be revised by the Municipality of Eurajoki during the coming years in a separate local plan programme.

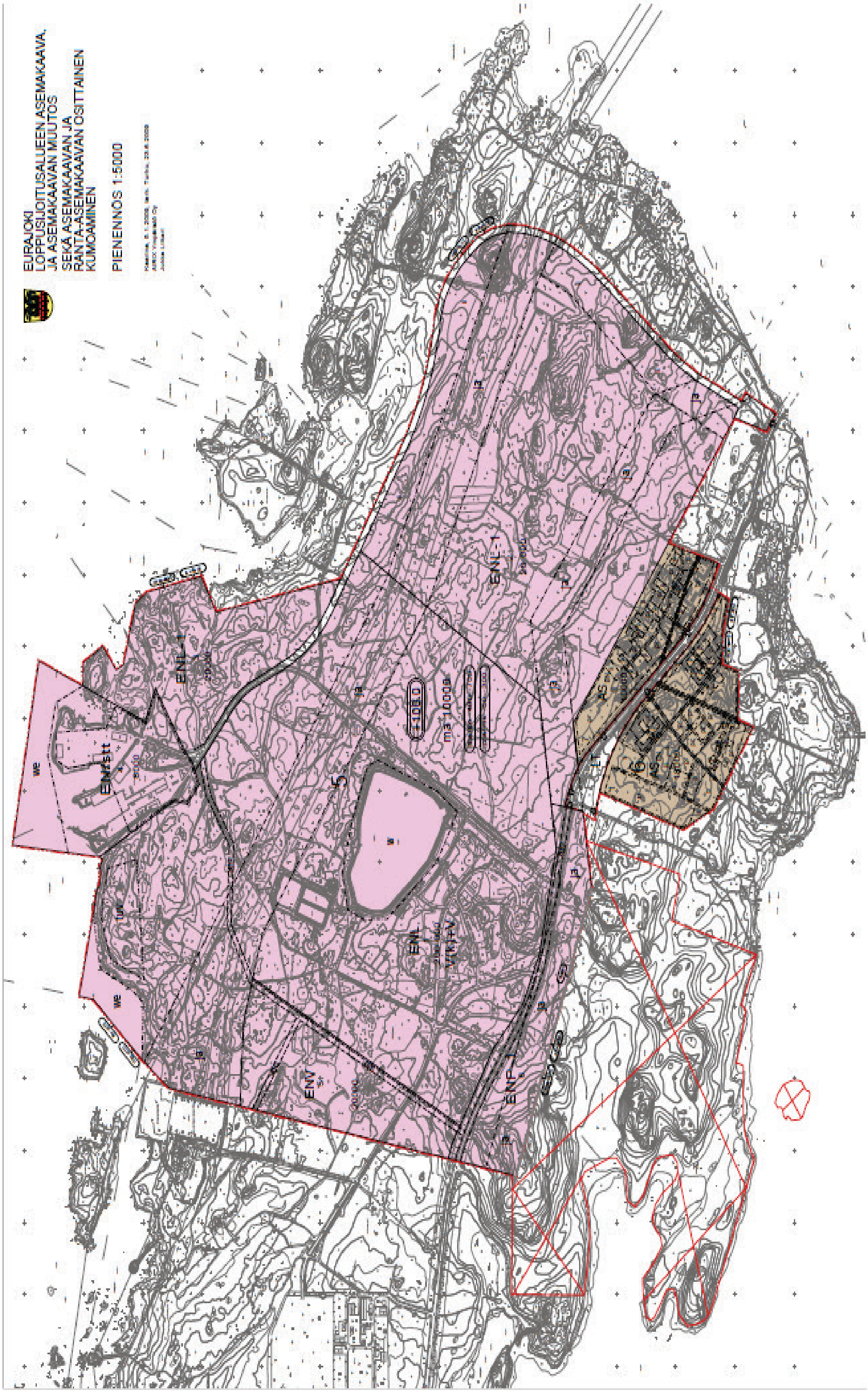

Figure 6-4. *The area designated for final disposal in the local plan.*

6.2.2 Work to be done and buildings to be built in the area

The entity entitled "Work to be done and buildings to be built in the area" includes the infrastructure for the area belonging to the encapsulation plant and disposal facility and structures above ground (traffic areas, cabling, water supply and drainage systems, fences, etc.) and all buildings above ground.

The implementation planning is based on the goal of having everything ready for the joint operating tests of the encapsulation plant and the disposal facility and their subsequent trial operation during 2018–2020. The planning for work to be done in the area between 2013 and 2018 is based on the area plan of 2012 shown in Figure 6-5. The structures and buildings included in the work to be done in the area, to be implemented by the time the operating licence application is submitted, are:

- The roads, courtyards and their associated structures, fences around the plants and work sites, storage areas, cabling, drainage and other work associated with the infrastructure of the area. The phasing of these operations is shown in Figures 6-5, 6-6, 6-8 and 6-9 illustrating the area.
- Infrastructure of the encapsulation plant.
- Preparations are made for building the clay component production plant and its product storage facilities in Olkiluoto, on a site to be decided separately.
- The foundation and cellar structures associated with the controlled area of the ventilation building will be implemented at the same time as phase 2 of the hoist building.
- The actual building of the controlled area of the ventilation building and the ventilation equipment will be implemented once the construction licence has been obtained.
- The plan is to implement phase 2 of the hoist building before obtaining the construction licence.
- Removal of the rock storage / implementation of the new storage.
- Removal of the entrance gate (gatehouse).
- Removal of the link mast away from the encapsulation plant area.
- The operational building (i.e. the office building) will be designed during 2013, and its location will be agreed upon separately.
- It is suggested that the maintenance hall for equipment and vehicles will be designed and implemented after 2015.
- Covering the vehicle ramp after 2015.
- Removal of the explosives store before constructing the disposal facility.
- Implementation of the washing hall after 2015.

The area plans show the operations regarding illumination as well as water supply and drainage/sewage systems to be performed in the area. When preparing the area plans, the requirements of Posiva's corporate security were also taken into account so that the roads and fences to be built in the area in phases meet the security requirements set by authorities. When planning the roads to be built in Olkiluoto, the transport routes for spent fuel must be taken into account, as they will be used by heavy fuel transports. This requires the load-bearing capacity of the roads to be such that special haulage is possible. The design solutions made for Posiva's area take into account the road arrangements to be implemented jointly with TVO and the storage function.

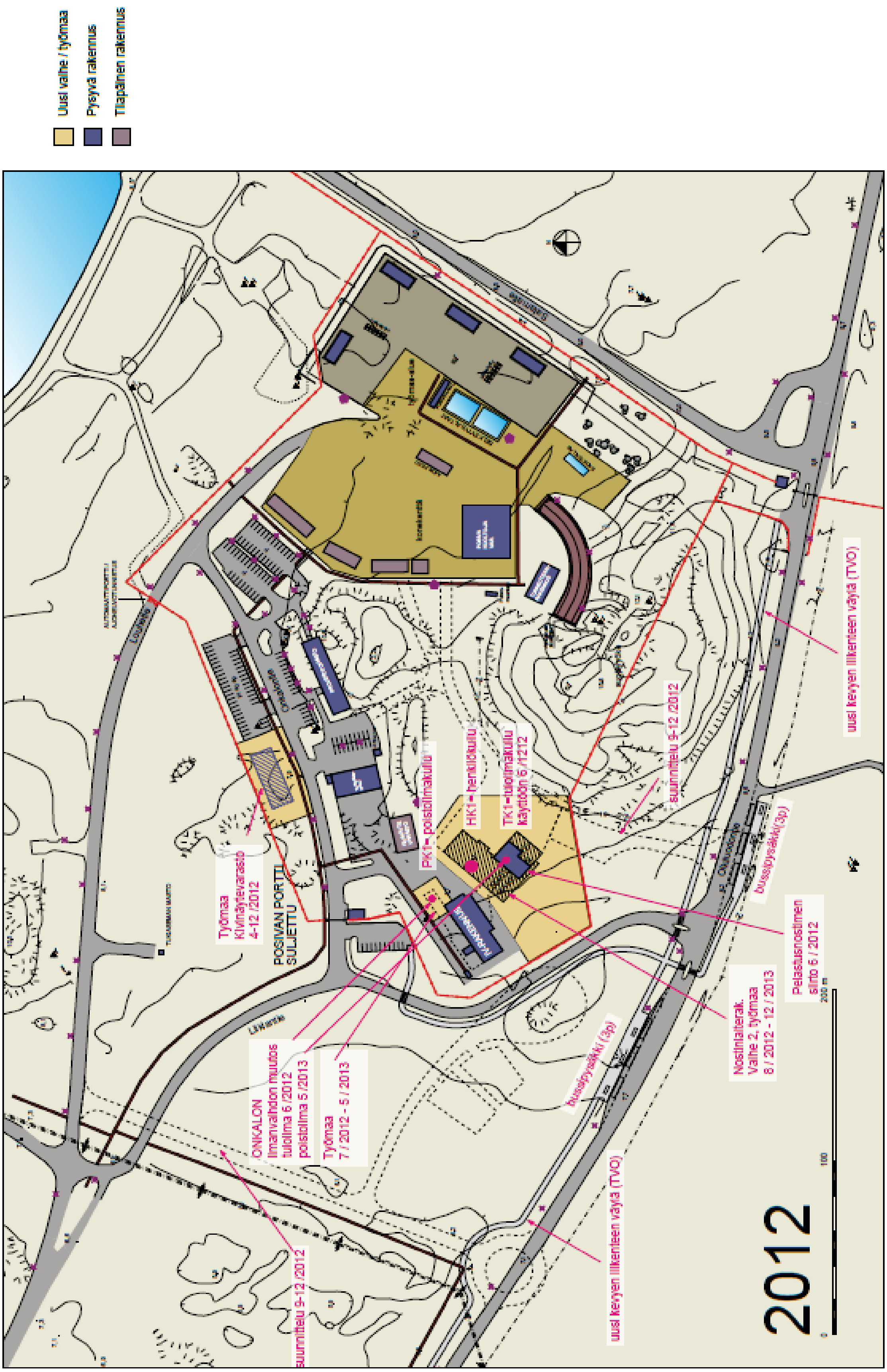

Figure 6-5. *Area plan for 2012.*

6.2.3 Schedule of work in the area

Implementation planning of the roads and other infrastructure in the area will be performed in stages between 2013 and 2018 as the construction projects in the area progress.

The plan is to start the construction of phase 2 of the hoist building in 2013 at the earliest. The design of the building with its associated arrangements was completed during 2012. The arrangements of the area and use of the courtyard area have been planned so that they will support the functions of the planned operational activities. The removal of the rock storage will be implemented either in connection with implementing phase 2 of the hoist building and making its courtyard arrangements or in connection with the preparations for constructing the encapsulation plant. The ventilation connections from the cellar of phase 2 of the ventilation building to the previously built ventilation building will be implemented at the same time.

Construction of the roads and other infrastructure designed in 2012 will commence during 2013–2014 to the extent shown in Figure 6-6. The planned changes in the roads and infrastructure will support the encapsulation plant construction project commencing later. The purpose of changes in the traffic arrangements in the area is to separate the encapsulation plant construction site so that the handling of materials taking place there will not disturb the underground construction work, and vice versa. The road arrangements to be made will also allow surrounding part of the area with the final plant perimeter fence. It must also be taken into account that the link mast currently standing at the encapsulation plant site will have to be moved to a new location before establishing the construction site.

Figure 6-6 also shows the location of the quarried material dumping site near the harbour area, to be moved when the OL4 project starts, as well as the roads leading there and the associated infrastructure.

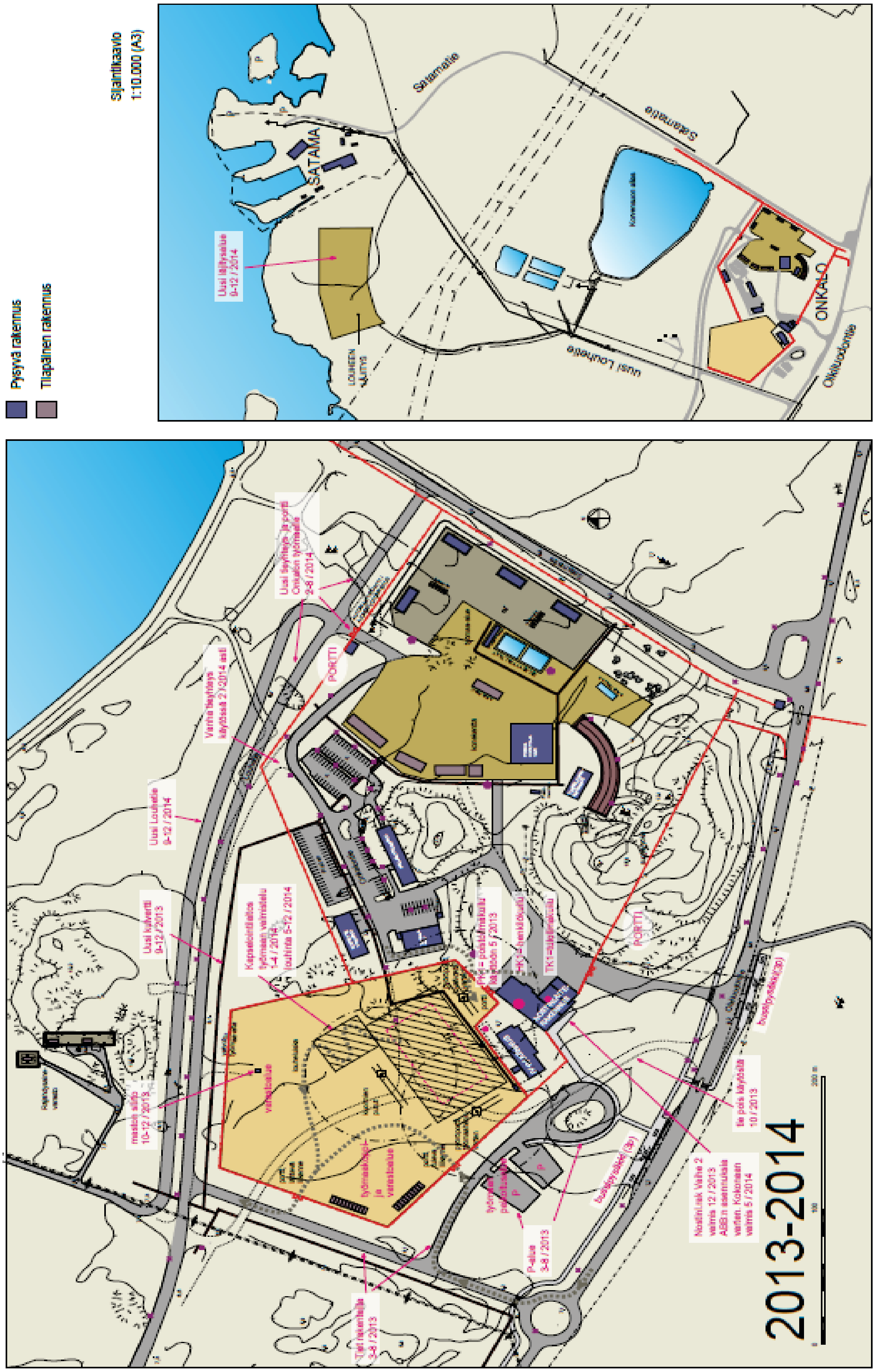

Figure 6-6. *Area plan for 2013–2014.*

The implementation plans for Posiva's office building will be produced during 2013 (Figure 6-7). The building will be used by Posiva's personnel and contractors. Before commencing the implementation planning, a project investigation will be performed and plans of a general nature produced to support the investment decision.

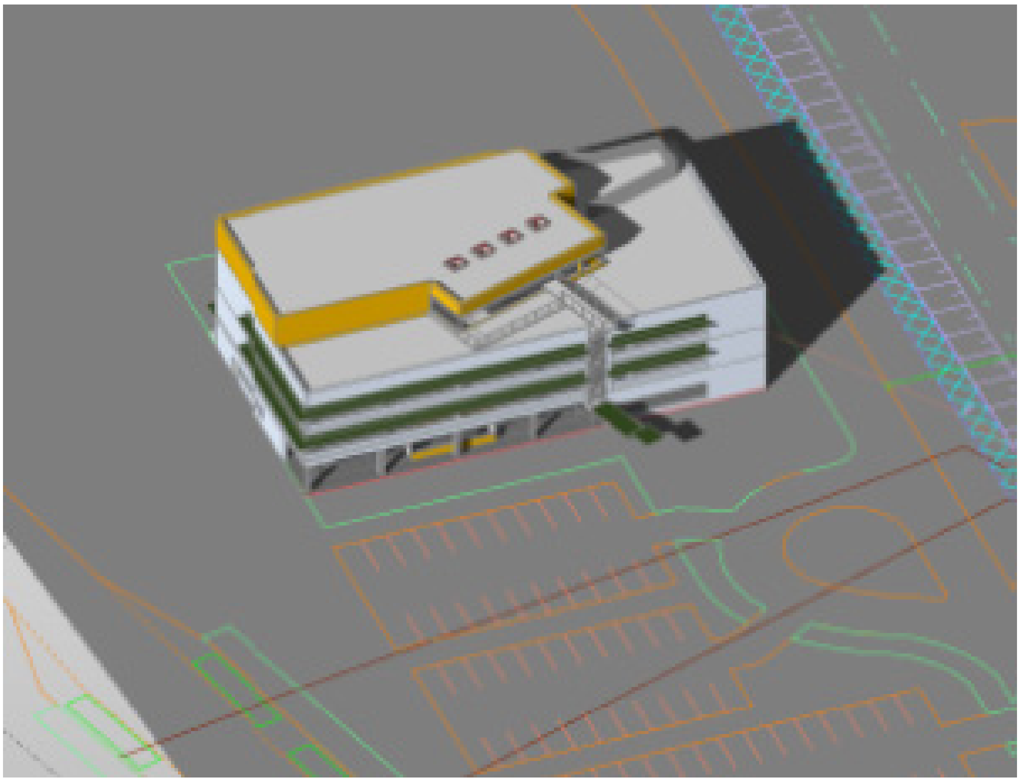

Figure 6-7. *Draft illustration of Posiva's office building.*

Figure 6-8 illustrates the period 2015–2017, when the actual construction work of the encapsulation plant commences in the western part of Posiva's areas following receipt of the construction licence and building permit. The plan is to start the construction of Posiva's office building during 2014. At the same time, the washing hall required for the underground construction work will be constructed and preparations will be made for the disposal operations by designing and implementing a canopy structure over the vehicle ramp and fencing arrangements for the sluice gate structure. The construction project for phase 3 of the ventilation building, including the ventilation equipment for the controlled area underground, will be implemented during the first half of 2015.

The clay component production plant to be located on the quarried material site near the Olkiluoto harbour must be designed after 2015 if the decision is taken to implement it in Olkiluoto. The construction of the plant must be timed so that it will be ready to serve the underground joint operating test.

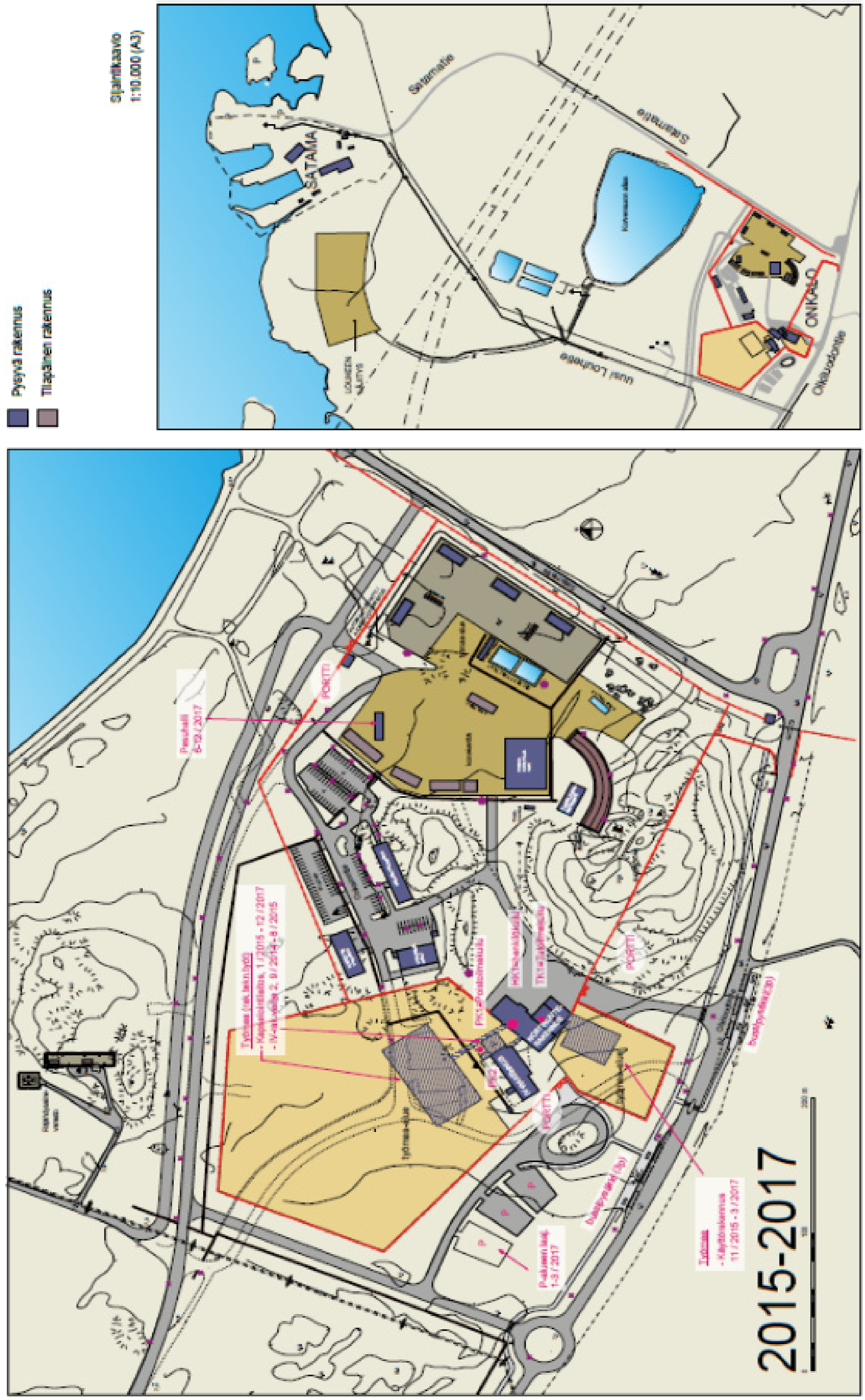

Figure 6-8. *Area plan for 2015–2017.*

Figure 6-9 shows the situation regarding area construction during 2018–2020. Posiva's area above ground will be finalised to meet the needs of disposal operations. The area must be completed to the extent required for obtaining the operating licence so that the operating tests and functions required for the operating licence can be implemented. This phase includes the ability of buildings constructed above ground to operate together and their connections to TVO's functions in the plant area.

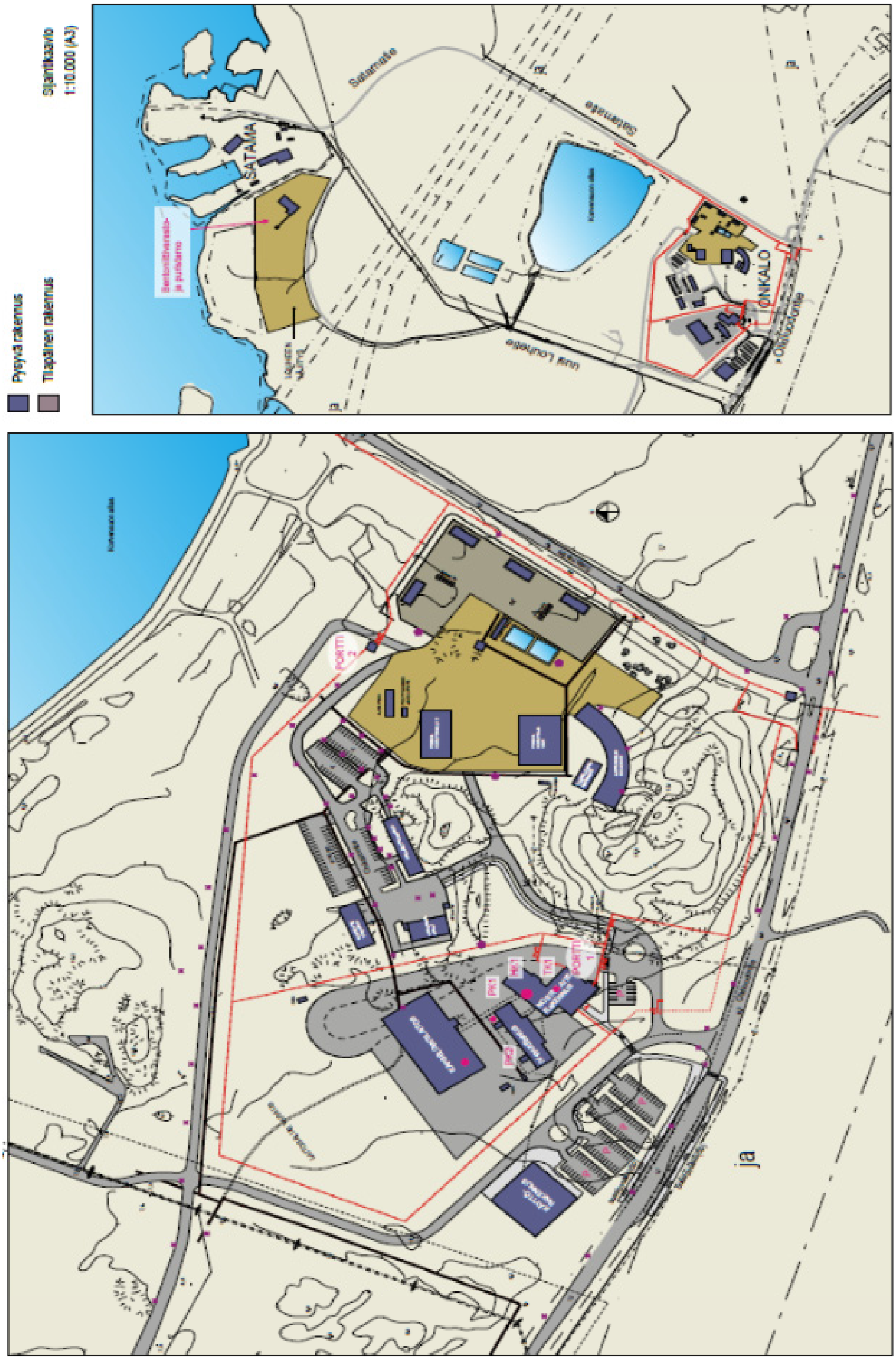

Figure 6-9. *Area plan for 2018–2020.*

6.3 Encapsulation plant

6.3.1 Plant design

The basic principle of the plant design work has been to develop the encapsulation plant concept, technical plans and encapsulation process based on them to a standard that is both acceptable and required for nuclear facilities. A plant model including the structures, systems and equipment of the encapsulation plant has been maintained for the purpose of aiding and supporting the plant design work. The plant model has been constantly developed as the system and equipment plans have become more specific.

All principal plans for the encapsulation plant and process have been documented. The documentation has been implemented with the help of 3D design models and Posiva's working reports.

6.3.1.1 System design and prototype systems

The encapsulation process involves systems that have not been qualified anywhere for their intended operation because a similar encapsulation plant for spent fuel has never before been implemented. In order to ensure the operability of plans and the smooth flow of the validation process for the final production systems, the plan is to construct prototypes of the encapsulation process systems deemed most important for safety before implementing the final production equipment. Such systems of the encapsulation plant are:

- the fuel transfer machine and maintenance manipulator,
- the canister transfer trolley, and
- the remote controlled mover for disposal canister transfer (previously an AGV).

The design work for some of these prototypes has already begun, and the design, manufacture and testing will continue beyond 2015. In order to ensure the operability of the plans, the quality assurance procedures for the manufacture, installation and commissioning of the final equipment will also be developed jointly with authorities in connection with the prototypes.

Development work will be done for defining the requirements for the systems most critical to safety. The procedures for systematic requirement management were developed during the pilot phase of the work. The fuel transfer machine was used as an example system. The work for defining the requirements can be utilised for further development of the system and for its procurement, among other things. The intention is to follow the procedure to be established and define the requirements for all safety-classified systems. When defining the requirements, the system-related requirements in acts, decrees, official guides and applicable standards will be compiled in one location (expansion of Posiva's VAHA system) where they can be administered and utilised. The VAHA system can be used to compile lists of requirements for further system design or manufacture, among other things.

The design, manufacture and trial operation of prototypes will be implemented and documented in compliance with the applicable safety class as if it were a question of final systems. If prototype equipment of parts of it are used as part of the final systems, the regulatory oversight by authorities will apply to them just like to the final systems.

In these cases, the procedure must be agreed with the authorities in advance. The design work for final production systems will rely on the plans and test results for the prototypes. The systems will be mainly manufactured and installed during 2016–2018.

When designing the plant and its systems, the installation of systems and equipment is taken into account, including the routes for their haulage. The need to replace all systems several times during the service life of the plant will be taken into account. Therefore, the maintenance requirements and haulage routes must be designed so that equipment can be replaced without significant dismantling the structures.

The operability of all systems (including those for which no prototypes will be produced) will be ensured by sufficiently comprehensive Factory Acceptance Tests (FAT) before the systems are delivered to the plant, as well as with Site Acceptance Tests (SAT) conducted for ensuring the operability of the systems in their final place of operation. The contents of FATs and SATs will be defined during the equipment design phase. Other important systems of the encapsulation plant and their design and testing work are presented in section 5.4.1.1.

6.3.1.2 Licensing of the systems

Licensing of the encapsulation plant systems is a process involving many phases, where the unique nature of the plant and evolution of the plant concept details even after submitting the construction licence application must be taken into account.

System descriptions will be produced for all plant systems to be used as part of the Preliminary Safety Analysis Report (PSAR) for the plant. The PSAR will be submitted to STUK in connection with the construction licence application. These descriptions will be based on the status of design at that time, and they will focus on describing the systems, their duties and their design requirements. The descriptions will present the implementation of systems and their associated equipment with the degree of detail required at the design stage. One basic premise is that the system design must be advanced far enough to ensure sufficient space allocations at the plant. This helps avoid any changes to plant layout even if details of the systems are changed as the design work progresses. As the design work progresses, the preliminary system descriptions included in the construction licence application will be defined further so that the level of detail required in STUK's new YVL Guide B.1 is achieved before starting construction, most likely by 2015.

The actual detailed system design work will take place after submitting the construction licence application. The results of implementation planning will be presented on a system-specific basis in the final system descriptions included in the operating licence application. In connection with the implementation planning work, preparations will also be made for updating the system descriptions and for the construction plans of equipment included in the systems. The requirements concerning construction plans are presented on an equipment type-specific basis in STUK's YVL Guides. The preparation of equipment-level instructions to be produced as a result of the on-going YVL Guide reform work is still in progress. The construction plans for the equipment will be processed by STUK, or by an inspection organisation approved by STUK, using the procedures described in the YVL Guides.

The inspections and other quality control measures regarding the equipment will be described in a quality control plans included in the construction plans. Manufacture of the equipment will only begin after its construction plan has been approved.

6.3.1.3 Planning operating activities

The operating activities of the encapsulation plant are planned on the basis of the quantity of spent nuclear fuel eligible for final disposal. The fuel that has been cooled down in interim storage and allows the forming of disposal canisters fulfilling the criteria is eligible for final disposal. The design capacity of the encapsulation plant is 100 canisters per year. During the early phases of disposal operation, fuel eligible for disposal will be produced at a rate corresponding to 40 canisters per year at a steady pace, when the thermal optimisation of the canisters is taken into account. This means that the intention is to have the thermal power of all canisters as close as possible to the same value just below their design rating. This means the bedrock suitable for final disposal will be optimally utilised.

The annual production rate of 40 canisters will allow the encapsulation process to be operated in stages. This means, for example, that the entire contents of one transport container are encapsulated as quickly as possible. Canisters can be produced for the canister storages above ground and underground so that all canisters for one deposition tunnel are ready before starting the disposal process. As the deposition holes will be bored in good time before the disposal operation, the number of canisters to be accommodated in the tunnel concerned will be known in advance. Hence, the production of canisters can be planned to match this number. All canisters to be disposed of in an individual tunnel will be of the same type. However, as all fuel assemblies contained in one transport cask must be encapsulated before returning the transport cask to the interim storage facility, there may be individual canisters that have to wait for final disposal, even for a long time, in case the number of canisters does not match the number of holes in the deposition tunnel.

During the coming programme period, the encapsulation process will be designed in greater detail so that the required number of personnel can be estimated and preparations can begin for training the operating personnel. Analysis of the process can also help investigate which work phases can be performed by the same individuals. More detailed information on the times taken by the different phases of the process will be obtained from the testing and trial operation of prototypes and final systems.

6.3.2 Implementation planning

The detailed implementation plans for the encapsulation plant will present the information required for the manufacture and implementation of the structures, systems and equipment of the encapsulation plant. The implementation plans will be based on a plant model that will also be maintained throughout the implementation planning process for the purpose of managing the equipment configuration. The intention is to use the detailed implementation plans to define more closely the implementation and procurement schedule for structures, equipment and systems and to demonstrate, in greater detail, the fulfilment of requirements regarding the components to be implemented.

The implementation planning of the encapsulation plant will be implemented in compliance with the design basis prescribed in the Land Use and Building Act for demanding sites, taking into account the special regulations concerning nuclear facilities, set out, *inter alia*, in the Nuclear Energy Act and the Nuclear Energy Decree, as well as in Government decrees and STUK's YVL Guides.

Construction design work

The building plans for the encapsulation plant will present the matters related to the operation and operational safety of the buildings. The building plans will take into account, among other things, the following matters:
- the intended use of rooms,
- fire partitioning,
- fire load categories,
- fire-fighting routes in and smoke extraction from cellars,
- fire hydrants,
- exit routes and their widths, and
- ambient condition requirements of the buildings.

The building planning work will also take into account the position of the building in relation to its surroundings and its access and traffic arrangements. At the same time, the access of fire-fighting and rescue services is taken into account.

The building plans for the encapsulation plant will be produced during 2012–2018 so that the main drawings will be available for the construction licence application in 2012. After the construction licence application has been submitted, the dimensioned drawings, work instructions and other documents will be produced so that the construction-related plans will be available in time for different tender invitations.

The implementation planning for the encapsulation plant will continue after the tender invitation phase with the production of more specific plans where the needs for change during the implementation phase are taken into account. As-built drawings will be produced regarding the construction of the plant, and they will be appended to the as-built and handover documentation of the building contracts. This work will continue until the commissioning of the plant.

Structural design

The structural design of the encapsulation plant is based on the main drawings and other implementation plans. Their compliance with requirements must be ensured. The matters to be taken into account in structural design include the following:
- the safety and loading of the structures,
- any special loads during operation,
- any loads during accident situations,
- the aircraft collision load and earthquake load derived from YVL Guides,
- the ground and foundation conditions,
- the equipment and systems to be installed in the building,
- draining of the building, and

- the types of structures used for the ground floor, walls, mezzanine floors and ceiling.

The implementation plans can be used for determining a more accurate cost estimate for the building based on partial estimates of the building work and for producing a work method plan for implementation.

HPAC, electrical, I&C and mechanical design

The heating, water supply, sewage and ventilation design of the encapsulation plant, its electrical design, automation design and mechanical design involve checking the space requirements and the technical rooms required for each system in a detailed manner. The facilities were preliminarily designed as part of the plant design, but during implementation planning, the plans will be made compliant with the equipment manufacturers' specifications so that the operational safety of the equipment is taken into account. At the same time, the matching of functions specified in the system descriptions with each other and their implementation in the building frame will be taken into account.

The matters to be taken into account in the HPAC design of the encapsulation plant include the following:
- the compliance with requirements of the water supply and sewage systems of the building,
- air conditioning and ventilation,
- air conditioning and ventilation of special facilities,
- the locations and functionality of ventilation equipment, and
- the capacities of ventilation equipment.

The matters to be taken into account in the electrical design of the encapsulation plant include the following:
- the compliance with requirements of the building's electrical installations,
- the required ambient classification of the electrical facilities and equipment,
- the electrical systems of special facilities,
- the locations and functionality of electrical equipment,
- the power rating of electrical equipment,
- the back-up arrangements for electrical equipment,
- the operational safety of electrical equipment, and
- the connection capabilities of I&C equipment.

The matters to be taken into account in the I&C design of the encapsulation plant include the following:
- the compliance with requirements of the equipment, and
- matching of the equipment with other systems in terms of mechanics and programming.

The matters to be taken into account in the mechanical design of the encapsulation plant include the following:

- the compliance with requirements of the water supply and sewage systems of the building,
- the operational safety of mechanical equipment, and
- the co-operation of mechanical equipment with I&C, as applicable.

The HPAC, electrical, I&C and mechanical design work will be implemented in cooperation with construction design work so that the required space allocations are taken into account in implementation planning.

6.3.3 Implementation

6.3.3.1 Method of implementation

The current design is that implementation of the encapsulation plant will be organised by Posiva. The implementation will be divided into the preparatory part during 2013–2015 and the implementation part during the years following receipt of the construction licence (2015–). The procurement required for implementation will be divided into packages that are rational from the point of view of planning and implementation. The basic premise for commencing implementation is that plans approved by the buyer (and also by authorities, where applicable) are available for procurement and implementation, even during the preparatory phase. The implementation phase will be described in detail in the YJH programme to be produced in 2015.

Preparatory phase following submission of the construction licence application

The work will begin with clearing the site and with establishing the facilities required for the site (the facilities for the construction management and the contractors) as well as the roads, fences and access control systems.

The basic excavation required for the encapsulation plant will be excavated as an open quarry under a separate contract. The dumping site for the quarried material must be available when the excavation work begins. The dumping site and its access roads will be built in connection with area work.

The leak-tightness of the canister shaft and other starting prerequisites for opening it must be ensured during the preparatory phase, before the actual construction of the encapsulation plant. The 'starting prerequisites' refer to the grouting of the top section of the canister shaft, to be performed once the basic excavation work has been completed, from level +1.6 m of the basic excavation all the way to level -90 m. The excavation of the shaft end at level -90 m must also begin as soon as possible. The starting prerequisites will ensure that the actual construction process of the encapsulation plant will progress in a controlled manner in keeping with the time schedule.

The top section of the canister shaft can only be excavated (by raise boring) once the shaft end has been excavated and the basic excavation has been grouted. The above preparatory work and raise boring should be completed before commencing the construction work. Performance of this work before obtaining the construction licence will require a separate approval by the authorities.

Implementation phase after obtaining the construction licence

Once the construction licence has been obtained, the work required for the canister shaft below the level -90 m can begin (grouting, shaft ends, raise boring operations). Ventilation shaft 2 will also be implemented in the same manner, if it is deemed necessary.

A building contractor will be appointed for the actual construction work subject to the construction licence (foundation, frame and supplementary structures). This contractor will be the main contractor during the construction phase, and also during the installation phase, if required. The required contracts for building automation (electricity, HPAC, I&C) will be concluded by the buyer who may subordinate them as sub-contracts to the main contractor.

The equipment and systems related to the encapsulation process, particularly those subject to safety classification, will be procured by Posiva itself. These should be procured ready installed. The installation contracts will either be subordinated to the building contractor while it acts as the main contractor, or implemented as simple by-contracts.

The order in which construction and installation operations are performed will be constantly monitored by the buyer's organisation in order to ensure the optimal progress and interlacing of work.

The responsibilities and job descriptions of persons appointed to the project organisation will be specified further in the project plans to be produced.

6.3.3.2 Construction engineering work

In line with the current practice, Posiva may perform some work in preparation for constructing the encapsulation plant before obtaining the construction licence prescribed in the Nuclear Energy Act. Such work includes clearing the top soil, quarrying the basic excavation and earth-moving operations, as well as work performed in preparation of opening the canister shaft.

The estimated quarrying volume of the encapsulation plant foundations is about 23,000 m^3. The preliminary estimate of the duration of excavation and reinforcement work is 6–8 months. If the top section of the canister shaft can be excavated before obtaining the construction licence, this work should be started so that excavation and reinforcement of the top section of the canister shaft can be carried out before the scheduled commencement of construction operations.

The actual structures of the encapsulation plant, i.e., its foundations, ground slab and frame, will probably be made of concrete cast on site in line with the preliminary plans, once the construction licence has been obtained. The total volume of concrete is estimated at some 12,000 m^3.

6.3.3.3 Installation work

Most of the installation work for the systems of the encapsulation plant will take place after 2016.

The installation work must be synchronised with the construction work by setting certain stages of readiness in the construction schedule in order to take into account the needs of installation work.

6.3.4 Trial operation and joint operation tests

A preliminary trial operation plan will be produced for the encapsulation plant in connection with the construction licence application. This plan will present the principles and preliminary plans for trial operation. Trial operation will initially take place on a system-specific basis: first with factory acceptance tests (FAT) and then with site acceptance tests (SAT) after installation. After system-specific trial operation, joint operating tests will be performed at the encapsulation plant for verifying the interoperability of systems and the operation of the plant's control system. At the same time, the correctness and comprehensiveness of operating instructions will be verified. The current schedule includes the performance of a non-nuclear joint operating test (without nuclear fuel) after 2018. The nuclear joint operating test (with spent nuclear fuel) can be performed around 2020 when the permission for handling nuclear fuel has been obtained. A successful nuclear joint operating test will demonstrate that the capabilities for initiating disposal operations are in place with regard to the encapsulation plant.

6.4 Disposal facility

6.4.1 Plant design

The basic mission of the plant design work has been to develop the disposal facility concept suitable for the Olkiluoto bedrock, its technical plans and a disposal process are based on standards that are both acceptable and required for nuclear facilities. Another task has been to integrate the Underground Rock Characterisation Facility ONKALO with the underground parts of the disposal facility. The practical tool used for this integration is the 3D plant model that is being constantly updated and forms the basis of all further design work. The plant model also seeks to take into account all the needs of the plant operation. The latest information on Olkiluoto bedrock and layout-determining features (LDFs) as well as of the holes drilled in Olkiluoto that the tunnel network must not touch have been entered as initial data for the plant model.

The plant model for the underground facilities will be kept up to date during the coming programme period 2013–2015. The updated information on various subjects, including the quantity and properties of spent fuel generated by Posiva's owners, the construction methods, the equipment related to implementation and operation as well as the Olkiluoto bedrock, will be taken into account when updating the plant design. The next update of the plant design will be completed by the end of 2015. This plant design will be used, among other things, for updating the total cost estimate and for the assessment of long-term safety performed for the operating licence application. An update of the plant design will be produced during the subsequent programme period (2016–2018), and it will be used in Posiva's operating licence application material to describe the implemented plant.

6.4.2 Design and implementation of the part of the facility located above ground

Implementation planning for the ventilation building

The design work for the supplementary parts and extension of the ventilation building was completed during the TKS period now ending in connection with designing the first phase. The contents of the plans will be revised with respect to the changes introduced in connection with the design work for the hoist building and the encapsulation plant, both adjoining the ventilation building. The change planning mainly concerns taking the plans regarding corridors between the buildings into account.

Implementation of the ventilation and hoist buildings

The ventilation and hoist buildings will consist of three different construction phases. The first implementation phase consisted of the construction work for the uncontrolled area of the ventilation building and first phase of the hoist building. This phase was implemented during the TKS period of 2010–2012.

The second implementation phase will include the actual hoist equipment entity, including the actual structures of access routes and social facilities. During the second phase, a ventilation channel will be built in the cellar of the ventilation building for the ventilation of the ONKALO during construction. The construction work for the second phase will begin with excavation work at the end of 2012, with the actual construction work possibly beginning in spring 2013. Once the hoist building is completed and the personnel shaft reinforced, installation work for the personnel hoist will begin in the hoist building. The intention is to also use the personnel hoist for installing building automation systems in the personnel shaft. In addition, part of the controlled area adjoins the ventilation building; it will be built once the construction licence has been obtained.

6.4.3 Design and implementation of ONKALO of the part of the underground facility

6.4.3.1 Implementation extent of ONKALO

ONKALO reached the disposal depth in summer 2010, and excavation of the access tunnel was completed in spring 2012 (Figure 6-10). Following the excavation phase ended in spring 2012, the excavated premises will be equipped and furnished with concrete structures and technical rooms with the required equipment. The excavation of facilities included in the implementation extent of ONKALO will continue during 2013–2014 when preparations are made for starting the construction of the disposal facility. The future construction activities regarding ONKALO are discussed in greater detail in section 6.4.3.3.

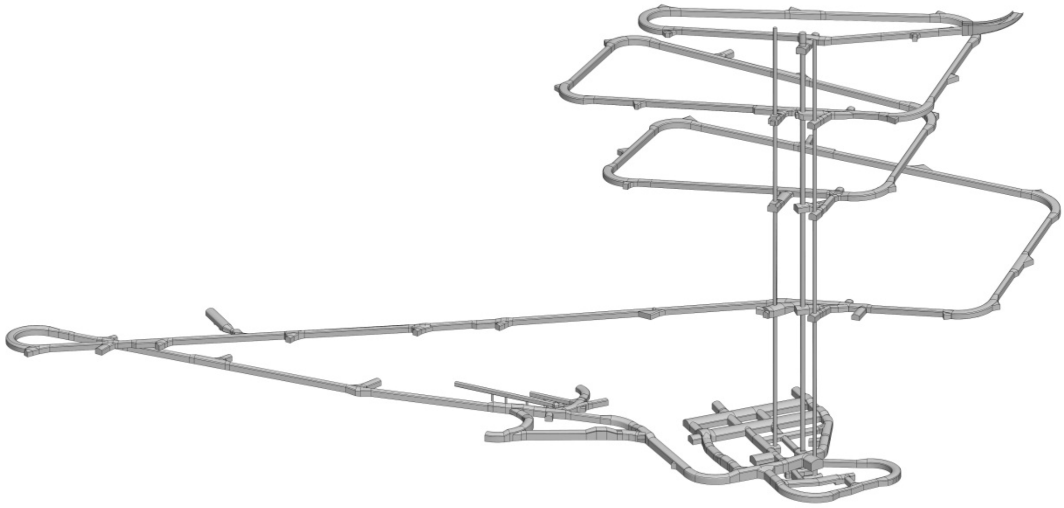

Figure 6-10. *Underground Rock Characterisation Facility ONKALO (June 2012).*

Equipping the excavated facilities and construction of the supplementary structures will facilitate the performance of research and development facilities essential for the construction and operating licences. The design work for these facilities was guided by the following design principles:

- The risk of transients caused by all constructed and open underground facilities shall be mitigated.
- Underground facilities will only be constructed for the research and development needs essential for obtaining the construction licence.
- The possibilities for making changes will be maintained for any later development of the plant design.

More detailed design requirements have been derived from these basic principles for implementation planning. The facilities to be constructed in compliance with them must allow bedrock characterisation work and other required investigations at the disposal depth. In addition, the facilities must provide possibilities for testing the disposal system. The facilities to be constructed must also fulfil the needs and requirements related to their use as part of the disposal facility.

Figure 6-11 shows the implementation extent of ONKALO at the main research level in summer 2012 and the part yet to be implemented (the final extent of ONKALO). Ventilation shafts connect ONKALO to the ventilation building completed in 2011. The temporary ventilation arrangements will be dismantled once the shafts are opened.

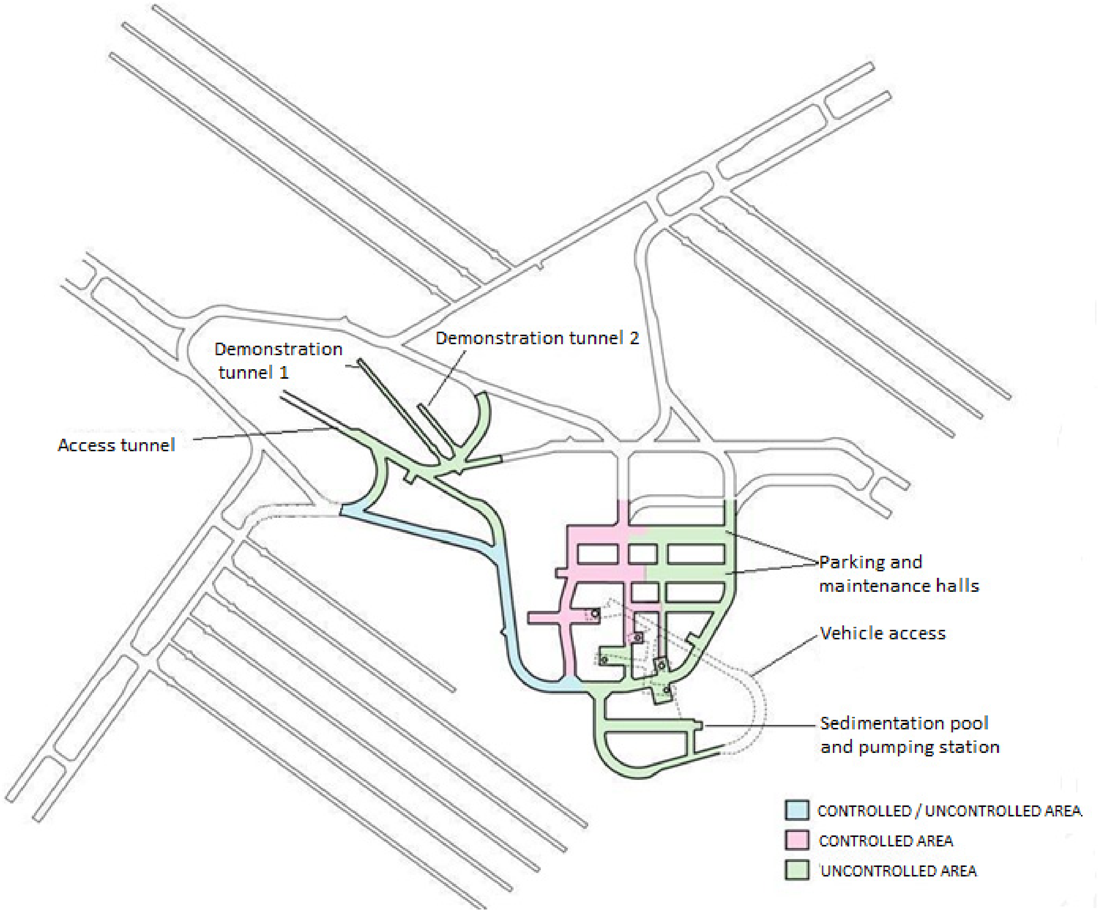

Figure 6-11. *Extent of ONKALO at the main research level.*

6.4.3.2 Implementation planning for ONKALO and the part of the facility located underground

The purpose of implementation planning is to develop the principal solutions of plant design into implementable plans. The work is based on the plant model that has been constantly developed as the system and equipment plans have become more specific. The detailed-level implementation plans for the disposal facility will present the plant structures, systems and equipment included in the plant model for the disposal process. The intention is to use the detailed implementation plans to define more closely the implementation and procurement schedule for structures, equipment and systems and to demonstrate, in greater detail, the fulfilment of requirements regarding the components to be implemented.

The principal plans for the disposal facility and the disposal process have been documented, and they will be used as the basis for producing detailed plans. The plans were documented with the help of 3D design models and Posiva's working reports.

The implementation planning of the disposal facility will be implemented in compliance with the design basis prescribed in the Land Use and Building Act for demanding sites, taking into account the special regulations concerning nuclear facilities, set out, amongst other things, in the Nuclear Energy Act and the Nuclear Energy Decree, as well as in Government decrees and STUK's YVL Guides.

Construction design work

The construction design work for the disposal facility will present the matters related to the operation and operational safety of the buildings, and the construction plans will take into account, amongst other things, the following matters:

- the intended use of rooms,
- fire partitioning,
- fire load categories,
- fire-fighting routes in and smoke extraction from the cellars above ground,
- fire hydrants,
- exit routes and their widths, and
- ambient condition requirements of the buildings.

The building planning work will also take into account the position of the building in relation to its surroundings and its access and traffic arrangements. At the same time, the access of fire-fighting and rescue services is taken into account.

Construction design work will be performed throughout the preparation and construction period. The main drawings will be available for the construction licence application in 2012. After the construction licence application has been submitted, the dimensioned drawings, work instructions and other documents will be produced so that the construction-related plans will be available in time for different tender invitations.

After the tender invitation phase, implementation planning will continue with more specific plans where any changes required regarding implementation are taken into account. As-built drawings will be produced as part of the implementation planning work after each implementation phase. They will be appended to the as-built and acceptance documentation of the building contracts. This work will continue until the commissioning of the plant.

Structural design

The structural design of the disposal facility is based on the plant design and on the main drawings produced on that basis. The compliance of these drawings with the requirements has been separately verified. The matters to be taken into account in structural design include the following:

- the safety and loading of the structures,
- any special loads during the operating state,
- any loads during accident situations,
- the ground and foundation conditions,
- the equipment and systems to be installed in the building,
- draining of the building, and
- the types of structures used for the ground floor, walls, mezzanine floors and ceiling.

The structural design plans can be used as the basis for determining a cost estimate for each part of the construction work and for producing a plan for their implementation.

HPAC, electrical, I&C and mechanical design

The heating, water supply, sewage and ventilation design of the disposal facility, its electrical design, automation design and mechanical design involve checking the space requirements and the building automation facilities required for each system in a detailed manner. The facilities were preliminarily designed as part of the plant design, but during implementation planning, the facilities will be made compliant with the equipment manufacturers' specifications so that the operational safety of equipment is taken into account. At the same time, the matching of functions specified in the system descriptions with each other and their implementation in the building parts will be taken into account.

The matters to be taken into account in the HPAC design of the disposal facility include the following:
- the compliance with requirements of the water supply and sewage systems of the building,
- air conditioning and ventilation,
- air conditioning and ventilation of special facilities,
- the locations and functionality of ventilation equipment, and
- the capacities of ventilation equipment.

The matters to be taken into account in the electrical design of the disposal facility include the following:
- the compliance with requirements of the building's electrical installations,
- the required ambient classification of the electrical facilities and equipment,
- the electrical systems of special facilities,
- the locations and functionality of electrical equipment,
- the power rating of electrical equipment,
- the back-up arrangements for electrical equipment,
- the operational safety of electrical equipment, and
- the connection capabilities of I&C equipment.

The matters to be taken into account in the I&C design of the disposal facility include the following:
- the compliance with requirements of the equipment, and
- matching of the equipment with other systems in terms of mechanics and programming.

The matters to be taken into account in the mechanical design of the disposal facility include the following:
- the compliance with requirements of the water supply and sewage systems of the building,
- the operational safety of mechanical equipment, and
- the co-operation of mechanical equipment with I&C, as applicable.

The implementation planning will take place in cooperation with construction design work so that the required space allocations for systems and equipment are taken into account in implementation planning.

6.4.3.3 Implementation

Implementation of the final phase of ONKALO during 2013–2015

Even before the construction licence is granted, minor excavation work can be performed in ONKALO for research and development purposes under the supervision of STUK in line with the established practice. The excavation work planned for the next few years in ONKALO includes the second parking hall and certain facilities required for research purposes. Other large operations included within the scope of ONKALO include the construction and building automation work for ONKALO. Most of this work will be carried out at level -437 m in the technical rooms and pumping station, and includes rescue chambers, the bottom structures of shafts that have already been raise bored, pumping station structures, structures at the interfaces of fire partitions, hall structures and the building automation and other fittings required for them. The already raise bored shafts (personnel shaft, exhaust air shaft 1, inlet air shaft) as well as the rest of the access tunnel will be reinforced before 2015. Such access tunnel reinforcement operations include preparations for the excavation work above ground for the encapsulation plant and for the second phase of the hoist building.

Implementation of the underground part of the facility during 2015–2018

Construction of the underground part of the facility will begin after obtaining the construction licence in 2015, provided that the licence is obtained as planned. The work to be initiated in early 2015 includes the opening of the canister shaft and the possible second exhaust air shaft with their associated grouting operations. Another major work package comprises the excavation and grouting work of the central tunnels and vehicle routes leading to the actual deposition tunnels, as well as of the shaft connections for the canister shaft (and the possible second exhaust air shaft) and the canister storage at level -437 m. The building automation and construction engineering work will always be performed following the excavation work, once the safety and availability of the excavated facilities have been ensured.

Once the construction licence has been obtained, the excavation work for the disposal facility will begin with excavating the central tunnels, followed by the excavation of deposition tunnels and the construction engineering work for the disposal facility, including the building automation, canister lift and other systems to be installed in the disposal facility. The structures and installations related to the canister shaft are among the largest individual work packages.

6.4.4 Development of construction methods

The work for developing construction methods will continue during the future programme periods. This work includes both in-house work and work performed outside Posiva, such as equipment development work with cooperation partners and work performed in cooperation with SKB. The subjects important to long-term safety include further investigations regarding the properties of the excavation damaged zone (EDZ) and improvement of the controllability of the excavation process.

6.4.4.1 EDZ studies

The excavation damaged zone has been investigated for several years in several R&D programmes investigating, among other things, the connection between excavation methods and the EDZ formed, as well as the methods for characterising the EDZ. The subject of the investigation initiated in 2012 is the hydrological nature of the EDZ. The investigations will continue in 2013 with work compiling all investigations performed so far, formation of the EDZ in the produced facilities, as well as its control, measurement and significance to long-term safety. The development of methods will continue for the purpose of productizing the quality management equipment and quality measurement methods for the quality control of repository facilities. The goal is to create an easily repeatable and reliable set of quality management tools for the construction of deposition tunnels.

6.4.4.2 Construction methods

The current opinion is that both low-pH grouting mixes and silica mixes will be used for grouting the bedrock in the disposal facility. The development work regarding silica grouting of the tunnel began during the previous programme period. During the coming programme period, grouting will be further developed and the long-term behaviour of materials (e.g. silica) in the bedrock will be investigated in cooperation with SKB.

Sufficient evenness of the deposition tunnel floors is a prerequisite for installing the tunnel backfill. An even floor will make all operations after excavation easier. The development of foundation layer methods after excavation has begun with a rough grinding implement consisting of a rough grinding head installed in an excavator for producing an even floor surface. Development work for the rough grinding method will be continued by rough grinding test areas in demonstration tunnel 2. When developing the rough grinding implement, the other targets suitable for rough grinding will also be taken into account. These include the removal of sprayed concrete or loose pieces of rock from rock faces. In turn, SKB has investigated the possibilities of using sawing to produce even rock surfaces.

Posiva will participate in the planned DOPAS project where a plug will be constructed in ONKALO during the period 2013–2015. The tunnel walls at the planned plug location must first be treated to make them suitable for the plug. Sawing with a steel cable, tested by SKB in Sweden, has so far proven to be the most promising method, and it will be tested during the coming period as a possible method. The plans regarding the plug test are discussed in greater detail in section 5.4.1.3 .

The methods development work includes the development of materials (such as grouting mixes) and the validation of dimensioning calculations (such as the dimensioning of pressure-bearing walls), performed whenever possible. This work benefits the design work. The design age of disposal facility is over one hundred years, which sets certain demands for the choice of materials. The vertical shafts are among the disposal facility subjects that are difficult to maintain. The material testing work includes simulations of the long-term behaviour of concrete in the shafts. The volume of the underground facilities must be designed to be as small as possible, which is why the effects of different functions required in the disposal facility (taking into account the different phases of final disposal, air conditioning, fire safety, etc.) on the excavation volume have been estimated and dimensioned using different types of modelling. During the disposal period, the concrete-sprayed areas will be exposed to increasing thermal stresses and may become damaged. Once the third phase of the POSE test has been performed, investigation hole ONK-EH3 will be cleared of any loose rock and covered with a layer of sprayed concrete in order to perform a test for investigating the thermal spalling resistance of sprayed concrete. The concrete-sprayed surface of the investigation hole has a shape similar to that of a concrete-sprayed shaft, and this will produce relevant research information regarding the behaviour of sprayed concrete in an increasing stress field. This information will be used for planning the reinforcement of repository facilities and shafts. The ageing process of other materials used for the construction work (such as bolts and wire meshes) will also be monitored in ONKALO.

One factor affecting the dimensioning of central tunnels and vehicle access routes of the disposal facility is the space required for the structures located in the tunnel network. The structural strength of the ventilation channels and electrical installations, and consequently also the space required for them, is affected by the requirement that they must withstand the pressure loads caused by excavation blasting. It is foreseen that the excavation of facilities and the disposal operations will take place simultaneously in the disposal facility. Since the tunnels are excavated using the drill and blast method, the explosions will cause pressure impacts on the existing facilities and the structures contained in them. Individual explosion pressure measurements have been performed in ONKALO. The efficiency of methods for dampening the pressure impacts caused by explosions, or the pressure impacts caused by excavation of tunnels similar to the deposition tunnel, have not been investigated before. The investigation will look for ways to reduce the pressure loads exerted on different surfaces and for ways to make the structures lighter.

6.4.4.3 Development of construction equipment

The underground production (final disposal) requires equipment for research (personnel lifts, drilling equipment), for production (drilling, blasting, removal of quarried rock, grouting and reinforcement of the bedrock, possible levelling of the floor) and for final disposal (removal of tunnel reinforcement, different disposal machines. In preparation of the implementation, the required equipment and their numbers, their requirements and the development needs for any special equipment required must be determined during the next programme period. According to the reference design, the disposal facility will be implemented using the drill and blast (D&B) method, for which equipment is available on the market. Development work will still be required for some special machines, including the device for removing tunnel reinforcements and the boring rig for deposition holes.

The development work for other disposal equipment apart from that intended for machining the bedrock is described in section 6.4.5. When required, the production techniques will be developed while monitoring the development of other techniques and equipment, such as those intended for rough grinding hard rock. The development of tunnel boring machines (TBMs) around the world will also be monitored.

Prototype rig Sanna (Figure 6-12) was used to produce deposition holes in the demonstration tunnels. Posiva must have a device produced, tested and approved for boring the deposition holes for the joint operating test, which is why the design and implementation work for the production machine will commence during the coming programme period. The methods for finishing the bottom of deposition holes are being developed. The solution may either be the introduction of a new work phase and adding a rock machining implement to the deposition hole boring rig, or the development of a separate levelling machine.

Figure 6-12. *Prototype rig Sanna for boring test depostion holes.*

6.4.5 Installation and transfer techniques

6.4.5.1 Canister lift

Implementation plans will be produced for the canister lift during the coming programme period. The design work for the shock absorber to be placed at the bottom of the canister shaft will continue on the basis of the results of the small-scale tests conducted. Further investigations will be performed regarding the shock absorber material in order to specify the optimal material. As a result of these investigations, the shock absorber material will be determined and the dimensions of the shock absorber fixed for its construction design work.

6.4.5.2 Canister transfer and installation device

The installation tests using the prototype of a canister transfer and installation device will begin during the coming programme period in 2013–2015. Initially, the tests will be conducted above ground. When the operability of the device has been verified in the tests above ground, it will be taken to the demonstration tunnel of ONKALO for installation tests in actual disposal conditions. These tests will concentrate on the operation of the canister handling devices and on the installation of a canister in a deposition hole lined with bentonite buffer material, among other things for the purpose of verifying the sufficiency of installation tolerances.

The second phase of the installation device will also be designed and implemented during the programme period. It will concentrate, amongst other things, on finalising the undercarriage solution for the device and on planning the final transfer solutions for the device. In addition, the development subjects detected in the tests during the first prototype phase will be taken into account. The results of prototype tests will be taken into account when producing the construction plan for the final installation device.

6.4.5.3 Buffer installation device

The prototype of the buffer installation device will be initially tested above ground. When the operability of the device has been verified, the tests will continue in the demonstration tunnel of ONKALO. The tests will be conducted in order to verify the feasibility of the device design and to provide a good idea of the sufficiency of installation tolerances. Different transient situations and overcoming them will also be tested. Once the tests have been conducted, conclusions will be drawn regarding any areas for development in the installation device, and the final construction plan will be produced for the device on their basis. Buffer development work is described in greater detail in section 5.4.1.2.

6.4.5.4 Backfill installation device

The design work for the backfill installation device prototype began in 2012, and it will continue during the coming programme period so that manufacture of the prototype could begin in 2013. The device will be tested towards the end of the programme period. The initial tests will be conducted above ground, while further testing will take place in the demonstration tunnel of ONKALO. In connection with designing the prototype, the entire backfill operation will be revised on a principal level in order to ensure that the backfill operation can be performed quickly enough and any bottlenecks in the process identified. In this connection, the logistics of backfill material from above ground to the deposition tunnel will also be planned. The results of prototype tests will be taken into account when designing the final installation device. Backfill development work is described in greater detail in section 5.4.1.3.

6.5 Joint operating test underground

The purpose of the joint operating test performed underground is to test and verify the overall operability of the disposal facility in the conditions prevailing at the disposal depth. The preliminary commissioning plan to be supplied together with the construction licence application to be submitted in 2012 will also present the principles of the joint operating test.

Partial tests of the disposal system will be implemented in the demonstration tunnels of ONKALO during the next few years. The detailed operation of machines, devices and work methods will be verified in these tests. At this stage, the partial tests do not constitute a continuum from one disposal system phase to the next. For this purpose, a joint operating test of machines, equipment and methods related to final disposal will be carried out for analysing the compatibility of methods approved in the partial tests. The purpose is to verify the seamless compatibility of all the key systems in the conditions prevailing in ONKALO. The joint operating tests will be conducted separately for the encapsulation plant and for the disposal facility. The transfer of the disposal canister to the deposition tunnel on the transport vehicle is considered to be the interface between the two. The joint operating tests are part of the construction operations for the encapsulation plant and disposal facility. The related procedures are described in YVL Guide A.5.

When Posiva applies for the operating licence, the machines, equipment, methods and component manufacturing processes to be used in disposal operations must be ready. In this context, the joint operation must also have been verified. The joint operating tests of the systems and the plant will be conducted on the basis of separate trial operation plans even before submitting the operating licence application, provided that the administrative and technical capabilities for trial operation exist. The nuclear trial operation can only be performed on the basis of the trial operation permit probably granted on the basis of the operating licence application.

The joint operating test performed underground will consist of the following three phases (Figure 6-13):

1. Selection of the test location with the associated suitability assessment as well as implementation planning and the approval of authorities.

2. Implementation of the required excavation and drilling operations, equipping the test location and procurement of the devices and materials to be used (including the disposal system components, instrumentation as well as monitoring and quality assurance tools).

3. Implementation of the joint operating test. Quality management, monitoring and regulatory oversight will also be taken into account for this phase.

The purpose of this work is to perform the disposal-related operations in the order to be used for actual disposal. The need for long-term monitoring will be analysed at different stages of planning, and such monitoring will be planned on the basis of requirements and needs to be separately established. If all devices or components have not been dealt with in partial tests with authorities, this will be done in the joint operating tests.

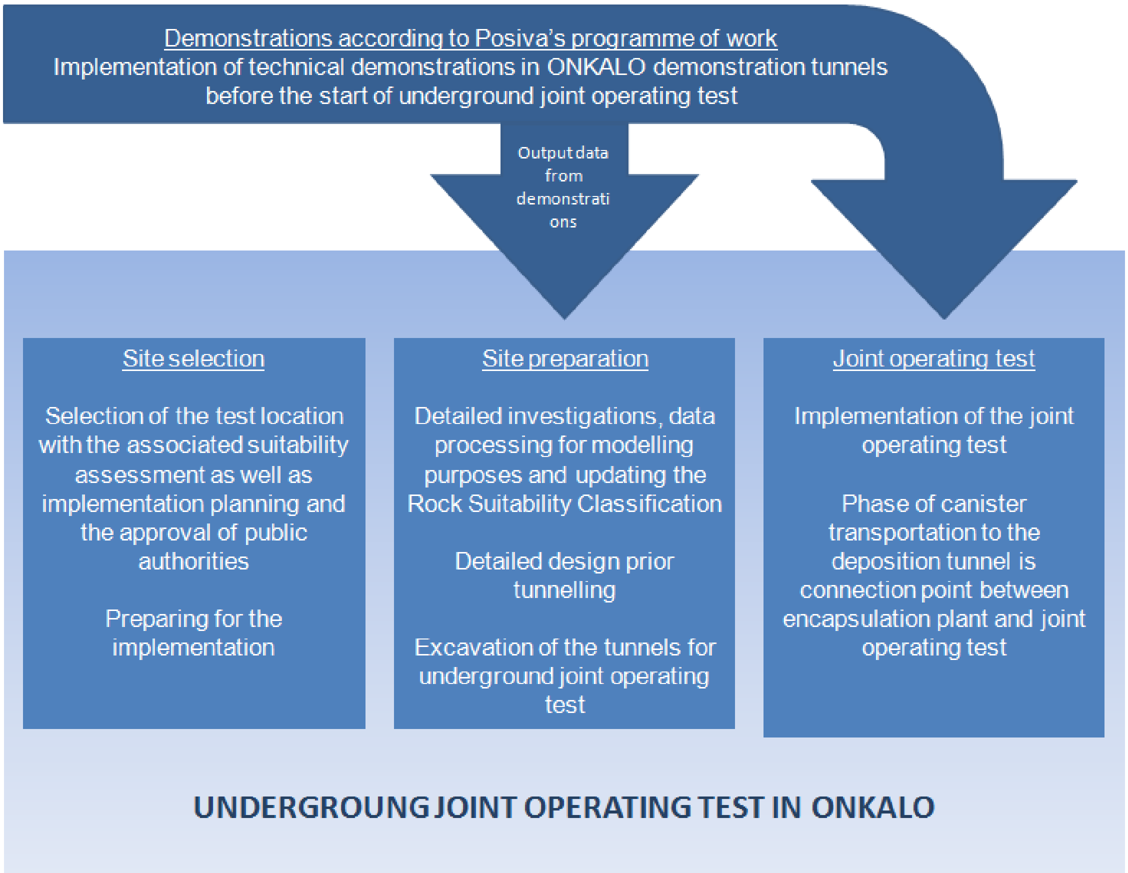

Figure 6-13. *The preliminary framework for preparing and implementing the joint operating test, linked with the implementation of excavation work for ONKALO and the work performed in demonstrations. Individual tests may be continued while the joint operating test is being constructed.*

6.5.1 Selection of the test location

The location for the joint operation test will be selected on the basis of available research information (section 5.3.1). In this connection, the scope of modelling work will be taken into account. The current small-scale model covers the demonstration area of ONKALO, its technical rooms and the area of the first disposal panel (section 5.3.2.4). If required, the small-scale modelling will be extended. When selecting the location, the rock suitability classification method will be applied (section 5.3.2) to determine the bedrock area suitable for the joint operating test. The test location in ONKALO may either be on the eastern side of the current demonstration tunnels or in the area of the first disposal panel, preferably so that the area can be accessed as early as possible. When selecting the location, the requirements of disposal operations and the restrictions imposed by it as well as the need for long-term monitoring of the location will be taken into account.

At the final stage of the location selection progress the work will first concentrate on rock suitability classification and then on planning the implementation phase. The data from site investigations and modelling work will be used as the initial data for implementation planning so that all required information is available. Preparations will be done at this stage for, among other things, applying the Observational Method in connection with constructing the test tunnel for the joint operating test.

6.5.2 Design and construction of the undergrouns openings

The joint operating test tunnel will be implemented in compliance with the requirements applicable to actual deposition tunnels. The requirements and the space required for implementing the entire complex will be specified during the early phases of the design work. The specification work will take into account, among other things, the number of deposition holes as well as the amount of reinforcement and grouting work required. The tunnel excavation and quality assurance procedures will be available at this stage.

The other factors to be taken into account during the design work include the possibility for retrieving the installed components, long-term monitoring and possible gradual dismantling of the test.

6.5.3 Procurement and component manufacture

The manufacture of components and equipment will be implemented on the basis of results from the research, development and testing programme for the engineered barrier system (section 5.4). Procurement operations will be implemented in the manner described in section 6.6.

6.5.4 Joint operating test

The purpose of the joint operating test is to perform the disposal-related operations in the order to be used for actual disposal. The goal is to complete the tests on different components before starting the joint operating test. During the partial tests, the operability of methods in disposal-level conditions will be ensured and preparations will be made for implementing the entire complex.

Attention will be paid, among other things, to the occupational and long-term safety of the implementation, quality management, implementation of monitoring, as well as to licensing and regulatory supervision. The later monitoring of the KBS-3V solution to be appended to the joint operating test, as well as any other collection of information will be planned during the programme period and presented in the nuclear waste management programme to be produced in 2015.

6.6 Procurement of canisters and clay components

The disposal canister, buffer and backfill solution components can alternatively be purchased from external sources by concluding the necessary supply agreements, or they can be produced in-house, possibly with a partner. The planning work for these procurement operations will begin during the programme period now commencing. The goal is to make the related decisions in the next few years and to develop the required procedures and production methods.

6.6.1 Procurement of canister components and canisters

A cost and risk management analysis regarding the procurement of canisters has been performed jointly with SKB. The analysis shows that the most economical solution would be to establish a joint venture plant. The plant would machine and inspect the semi-finished canister components procured from suppliers, weld a bottom to the copper tube when required and install the insert inside the copper canister. Since the analysis was performed, the starting date for disposal operations in Sweden has been postponed until about five years later than the starting date in Finland. SKB has also announced, in connection with choosing the disposal site, that it will build a canister assembly plant in Oskarshamn. The planned starting date of the plant is currently such that Posiva cannot rely on this plant due to its own target schedule. Therefore, the procurement method investigation regarding canisters will be updated during the coming programme period, and the updated version will be used as the basis for identifying the potential canister suppliers. The method that Posiva will use for procuring canisters will be decided using a schedule that ensures there will be enough time to complete the required preparations irrespective of the solution chosen for canister production.

According to the current plan, the canister components required during the first few years of disposal operations will be procured as finished canister components, machined to their final dimensions: copper canisters with bottoms, copper lids, cast iron inserts and steel lids. When the disposal operations start in Sweden, it may become possible to procure canister components from the canister factory to be built in Oskarshamn, Sweden.

According to section 609 of STUK's draft YVL Guide D.5 *"The licence holder shall have adequate control procedures for the fabrication of such components needed in the operation of the disposal facility (e.e. buffer and backfill blocks, disposal containers) which will be made in an external fabrication facility. If the safety class of such components is 3 or higher, licence holder shall qualify the manufacturing method and organisation of the component.*

The canister insert, insert lid, copper overpack and copper lid have been preliminarily classified as safety class 2 components. The manufacturing methods of canister components will be qualified when the supplier manufactures a pilot series. For the validation, a description of each canister component manufacturing process will be produced, the parameters important for the properties of the end product will be determined, and the control methods for these parameters, the component identification and documentation procedure as well as the manufacturer's quality system will all be described.

For the purpose of preliminary preparations for canister procurement, supervision of manufacture and validation, a description has been produced of the canister production chain, i.e., a production line report, which includes a preliminary description of the organisation related to canister manufacture, the supervisory procedures, component specifications and drawings. The instructions and procedural descriptions will be supplemented as the development work progresses so that the quality control programme for canister manufacture will be available for use in the manufacturing methods validation process described above.

During the first planned three-year period in 2013–2015, canister components will be manufactured in pilot series with the objective of using them to qualify the manufacturing methods. The work will continue during the latter three-year period, when the pilot series manufacture of canister components will be a part of the joint operating test of the encapsulation plant, performed for the purpose of demonstrating the feasibility of disposal.

6.6.2 Procurement of clay materials and clay components

An investigation similar to that conducted for the canister has not been performed for buffer components. Therefore an investigation will be performed for the purpose of selecting the production method for buffer components. This investigation will cover the manufacturing costs, risks, availability, personnel requirements, transportation and storage regarding buffer components, as well as the location of the production plant, if in-house production is chosen. Construction of the production plant and the installation of equipment or the operational readiness of an existing plant will be timed so that the trial operation of the plant production tests and licensing of the manufacture can take place in good time before commencing the disposal operations.

The manufacture of buffer blocks by an external manufacturer will be tested during the first three-year period. Pilot manufacture will be started during the second three-year period, either by an external suppler or by Posiva, which may procure its own manufacturing equipment, if necessary.

The final material specifications will be determined during the programme period to allow the selection of the initial raw material suppliers for the buffer and backfill solutions. Raw materials compliant with the final specification will be required for the joint operating test.

The preliminary safety classification of the buffer is SC 3, which is why its manufacturing method must be qualified. The validation will be performed in connection with pilot manufacture. The validation will follow the same process and schedule as the validation of canister component manufacturing methods. For the validation, a description of the manufacturing process will be produced, the parameters important for the properties of the end product will be determined, and the control methods for these parameters, the material identification and documentation procedure as well as the manufacturer's quality system will all be described.

The safety importance of the deposition tunnel backfill solution is estimated to be smaller than that of the buffer, and its nuclear safety class is currently EYT. Even if different manufacturing methods were used for backfill blocks and buffer blocks, it pays to investigate their manufacturing methods at the same time.

In principle, the procurement strategy for backfill components follows the same lines as that for buffer blocks. During the first three-year period, the backfill blocks will be procured from an external supplier, whose equipment will also be used for manufacturing tests. During the latter three-year period, the manufacture of backfill components advances to the trial operation phase. For that, a decision will have to be taken on whether the blocks will still be procured from an external supplier, or will Posiva procure its own production plant for the blocks.

According to current plans, the backfill components related to the closure of repository facilities other than the deposition tunnels will be manufactured at the same plants as the backfill components for deposition tunnels. These components will not be required for many decades, which is why no specific plans will be produced at this stage regarding their production plant.

6.7 Transports of spent nuclear fuel

The intention is to start the transports of spent nuclear fuel in Finland around 2020 when the final disposal operations begin.

Preliminary investigations were performed during the previous three-year period (2009–2012) regarding potential suppliers of transport casks for spent nuclear fuel and regarding the possibilities for implementing the transports in practice. Also the risk analysis for spent nuclear fuel transportation was updated (Suolanen & Rossi 2012).

6.7.1 Transport casks

Spent fuel will be transported from the interim storages to the encapsulation plant in purpose-built transport casks. A type B transport cask will be procured for transporting the fuel from Loviisa NPP. For the fuel from Olkiluoto NPP, Posiva will either procure its own type B cask or use TVO's cask, if possible. According to the current plans, one cask is required for moving the spent fuel from Olkiluoto NPP. One or more transport casks will be procured for transporting fuel from Loviisa, depending on the selected mode of transport (road, railroad or sea transport).

The decision will be taken during 2013 whether gas- or water-filled casks will be used for transporting the fuel from the Loviisa and Olkiluoto NPPs. The same solution will not necessarily have to be used for both types of fuel. The solution chosen for filling the cask may have a significant impact on the timing of its procurement. Before taking this decision, the impacts of the cask filling solution on the interim storages, the encapsulation plant and their systems will be investigated.

The casks suitable for the fuel types to be transported, available from the selected suppliers, will be investigated during the coming three-year period 2013–2015. If no suitable, licensed casks can be found, the cask procurement process must be initiated in 2013 at the latest if the target schedule of "around 2020" is to be adhered to. In that case, the period 2013–2015 will involve cask design work, safety analyses and licensing as well as possible additional investigations and tests related to them. The licensing process will continue and cask manufacture will begin during the period 2016–2018.

If a suitable, already designed and licensed cask for fuel is found from the manufacturers, the procurement process will mainly take place during 2016–2018, because such a cask will have a shorter delivery time, and having an already licensed cask approved in Finland will be less time-consuming.

6.7.2 Planning the transports

A separate licence will be required for the transports of spent fuel. According to draft YVL Guide D.2, the transport licence application must be submitted to STUK three months before the first transport. If required, preparations for the investigations related to the transport licence application will begin in 2018.

Transports of spent fuel from the Loviisa power plant

The fuel from Loviisa will be transported to the encapsulation plant in Olkiluoto either as a road, railroad or sea transport. The transports may also take place as combinations of different modes of transport.

Posiva intends to select the mode of transport for the fuel from Loviisa and obtain the approval for it from STUK in 2016. During 2013–2015, before obtaining the approval for the mode of transport, an investigation will be performed regarding different modes of transport and transport routes as well as the required equipment and its procurement. At the same time, the risk assessments regarding transports, i.e., the assessments regarding their environmental impacts and accident risks, will be updated. The above mentioned investigations will be used as initial data for obtaining the approval for the mode of transport.

The space required for the spent fuel transports and other factors, such as the condition of the respective transport routes in Olkiluoto, will be taken into account in area planning.

During 2016–2018, procurement of the required systems, vehicles, etc., will begin, or agreements will be concluded regarding their use in line with the selected mode of transport.

Transfers of spent fuel from the Olkiluoto power plant

The spent fuel from the Olkiluoto NPP will be transferred from the interim storage by road to the encapsulation plant located some two kilometres away. During the period 2013–2015, the road sections from the power plant site to the encapsulation plant, their state of repair and possibilities for their use will be investigated. The condition of the routes will be subjected to closer scrutiny during 2016–2018, and road improvement work will be planned and started, as required. In connection with assessing the routes during the period 2016–2018, the risks associated with the fuel transfers in Olkiluoto will also be assessed.

The need for a fuel transfer vehicle and a trailer to be connected to it will be analysed during the period 2016–2018. A vehicle owned by TVO can possibly be used for the transfers. However, if a separate vehicle has to be procured for the transfers, its design and procurement work will begin during the period 2016–2018.

6.8 Development of operations

6.8.1 Development of the safety culture and management system

Posiva is committed to a culture of absolute adherence to a high standard of safety and observance of safety in all its operations so that it always takes precedence over financial aspects in all activities. The safety culture includes nuclear safety, radiation safety, corporate security and personnel safety. Every Posiva employee knows the safety implications of his/her work and is responsible for his/her own actions and ensures that they comply with the instructions, requirements and regulations and are transparent.

In the coming years, the focus will be on developing procedures in order to promote the systematic handling of safety matters. Examples of the areas for development include:

- production of a safety development programme for the construction and operation of the plant complex,
- development of the technical specifications for operating activities and for integrating the operating and construction activities, and
- development of a tool for assessing the safety culture.

The procedures thus developed will be included in Posiva's operations management system.

Posiva's operations management system will ensure that the management of nuclear and radiation safety, quality, environment and corporate safety is taken into account in the company's operations. The operations management system must facilitate systematic actions for measuring and improving quality and safety. The meters guiding the operations are used to monitor the attainment of goals. They will be derived from the company's strategic plan and operations policy.

The overall performance of nuclear and radiation safety, quality management, environmental management as well as corporate security and occupational safety will be constantly improved. The improvement includes the planning, implementation, guidance, monitoring and assessment of activities as well as their development.

Posiva's operations management system is based on legislation, quality management standard ISO 9001, environmental management standard ISO 14001, occupational health and safety standard OHSAS 18001 as well as on general principles, and it takes into account STUK's YVL Guides and the standards of the International Atomic Energy Agency (IAEA), as applicable. The compliance of the operations management system with the applicable standards will be ensured by regular annual audits conducted by external auditors.

Internal audits are organised annually for developing the operations management system. They will ensure the conformity of processes and seek to develop their performance. The operational experience feedback activities based on deviations and other observations collect and analyse information, utilising the observations in a versatile manner.

Posiva's operations management system must fulfil the requirements set out in legislation, official regulations and permissions at all stages of operations. As Posiva's operations shift from the current research and development-oriented approach to implementation with the construction licence for the nuclear waste facilities, the operations management system must be developed to reflect the changed requirements and organisation. Later on, the focus of operations will shift to preparations for the operating phase, and this will pose its own demands for the operations management system.

6.8.2 Quality of construction work

General principles of quality management for construction work

The quality of the future construction work of nuclear facilities will be managed by acting in compliance with the guidelines of Posiva's operations management system. The key principles, objectives and procedures of quality management are described in the operational and organisational manuals as well as in the description of the quality management process. The general descriptions in the operational and organisational manuals have been specified further, and their contents have been supplemented with instructions becoming more specific from top to bottom. The instructions range from those concerning Posiva's administration to those describing the research activities and implementation procedures for construction work and to detailed work- and research task-specific method descriptions and work instructions. Availability of the instructions has been ensured by saving them in Posiva's electronic document management system.

Posiva has been preparing for the construction of the disposal facility and buildings above ground since 2004 by constructing the underground research facility ONKALO and the buildings above ground supporting it. Finnish legislation, official regulations and the applicable plans have been observed in the construction work. Posiva has supervised the construction of ONKALO and the buildings above ground supporting it in keeping with the applicable instructions and plans. STUK has supervised the construction of ONKALO and the buildings above ground supporting it by applying procedures compliant with separately agreed YVL Guides. The purpose of the regulatory supervision (by STUK) of the construction of ONKALO and the buildings above ground supporting it has been to ensure that the subject bedrock facilities, systems and buildings can be integrated with Posiva's nuclear facilities, the disposal facility and the encapsulation plant, at the construction licence or operating licence phase of the nuclear facilities to be later separately agreed upon.

During 2013–2015, when Posiva's construction licence application for nuclear facilities is being processed, ONKALO and the buildings above ground supporting it will be constructed to the extent possible before obtaining the construction licence. The quality management procedures used during previous construction operations will be adhered to in the construction work, and these procedures will be extended, as required, to cover new construction complexes, systems and equipment.

Quality assurance

Posiva will appoint a quality assurance organisation, independent of the organisation implementing the construction work, to ensure that the construction work is implemented in compliance with the procedures and instructions of Posiva's operations management system and the technical and operational requirements set and that the end product complies with the plans. The working methods of quality assurance regarding the construction of Posiva's nuclear facilities include supervision and guidance of work processes, inspection and approval of plans and other documents, internal and external audits, as well as participation in the operations of and cooperation with authorities. Another purpose of quality assurance is to ensure that the aspects of nuclear safety have been taken into account and sufficiently analysed in all areas of construction work.

Supervision of design and construction work

Posiva's plant design and implementation planning processes produce the technical plans used in construction work. The design basis, requirements and technical solutions used in plant design and implementation planning are based on the long-term research and development activities performed by Posiva and its partners, such as SKB. The plant design and implementation planning processes include the procedures and reviews where Posiva satisfies itself that each plan is acceptable from the nuclear safety point of view. The organisation, duties and instructions regarding Posiva's plant design and implementation planning are described in the planning manual.

In order to handle the quality control tasks of construction assignments, Posiva will produce a quality control plan suitable for the implementation and delivery method of the subject assignment, presenting Posiva's quality control organisation and Posiva's quality control procedures and tasks as well as the persons responsible for them. In practice, the quality control of construction work will be performed by Posiva's own employees in the course of the construction process, as well as by TVO's employees within the framework of the Olkiluoto infrastructure agreement concluded with TVO. When required, more QC personnel will be recruited for quality control work. Irrespective of the method of implementation, a sufficient number of internal project, implementation phase and work phase inspections and reviews will be organised in the course of implementation. Their purpose is to ensure the fulfilment of targets regarding quality, schedules and economy. A separate review plan will be produced for the inspections and reviews on an implementation method- and implementation complex-specific basis.

The requirements necessitating the quality control, inspections and tests during construction as well as the other activities guiding implementation are described in the system-, structure- and equipment-specific implementation plans. The supervision, inspection and testing plans as well as the inspection, testing and supervision lists of work type-specific method descriptions will be produced on the basis of the implementation plans.

For each assignment, the party implementing the work, the design company, the contractor and the individual performing the work will produce a written method description or working plan where the party implementing the work describes the procedures and the organisation that will provide Posiva with the product and performance compliant with the plans and the agreement. The party implementing the assignment shall also produce a plan for the quality control measures during work as required by the technical plans and work plans. The party implementing the assignment shall operate in compliance with the plans and demonstrate the conformity of its operations and product with the work records and quality control documents it produces.

Development of quality management

In connection with producing the construction licence application, Posiva defined, in compliance with section 4 of Government Decree 733/2008, the safety functions of the disposal facility and the encapsulation plant and classified their associated systems, structures and equipment on the basis of their respective safety significance. Posiva will produce the following documents to be used as the basis for classification: a list of systems in the disposal facility and the encapsulation plant, system descriptions as well as lists of structures and devices of the systems with important safety functions. On their basis, Posiva will produce a proposal for the classification document of its nuclear facilities to be submitted to STUK in connection with the construction licence application.

In order to implement the connection between safety classification and quality, Posiva will during the coming programme period in 2013–2015 specify the quality management principles and standards for each safety class shown in the classification document. They will be observed in the design, manufacture, installation, operation and inspections of safety classified objects. At the same time, Posiva will specify the design, manufacture, installation and operation of the systems, structures and equipment important for the safety of the nuclear plants so that their quality level and the assessments, inspections and tests required for verifying their quality level (including their environmental qualification) will be commensurate with their safety significance. Instructions will be issued for the measures related to achieving and verifying the quality level, and these instructions will be included, as manuals or other suitable packages, in Posiva's operations management system.

Selection of suppliers and quality management of the supply chain

The selection of suppliers and quality management of the supply chain are a significant part of the quality management of construction activities. The procurement and selection of supplier's for Posiva's construction work have been done in keeping with the general procurement and supplier selection procedures included in Posiva's operations management system. When preparing for the construction and operation of Posiva's nuclear facilities during the coming programme period 2013–2015, the supplier selection process will be developed by specifying further the requirements regarding suppliers and by harmonising the procedures for verifying the fulfilment of these requirements. A supply and supplier classification method based on the significance of the supply in terms of safety, economy, schedule and other factors, together with methods for verifying the requirements set for suppliers, will be created for the supplier selection process. The procedure will be introduced to all of Posiva's procurement and supplier selection activities. The requirements regarding suppliers will be extended contractually to all suppliers in the supply chain.

6.8.3 The environment and occupational safety

Posiva maintains a certified environmental management system. It is important to regularly asses the environmental impacts of operations and to use these impacts as the basis for producing and implementing an annual environmental programme in order to mitigate the harmful environmental impacts of operations.

The environmental permit for dumping the quarried material produced when constructing ONKALO will expire in 2015. The dumping of quarried material generated during the construction and operation related to final disposal must be planned and a permit for it obtained, as required, during 2013. This also applies to the excavation of foundations for the encapsulation plant and raise boring of the canister shaft.

The waste management of the disposal facility during construction must be planned during 2014 before commencing the construction work. Likewise, the waste management of the encapsulation plant construction and other construction work above ground must be planned before commencing the construction work. The monitoring of environmental aspects during construction and operation is described in the Olkiluoto monitoring programme. Any other aspects to be followed will be presented separately in the environmental action plan.

Posiva maintains and develops a certified management system for occupational safety and health. A particular area for development is the holistic development of safety culture during the construction phase in cooperation with key suppliers. The safety organisation must actively participate in the design and implementation of final disposal so that the occupational safety aspects are sufficiently taken into account.

6.8.4 Nuclear and radiation safety

The projects concerning nuclear and radiation safety will continue during 2013–2018. These include the investigations regarding radiation protection of the personnel, i.e., specifications of the general principles of radiation protection in nuclear facilities, the construction aspects of the plant related to radiation protection of the personnel, the radiation doses received by the personnel during normal operating conditions of the plant and in certain generic operational transient and accident situations. The following documents will also be updated for the operating licence application: the reports regarding protection of the environment, population and fauna around the nuclear facility, including the reports of emissions from the nuclear facility and the radiation exposure of the population under normal operating conditions and during operational transients and accidents, as well as the reports regarding the release routes of radioactive materials and their radiation and release monitoring.

The design work for radiation measurement systems in compliance with the life cycle model, as well as the assessment of the system descriptions of the plant's other structures, systems and equipment from the point of view of radiation protection will also continue in 2013–2018 so that the final system descriptions are completed by the time the operating licence application is submitted in 2018. The probabilistic risk analysis describing the operation of the systems as well as the classification document covering the safety classes of structures, equipment and systems will be updated to correspond to the final system descriptions of the nuclear facility.

Several other projects will also be initiated during the coming programme period. Some of these are listed as plans in the construction licence application. In connection with its construction licence application, Posiva will submit its plans for the investigation of the basic state of the environment as well as for the meteorological measurement system and its related measurements. The initiation of investigations regarding the basic state of environment and the meteorological measurements according to the plans will be taken care of at the latest when the construction of the nuclear facility starts so that the status of the environment around the nuclear facility can be assessed before starting its operation. The basic state investigation will also constitute the basis for the environmental radiation monitoring programme, for which a plan will be submitted for approval in connection with the operating licence application. During 2013–2018, Posiva will ensure that the descriptions regarding the meteorological measurement system and the information on the meteorological conditions at the plant site will be sent for assessment in connection with submitting the operating licence application.

In connection with the construction licence application, Posiva presented its plans regarding the tests to be conducted for the purpose of demonstrating the performance of the release measurement system of the encapsulation plant and disposal facility, including the representativeness of sampling. During the coming programme period, Posiva will ensure that these tests and analyses are conducted and their results are reported in the operating licence application. The definition of technical specifications, particularly regarding the release limits of the nuclear facility, will be included in the operating licence application.

6.8.5 Security arrangements

The purpose of security arrangements for Posiva's plants is to ensure that the safety of the nuclear facility and the nuclear waste processed at it is not compromised as a result of unlawful action. The security arrangements consist of structural and technical systems and administrative measures, and they cover the research phase now in progress, the construction phase and the operating phase of the disposal facility until its closure.

6.8.5.1 The bases of security arrangements

The obligations regarding security arrangements in the use of nuclear energy are presented in the Nuclear Energy Act (880/1987), the Nuclear Energy Decree (161/1988) and in the Government Decree concerning security arrangements in the use of nuclear energy (734/2008). YVL Guide 6.11 concerning the security arrangements in nuclear power plants is only intended to be applied to NPPs. It and YVL Guide 6.21 concerning the security arrangements for transports of nuclear fuel are both in the process of being revised, and the requirements included in the new guides will be taken into account to the extent that the status of the guide review process allows.

The security arrangements in Posiva's plants will be designed compliant with the said regulations and described in the preliminary security arrangement plan, referred to in section 35 of the Nuclear Energy Act and submitted to STUK in connection with submitting the construction licence application. The plan will take into account, at a principal level, the transports of fuel from the nuclear power plants to the encapsulation plant. The material is subject to the obligation of secrecy prescribed in section 78 of the Nuclear Energy Act.

The legislation defines the security means as the measures needed to protect the use of nuclear energy against unlawful action in the nuclear facility, its precincts, other places or vehicles where nuclear energy is used. In turn, unlawful action shall refer to a deliberate activity or measure aimed at endangering the safety of a nuclear power plant or the integrity of nuclear material or nuclear waste, or posing some other kind of direct or indirect threat to nuclear or radiation safety, or the other negligent infliction of damage on a nuclear facility, nuclear material or nuclear waste. Threat shall refer to a situation during which unlawful action against a nuclear power plant, nuclear material or nuclear waste is ascertained, or reason to suspect such is found.

According to section 7 of the Nuclear Energy Act, sufficient physical protection and emergency planning as well as other arrangements for limiting nuclear damage and for protecting nuclear energy against illegal activities shall be a prerequisite for the use of nuclear energy. According to section 3 of the Government Decree on the Security in the Use of Nuclear Energy, the design of security shall be based on risk analyses of the activity to be secured, and protection requirements assessed on the basis thereof.

Security shall be consistent with the operation, fire safety and emergency response arrangements for nuclear energy. Furthermore, security shall be consistent with the rescue service, emergency and special situational plans drawn up by the authorities.

Posiva will submit to STUK the preliminary security arrangement plan referred to in section 35 of the Nuclear Energy Decree in connection with the construction licence application and the final security arrangement plan referred to in section 36 of the Nuclear Energy Decree in connection with the operating licence application. Posiva's security arrangements will be supported by TVO's security arrangements, and TVO will be responsible for the security arrangements in the areas outside ONKALO.

6.8.5.2 Period of processing the construction licence application, 2013–2014

While the construction licence application is being processed in 2013–2014, Posiva will make preparations for the construction work and start implementing the security arrangements presented in the preliminary security arrangement plan. The security arrangements include building up the security arrangements for the encapsulation plant and disposal facility construction sites so that they will form the basis for implementing the security arrangements required in the Nuclear Energy Act and the Nuclear Energy Decree during the actual construction phase of the nuclear facility. The arrangements created during that phase are presented later in this document, in a section describing the activities during the actual construction phase.

6.8.5.3 Construction phase 2015–2018

Once the Government has granted the construction licence, Posiva can build the encapsulation plant and first phase of the disposal facility. During these years, the capabilities for submitting the operating licence application will be created and the application documentation prepared for submission so that final disposal could begin around 2020. This application material will be appended with the final security plan referred to in section 36 of the Nuclear Energy Decree. The systems, equipment and structures compliant with the security arrangement plan will be built and tested during the construction phase.

The security arrangements for the construction phase will be implemented in keeping with the plan for the construction phase included in the preliminary security arrangement plan. If required, the plan will be updated as the construction work progresses.

The purpose of security arrangements during construction is to implement the following security-related functions:

- To detect unlawful action and initiate the countermeasures described in the preliminary security instructions.
- To prevent unlawful action intended for causing damage to life, health or property at the work site.
- To prevent unauthorised entry to the area.
- To ensure, using access control, that only authorised persons enter the area or the facilities.
- To prevent theft, acts of violence, being intoxicated (zero tolerance) and other prohibited matters at the work site (alcohol, narcotics).
- To remove any unauthorised persons from the area.
- To protect employees from accidents and damage to the extent that this is related to security arrangements.
- To prevent the creation of a hazard or inadvertent damage (explosives, inspections of lifting equipment, etc.).

People's movements at the work site are monitored, and access to the area requires identification. Working in the area requires advance security clearance and induction training for ensuring the person's eligibility and for providing him/her with the necessary information for correct and safe actions in the area. The authorisation of materials and vehicles will be checked at the gate.

During the construction phase, Posiva will produce the final plan for security arrangements and build up the planned arrangements so that they can be introduced when the plant complex is commissioned.

6.8.5.4 Analysis of operational risks

The risks associated with the final disposal of spent nuclear fuel can be analysed using the following categorisation:

- nuclear and radiation safety,
- nuclear material safeguards, and
- continuity of transient-free operation and maintenance of acceptability.

The radiation safety and radiation doses of the Olkiluoto encapsulation plant and disposal facility during normal operation, operational transients and accident situations are discussed in Chapters 8 and 9 of the preliminary safety analysis report. The results of the analysis can also be used for seeing the magnitude of the risks caused by unlawful actions in correct proportion when related to the radiation safety requirements set out in legislation.

The conclusions of the analyses can be summarised as follows: the normal operation of or the transients and analysed accidents at the encapsulation plant and disposal facility will not cause any hazard to the plant's personnel or the environment. In the context of security arrangements, this can be interpreted so that no individual deliberate action can cause a release that would have a significant impact on the safety of the environment. In addition, the simultaneous occurrences of inadvertently or deliberately created faults can also be prevented by administrative arrangements, such as inspections or operating tests. The use of explosives required for further construction of the disposal facility must be prevented in the facilities where fuel is handled or stored. This will be taken into account when storing and handling explosives in connection with the expansion of repository facilities. The requirement will also be taken into account when designing the impact resistance of the interfaces between controlled and uncontrolled areas. The area being excavated is kept physically separate from completed repository facilities. The phasing of work and observance of safety issues will be guided with administrative arrangements, such as the Technical Specifications.

6.8.5.5 Safety of spent fuel transports

Pursuant to the Nuclear Energy Act, the transports of nuclear waste are subject to a licencing procedure that is separate from that applicable to the encapsulation plant and disposal facility. The safety principles of transports are also described in the safety analysis reports (PSAR/FSAR) of the encapsulation plant and disposal facility.

The security arrangements of transports will be implemented in compliance with the valid regulations and presented in the relevant security plan. Posiva has investigated alternative modes of transport as well as the implementation methods and routes and their associated risks (Suolanen & Rossi 2012). In the above reports, the analyses will also be performed from the perspective of security arrangements. The investigations carried out cover all applicable modes of transport, i.e., road, sea and railroad transports. The decision regarding the mode of transport and the associated technical solutions will be taken by 2016.

The transport preparations will be implemented in compliance with the valid requirements and presented in the emergency arrangement plan to be appended to the transport plan.

The conducted investigations indicate that even in the worst case scenario, the fuel transports will only require protection against radiation in the immediate vicinity of the transport cask. Therefore the transports will not cause any hazards to other people using the same route or living alongside it, or to the environment.

6.8.6 Emergency arrangements

According to section 6 of Government Decree 735/2008, "the preliminary emergency plan, as referred to in section 35 subsection 1 point 5 of the Nuclear Energy Decree (161/1988), and the emergency plan as referred to in section 36 subsection 1 point 7 of the aforementioned Decree, and any amendments thereto, must be submitted to the Radiation and Nuclear Safety Authority (STUK) for approval. The emergency plan forms part of the rescue plan as referred to in section 9 subsection 2 of the Rescue Act."

The purpose of Posiva's emergency response arrangements is to prepare for the limitation of radiation accidents (and their consequences) possibly threatening the personnel of the encapsulation plant and disposal facility, its surrounding environment and the facility itself. The emergency response arrangements will be planned and implemented for the purpose of guiding actions in emergency response situations so that the actions expected of Posiva are implemented.

The operational capabilities to be maintained for the eventuality of emergency response situations include the following:
- provision of status reports on emergency response measures,
- formation and maintenance of a picture of the situation on the basis of analyses and measured data,
- participation in rescue and fire-fighting activities in the plant area,
- warning the population in the plant's vicinity (0–5 km) when required,
- participation in radiation measurement work in the plant area and its vicinity,
- provision of information, action recommendations and other expert assistance as the accident develops, and
- implementation of a temporary evacuation from the plant area with the support of the rescue organisation, when required.

The planned capabilities will be achieved and maintained with basic and further training, emergency response exercises and briefing.

The needs of emergency response arrangements will already be taken into account when designing the disposal facilities, their radiation measurement systems and communication systems, as well as when determining the necessary release and spread estimates. According to YVL Guide C.5, the emergency response arrangements shall be commensurate with the encapsulation and disposal operations as required by the hazard caused by a possible nuclear accident. In a manner analogous to nuclear power plants, where the design bases for emergency response arrangements include so-called serious accidents where the reactor core has become damaged and a significant release may occur, the emergency response arrangements of the encapsulation plant and disposal facility are designed on the basis of the activity content of the fuel being processed and a situation where several systems have failed. If the arrangements were based on the design basis accidents (DBAs) chosen in the accident analyses, the preparations and emergency response arrangements would at their most extensive only apply to the personnel participating in the final disposal of fuel.

The emergency response planning is limited to the operating phase of the plant. During the construction phase of the encapsulation plant and disposal facility in 2015–2018, the emergency response organisation will be appointed and trained, and the facilities and systems required for emergency response activities will be built.

The encapsulation plant and disposal facility is located in the immediate vicinity of TVO's nuclear power station. This will, for example, allow looking after the obligations related to preparedness, such as emergency response arrangements, fire protection and security arrangements, in cooperation with TVO. For emergency response arrangements, this means the utilisation of TVO's existing resources and infrastructure, including the monitoring and measurement systems, training, exercises and technical monitoring.

6.8.7 Nuclear material safeguards

The nuclear non-proliferation control implemented during the construction of ONKALO has created the basis for future nuclear material safeguards. During the construction phase of the disposal facility, the current monitoring and verification system of the excavations will form part of the new system. The other part of the system is the development of control systems for the actual nuclear material and its transport routes.

6.8.7.1 Requirements set by authorities

The requirements set by authorities regarding the geological disposal of spent fuel are still being developed. This section contains a compilation of important requirements contained in the YVL Guide regarding nuclear material safeguards currently being revised and in the relevant Regulation of the European Commission.

According to draft YVL Guide D.1, the organisation of nuclear material safeguards must be taken into account when designing, constructing and operating a nuclear waste facilities and in particular its underground facilities. The transport routes, buffer stores, handling processes and monitoring of nuclear material must be planned so that the continuity of information regarding the nuclear material can be ensured at all times. Control of the material flows to and from underground facilities must be possible.

The licensee must inform STUK of the plans regarding the construction of a nuclear waste facilities and report on their implementation. In addition, the licensee must see to it that there are no unreported activities relevant to the nuclear material safeguards in the disposal area (the area designated in the decision-in-principle). During the construction of the nuclear waste facilities, and particularly its underground parts, the licensee must demonstrate that the plant is being built in compliance with the information submitted.

The licensee must design the nuclear waste facilities in such a manner that the fuel elements and waste packages can be individually identified during the operation of the nuclear waste facilities. The nuclear material details of each fuel element must be verifiable using NDT methods before the fuel elements are encapsulated. The continuity of control information after verification of the fuel elements must be ensured.

According to Commission Regulation No 302/2005, each Member State who is party to the Additional Protocol must designate a site representative, who is responsible for submitting a declaration containing a general description of the site to the Commission. Any person or undertaking setting up an installation shall declare to the Commission the basic technical characteristics of the installation. On the basis of the basic technical characteristics, the Commission issues particular safeguard provisions, specifying, among other things, the material balance areas and key measurement points for determining the flow and stocks of nuclear materials. In addition, any changes to the basic technical characteristics (these must be notified in advance) and procedures for the nuclear materials accounting and reporting for each material balance area shall be notified. The safeguards regulations also specify the frequency of and procedures for physical inventory taking performed for accounting purposes as part of the nuclear material safeguards.

The undertaking shall maintain a system of accountancy and control for nuclear materials. This system shall include accounting and operating records and, in particular, information on the quantities, category, form and composition of these materials, their actual location and the particular safeguards obligations, together with details of the recipient or shipper when nuclear materials are transferred. Inventory change reports regarding nuclear materials shall be sent every month to the Commission for each material balance area. For each material balance area, material balance reports and physical inventory listing shall also be sent as soon as possible after the physical inventory taking to be performed once per every calendar year. In addition, special reports shall be submitted regarding unusual events, such as any loss or increase of nuclear material.

6.8.7.2 Posiva's plans

A nuclear material safeguards manual will be developed to include instructions for the notifications, accounting, reports and other monitoring obligations required by international safeguards. The manual will be submitted to STUK for approval, and it will be kept up to date. The nuclear material manual will be introduced at the operating licence phase preliminarily in 2018. A responsible director and his/her deputy will be appointed for the construction and operation of the facilities, and persons responsible for emergency response arrangements, security arrangements and nuclear material safeguards, respectively, will also be appointed.

The encapsulation plant and the disposal facility will either constitute one common material balance area or several areas including key measurement points, such as the reception area, handling cell, canister storages and deposition tunnels and deposition holes. The nuclear material balance of the encapsulation plant and the disposal facility can be calculated on the basis of nuclear material coming in and going out (finally disposed of). The nuclear material will be verified on the basis of identification details, quantity and possible measurement data. The balance of nuclear material taken to the disposal facility cannot be verified without bringing the canisters back to the encapsulation plant.

The initial data for nuclear material accounting is obtained from the owner companies. The identification and location details of each fuel element to be disposed of will be verified and recorded at each fuel handling and processing stage from the interim fuel storage of the NPP to the deposition hole. Up-to-date storage maps are maintained of the storage facilities.

The spent fuel will be transported to the encapsulation plant from the interim storage facilities in Loviisa and Olkiluoto. The mode of transport is yet to be decided. The security arrangements together with the requirements of nuclear material safeguards must be taken into account when planning the transports. The safeguards control may include sealing of the transport cask and inspecting it.

The identification of the fuel elements and the canisters after encapsulation will be arranged at the key measurement points. Before the assemblies are emplaced in the canisters, they are subjected to a verification measurement performed by authorities for the purpose of ensuring that the nuclear material is as reported and that the fuel assembly is intact (complete) for the purposes of nuclear material safeguards. The method of measurement and the quantity have not been decided yet. Procedures have to be developed for processing, analysing and approving the verification measurement results. Posiva must provide the required conditions for the equipment developed by authorities. In addition, Posiva will assist in the practical arrangement of measurements.

The fuel elements are identifiable at different stages of processing, such as when they are lifted out of the transport cask, at the drying station, in connection with verification measurements, when they are transferred to the canister and finally before the inner lid is closed. The identification will be based on visually reading element numbers with a camera. The canister identification number to be read with a camera will probably be engraved both on the copper lid and on the inner lid. After the copper lid has been inserted and welded, the canister can be identified using a so-called fingerprint identifier, based either on the visual, ultra sonic, eddy current or radiographic inspection of the weld. The canister's unique neutron and gamma radiation pattern can possibly also be used as its identifier. The canister identification might be required at the canister storage of the encapsulation plant, in the interim storage facility of the disposal facility and when being lowered into the deposition hole.

Cameras and radiation detection devices will be installed at the possible exit routes at the encapsulation plant and the disposal facility to ensure that no canister or other package containing nuclear material can be taken out unobserved. On the other hand, radiation detectors can be used to verify that the nuclear material was moved along the reported route to the reported place. The purpose of safeguards arranged by Posiva is to ensure that no canisters containing nuclear fuel are brought out of the encapsulation plant or the disposal facility. Monitoring of the canister's movements in the underground facilities can be made easier by utilising the borders of the radiation control area. Disposal operations and expansion work of the disposal facility will be in progress simultaneously in the underground facilities. The areas must be separated from each other by a radiation control boundary. This allows using the radiation detectors at the gates for ensuring that no canisters are moved out of the controlled disposal area. The entire disposal facility must be monitored in order to ensure that no undeclared facilities are constructed in it and that nobody intrudes from outside. A micro-seismic monitoring system is currently used for this purpose.

6.8.7.3 Construction licence processing phase

The site works above ground will continue during the licence processing phase in 2012–2014. The second phase of the ventilation and hoist building (part of the disposal facility buildings above ground) will be constructed at the same time. Preparations will be made at the underground facilities for initiating the construction of the disposal facility, and the excavation of facilities required particularly for characterising the bedrock and testing the disposal system will continue. Construction engineering and building automation work will mainly be performed at the technical rooms. During this work, the control system implemented during 2004–2012 will be constantly in operation. The preliminary, as-built and monitoring data will be reported to STUK three times a year. In addition, annual reports and action plans will be produced, together with the reports required for international control. Instructions for the control will be provided by updating the nuclear non-proliferation control manual. The requirements of nuclear material safeguards are taken into account in the design of the encapsulation plant and disposal facility (safeguards by design).

6.8.7.4 Phase preceding the operating licence

Once the construction licence has been granted, construction of the encapsulation plant begins, together with the preparatory construction and excavation phase of the disposal facility. The canister shaft, exhaust air shaft 2 (if required), the canister reception station and interim storage as well as the disposal and central tunnels with vehicle access routes required for the first disposal phase will be completed at this stage. The preliminary plan is to start this phase in 2015 so that the required facilities would be completed by 2018.

The control system used during construction will be developed further to meet the requirements, and the nuclear material accounting and reporting system of the facility complex will be developed at the same time. The safeguards system will include the nuclear materials accounting and reporting system. Instructions for the control system of the encapsulation plant and the disposal facility are provided in the nuclear material safeguards manual.

6.9 Applying for licences

Posiva will submit the construction licence application for the encapsulation plant and disposal facility by the end of 2012. The intention is to have the contents of the application submitted to the Government finalised to such a high degree that there will be no need for Posiva to change them at its own initiative during the process. Instead, the reports submitted to STUK in connection with the application are by their nature documents that are constantly updated, which is why even minor changes in the plant design data or the results of safety analyses may result in a need to amend the reports submitted.

STUK has announced that it will take into account any supplements to the construction licence application received before it produces the safety assessment required for the licence decision. It is already known that the system descriptions included in the safety report will be revised during 2013. Due to the fact that STUK's regulation reform work is still in progress, the conformity assessment included in the application material can only be finalised once the reform work has been completed, or when sufficiently advanced (L4) versions of the YVL Guides become available. STUK has announced that the YVL Guide reform project will be completed by the end of 2012.

It is expected that the application material will also have to be supplemented with regard to the reports concerning the demonstration of long-term safety, and possibly regarding other application documents as well. Posiva is also preparing for a situation where the material submitted to STUK in connection with the application has to be updated following STUK's inspection of the documents. STUK has announced that it will perform a comprehensiveness check on the application material during the first half of 2013, followed by a detailed inspection of the application material. Consequently, requests for further reports and updates may be received from mid-2013 to early 2014. The statements of opinion submitted by different parties by request to the Ministry of Employment and the Economy will also cause additional work for Posiva during 2014. In line with the practice adopted by the Ministry of Employment and the Economy, the applicant will prepare to issue responses to the statements of opinion received by the ministry.

The outlines of implementation for the disposal project are described in a project plan intended for Posiva's internal use. The work for converting that plan into feasible action models began with the TOVA project that was implemented and reported in 2011. As the plans and schedules become more specific, this work will continue with the TOVA-2012 continuation project that was initiated in early 2012. Besides the preparations for construction work, the continuation project will also address the actual construction work up to the commissioning of the plant complex. For example, the reports regarding the practical implementation of construction work (project plan) and the organisation during the construction phase will be produced as part of the TOVA-2012 project. Posiva intends to complete TOVA-2012 during 2012 but most of the development actions defined in the project will only be implemented from 2013 onwards.

An outline of the quality management regarding construction work will be presented in a report to be submitted to STUK in connection with the construction licence application. The basic premise is that the quality management of construction operations is included in Posiva's existing operations management system. The creation of a comprehensive quality management system (quality control and assurance) will require substantial development of the existing operations management system, particularly with regard to the instructions system. The instructions required for construction work will be described in a report to be produced during 2012. The required quality instructions (quality manual for construction work) will have to be produced at least for construction engineering work (bedrock and concrete construction) by the first half of 2014. Development of the quality system will require substantial additional resources, at least temporarily.

The report regarding the organisation during the construction phase will be submitted to the Government (to the Ministry of Employment and the Economy) pursuant to section 32 of the Nuclear Energy Decree as part of the construction licence application. The report will include the proposal that Posiva will appoint a director responsible for construction work, the persons responsible for security arrangements, emergency response arrangements and nuclear material safeguards, plus deputies for all of them, before starting the construction work for the nuclear facility on the basis of the construction licence. These appointments will require the advance approval of STUK on the basis of qualification conditions it has defined and the oral hearing it conducts, among other things. The process for selecting and qualifying these persons responsible for their respective posts will start during the first half of 2013.

The process of licensing a nuclear facility takes place at three levels. The plant complex is described and discussed in the general section of the preliminary safety analysis report (PSAR), which is submitted to STUK for approval during the construction licence phase. Compliance of the implementation with the requirements and plans will be verified by the commissioning of the plant complex and the joint operating tests included in the commissioning process. Summary reports on the results of different phases of the commissioning process will be submitted to STUK for approval. System-level licensing will be done with the system descriptions included in the PSAR and with the system tests verifying their implementation. STUK will be involved in the qualification of all safety classified systems. The elements related to the qualification of components at the device and structure level include, irrespective of their safety class, the structural plans as well as the structural, installation and commissioning inspections. Whether or not STUK will be involved in the qualification of device- and structure-level components depends on their safety class.

It is vitally important for Posiva's overall schedule that the system descriptions and structural plans are processed, even by authorities, without undue delays and by taking into account the schedule implications of the package being processed. Posiva will endeavour to obtain official approvals, or advance decisions, for work to be started immediately on receipt of the construction licence while the application is being processed, whenever possible.

7 RESEARCH AND DEVELOPMENT WORK REGARDING WASTE MANAGEMENT AT THE LOVIISA NPP DURING 2013–2018

Commercial operation of the Loviisa NPP began in 1977. The Loviisa power plant has been using the storage and handling/processing methods of spent fuel and operational waste as well as its operational waste repository for a long time. Decommissioning and dismantling of the power plant has been planned since 1982.

The operating licences for the LO1 and LO2 plant units of the Loviisa power plant and for their nuclear fuel and nuclear waste management facilities are valid until the end of 2027 for LO1 and until the end of 2030 for LO2. The operating licence for the operational waste repository (VLJ repository) is valid until the end of 2055.

The summary of nuclear waste management operations at the Olkiluoto and Loviisa power plants in 2011 presents the quantities and locations of spent fuel, internals of reactors and operational waste at the end of 2011 (Posiva 2012b).

The decommissioning plan for the Loviisa power plant was last updated in 2008 (Kallonen et al. 2008). The next update is due in 2012. The planned operating life of the power plant is 50 years.

7.1 Handling and storage of spent fuel

Spent fuel of the Loviisa power plant is stored in water pools at plant units LO1 and LO2 and in interim stores 1 and 2. The expansion of interim store 2 by four additional pools was commissioned in 2000.

The plans for increasing the storage capacity for spent fuel were made during 2004–2005, and the decision was taken to partially equip the existing pools with high-density racks. This will produce additional capacity up to 2020. The first two racks were installed in February 2007, and a total of four racks have been installed after that in 2009 and 2011. The intention is to install the rest of the high-density racks by 2016. Each high-density rack has 352 positions. Each storage pool could accommodate four high-density racks, but the intention is to place two high-density racks and two open racks in each pool, as that will make it easier to comply with the requirement of authorities regarding the emptying of one pool. The intention is to store at the plant the old fuel racks decommissioned due to the installation of new high-density racks.

New investigations during 2013−2015

It is important for the safe disposal of spent fuel that the surface temperature of the disposal canister is not too high. This will be affected by the decay heat produced by the fuel assemblies inside the canister. The decay heat produced by a fuel assembly can be measured calorimetrically. Calorimetric equipment suitable for measuring the decay heat of spent fuel at the plant has been designed, but the equipment has not been built yet. The design and licensing of the calorimetric equipment and measurements to be made using it will be completed during the current period. The calorimetric measurements can be used for developing and verifying calculation methods.

In 2011, the highest accectable burnup value of fuel was 57 MWd/kgU. An increase of burnup value will affect the decay heat of spent fuel and the length of the required cooling period before final disposal. An investigation will be conducted during the next programme period on how the increase of burnup value affects the overall cost of nuclear waste management. The intention is also to investigate ways in which the removal of decay heat from fuel pools can be ensured as part of the plant improvements following the Fukushima accident.

Preliminary plans for 2016–2018

The current plan is to install the rest of the high-density racks in the interim storage for spent fuel by 2016. Investigations into the alternatives for long-term storage of spent fuel will continue during the programme period. The alternatives are to expand the current spent fuel storage facility in Loviisa or to equip all of its pools with high-density racks.

7.2 Processing, storage and disposal of operational waste

A number of changes related to the processing of operational waste were made at the Loviisa power plant during the TKS-2009 period. A project aimed at renovating the low-level operational waste processing and storage facilities (VAJAKO) was initiated in autumn 2007 and completed during the TKS-2009 period. At the end of 2011, waste management operations in the controlled area had at their disposal new operational waste processing facilities at the LO1, and new metal waste processing facilities, which are only waiting for finishing touches at LO2. In the future, metal waste will be processed at LO2, while all other operational waste will be processed at LO1.

Following the changes, the plant now has better facilities for processing waste and for storing waste barrels. A radiation shield is provided for barrels with the highest activity levels. It reduces the radiation exposure of personnel. Fire safe cabinets for chemical waste and a separate chemical container for chemical barrels are provided. A dedicated fork-lift truck has been procured for waste management. It can be used for moving barrels. The fork-lift truck and cranes in the waste management facility can be used for heavy lifting operations. A separate room is available for measuring metal scrap to release it from control, and dedicated tools are now available for light decontamination and chopping of metal scrap. Condor tool monitors have been introduced for the activity measurements of waste bags and metal scrap. The gamma measurement instrument for operational waste barrels was also replaced and the new instrument introduced in 2010. Permanent staff has now been recruited for the waste packing station.

Epoxy-coated barrels are now used in the waste packing station, because it was found that the previously used barrels could rust through in the repository under certain conditions. The matter was investigated at STUK's request, and it was found that the through-rusting of barrels was mainly due to inside corrosion of the barrels caused by waste packed while still wet. In 2012, a sieve press will be procured for the waste packing station. It can be used to dry solvent-containing rags before packing them into barrels.

The following developments have taken place with regard to the processing of liquid waste: low-level solvents were solidified in 2011 using equipments borrowed from TVO. The storage container for low-level resin and active charcoal was emptied and the contents were solidified into barrels using TVO's equipment. Loviisa will procure its own solidification equipment for this type of wastes during 2012. The storage capacity of intermediate-level resin will be increased by converting one low-level resin storage container into an intermediate-level resin container. The conversion is expected to be completed in late 2012. Development of the waste resin pumping system and its installation in tank TW30B01 is planned for 2012–2013. The trial operation of Loviisa's solidification plant still continues. Personnel are being recruited for the plant.

Different filters are used when purifying the plant's process waters, and they have to be finally disposed of. A new waste container made of concrete was designed for the filters during 2011–2012.

The construction work for Operational waste Facility 3 (HJT3) and the connection tunnel began in October 2010; the excavation work (about 16,000 m^3) was completed in 2011. The expansion will improve the facilities for interim storage and sorting of operational waste barrels. The process for obtaining the licences and permits for the HJT3 for the interim storage of waste barrels is in progress. The changes taking place in the repository environment are monitored by dedicated measurements and investigations. In addition to temperature and humidity, the monitoring includes changes in observed groundwater (water inflow volumes, groundwater chemistry and the interface between fresh and saline water) as well as rock-mechanical measurements (rock movements and weathering). The condition of the repository is also monitored visually.

The plan is to cast concrete in the spaces between the concrete waste containers disposed of in the solidified waste repository. This concrete mantling operation was simulated in 2012 using moulds placed in the solidified waste trough. A fibre optic cable was installed in the casting for monitoring it.

The possibilities for selective separation of problematic radionuclides from the process and waste water were investigated during 2010–2012 with the Laboratory of Radiochemistry of the University of Helsinki. The development work for separating antimony has advanced to a testing phase at the Loviisa plant.

Investigations during 2013−2015

An investigation will be performed in 2013 regarding the replacement of waste compactors used for packing waste into barrels. The regulations regarding the handling of explosive materials will also be taken into account when selecting the compactors.

Testing of the cast filling method for the solidified waste trough continues. Monitoring tests using a fibre optical cable will be planned on the basis of earlier results.

The periodic safety review of the VLJ repository in Loviisa will be produced by the end of 2013. The periodic safety review will include assessments of the status of safety of the repository and of any development subjects for maintaining and improving safety, taking into account the latest results of the research and monitoring programmes. When producing the safety assessment, the up-to-dateness of the documents referred to in section 36 of the Nuclear Energy Decree is checked, and the documents are updated if the assessment indicates a need for that. No separate long-term safety case will be produced for the periodic safety assessment; instead, separate comments will be made regarding issues brought up since the analysis of 2006 was completed, and a plan for producing a safety case in 2018 will be presented.

The joint project with TVO, investigating the long-term durability of concrete in disposal conditions, will continue. The matter is discussed in greater detail in Chapter 8

When investigating the long-term durability of concrete in disposal conditions, one of the damage mechanisms of reinforced concrete structures has been found to be the carbonatisation of concrete structures, that is, the neutralisation of concrete shielding the reinforcement steel bars due to the effect of carbon dioxide during the backfilling phase of the VLJ repository that takes decades. For this reason, the repository monitoring programme includes monitoring of the parameters required for assessing the long-term durability of concrete structures (temperature, relative humidity, CO_2 content of air and the depth of carbonatisation in concrete structures). The depth of carbonatisation, microstructure and strength of the concrete structures were first determined in autumn 2006. The tests are continuing, and samples may be taken, depending on the results, in 2015 and 2020.

Storage testing of radioactive ion exchange resin solidified in half-scale disposal containers in 1987 continues. The waste packages have been stored in groundwater at the Loviisa power plant and, as expected, they are still in good condition. In 1980, old inactive ion exchange resin from the Loviisa power plant was solidified in a full-scale disposal container. The disposal container has since been kept in slowly flowing fresh water at the Pyhäkoski power plant. The condition of the disposal container has been monitored at regular intervals. These tests will continue.

The development work regarding the use of selective ion exchange materials in purifying radioactive waste and process waters will continue with the Laboratory of Radiochemistry of the University of Helsinki.

An investigation on the cleaning-up operation following a severe reactor accident will be performed during the next programme period. The investigation will include a review of actual cleaning operations at damaged reactors around the world.

During the period 2013–2015, modelling tools will also be maintained and developed (statistical processing / PRONEFA, biosphere modelling / AMBER, groundwater flow / FLUENT, etc.) for the purpose of producing safety cases. In addition, the impact of the discharge burnup value of spent nuclear fuel on its final disposal will be investigated.

Preliminary plans for 2016–2018

After 2012, the next update of the decommissioning plan is due in 2018. A new long-term safety case will also be produced for this update. The intention is to produce the safety case for the entire VLJ repository so that it covers the final disposal of both operational and decommissioning waste. The excavation of HJT3, sorting of operational waste and changes in the solidification plant development work will be among the matters to be taken into account in the safety case work.

7.3 Decommissioning

Preparations are made for decommissioning the Loviisa power plant by conducting various decommissioning-related investigations. The investigations will serve the purpose of specifying further the background data for the safety case, the technical implementation planning and the calculations performed for preparing financially for the decommissioning.

The operating and maintenance personnel of the power plant collects operating experience (regarding, for example, the reparation or replacement of components, the numbers of hours used for different operations, the work methods and contamination issues), and the activity levels of systems, equipment and structures are monitored as part of routine operations.

The annual monitoring of activity levels of the power plant systems, equipment and structures will continue during the next programme period. The monitoring programme covers contamination, the accumulation of waste and the monitoring of dose rate levels in different facilities. The monitoring programme will be utilised for decommissioning investigations and decommissioning plans (including the safety case for the final disposal of decommissioning waste).

The capabilities for decommissioning and the competence regarding the safety case are being constantly developed. As part of this work, the international research is monitored, particularly regarding the factors affecting the choice of parameters for the safety case (sorption, diffusion and solubility parameters), the impacts of corrosion gases and other corrosion products generated, the interactions between the backfill materials, as well as the interactions between groundwater and the backfill materials. In addition, the international developments in the field of decommissioning is monitored (particularly regarding decommissioning projects and decommissioning experiences, decommissioning equipment, instruments for measuring contamination, costs, etc.) with the help of various sources of information, seminars and plant visits. All this will also serve the final disposal of operational waste.

The risks associated with the decommissioning of the Loviisa power plant are assessed in a separate report and in a Master's Thesis. The decommissioning will carry technical and financial risks which must be prepared for before starting the actual decommissioning operation. The major risks associated with decommissioning include those related to large external and internal radiation doses, spillages of contaminated liquids, fires, explosions, toxic and hazardous materials, electrical accidents, cases of falling loads, accidents involving injuries as well as human errors, which may cause injuries or fatalities or external or internal radiation doses. The uncertainties related to the quantity of material to be dismantled and the dismantling schedule are the cause of the biggest financial risks.

The factors affecting licensing of the decommissioning operation and the final disposal of decommissioning waste are assessed in a separate report. Licensing of the decommissioning operation is governed by official regulations included in the Nuclear Energy Act and the Nuclear Energy Decree, Government decrees and the YVL Guides. The plan is to start dismantling the Loviisa power plant immediately when its operation ends. Therefore, preparations have to be made for the licensing process in good time.

The issues to be assessed for the purpose of updating the decommissioning plan include the implementation of the ALARA (As Low As Reasonably Achievable) principle in decommissioning planning, the effect of primary circuit decontamination on the radiation doses of employees and the use of protective equipment at different stages of the decommissioning process.

The activity inventory of waste in the dry silos in Loviisa and the plan for processing the waste are to be revised in 2012.

A speciation study on the ^{14}C present in activated waste has been planned in cooperation with VTT during 2011–2012.

Investigations during 2013−2015

During 2013–2015, answers will be produced in response to the comments of authorities regarding the updated decommissioning plan to be submitted at the end of 2012. The cost estimate for the decommissioning operation will also be updated.

The possibilities for disposing of part of the decommissioning waste in a near-surface final disposal facility will be investigated during the programme period.

The work for investigating issues related to the speciation of ^{14}C will continue in cooperation with VTT in order to reduce the uncertainties associated with the long-term safety case.

In addition, the investigations related to decommissioning include those regarding the dose rates affecting the processing of the pressure vessel, the re-use and recycling of the decommissioned concrete as well as the generation of dust when sawing concrete.

Investigations during 2016−2018

During the period 2016–2018, the investigations performed in earlier decommissioning plans will be continued and revised for the decommissioning plan update in 2018. Updating the long-term safety case is an important part of this work; it will be performed by the end of 2018.

Regarding the costs of nuclear waste management, reports of the total cost estimate for nuclear waste management will be produced in cooperation with Posiva.

8 RESEARCH AND DEVELOPMENT WORK REGARDING WASTE MANAGEMENT AT THE OLKILUOTO NPP DURING 2013–2018

8.1 Handling and storage of spent fuel

The spent fuel generated by the Olkiluoto power plant is stored in water pools located in plant units OL1 and OL2 for about four years after it has been removed from the reactors. In the OL3 unit, this storage period will be about six years. After that, the fuel is transported from the power plant units to the interim storage for spent fuel located in the vicinity of the reactor units.

The capacity of the interim storage for spent fuel in Olkiluoto will be increased by building three new water pools. The expansion will also take into account the needs of the OL3 power plant unit. This storage extension will be commissioned around 2014.

Damaged fuel rods from OL1 and OL2 reactors are encapsulated individually into hermetically sealed canisters and stored in water pools located at the power plant units.

Investigations during 2013–2015 regarding the processing of spent fuel

The current maximum for the assembly-specific discharge burnup value of fuel at the OL1 and OL2 plant units was approved in 2011 and is now 50 MWd/kgU. TVO intends to have further a higher assembly-specific discharge burnup value, 55 MWd/kgU, approved for the OL1 and OL2 plant units. For the moment, TVO has a test assembly programme in progress where the burnup values of individual fuel assemblies will reach 55 MWd/kgU in the next few years. This increase of the burnup value will most likely take place in connection with the renewal of the operating licence in 2018.

The currently approved assembly-specific burnup value for the fuel of OL3 is 45 MWd/kgU. However, TVO intends to increase the discharge burnup value to 50–53 MWd/kgU after the plant has been started up; this is necessary particularly when a two-year refuelling cycle is used in stead of the current one-year practice. The increase of the burnup value will require updating of corresponding safety analyses and planning and implementing of a fuel research programme for this.

Assessment of the technical and financial implications of an increase of the burnup value will require:

- radiation tests performed in research reactors and plant tests as part of international research programmes as well as calculation of decay heat to be used as the basis of determining the possibilities for increasing the burnup value and the corresponding cooling period required,
- studies for the factors associated with the handling, processing and storage of fuel as a result of the increase of burnup value in compliance with the approval of public authorities, and
- determining, using an optimisation approach, the burnup values that are feasible in the future.

The construction of the interim storage extension for spent fuel will continue so that it will be commissioned during 2014 for the needs of OL1 and OL2. The storage of spent fuel from the OL3 plan unit will begin during the latter half of the current decade in this facility. New fuel racks will be required for both BWR and EPR fuel assemblies.

The new OL4 project will include new fuel storage pools in the reactor unit for storing the spent fuel for the few first years after the use. The same applies to OL1-3 units too. After the first storage the fuel will be moved to the interim storage for spent fuel located in the plant area. The storage capacity required for the spent fuel of the OL4 plant unit will be analysed separately when the reactor type has been chosen.

Posiva is applying the burnup credit calculations in assessing the criticality for the safety analyses concerning the spent fuel disposal. Studies for the application of the burnup credit to the criticality safety analyses for the interim storage of spent fuel may also become topical during the planning period. For many years now, TVO has a representative in the Working Party OECD/NEA on Nuclear Criticality Safety (WPNCS) and its expert groups. One of the objectives of this WPNCS and its Expert Group on Burnup Credit (EGBUC) is to create the basis for the methods used for the burnup credit. The work of this group is focused on the assessment of computational analyses and on benchmarking activities. Participation to the working group will continue during the years covered by the plan.

Research on spent fuel takes place as well in Euratom FIRST (Fast/Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel) project which started in early 2012. TVO participates the project by supplying fuel samples with a high burnup for examinations. The objective is to investigate the rapid/instant release of radionuclides from UO_2 fuel with a high burnup and their migration in the bedrock. The TVO fuel samples are included in the dissolution-based release investigations where the measured nuclides are ^{14}C, ^{129}I, ^{135}Cs and ^{79}Se. The nuclide inventory of the fuel is calculated in the FIRST project, but analytical determination may also come to question in the future. The project will continue until the end of 2015.

Investigations during 2016–2018 regarding the processing of spent fuel

During the period 2016–2018, investigations on the impacts of increasing the burnup value on nuclear waste management and on its total costs will continue. The objective is optimising the cooling time and the increase of burnup. Investigations related to burnup credit will be carried out as well for the criticality safety analyses of the interim storage of spent fuel as required.

8.2 Processing, storage and disposal of operational waste

Operation of the Olkiluoto NPPs generates low- and intermediate-level waste (abbreviated 'MAJ' and 'KAJ' in Finnish, respectively). The waste is generated in connection with maintenance and repair operations, and it consists of different materials (plastic, paper, wood and various materials included in personal protective equipment). In addition, waste is generated in different water treatment systems (filter bars, ion exchange resins, slurries created in evaporation processes, and decontamination solutions). Typically, about 100–200 m^3 of operational waste is generated annually at the plants currently in operation. When OL3 starts operating, the annual quantity of waste will increase by about one-third.

Most of the operational waste is packed right away for processing, storage and disposal. The low-level waste to be compacted is packed in waste barrels using a hydraulic press, after which the barrels are compacted to half of their original height while maintaining their original diameter. The low-level waste unsuitable for compacting is packed in stainless steel containers or in concrete containers and waste barrels. Certain metal components, such as pipes, can be compacted before packing them in order to reduce their volume. During 2002–2006, the waste processing methods were developed with several technical improvements. The latest subjects of development were:

- Since spring 2004, the plant units have been able to use a wet blowing cabinet installed in the decontamination facility of OL1 for decontaminating large components and equipment. The decontamination can be performed using high-pressure water, mechanically or chemically. Decontamination reduces the activity level considerably. The washing equipment in the wet blowing cabinet at the decontamination facilities was replaced by an industrial robot during winter 2011–2012.
- One low pressure evaporator was installed in late 2003 and another in 2008. They can be used to reduce the volume of slurries and mixtures. The equipment has a maximum capacity of 500 l/day, and it is capable of reducing the liquid volume of waste materials by a factor of 50–70.
- The laundry in the annual maintenance building was commissioned in 2009. It handles the laundry from the controlled areas of OL1 and OL2. The laundry has further reduced the aquatic emissions of radioactive substances.
- The used ion exchange resins from water treatment systems, dried evaporation slurries or decontamination solutions are dried, mixed with hot bitumen and packed into waste barrels. The bitumizing station equipment at both plant units was renewed in late 2006. Different solutions and slurries from tank bottoms, drain holes and evaporators are solidified into concrete or mixed with particular solidification agents in the waste barrels. Following investigations, the bitumen grade was changed and the temperature of the process reduced by 15 ^{o}C.
- The ^{14}C contents of used ion exchange resins were analysed during 2002–2006. The measured ^{14}C concentrations are higher than those found in the analyses performed during 1983–1985. Estimates of the ^{14}C activity of operational waste are based on the latest measurement results.
- A report of the new packing and disposal techniques available for low- and intermediate-level waste was produced in 2006 (Kekki & Tiitta 2006). The work for investigating the possibility of disposal in the soil, brought up in the report, still continues, particularly with respect to decommissioning waste.
- The chopping and melting of reheaters in Studsvik during 2010–2012 went well. The material classified as intermediate-level operational waste will be separated in Studsvik and returned to Olkiluoto for disposal in the VLJ repository.
- Decommissioned high pressure and low pressure turbines will be chopped and melted in Studsvik during 2012–2013.

During the planning period, the processing, transport and disposal of waste generated in the operation of the Olkiluoto NPP will continue as before. The annual consumption of ion exchange resins in powder form has remained the same since 2004 (about 4,200 kg/year) as a result of improvements in the process equipment of the purification systems and optimisation of the use of filters and ion exchange resins in the condensate purification system.

The waste generated in the course of operation is stored temporarily in the storage facilities at the power plant units as well as in the storage facilities for low- and intermediate-level waste. All plant units also have limited facilities for the temporary storage of minor quantities of spent fuel. Large metal components of low activity, such as certain heat exchangers, are stored in a separate building at the plant area until their radioactivity has decreased sufficiently so that they can be released from control, recycled or finally disposed of.

Finally, the waste is transported from the interim storage to the VLJ repository. The VLJ repository was commissioned in 1992, and its two silos for the waste from low- and intermediate-level storages will suffice for the plant units' originally planned service life of 40 years. The repository has to be extended in the 2030s, because the expected service life of the OL1 and OL2 plant units used for estimating the accumulation of waste and for planning their decommissioning has been extended from 40 to 60 years. The expansion is also necessary in order to cater for the needs of the new OL3 plant unit. The expansion will be particularly required for the low-level waste generated in the OL3 plant unit; the current assessment is that the other waste fractions can be accommodated in the current silos. Part of the VLJ repository has been leased to the Ministry of Social Affairs and Health for the interim storage of various radioactive hospital waste materials and radioactive waste materials generated by the Finnish Defence Forces and universities. STUK is responsible for waste accounting regarding these materials.

If the activity level of waste exceeds the permissible limit for transportation, it is placed into the storage facilities for low- and intermediate-level waste at the plant area or taken for appropriate further processing. It was decided in 2002 to continue the filtration of oils stored in the controlled area in order to release them from control for recycling. The locations, quantities and activity levels of waste materials are reported annually (Posiva 2012b). Quantities of waste oil have been released from control every year.

The dry solid waste generated at the OL3 plant unit, consisting of maintenance waste and metal scrap, is expected to be similar to that generated by the OL1 and OL2 units. The activity and other properties of the waste will also be similar. The waste will be processed using the same methods that are already used at the OL1 and OL2 plant units.

The wet waste materials consist of ion exchange resins, evaporation residues, slurries and filter cartridges used for processing the contaminated water. The filter cartridges are packed in 200-litre barrels without any further processing. In order to minimise the amount of waste, the ion exchange resins, evaporation residues and slurries are processed directly into 200-litre barrels using the in-drum drying method.

Low-level waste from the OL3 plant unit is packed into concrete boxes for final disposal and transported to the low-level silo in the VLJ repository. The waste from OL1 and OL2 is treated in the same manner.

Two main alternatives have been presented for processing the intermediate-level waste generated in the OL3 plant unit. Both of these alternatives will be analysed until OL3 has received its operating licence and the method of implementation has been chosen:
- interim storage and final disposal in an extension of the current VLJ repository, and
- final disposal in the existing intermediate-level silo in the VLJ repository.

In the first alternative, the intermediate-level storage in Olkiluoto would serve as the interim storage facility. The waste generated in OL3 will take up at most 583 m^3 (one-sixth) of the total volume of the facility, which is 3,500 m^3. The extension of the VLJ repository would be available for use by 2040 at the latest, at which time the current intermediate-level storage facility is expected to be filled with waste from OL1/OL2 units. The other alternative is to have the extension ready by year 2030 when the current low-level silo is expected to be fully used. The waste generated by OL3 will be taken into account when planning the extension of the VLJ repository. The existing intermediate-level silo was originally planned for storing only waste mixed with bitumen.

In the second alternative, the spreading of radioactivity from the final disposal location would be prevented by using a disposal package that would be at least as efficient as the bitumen used for the OL1/OL2 waste. The plan is to totally surround the waste barrels with a layer of concrete at least 20 cm thick. This protection also determines the final external dimensions of the barrels, which would not fit into the current concrete boxes. Such a method of packing and protection would require detailed equipment design for processing and packing. The final disposal of these packages would start in 2018 when the barrel storage of OL3 is expected to become full. However, it is expected that moving the barrels to the intermediate-level storage facility would allow much more time for choosing the solution. Using the second alternative would require further modifications in the VLJ repository:
- a new protective box, or one box modified from the existing waste boxes, and
- a new hoisting tool for stacking the barrels in front of the repository crane, compliant with the changed dimensions.

At this stage, the first alternative is preferred. Reports of the suitability of the intermediate-level store must also be appended to the operating licence of the OL3 unit. More detailed investigations regarding the VLJ repository extension will be performed closer to the time of expansion, around 2020–2030.

The work for planning the storage, packing and final disposal of operational waste from OL4 will begin when the type of plant has been chosen.

R&D work supporting disposal

Monitoring the bedrock in the VLJ repository during its operation has continued according to the plan. The basis of the plan was produced in 1998, it was updated in late

2005 and it covers the monitoring until 2017. The programme includes the rock mechanical, hydrogeological, hydro-geochemical and air quality investigations performed in the repository for assessing long-term impacts. Hydro-geochemical monitoring during the operation of the repository has been performed since it was commissioned. In addition, the results of more extensive rock mechanical, hydrogeological and air quality monitoring work is reported at three-year intervals, with concise reports produced in the years between the extensive reports. The latest reports were produced in 2011 and 2012 (Lehtonen 2011, 2012; Johansson 2011, 2012). The measurement results indicate that the conditions in the VLJ repository are stable.

Microbiological decay of low-level operational waste in repository conditions is studied in a large-scale gas generation test. The test consists of test equipment erected in the VLJ repository excavation tunnel (Figure 8-1). The study has continued since 1997. The study serves to specify further the estimate on the amount and generation rate of gas generated from maintenance waste. For this purpose, knowledge is to be increased regarding the impact of microbial activity on the whole decay process and of the corrosion of steel under conditions which are similar to those after the VLJ repository has been sealed off. The most recent microbiological analyses were conducted in 2005. New sampling will be performed in 2012. The objective of the study is to produce an estimate of the gas generation rate for the safety analysis of the VLJ repository that was last updated in 2006. Over a longer period, the gas generation rate has stabilised to 60–90 dm^3/month, which is almost one order of magnitude smaller than the value taken for the initial safety analysis of the VLJ repository. During the test, the pH level of the water between the waste barrels has decreased from alkaline (> 10) to neutral, at the level of 7.5. This is thought to be caused by the metabolic products of microbes, and the decrease is greater than was expected based on the alkalinity of the concrete material in the system.

Figure 8-1. *Gas generation test equipment in the VLJ repository of Olkiluoto.*

An interim assessment of the test results was reported in 2011 for the purpose of establishing the changes in test tank conditions as well as any future development or actions required (Nykyri 2012). STUK has given its permission to continue the gas generation test, a deviation from the Technical Specifications for the VLJ repository until 2017. Microbiological analysis work will become topical at the latest when the test programme ends. Information on the development of pH values during the test can probably also be utilised in the future when the assessment of long-term safety of the disposal of operational waste is revised.

The long-term behaviour of concrete structures is investigated in a project entitled Betonin pitkäaikaiskestävyys (Long-term durability of concrete), initiated in 1997 in cooperation with Fortum Power and Heat Oy. Until December 2010, the pilot-scale simulated test was in progress in Myyrmäki, in the facilities of former IVO. After the intended use of the facilities changed, the decision was taken to move the test to the research facility of the VLJ repository in Olkiluoto at a level of -60 m. The tests were re-started in the VLJ repository in early 2011.

The results of the study are used for estimating the impact of the long-term behaviour of concrete on the solubility and migration of radionuclides under repository conditions as well as the weathering of concrete under groundwater conditions corresponding to actual operating conditions. The purpose of the study is to identify concrete types and compositions that are the most durable under the prevailing conditions so that the requirement of 60 years' service life set for the VLJ repository can be achieved, and to produce information for the modelling of long-term durability of concrete materials and for developing these models.

Nine test pieces of concrete under simulated water conditions were subjected to extensive sampling in connection with moving the test site. The purpose of this sampling was to investigate the state of the test pieces and solutions during the change of the test location. Furthermore, the purpose was to establish more systematically the penetration profiles of aggressive ions as well as the changes in micro-structure and strength properties of the concrete samples. This investigation was carried out by the power companies, and the extensive test material was also made available to the KYT2014 programme in 2011 for more extensive research and modelling and for increasing international cooperation on a subject that can be utilised more widely than just for the VLJ repository. In addition to the pilot test, similar concrete test pieces are being studied under actual groundwater conditions in boreholes located in the Olkiluoto VLJ repository.

Solubility tests on the waste metals from decommissioning (long-term corrosion tests on carbon steel and galvanised steel as well as zinc plates) are in progress in the boreholes located in the Olkiluoto VLJ repository and as a VTT follow-up study in laboratory conditions. The purpose of the decommissioning waste metal dissolution test, initiated in 1998, is to study the dissolving of steel under repository conditions in order to obtain a realistic picture of the corrosion rate of steel under the conditions prevailing in the Olkiluoto VLJ repository after its closure. At the end of 2011, there were a total of 79 sheets in the test positions: 62 steel plates, 9 zinc plates and 8 galvanised steel plates.

In the KYT2014 research programme, the test material has been supplemented with stainless steel samples. The test environment is actual groundwater from VLJ repository. The first results for stainless steel are expected by 2014.

Groundwater chemistry in the boreholes is regularly monitored with pH, oxygen, redox potential and conductivity measurements. Water samples are also taken every year for chemical analyses. The results were last reported in January 2011 (Carpén 2011). In the sampling campaign of 2010, microbiological samples were taken from the surface of carbon steel and zinc samples for preliminary microbiological analyses. Some of the samples were also deep-frozen for DNA analyses. The analysis of these DNA samples is in progress for the purpose of comprehensively determining the strains of bacteria present on the surface of carbon steel samples. The results will be reported during 2013. The research results obtained so far indicate that both the local water chemistry and microbiological activity in boreholes affect the corrosion rate and consequently also the predictability of corrosion and therefore also the estimates on corrosion rates.

In the context of investigations into the packaging and disposal techniques, an assessment, compliant with the Technical Specifications of the VLJ repository, of the safety and operational experience of the VLJ repository as well as the new packing and disposal techniques of operational waste was performed in late 2006. A decision of the Ministry of Employment and the Economy has been received regarding this assessment, containing no comments. The final safety analysis report for the VLJ repository (VLJ-FSAR) was updated at the same time. STUK approved this update of the VLJ-FSAR, following the processing of a few comments, in 2010. The update takes into account the final disposal of operational waste generated by OL3 and includes an outline description of the interim storage solution of drum-dried waste from OL3.

Investigations during 2013−2015 into the processing of operational waste

The investigations presented above will be continued and the general development in the field will be followed during 2013–2015. In addition, the following R&D tasks and projects will be carried out:

- A summary of the test results and analyses regarding the long-term gas generation test in the VLJ repository and a decision on whether the test is to be continued, by 2016.
- The modelling results for the gas generation test were published in 2008 (Small et al 2008). The modelling work can be continued on the basis of the summary report regarding the results of 2006–2011 (Nykyri 2012). It will be topical, at the latest, when the test ends. For this purpose, the data collection and recording systems of the equipment will be updated during 2013–2014.
- Continuation of the rock mechanical, hydrogeological and hydro-geochemical research programme for estimating the long-term impacts, plus an update of the measurement programme after the next extensive tests (2015) before ending the programme in 2017.
- Continuation of the concrete dissolving tests and investigations into the durability of steel structures and the solubility of metallic decommissioning waste for the purpose of estimating long-term impacts. The investigation will be performed in

cooperation with the working groups modelling the long-term durability of concrete (VTT and Aalto University) for the purpose of analysing the collected test material.
- Reporting of the research results related to the damage mechanisms of concrete structures for different concrete types during 2012–2015, with the first part published during spring 2012 (Vesikari & Koskinen 2012).
- Investigation into matters related to the safety case for the plant.
- Annexation of the research subjects necessitated by the new plant units to the VLJ research programme, or their implementation in cooperation with research institutes. In the context of processing/disposal of the intermediate-level waste generated by OL3, a test will be performed during the commissioning of OL3 where the used ion exchange resins and evaporation concentrates are dried in a barrel. The purpose of the test is to establish the distribution of different particles in the waste barrels. The test will be performed before loading fuel into the reactor.

Investigations during 2016−2018 into the processing of operational waste

Several research projects regarding the disposal of low- and intermediate-level waste will be implemented during 2016–2018. They are listed below:
- The gas generation test in the VLJ repository and its associated analyses are now scheduled to last until 2017. When deciding on the duration of the test, the summary report of 2011 and the subsequent plan regarding the completion of the test will be utilised.
- Monitoring of the chemistry, rock mechanics, groundwater and air in the VLJ repository will continue in compliance with the revised research and monitoring programme produced for the repository in 2005. Extensive reporting will be performed at three-year intervals, with concise reports published in the years between. The next extensive reporting is in 2015. The programme extends to 2017, which means that the composing of a new plan and initiation of the programme will become topical at the end of 2015 at the latest.
- Continuation of the concrete dissolving tests and investigations of the durability of steel structures and the solubility of metallic decommissioning waste for the purpose of estimating long-term impacts. The tests will end when the materials subjected to exposure have all been used up in the sampling campaigns. It is also possible that the tests will be continued and new types of concrete or steel grades are added to the test programme, depending on the development of structural materials and changes in their use.
- Low-temperature plasma incineration tests were conducted at VTT until 2008 for the purpose of reducing the volume of ion exchange resins. The future investigations will focus on using either higher-temperature plasma or other incineration methods. The developments in related technologies will be monitored.
- Annexation of the research subjects necessitated by the new plant units to the VLJ research programme, or their implementation in cooperation with research institutes.
- The investigation into the impacts of increasing the burnup value on nuclear waste management and on its total costs will continue with the objective of optimising the cooling time and the increase of burnup.

8.3 Decommissioning

The long-term safety analysis regarding the disposal of decommissioning waste from the Olkiluoto nuclear power plant was last updated during 2008. As prescribed in the Nuclear Energy Act, the plan is updated at least every six years, which means that the next update is due in 2014. However, inclusion of OL3 in the nuclear waste management arrangements has the result that a separate decommissioning plan for OL3 will be submitted in connection with its operating licence application. The current project schedule suggests that this would take place during 2013. The decommissioning of the OL4 plant unit will be a topical issue in the construction and operating licence applications once the type of plant has been chosen.

The decommissioning studies are aimed at the technical and economic development of the dismantling plan and at specifying the initial data for the safety analysis. The framework for producing the decommissioning plan is set out in the legislation and official regulations. The most important official regulation governing the decommissioning planning work is YVL Guide 8.2. "Clearance of nuclear waste and decommissioned nuclear facilities", but draft YVL Guide D.4 "Processing of low-and intermediate level nuclear waste and decommissioning of nuclear facilities" will also be taken into account at the planning stage of new plants. The plan presented in 2008 also discusses immediate decommissioning compared with the strategy of delayed decommissioning which TVO has opted for.

The decommissioning plan of 2008 is based on having the plant units OL1 and OL2 in operation for 60 years and then decommissioning them after 30 years of controlled preservation. The waste volumes and activity levels are estimated on the basis of these basic premises. The collective dose resulting from the dismantling work is based on the dose levels estimated on the basis of the plant's activity level, on the duration of the dismantling work and on estimates of the amount of work. The dismantling waste from four plant units was used as the basis for the safety case for the final disposal of decommissioning waste.

The investigations performed regarding OL1 and OL2 after 2008 include a re-assessment of the project activities, planning and operating costs related to dismantling as well as a re-assessment of the extent of decommissioning activities. Needs for increasing the 2008 estimate regarding the costs of project activities were identified, and these are taken into account in the waste management diagrams. The decommissioning costs already include a provision for increasing the scope, and this preliminarily covers the increase in the scope of dismantling work due to stricter limits for release from control. Therefore, the investigation carried out is not likely to result in pressures to increase the current cost estimate for decommissioning.

A cost estimate for decommissioning OL3 has been produced, together with an estimate of conventional dismantling costs outside the scope of nuclear energy legislation. A separate estimate of the radiation doses received during the decommissioning of OL3 has been produced for the purpose of assessing the information provided by the plant supplier.

The results of investigations regarding the cost estimate have been taken into account in the estimates of total cost of nuclear waste management.

As such, the on-going extension project of the interim fuel storage facility does not affect the decommissioning plan, because the extension was already taken into account in the original decommissioning plan for the interim fuel storage facility. The waste quantity and activity estimates regarding the decommissioning of the interim fuel storage facility were updated during 2011–2012. They are somewhat lower that the original estimates made at the time of constructing the interim fuel storage facility, but they are not expected to have major cost implications.

The waste quantities related to the disposal of decommissioning waste from the interim storage facility of the spent fuel have been taken into account when planning the VLJ repository, but the disposal of decommissioning waste from the interim fuel storage facility into the VLJ repository is not likely to be feasible from the point of view of time schedules. Final disposal of the interim storage of the spent fuel into the spent fuel repository has been suggested as an alternative, and the intention is to investigate this in cooperation with Posiva. As an alternative solution an investigation of using near surface disposal was made during 2011–2012. The preliminary investigation carried out indicates that near surface disposal can be implemented safely and cost efficiently for the decommissioning waste from the interim fuel storage facility.

Decommissioning investigations during 2013–2015

During the period 2013–2015, the investigations performed in earlier decommissioning plans will be continued and revised for the next decommissioning plan update. A substantial part of this work is related to the inclusion of OL3 in the decommissioning plan for the whole plant. The aim is to produce the plan in 2020 at the latest including the individual plans of the OL1, OL2 and OL3 units. It is likely that this combined plan will be produced before that, because the first decommissioning plan for OL3 will be submitted at the time the operating licence application for OL3 is submitted, and it must be updated within six years. In addition, an investigation is planned for modifying the cost estimate for decommissioning according to International Structure for Decommissioning Costing (ISDC) of Nuclear Installation by the OECD.

Experience of melting low-level metal scrap abroad has been gained from the replacement of large components in connection with the annual maintenance outages of the OL1 and OL2 plant units. The good experience shows that the possibilities of re-processing should also be investigated for the decommissioning plans. When this process is applied to waste with very low activity levels, the release from radiation control, for example, becomes easier because the activity content of components melted during re-processing can be determined accurately. The procedure will increase the costs compared with the current cost estimate in the decommissioning plan, but, on the other hand, the decrease in the disposal space required will reduce the costs. A new topical issue will be decommissioning and final disposal of spent fuel storage racks.

Decommissioning investigations during 2016–2018

The plan for decommissioning the reactor pressure vessel as one entity was updated in 2006 to conform with the 60-year service life of the Olkiluoto NPP. This also includes the plan to pack the activated internal parts of the reactor and the control rods inside the pressure vessels. A preliminary plan for expanding the VLJ repository by adding a decommissioning waste silo and a shaft suitable for the pressure vessel was also produced in 2006. As the project advances, an investigation should also be conducted for determining a suitable, flexible material for backfilling the pressure vessel shaft.

The MADAC and DOSRAT measurements are used for collecting information on contaminated dismantling waste. These measurements will continue according to the current programme. The information obtained from the used parts removed from inside the reactor is used for estimating the activity of activated dismantling waste.

The sampling of pieces of carbon steel from drill holes in the VLJ repository and from laboratory tests will continue according to the current test plan, which is a part of the long-term corrosion test programme for carbon steel in the repository.

The study regarding the long-term durability of concrete in disposal conditions will continue according to current plans. Samples will be taken every year from drill holes and laboratory tests.

In addition, the development of decommissioning techniques and experiences gained from decommissioning projects will be actively followed.

9 REFERENCES

Safety Case -reports

Olkiluoto Site Description 2011. POSIVA 2011-02. Posiva Oy, Eurajoki. ISBN 978-951-652-179-7.

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Design Basis 2012. POSIVA 2012-03. Posiva Oy, Eurajoki. ISBN 978-951-652-184-1. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Performance Assessment 2012. POSIVA 2012-04. Posiva Oy, Eurajoki. ISBN 978-951-652-185-8. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Description of the Disposal System 2012. Posiva 2012-05. Posiva Oy, Eurajoki. ISBN 978-951-652-186-5. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Olkiluoto Biosphere Description BSD-2012. POSIVA 2012-06. Posiva Oy, Eurajoki. ISBN 978-951-652-187-2. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Features, Events and Processes 2012. POSIVA 2012-07. Posiva Oy, Eurajoki. ISBN 978-951-652-188-9. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Formulation of Radionuclide Release Scenarios 2012. POSIVA 2012-08. Posiva Oy, Eurajoki. ISBN 978-951-652-189-6. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Assessment of Radionuclide Release Scenarios for the Repository System 2012. POSIVA 2012-09. Posiva Oy, Eurajoki. ISBN 978-951-652-190-2. (in print)

Safety case for the spent nuclear fuel disposal at Olkiluoto - Biosphere Assessment BSA-2012. POSIVA 2012-10. Posiva Oy, Eurajoki. ISBN 978-951-652-191-9. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Complementary Considerations 2012. POSIVA 2012-11. Posiva Oy, Eurajoki. ISBN 978-951-652-192-6. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Synthesis 2012. POSIVA 2012-12. Posiva Oy, Eurajoki. ISBN 978-951-652-193-3. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Data Basis for the Biosphere Assessment BSA-2012. POSIVA 2012-28. Posiva Oy, Eurajoki. ISBN 978-951-652-209-1. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Terrain and ecosystems development modelling in the biosphere assessment BSA-2012. POSIVA 2012-29. Posiva Oy, Eurajoki. ISBN 978-951-652-210-7. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Surface and near-surface hydrological modelling in the biosphere assessment BSA-2012. POSIVA 2012-30. Posiva Oy, Eurajoki. ISBN 978-951-652-211-4. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Radionuclide transport and dose assessment for humans in the biosphere assessment BSA-2012. POSIVA 2012-31. Posiva Oy, Eurajoki. ISBN 978-951-652-212-1. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Dose assessment for the plants and animals in the biosphere assessment BSA-2012. POSIVA 2012-32. Posiva Oy, Eurajoki. ISBN 978-951-652-213-8. (in print)

Safety case for the disposal of spent nuclear fuel at Olkiluoto - Models and Data for the Repository System 2012. POSIVA 2013-01. Posiva Oy, Eurajoki. (in print)

Production Line Reports

Canister Production Line 2012 – Design, production and initial state of the canister. Raiko, H. (ed.), Jalonen, T., Nolvi, L., Pastina, B., Pitkänen, J. & Salonen, T. POSIVA 2012-16, Posiva Oy, Eurajoki. ISBN 978-951-652-197-1.

Buffer Production Line 2012 – Design, production and initial State of the buffer. Juvankoski, M., Ikonen, K. & Jalonen, T. POSIVA 2012-17. Posiva Oy, Eurajoki. ISBN 978-951-652-198-8.

Backfill Production Line 2012 – Design, production and initial state of the deposition tunnel backfill and plug. Keto, P. (ed.), Hassan, Md. M., Karttunen, P., Kiviranta, L., Kumpulainen, S., Sievänen, U., Korkiala-Tanttu, L., Koskinen, V., Koho, P. & Jalonen, T. POSIVA 2012-18. Posiva Oy, Eurajoki. ISBN 978-951-652-199-5. (in print)

Closure Production Line 2012 – Design, production and initial state of underground disposal facility closure. Sievänen, U., Karvonen, T. H., Dixon, D., Hansen, J. & Jalonen T. POSIVA 2012-19. Posiva Oy, Eurajoki. ISBN 978-951-652-200-8. (in print)

Underground Openings Production Line 2012 – Design, production and initial state of the underground openings. Mustonen, S. ym. POSIVA 2012-22. Posiva Oy, Eurajoki. (in print)

Other

Aalto, P. (ed.), Helin, J., Lindgren, S., Pitkänen, P., Ylä-Mella, M., Ahokas, H., Heikkinen, E., Klockars, J., Lahdenperä, A-M., Korkealaakso, J., Lamminmäki, T., Pedersen, K. & Karvonen,T. 2011a. Baseline Report for Infiltration Experiment. Working Report 2011-25. Posiva Oy, Eurajoki. 152 s.

Aalto, P. (ed.), Lahti, M., Kosunen, P., Pere, T., Toropainen, V., Tarvainen, A-M., Pekkanen, J., Pöllänen, J. & Lamminmäki, T. 2011b. Drilling and associated drillhole measurements of the pilot hole ONK-PH14. Working Report 2011-64. Posiva Oy, Eurajoki. 178 p.

Aalto, P., Aaltonen, I., Ahokas, H., Andersson, J., Hakala,M., Hellä, P., Hudson, J., Johansson, E., Kemppainen, K., Koskinen, L., Laaksoharju, M., Lahti, M., Lindgren, S., Mustonen, M., Pedersen, K., Pitkänen, P., Poteri, A., Snellman, M. & Ylä-Mella, M. 2009. Programme for Repository Host Rock Characterisation in the ONKALO (ReRoC). Working Report 2009-31. Posiva Oy, Eurajoki. 64 p.

Aaltonen, I. (ed.), Lahti, M., Engström, J., Mattila, J., Paananen, M., Paulamäki, S., Gehör, S., Kärki, A., Ahokas, T., Torvela, T. & Front, K. 2010. Geological Model of the Olkiluoto Site - version 2.0. Working Report 2010-70. Posiva Oy, Eurajoki.

Ahokas, H., ym. 2012. Quality review of transmissivity data from Olkiluoto Site - Drillholes OL-KR1–OL-KR50. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Ahokas, T. & Heikkinen, E. 2012. Mise-à-la-masse survey in the ONKALO demo area in 2010. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Ahokas, T. & Paananen, M. 2010. Updated and intergrated modelling of the 1995–2008 mise-à-la-masse survey data in Olkiluoto. Working Report 2010-08. Posiva Oy, Eurajoki. 276 p.

Ahokas, T. 2010. Preliminary modelling of the 2010 MAM survey data. Working Report 2010-75, Posiva Oy, Eurajoki. 72 p.

Ahokas, T., Heikkinen, E. & Hurmerinta, E. 2011. Mise-à-la-masse survey in the HYDCO niche 2011. Working Report 2011-89. Posiva Oy, Eurajoki. 37 p.

Anttila, M. 2005a. Radioactive Characteristics of the Spent Fuel of the Finnish Nuclear Power Plants. Working Report 2005-71. Posiva Oy, Eurajoki.

Anttila, M. 2005b. Criticality Safety Calculations for Three Types of Final Disposal Canisters. Working report 2005-13. Posiva Oy, Eurajoki.

Arenius, M., Hansen, J., Juhola, P., Karttunen, P., Koskinen, K., Lehtinen, A., Lyytinen, T., Mattila, J., Partamies, S., Pitkänen, P., Raivio, P., Sievänen, U., Vuorinen, U. & Vuorio, M. 2008. R20 Summary Report: The Groundwater Inflow Management in ONKALO - the Future Strategy. Working Report 2008-44. Posiva Oy, Eurajoki.

Arilahti, E., Carpén, L., Lehtikuusi, T., Olin, M., Saario, S. & Varis, P. 2011. Sulphide induced stress corrosion cracking of copper – Final Report. VTT-R-00467-11.

Aro, L., Derome, J., Helmisaari, H-S., Huhta, A-P., Hökkä, H., Lindroos, A-J. & Rautio, P. 2011. Results of Forest Monitoring on Olkiluoto Island in 2010. Working Report 2010-61. Posiva Oy, Eurajoki.

Aro, L., Derome, J., Helmisaari, H-S., Hökkä, H., Lindroos, A-J. & Rautio, P. 2010. Results of Forest Monitoring on Olkiluoto Island in 2009. Working Report 2010-65. Posiva Oy, Eurajoki. 68 p.

Autio, J. & Kirkkomäki, T. 1996. Boring of Full Scale Deposition Holes Using a Novel Dry Blind Boring Method. POSIVA 1996-7. Posiva Oy, Helsinki.

Autio, J., Anttila, P., Börgesson, L., Sandén, T., Rönnqvist, P-E., Johansson, E., Hagros, A., Eriksson, M., Halvarsson, B., Berghäll, J., Kotola, R. & Parkkinen, I. 2008. KBS-3H Design Description 2007. POSIVA 2008-01, Posiva Oy. SKB R-08-44, Svensk Kärnbränslehantering AB.

Autio, J., Hassan, Md. M., Pintado, X., Keto, P. & Karttunen, P. 2012. Backfill Design 2012. POSIVA 2012-15. Posiva Oy, Eurajoki.

Batchelder, M., Cressey, G., Mather, J.D. & Joseph, J.B. 1996. Smectite-to-illite transformation at low temperature and implications for landfill containment. Chem. Contain. Wastes Geosphere

Brovkin, V., Ganopolski, A., Archer, D. & Munhoven G. 2012. Glacial CO_2 cycle as a succession of key physical and biogeochemical processes. Climate of the Past, Vol. 8, 251-264.

Bäckblom G. & Lindgren E. 2005. KBS-3H - Excavation of two horizontal drifts at the Äspö Hard Rock Laboratory during year 2004–2005. Work description, summary of results, and experience. SKB R-05-44. Svensk Kärnbränslehantering AB.

Börgesson, L., Dueck, Johannesson, L.-E. 2010. Material model for shear of the buffer - evaluation of laboratory rest results. SKB TR-10-31.

Carpén, L. 2011. Purkujätemetallien liukeneminen - Kokeelliset tutkimukset vuonna 2010. Tutkimusraportti VTT-R-10246-10. (in Finnish)

Cosma, C., Cozma, M., Juhlin, C. & Enescu, N. 2008. 3D Seismic Investigations at Olkiluoto, 2007. Factual Report. Working Report 2008-43. Posiva Oy, Eurajoki.

Cosma, C., Enescu, N., Balu, L. & Jacome, M. 2011. ONKALO 3D Tunnel Seismic Investigations at Olkiluoto in 2009. Working Report 2011-21. Posiva Oy, Eurajoki. 75 p.

Cuadros, J. & Linares, J. 1996. Experimental kinetic study of the smectite-to-illite transformation. Geochimica et Cosmochimica Acta, 60, 439-453.

Cuss, R. J., Harringtong, J. F. & Noy, D J. 2010. Large scale gas injection test (Lasgit) performed at the Äspö Hard Rock Laboratory. Summary report 2008. SKB TR-10-38.

Delos, A., Trinchero, P., Richard, L., Molinero, J., Dentz, M. & Pitkänen, P. 2010. Quantitative assessment of deep gas migration in Fennoscandian sites. Report R-10-61. Swedish Nuclear Fuel and Waste Management Co. (SKB). Stockholm, Sweden. 52 p. ISSN 1402-3091.

Dight, P., Hsieh, A., Kemppainen, K., Johansson, E. & Hudson, J.A. 2012. A Test Case of the Deformation Rate Analysis (DRA) Stress Measurement Method. Working Report 2012-01. Posiva Oy, Eurajoki.

Dixon, D., Korkiala-Tanttu, L., Hansen, J., Sievänen, U. & Karvonen, T.H. 2012. Underground Disposal Facility Closure Design 2012. Working Report 2012-09. Posiva Oy, Eurajoki. (in print)

Döse, C. & Gustafsson, J. 2011. Geological signatures of drillhole radar reflectors in ONKALO. Working report 2011-90, Posiva Oy, Eurajoki. 44 p.

Eberl, D.D., Velde, B. & McCormick, T. 1993. Synthesis of illite – smectite from smectite at Earth surface temperatures and high pH. Clay Miner. 28, 49– 60.

Eichinger, F., Hämmerli, J., Waber, H.N., Diamond, L.W. & Smellie, J.A.T. 2012. Chemistry and dissolved gases of matrix pore water and fluid inclusions in Olkiluoto bedrock from drillhole ONK-PH9. Working Report 2011-63. Posiva Oy, Eurajoki. 168 p. (in print)

Eichinger, F., Hämmerli, J., Waber, H.N., Diamond, L.W. & Smellie, J.A.T. 2010a. Characterisation of Matrix Pore Water and Fluid Inclusions in Olkiluoto Bedrock from Drilling OL-KR47. Working Report 2010-58. Posiva Oy, Eurajoki. 134 p.

Eichinger, F., Meier, D., Hämmerli, J. & Diamond, L. 2010b. Stable Isotope Signatures of Gases Liberated from Fluid Inclusions in Bedrock at Olkiluoto. Working Report 2010-88. Posiva Oy, Eurajoki.

Eichinger, F. L., Waber, H. N. & Smellie, J. A. T. 2006. Characterisation of Matrix Pore Water at the Olkiluoto Investigation Site, Finland. Working Report 2006-103. Posiva Oy, Eurajoki.

Engström, J. & Kemppainen, K. 2008. Evaluation of the geological and geotechnical mapping procedures in use in the ONKALO access tunnel. Working Report 2008-77. Posiva Oy, Eurajoki.

Engström, J. 2012. Geological Mapping of Investigation Trench OL-TK18 at the Olkiluoto Study Site, Eurajoki, SW Finland. Working Report 2012-18. Posiva Oy, Eurajoki.

Engström, J., Paananen, M. & Klint, K. E. 2012. The Greenland Analogue Project. Geomodel version 1 of the Kangerlussuaq area on Western Greenland. Working Report 2012-10. Posiva Oy, Eurajoki. 35 s.

Eriksson, M. & Lindström, L, 2009. KBS-3H Post-Grouting Mega-Packer Test at -220 m Level at Äspö HRL. Working Report 2008-11, Posiva Oy. SKB R-08-42, Svensk Kärnbränslehantering AB.

Euratom Treaty. Euratomin perustamissopimus 25.3.1957 ja siihen tehdyt muutokset: Asetus N:o 5, 22.12.1958 ja asetus N:o 9, 2.2.1960.

Euroopan komissio 2005. Komission asetus (Euratom) N:o 302/2005 Euratomin ydinmateriaalivalvonnan täytäntöönpanosta, 8.2.2005.

Follin, S., Stigsson, M., Rhén, I., Engström, J. & Klint, K. E. 2011. Greenland Analogue Project – Hydraulic properties of deformation zones and fracture domains at Forsmark, Laxemar and Olkiluoto for usage together with Geomodel version 1. Stockholm, P-11-26. Swedish Nuclear Fuel and Waste Management Co. (SKB), Sweden. 56 s. ISSN 1651-4416.

Fox ym. 2012. Geological Discrete-Fracture Network Model (version 2) for the Olkiluoto Site, Finland. POSIVA 2012. Posiva Oy, Eurajoki. (in print)

Fälth, B. & Hökmark, H. 2011. Modelling end-glacial earthquakes at Olkiluoto. Working Report 2011-13. Posiva Oy, Eurajoki.

Fälth, B. & Hökmark, H. 2012. Modelling end-glacial earthquakes at Olkiluoto. Expansion of the 2010 study. Working Report 2012-08. Posiva Oy, Eurajoki.

Ganopolski, A., Calov, R. & Claussen, M. 2010. Simulation of the last glacial cycle with a coupled climate ice-sheet model of intermediate complexity. Climate of the Past, Vol. 6, 229-244.

Gascoyne, M. 2005. Dissolved Gases in Groundwaters at Olkiluoto. Working Report 2005-56. Posiva Oy, Eurajoki.

Geology of Olkiluoto. POSIVA 2013. To be published 2013.

Gribi, P., Johnson, L., Suter, D., Smith, P., Pastina, B. & Snellman, M. 2007. Safety assessment for a KBS-3H spent nuclear fuel repository at Olkiluoto - Process Report. POSIVA 2007-09, Posiva Oy. SKB R-08-36, Svensk Kärnbränslehantering AB.

Gripenberg, H. 2009. Residual Stress Investigation of Copper Plate and Canister EB-Welds: Complementary Results. Working Report 2009-21. Posiva Oy, Eurajoki.

Haapanen, A. (ed.) 2009. Results of Monitoring at Olkiluoto in 2008 – Environment. Working Report 2009-45. Posiva Oy, Eurajoki.

Haapanen, A. (ed.) 2010. Results of Monitoring at Olkiluoto in 2009 – Environment. Working Report 2010-45. Posiva Oy, Eurajoki.

Haapanen, A. (ed.) 2011. Results of Monitoring at Olkiluoto in 2010 – Environment. Working report 2011-45. Posiva Oy, Eurajoki.

Haapanen, A. (ed.) 2012. Results of Monitoring at Olkiluoto in 2011 – Environment. Working report 2012-45. Posiva Oy, Eurajoki.

Haapanen, R. & Lahdenperä, A-M. 2011. Olkiluodon maalta merelle -linjaston maaosuuden inventointi vuonna 2008 ja Olkiluodon ympäristön ruovikkotutkimukset vuosina 2007–2008. Working report 2011-67. Posiva Oy, Eurajoki. (in Finnish)

Haapanen, R. (ed.) 2005. Results of Monitoring at Olkiluoto in 2004 – Environment. Working Report 2005-31. Posiva Oy, Eurajoki.

Haapanen, R. (ed.) 2006. Results of Monitoring at Olkiluoto in 2005 – Environment. Working Report 2006-68. Posiva Oy, Eurajoki.

Haapanen, R. (ed.) 2007. Results of Monitoring at Olkiluoto in 2006 – Environment. Working Report 2007-52. Posiva Oy, Eurajoki.

Haapanen, R. (ed.) 2008. Results of Monitoring at Olkiluoto in 2007 – Environment. Working Report 2008-25. Posiva Oy, Eurajoki.

Haapanen, R., Aro, L., Kirkkala, T., Koivunen, S., Lahdenperä, A-M. & Paloheimo, A. 2010. Potential Reference Mires and Lakes for Biosphere Assessment of Olkiluoto Site. Working report 2010-67. Posiva Oy, Eurajoki.

Haapanen, R., Aro, L., Koivunen, S., Lahdenperä, A-M., Kirkkala, T., Hakala, A., Helin, J. & Ikonen, A.T.K. 2011. Selection of real-life analogues for future lakes and mires at a repository site. Radioprotection 46(6): S647-S651.

Haaramo, M. & Lehtonen, A. 2009. Principle Plug Design for Deposition Tunnels. Working Report 2009-38. Posiva Oy, Eurajoki.

Hagros, A. 2006. Host Rock Classification (HRC) System for Nuclear Waste Disposal in Crystallinen Bedrock. Helsinki, Finland: University of Helsinki Press. Publications of the Department of Geology D8, University of Helsinki. ISBN 952-10-2607-3.

Hagros, A., McEwen, T., Anttila, P. & Äikäs, K. 2005. Host Rock Classification. Phase 3: Proposed Classification System (HRC-System). Working Report 2005-07. Posiva Oy, Eurajoki.

Hakanen, M., Ervanne, H. & Puukko, E. 2012. Safety case for a spent nuclear fuel repository at Olkiluoto: Radionuclide migration parameters for the geosphere. POSIVA 2012. Posiva Oy, Eurajoki. (in print)

Hansen, J. Korkiala-Tanttu, L., Keski-Kuha, E. & Keto, P. 2009. Deposition tunnel backfill design for a KBS-3V repository. Working Report 2009-129. Posiva Oy, Eurajoki.

Harper, J., Hubbard, A., Ruskeeniemi, T., Claesson Liljedahl, L., Lehtinen, A., Booth, A., Brinkerhoff, D., Drake, H., Dow, C., Doyle, S., Engström, J., Fitzpatrick, A., Frape, S., Henkemans, E., Humphrey, N., Johnson ,J., Jones, G., Joughin, I., Klint, K. E., Kukkonen, I., Kulessa, B., Landowski, C., Lindbäck, K., Makahnouk, M., Meierbachtol, T., Pere, T., Pedersen, K., Pettersson, R., Pimentel, S., Quincey, D., Tullborg, E.-L. & van As, D. 2012a. The Greenland Project. Yearly report 2010. Working Report 2012-16. Posiva Oy, Eurajoki. 174 s.

Harper, J., Hubbard, A., Ruskeeniemi, T., Claesson Liljedahl, L., Lehtinen, A., Booth, A., Brinkerhoff, D., Chandler, D., Drake, H., Dow, C., Doyle, S., Engström, J., Fitzpatrick, A., Frape, S., Helanow, C., Henkemans, E., Humphrey, N., Johnson, E., Johnson, J., Jones, G., Klint, KE., Kulessa, B., Landowski, C., Lindbäck, K., Luckman, A., Maddoc, L., Makahnouk, M., Meierbachtol, T., Pere, T., Pettersson, R., Pimentel, S., Quincey, D., Tullborg, E-L. & van As, D. 2012b. The Greenland Analogue Project, Yearly report 2011. Working Report 2012-79. Posiva Oy, Eurajoki.

Hartikainen, J. 2012. Simulations of Permafrost evolution at Olkiluoto. Working Report 2012-34. Posiva Oy, Eurajoki.

Hartley, L., Appleyard, P., Baxter, S., Hoek, J., Roberts D. & Swan, D. 2012a. Development of a Hydrogeological Discrete Fracture Network Model for the Olkiluoto Site Descriptive Model 2011. Working Report 2012-32. Posiva Oy, Eurajoki.

Hartley, L. ym. 2012b. Flow modelling for AOS. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Hartley, L. ym. 2012c. Modelling of open repository conditions, update of WR 2010-51. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Heikkinen, E. & Kantia, P. 2011. Suitability of ground penetrating radar for locating large fractures. Working report 2011-92. Posiva Oy, Eurajoki. 64 p.

Heikkinen, E. Ahokas, T., Heikkinen, P., Kristiansson, S., Tiensuu, K. & Pere, T. 2010. Summary of investigations in personnel shaft pre-grouting drillholes ONK-PP131, PP134 and PP137 in Olkiluoto, 2008. Working report 2010-34. Posiva Oy, Eurajoki. 126 p.

Heikkinen, E., Heinonen, S. & Ravimo, I. 2011. Semi-Automated Fracture Classification Procedure Based on Geophysical Drillhole Logging Data. Working Report 2011-88. Posiva Oy, Eurajoki.

Helin, J., Ikonen, A.T.K., & Salo, T. 2011. Crops and garden products near Olkiluoto repository site. Radioprotection 46(6): S35-S41.

Hellä, P. (ed.), Ikonen, A., Mattila, J., Torvela, T. & Wikström, L. 2009. RSC-programme - Interim Report. Approach and basis for RSC development, layout determining features and preliminary criteria for tunnel and deposition hole scale. Working Report 2009-29. Posiva Oy, Eurajoki. 118 p.

Helmisaari, H-S., Sah, S. & Aro, L. 2009. Fine roots on intensive forest ecosystem monitoring plots FIP4, FIP10 and FIP11 on Olkiluoto Island in 2008. Working Report 2009-127. Posiva Oy, Eurajoki. 29 s.

Holmberg, J. & Kuusela, P. 2011. Analysis of Probability of Defects in the Disposal Canisters. Working Report 2011-36. Posiva Oy, Eurajoki.

Holmström, S., Laukkanen, A. & Andersson, T. 2012a. EB-hitsatun kuparikapselin elastis-plastinen FEA-simulaatio sekä pitkäaikaisvirumiskokeiden analysointi. POSIVA 2012. Posiva Oy, Eurajoki. (in Finnish) (in print)

Holmström, S., Salonen, J. & Kinnunen, T. 2012b. Creep Properties of EB Welded Copper Overpack at 125–175 °C. Working Report 2012-3. Posiva Oy, Eurajoki.

Holowick, B. E., Dixon, D. A. & Martino, J. B. 2011. Enhanced Sealing Project (ESP): Project Status and Data Report for Period Ending 31 December 2010. NWMO APM-REP-01601-0004. Nuclear Waste Management Organisation, Toronto. (draft)

Huhta, P. 2010. Studies of Quaternary Deposits in Investigation Trench OL-TK17 on the Olkiluoto Study Site, Eurajoki, SW Finland. Working Report 2010-40. Posiva Oy, Eurajoki.

Hultquist, G., Szakálos, P., Graham, M. J., Sproule, G. I. & Wikmark, G. 2009. Detection of hydrogen in corrosion of copper in pure water. NACE International 2009.

Hurmerinta, E., Pekkanen, J., Komulainen, J. & Rouhiainen, P. 2012. Pressure, Flow and Hydraulic Interference Measurements in ONKALO at Olkiluoto, Drillholes ONK-PP262 and ONK-PP274. Working Report 2011-86. Posiva Oy, Eurajoki. 66 p.

Hökmark, H., Lönnqvist, M. & Fälth, B. 2010. THM-issues in repository rock. Thermal, mechanical, thermo-mechanical and hydro-mechanical evolution of the rock at the Forsmark and Laxemar sites. Technical Report TR-10-23. Svensk Kärnbränslehantering AB (SKB). Stockholm, Sweden.

IAEA 2006. Geological disposal of radioactive waste – Safety requirements. Safety Standards Series WS-R-4. International Atomic Energy Agency (IAEA), Vienna, Austria. 49 s. ISBN 92-0-105705-9, ISSN 1020-525X.

Ikonen, A.T.K. & Lipping, T. (eds.) 2011. Proceedings of a seminar on sea level displacement and bedrock uplift, 10-11 June 2010, Pori, Finland. Working Report 2011-07. Posiva Oy, Eurajoki. 134 s.

Ikonen, K. & Raiko, H. 2012. Thermal dimensioning of Olkiluoto spent fuel repository. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Ikonen, K. 2009. Thermal Dimensioning of Spent Fuel Repository. Working Report 2009-69. Posiva Oy, Eurajoki.

INFCIRC/140. Ydinsulkusopimus, Treaty on the non-proliferation of nuclear weapons (NPT), 22.4.1970.

INFCIRC/193. EU:n ydinaseettomien jäsenmaiden, Euratomin ja IAEA:n välinen valvontasopimus, 14.9.1997. (Suomen osalta voimassa 1.10.1995 alkaen).

INFCIRC/193/Add.8. Euroopan unionin ydinaseettomien jäsenvaltioiden, Euroopan Atomienergiayhteisön ja IAEA:n valvontasopimuksen lisäpöytäkirja ydinaseiden leviämisen estämistä koskevan sopimuksen III artiklan 1 ja 4 kohdan täytäntöön panemiseksi, 30.4.2004.

Inoue, A. 1983. Potassium fixation by clay minerals during hydrothermal treatment. Clays Clay Miner. 31, 81–91.

Inoue, A. 1995. Formation of clay minerals in hydrothermal environments. In: Velde, B. (ed.), Origin and Mineralogy of Clays, Springer, pp. 268-329.

Jaquet, O., Namah, R. & Jansson, P. 2010. Groundwater flow modelling under ice sheet conditions: scoping calculations. SKB R-10-46.

Johansson, E. 2011. VLJ-luolan kallioperän kalliomekaaninen monitorointi vuonna 2010. Working Report VLJ-3/11. TVO, Eurajoki. (in Finnish)

Johansson, E. 2012. VLJ-luolan kallioperän kalliomekaaninen monitorointi vuonna 2011. Working Report VLJ-2/12. TVO, Eurajoki. (in Finnish)

Joutsen, A. 2012. The Use of Geological Data from Pilot Holes for Predicting FPI (Full Perimeter Intersection) Fractures. Working Report 2012-12. Posiva Oy, Eurajoki. 52 p.

Juvankoski, M. 2009. Description of Basic Design for Buffer. Working Report 2009-131. Posiva Oy, Eurajoki.

Juvankoski, M. 2012. Buffer Design 2012. POSIVA 2012-14. Posiva Oy, Eurajoki.

Kallio, U., Nyberg, S., Koivula, H., Jokela, J. & Poutanen, M. 2011. GPS operations at Olkiluoto, Kivetty and Romuvaara in 2010. Working report 2011-75. Posiva Oy, Eurajoki. 58 p.

Kallonen, I., Eurajoki, T., Mayer, E., Ketolainen, A. & Rämä, T. 2008. Decommissioning of the Loviisa NPP. TJATE-G12-109. Fortum Nuclear Services Ltd. ISBN 978-951-591-085-4.

Kangasniemi, V., Helin, J., Kirkkala, T. & Ikonen, A.T.K. 2011. Concentration ratios to aquatic plants at and near Olkiluoto repository site. Radioprotection. 46(6): S29-S34.

Karvonen, T. H. 2012. Closure of the investigation boreholes. Working Report 2012-63. Posiva Oy, Eurajoki. (in print)

Karvonen, T. 2011a. Olkiluoto surface and near-surface hydrological modelling in 2010. Working Report 2011-50. Posiva Oy, Eurajoki.

Karvonen, T. H. 2011b. Foreign materials in the repository - update of estimated quantities. Working Report 2011-32. Posiva Oy, Eurajoki.

Karvonen, T. 2010. Prediction of Long-Term Influence of ONKALO and Korvensuo Reservoir on Groundwater Level and Water Balance Components on Olkiluoto Island. Working Report 2010-55. Posiva Oy, Eurajoki. 86 p.

Kaukonen, V., Hakanen, M. & Lindberg, A. 1997. Diffusion and Sorption of HTO, Np, Na and Cl in Rocks and Minerals of Kivetty and Olkiluoto. POSIVA 1997-07. Posiva Oy, Helsinki.

Kekki, T. & Tiitta, A. 2006. Selvitys voimalaitosjätteiden uusista pakkaus- ja loppusijoitustekniikoista. Lokakuu 2006, VTT-R-10086-06. (in Finnish)

Keski-Kuha, E., Nemlander, R. & Koho, P. 2012. BACEKO II, Flow-Through, Open-Front and Saturation Tests of Pre-Compacted Backfill Blocks in a Quarter-Scale Test Tunnel.Working Report 2012-41. Posiva Oy, Eurajoki.

Keto, V. 2010. Developing Two-Phase Flow Modelling Concepts for Rock Fractures. Working Report 2010-10. Posiva Oy, Eurajoki.

King, F. 2007. Mixed-potential modelling of the corrosion of copper in the presence of sulhides. Working Report 2007-63. Posiva Oy, Eurajoki.

King, F., Lilja, C., Pedersen, K., Pitkänen, P. & Vähänen, M. 2011. An Update of the State-of-the-art Report on the Corrosion of Copper Under Expected Conditions in a Deep Geologic Repository. POSIVA 2011-01. Posiva Oy, Eurajoki.

Kinnunen, P. & Varis, P. 2011. Stress Corrosion Cracking Investigation of Copper in Groundwater withAmmonium Under Potential Polarisation. Working Report 2011-5. Posiva Oy, Eurajoki.

Kirkkala, T. & Ryömä, H. 2011. Eurajoen kasvillisuusselvitys 2009–2010. Pyhäjärvi-instituutin julkaisuja B21. Pyhäjärvi Instituutti, Eura. 29 s. (in Finnish)

Kirkkomäki, T. & Rönnqvist, P-E., 2011. KBS-3H-tekniikka, asemointi ja vaiheittainen rakentaminen. Working Report 2010-77. Posiva Oy, Eurajoki. (in Finnish)

Kirkkomäki, T. 2009. Loppusijoituslaitoksen teknisten tilojen sekä matala- ja keskiaktiivisen laitosjätetilan suunnitelmaselostus. Working Report 2009-120. Fortum Nuclear Services Oy. (in Finnish)

Kirkkomäki, T. 2012. Loppusijoituslaitoksen asemointi ja vaiheittainen rakentaminen 2012. Working Report 2012-69. Posiva Oy, Eurajoki. (in Finnish) (in print)

Kivikoski, H. & Marjavaara, P. 2011. Filling the Gap Between Buffer and Rock in the Deposition Hole. Working Report 2011-33. Posiva Oy, Eurajoki.

Kiviranta, L. & Kumpulainen, S. 2011. Quality Control and Characterization of Bentonite Materials. Working Report 2011-84. Posiva Oy, Eurajoki.

Koistinen, T. & Käyhkö, N. 2011. Eurajoen maisema- ja maankäyttöhistoria 1840–2007: paikkatietoaineistojen käsittely ja muutosten kartoitus. Working Report 2011-82. Posiva Oy, Eurajoki. (in Finnish)

Koivula, H., Kallio, U., Nyberg, S., Jokela, J. & Poutanen, M. 2012. GPS Operations at Olkiluoto in 2011. Working Report 2012-36. Posiva Oy, Eurajoki. 58 p.

Komulainen, J., Pöllänen, J. & Lamminmäki, T. 2012a. Electrical Conductivity and Water Sampling Measurements at the Olkiluoto Site in Eurajoki, Drillholes OL-KR50, OLKR54 and OL-KR55. Working Report 2012-30. Posiva Oy, Eurajoki.

Komulainen, J., Pöllänen, J., Hurmerinta, E. & Ripatti, K. 2012b. Difference Flow and Electrical Conductivity Measurements at the Olkiluoto Site in Eurajoki, Drillholes OL-KR54, OL-KR55, OL-KR55B and OL-KR47B. Working Report 2012-11. Posiva Oy, Eurajoki.

Korpisalo, A. & Niemelä, M. 2010. Cross-borehole research with EMRE-system: Radiofrequency measurements in drillhole section OL-KR40-OL-KR45 in Olkiluoto 2009. Working report 2010-24. Posiva Oy, Eurajoki. 88 p.

Koskinen, V. 2012. Uniaxial backfill block compaction. Working Report 2012-21. Posiva Oy, Eurajoki. (in print)

Kristiansson, S. & Heikkinen, P. 2009. Mise-a-la-Masse Measurements in Drillholes OL-KR4, OL-KR30 and OL-KR14–OL-KR18 at Olkiluoto. Working report 2009-10. Posiva Oy Eurajoki. 240 p.

Kukkola, T. & Eurajoki, T. 2009. Kapselointilaitoksessa syntyvät radioaktiiviset jätteet. Working Report 2009-49. Posiva Oy, Eurajoki. (in Finnish)

Kukkola, T. 2012. Encapsulation Plant Design 2012, Repository Connected Facility. Working Report 2012-49. Posiva Oy, Eurajoki. (in print)

Kukkonen, I., Suppala, I., Korpisalo, A. & Koskinen,T. 2011a. Measurements of Rock Thermal Properties in Olkiluoto with the TERO76 Device: Drillholes OL-KR30, OL-KR31 and ONK-PVA4. Working Report 2011-78. Posiva Oy, Eurajoki. 30 p.

Kukkonen, I., Korpisalo, A. & Koskinen, T. 2011b. Inverse Temperature Gradient Method for Estimating Thermal Conductivity in Drillholes. Working Report 2011-79. Posiva Oy, Eurajoki. 30 p.

Kukkonen, I., Kivekäs, L., Vuoriainen, S. & Kääriä, M. 2011c. Thermal Properties of Rocks in Olkiluoto: Results of Laboratory Measurements 1994–2010. Working Report 2011-17. Posiva Oy, Eurajoki. 96 p.

Kukkonen, I., Paananen, M., Elo, S., Paulamäki, S., Laitinen, J., Hire Working Group of the Geological Survey of Finland, Heikkinen, P. & Heinonen, S. 2010. HIRE Seismic Reflection Survey in the Olkiluoto Area. Working report 2010-57. Posiva Oy, Eurajoki. 62 p.

Kumpulainen, S. & Kiviranta, L. 2010. Mineralogical and chemical characterization of various bentonite and smectite-rich clay materials. Part A: comparison and development of mineralogical characterization methods. Part B: mineralogical and chemical characterization of clay materials. Working Report 2010-52. Posiva Oy, Eurajoki.

Kumpulainen, S. & Kiviranta, L. 2011. Mineralogical, chemical and physical study of potential buffer and backfill materials from ABM test package 1. Working Report 2011-41. Posiva Oy, Eurajoki.

Kumpulainen, S., Carlsson, T., Muurinen, A., Kiviranta, L., Svensson, D., Sasamoto, H., Yui, M., Wersin, P. & Rosch, D. 2010. Long-Term Alteration of Bentonite in the Presence of Metallic Iron. Working Report 2010-71. Posiva Oy, Eurajoki.

Kurimo, M. 2009. Aerogeophysical Survey in Olkiluoto 2009. Working report 2009-67. Posiva Oy, Eurajoki. 24 p.

Kuutti, J., Hakola, I. & Fortino, S. 2012. Analyses of disposal canister falling accidents. POSIVA 2012-36. Posiva Oy, Eurajoki. (in print)

Kuva, J., Timonen, J., Kelokaski, M., Ikonen, J., Siitari-Kauppi, M., Lindberg, A. & Aaltonen, I. 2012. Microstructure, Porosity and Mineralogy Around Fractures in Olkiluoto Bedrock. POSIVA 2012-02. Posiva Oy, Eurajoki. ISBN 978-951-652-183-4. 114 s.

Käpyaho, E. (ed.), Ahokas, H., Penttinen, T., Korkealaakso, J., Karvonen, T., Trinchero, P., Molinero, J., Luna, M., Jimenez, S., & Ruiz E. 2012. The Infiltration Experiment – Monitoring and Modelling results of 2009. Working Report 2012-31. Posiva Oy, Eurajoki.

Laakkonen, M. 2011a. Residual Stress Measurement of Electron Beam Welded Copper Plates Using Prism Hole Drilling Method. Stresstech Oy. Working Report 2011-96. Posiva Oy, Eurajoki.

Laakkonen, M. 2011b. Strain and Stress Measurement in Four Point Bending Device Using Prism Hole Drilling Method. Stresstech Oy. Working Report 2011-97. Posiva Oy, Eurajoki.

Lahdenperä, A-M. & Keskinen, A. 2011. Chemical and Physical Properties of the Surface Sea Sediments at the Olkiluoto Offshore, South-Western Finland. Working report 2011-80. Posiva Oy, Eurajoki.

Lahti, M. (ed.) & Siren, T. 2012. Results of monitoring in Olkiluoto 2010 - Rock mechanics. Working Report 2011-47. Posiva Oy, Eurajoki. 86 p.

Lehmuskoski, P. 2010. Precise levelling campaigns at Olkiluoto in 2008 and 2009. Working report 2010-30. Posiva Oy, Eurajoki. 252 p.

Lehtonen, A. 2011. Olkiluodon VLJ-luolan hydrologinen monitorointi vuonna 2010. Working Report VLJ-2/11. TVO, Eurajoki. (in Finnish)

Lehtonen, A. 2012. Olkiluodon VLJ-luolan hydrologinen monitorointi vuonna 2011. Working Report VLJ-3/12. TVO, Eurajoki. (in Finnish)

Leikko, J., Taskinen, P. & Karvinen., R. 2011. Simulation of Residual Stresses and Deformations in Electron Beam Welded Copper Test Plate. Tampere University of Technology. Working Report 2011-94. Posiva Oy, Eurajoki.

Leväniemi, H. 2008. Aeromagnetic Survey in Eurajoensalmi, Olkiluoto 2008. Working Report 2008-57. Posiva Oy, Eurajoki.

Lindberg, A. 2010. Geological Mapping of Investigation Trench OL-TK17 at the Olkiluoto Study Site, Eurajoki, SW Finland. Working Report 2010-1. Posiva Oy, Eurajoki.

Lund, B. & Schmidt, P. 2011. Stress evolution and fault stability at Olkiluoto during the Weichselian glaciations. Working Report 2011-14. Posiva Oy, Eurajoki.

Lunkka, J. P. & Erikkilä, A. 2012. Behaviour of the Lake District ice lobe during the Younger Dryas chronozone (12.8 – 11.6 ka). Working Report 2012-16. Posiva Oy, Eurajoki. 54 s.

Lusa, M., Ämmälä, K., Hakanen, M., Lehto, J. & Lahdenperä, A-M. 2009. Chemical and geotechnical analyses of soil samples from Olkiluoto for studies on sorption in soils. Working Report 2009-33. Posiva Oy, Eurajoki. 151 s.

Löfman, J. & Karvonen, T. 2012. Hydrogeological evolution at Olkiluoto. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Löfman, J., Mészáros, F., Keto, V., Pitkänen, P. & Ahokas, H. 2009. Modelling of Groundwater Flow and Solute Transport in Olkiluoto - Update 2008. Working Report 2009-78. Posiva Oy, Eurajoki. 274 p.

Löfman, J., Poteri, A. & Pitkänen, P. 2010. Modelling of salt water upconing in Olkiluoto. Working Report 2010-25. Posiva Oy, Eurajoki.

Marjavaara, P. & Holt, E. 2012. Customized Pellets for Buffer. Working Report 2012-62. Posiva Oy, Eurajoki. (in print)

Leoni, M. 2012. 2D and 3D finite element analysis of buffer-backfill interaction. POSIVA 2012. Posiva Oy, Eurajoki. (in print)

Martino, J.B., Dixon, D.A., Holowick, B. E. & Kim, C-S. 2011. Enhanced Sealing Project (ESP): Seal Construction and Instrumentation Report. NWMO APM-REP-01601-0003. Nuclear Waste Management Organisation, Toronto. (draft)

Martinsson & Sandström 2012. Hydrogen depth profile in phosphorous-doped, oxygen free copper after cathodic charging. (in print)

McEwen, T. (ed), Aro, S., Hellä, P., Kosunen, P., Käpyaho, A., Mattila, J., Pere, T. & RSC working group 2012. Rock Suitability Classification - RSC 2012. POSIVA 2012-24. Posiva Oy, Eurajoki. (in print)

Meuronen, I. & Salonen, T. 2010. Welding of the Lid and Bottom of the Disposal Canister. POSIVA 2010-05. Posiva Oy, Eurajoki.

Milnes, A. G., 2011. Understanding Brittle Deformation at the Olkiluoto Site. Literature Supplement 2010: An Update of Posiva Working Report 2006-25. Working Report 2011-38. Posiva Oy, Eurajoki. 80 s.

Mustonen, S., Norokallio, J., Mellanen, S., Lehtimäki, T. & Heikkinen, E. 2010. EDZ09 Project and Related EDZ Studies in ONKALO 2008–2010. Working Report 2010-27. Posiva Oy, Eurajoki. 404 p.

Mykkänen, J., Kiirikki, M. & Lindfors, A. 2012. Resuspensio ja kiintoaineen kulkeutuminen Eurajoensalmessa - Vesistömittausten loppuraportti. Working report 2012. Posiva Oy, Eurajoki. (in Finnish) (in print)

Mönkkönen, H. 2012. Models of bedrock surface and overburden thickness over Olkiluoto Island and nearby sea area. Working report 2012-15. Posiva Oy, Eurajoki.

Mönkkönen, H., Hakala, M., Paananen, M. & Laine, E. 2012. ONKALO Rock Mechanics Model (RMM) - Version 2.0. Working Report 2012-02. Posiva Oy, Eurajoki. 94 p.

Nieminen, J. 2012. Kapselointilaitoksen ilmastointijärjestelmät. Working Report 2012-55. Posiva Oy, Eurajoki. (in Finnish) (in print)

Nolvi, L. 2009. Manufacture of Disposal Canisters. POSIVA 2009-03. Posiva Oy, Eurajoki. 76 p.

Nummi, O., Kyllönen, J. & Eurajoki, T. 2012. Long-term safety of the maintenance and decommissioning waste of the encapsulation plant. POSIVA 2012-37. Posiva Oy, Eurajoki. (in print)

Nykyri, M. 2012. Suuren mittakaavan VLJ-kaasunkehityskoe, raportointikausi 2006–2011. Working Report VLJ-1/12. TVO, Eurajoki. (in Finnish)

Nykyri, M., Gardemeister, A., Keto, P., Kokko, M. & Riekkola, R. 2008. VLJ-luolan laajentamisen esisuunnitelma 2008. VLJ-4/08. Teollisuuden Voima Oyj. (in Finnish)

Olsson, M., 2010. Guidance document for tunnel blast design with focus to minimize the damage zone. Report 2010-4. Swebrec Oy.

Palmen, J., Nummela, J. & Ahokas, H. 2011. Correlation of Transmissive Fractures in Holes OL-PH1, ONK-PH2–ONK-PH7 and ONKALO Tunnel Fractures. Working Report 2011-11. Posiva Oy, Eurajoki. 36 p.

Palmen, J., Tammisto, E. & Ahokas, H. 2010. Database for Hydraulically Conductive Fractures - Update 2009. Working Report 2010-13. Posiva Oy, Eurajoki. 64 p.

Palomäki, J. & Ristimäki, L. 2012. Facility Description 2012. Working Report 2012-66. Posiva Oy, Eurajoki. (in print)

Paunonen, M., Kelokaski, P., Eurajoki, T. & Kyllönen, J. 2012. Waste Streams at the Encapsulation Plant. Working Report 2012-70. Posiva Oy, Eurajoki. (in print)

Pedersen, K., Arlinger, J., Edlund, J., Eriksson, L., Hallbeck, L., Johansson, J. & Rabe, L. 2012. Sulphate Reduction Experiment – SURE-1. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Pekkanen, J., Hurmerinta, E., Pöllänen, J. & Väisäsvaara, J. 2011. Difference Flow and Electrical Conductivity Measurements at the Olkiluoto Site in Eurajoki, Drillholes OL-KR51, OL-KR52, OL-KR52B, OL-KR53 and OL-KR53B. Working Report 2010-81. Posiva Oy, Eurajoki.

Penttinen, T., Partamies, S., Lahdenperä, A-M., Sireni, S., Lehtinen, A. & Lamminmäki, T. 2012a. Results of Monitoring at Olkiluoto in 2010 – Hydrogeochemistry. Working Report 2011-44. Posiva Oy, Eurajoki. (in print)

Penttinen, T., Partamies, S., Lahdenperä, A-M., Ahokas, T., Lehtinen, A. & Lamminmäki, T. 2012b. Results of Monitoring at Olkiluoto in 2011 – Hydrogeochemistry. Working Report 2012-44. Posiva Oy, Eurajoki. (in print)

Pere, T. (ed.), Ahokas, H., Lindgren, S., Mattila, J., Vaittinen, T. & Wikström, L. 2012. Layout determining features, their influence zones and respect distances at the Olkiluoto site. POSIVA 2012-21. Posiva Oy, Eurajoki.

Pimenoff, N., Venäläinen, A. & Järvinen, H. 2011. Climate scenarios for Olkiluoto on a time scale of 120 000 years. POSIVA 2011-04. Posiva Oy, Eurajoki.

Pitkänen, J. 2010. Inspection of bottom and lid welds of disposal canister. POSIVA 2010-04. Posiva Oy, Eurajoki. ISBN 978-951-652-175-9.

Pitkänen, J. 2012. Inspection of Disposal Canister Components. POSIVA 2012-35. Posiva Oy, Eurajoki. ISBN 978-951-652-216-9.

Pitkänen, P. & Partamies, S. 2007. Origin and Implications of Dissolved Gases in Groundwater at Olkiluoto. POSIVA 2007-04. Posiva Oy, Eurajoki.

Pitkänen, P., Ahokas, H., Ylä-Mella, M., Partamies, S., Snellman, M. & Hellä, P. (ed.) 2007. Quality Review of Hydrochemical Baseline Data from the Olkiluoto Site. POSIVA 2007-05. Posiva Oy, Eurajoki.

Pitkänen, P., Korkealaakso, J., Löfman, J., Keto, V., Lehtinen, A., Lindgren, S., Ikonen, A., Aaltonen, I., Koskinen, L., Ahokas, H., Ahokas, T. & Karvonen, T. 2008

Investigation Plan for Infiltration Experiment in Olkiluoto. Working Report 2008-53. Posiva Oy, Eurajoki.

Pohjola, J., Turunen, J. & Lipping, T. 2012. Statistical estimation of land uplift model parameters based on archaeological and geological shore level displacement data. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Posiva 1999a. Käytetyn ydinpolttoaineen loppusijoituslaitos - Ympäristövaikutusten arviointiselostus. Posiva Oy, Helsinki.

Posiva 1999b. Käytetyn ydinpolttoaineen loppusijoituksen periaatepäätöshakemus. Posiva Oy, Helsinki.

Posiva 2003a. TKS-2003 Nuclear Waste Management of the Olkiluoto and Loviisa Power Plants: Programme for Research, Development and Technical Design for 2004-2006. Olkiluoto, Finland: Posiva Oy. 288 s.

Posiva 2003b. Programme of monitoring at Olkiluoto during construction and operation of the ONKALO. POSIVA 2003-05. Posiva Oy, Eurajoki. 92 p. ISBN 951-652-119-3.

Posiva 2008a. Periaatepäätöshakemus käytetyn ydinpolttoaineen loppusijoituslaitoksen laajentamiseksi Olkiluoto 4 -yksikköä varten. Posiva Oy, Eurajoki.

Posiva 2008b. Käytetyn ydinpolttoaineen loppusijoituslaitoksen laajentaminen - Ympäristövaikutusten arviointiselostus. Posiva Oy, Eurajoki.

Posiva 2008c. Safety Case Plan 2008. POSIVA 2008-5.

Posiva 2009a. Periaatepäätöshakemus käytetyn ydinpolttoaineen loppusijoituslaitoksen laajentamiseksi Loviisa 3 -yksikköä varten. Posiva Oy, Eurajoki.

Posiva 2009b. Olkiluoto Site Description 2008. POSIVA 2009-01. Posiva Oy, Eurajoki. 714 p. ISBN 978-951-652-169-8.

Posiva 2009. TKS-2009. Nuclear Waste Management at Olkiluoto and Loviisa Power Plants: Review of Current Status and Future Plans for 2010–2012. Posiva Oy, Eurajoki.

Posiva 2011. The Greenland Analogue Project. Yearly Report 2009. Working Report 2011-54. Posiva Oy, Eurajoki. 114 s.

Posiva 2012a. Monitoring at Olkiluoto - a programme for the period before repository operation. POSIVA 2012-01.

Posiva 2012b. Nuclear waste management of the Olkiluoto and Loviisa nuclear power plants - Summary of the activities during 2011. Posiva Oy, Eurajoki.

Påsse, T. 2001. An empirical model of glacio-isostatic movements and shore-level displacement in Fennoscandia. SKB R-01-41.

Raiko, H. 2012. Canister Design 2012. POSIVA 2012-13. Posiva Oy, Eurajoki. ISBN 978-951-652-194-0.

Rantataro, J. & Kaskela, A. 2009. Acoustic seismic studies in the sea area close to Olkiluoto, 2008. Working Report 2009-112. Posiva Oy, Eurajoki. 84 s.

Rautio, T. 2006. Borehole plugging experiment in OL-KR24 at Olkiluoto. Working Report 2006-35. Posiva Oy, Eurajoki.

Ritola, J. & Peura, J. 2012. Buffer Moisture Protection System. Working Report 2012-05. Posiva Oy, Eurajoki.

Ritola, J. & Pyy, E. 2011. Isostatic Compression of Buffer Blocks - Middle Scale. Working Report 2011-62. Posiva Oy, Eurajoki.

Roaldset, E., Wei, H. & Grimstad, S. 1998. Smectite to illite conversion by hydrous pyrolysis. Clay Miner. 33, 147– 158.

Romppanen, A.-J. & Immonen, E. 2011. Residual Stress Measurement with Contour Method. Process Flow Oy. Working Report 2011-95. Posiva Oy, Eurajoki.

Rouhiainen, P. 1994. Paineellisen pohjavesinäytteen otto kaasuanalyysiä varten, esiselvitys. Working Report PATU-94-23. (in Finnish)

Ruotsalainen, P. (toim.), Alhonmäki-Aalonen, S., Aalto, E., Helenius, J. & Sellge, R. 1996. Paineellisten vesinäytteiden ottolaitteiston kehitys. Working Report PATU-96-82. (in Finnish)

Saanio, T., Ikonen, A., Keto, P., Kirkkomäki, T., Kukkola, T., Nieminen, J. & Raiko, H. 2012. Loppusijoituslaitoksen suunnitelma 2012. Working Report 2012-50. Posiva Oy, Eurajoki. (in print)

Saari, J. & Malm. M. 2011. Local seismic network at the Olkiluoto site, Annual report for 2010. Working report 2011-73. Posiva Oy, Eurajoki. 37 p.

Saari, J. 2012. Seismic Activity Parameters of the Olkiluoto Site. POSIVA 2012. Posiva Oy, Eurajoki. (in print)

Schatz, T. & Martikainen, J. 2011. Laboratory Studies on the Effect of Freezing and Thawing Exposure on Bentonite Buffer Performance: Closed-System Tests. POSIVA 2010-06. Posiva Oy, Eurajoki.

Schatz, T. & Martikainen, J. 2012. Laboratory tests and analyses on potential Olkiluoto backfill materials. Working Report 2012-74. Posiva Oy, Eurajoki. (in print)

Siren, T. 2011. Fracture Mechanics Prediction for Posiva’s Olkiluoto Spalling Experiment (POSE). Working Report 2011-23. Posiva Oy, Eurajoki. 30 p.

Siren, T., Martinelli, D. & Uotinen, L. 2011. Assessment of the Potential for Rock Spalling in the Technical Rooms of the ONKALO. Working Report 2011-35. Posiva Oy, Eurajoki. 40 p.

Sireni, S. (ed.), Ahokas, T. & Paananen, M. 2011. Suitability of seismic investigations for detailed characterisation of Olkiluoto bedrock. Working report 2011-91. Posiva Oy, Eurajoki. 210 p.

Sireni, S. 2011. Applicability of reflection seismic measurements in detailed characterization of crystalline bedrock. Working report 2011-24. Posiva Oy, Eurajoki. 122 p.

SKB 2012. KBS-3H Complementary studies 2008–2010. Report TR-12-01. Svensk Kärnbränslehantering AB. (in print)

Small, J., Nykyri, M., Helin, M., Hovi, U., Sarlin, T. & Itävaara. M. 2008. Experimental and modelling investigations of the biogeochemistry of gas production from low and intermediate level radioactive waste. Applied Geochemistry, Volyme 23, issue 6, June 2008.

Soler, J.M. 2010. Reactive Transport Modeling of Grout-Rock Interaction at the ONKALO Site. Working Report 2010-73. Posiva Oy, Eurajoki.

Soler, J.M. 2011. Reactive Transport Modelling of Grout-Water Interaction in a Fracture at the ONKALO Site - Effect of Different Potential Groundwater Compositions. Working Report 2011-83. Posiva Oy, Eurajoki.

Stotler, R.L., Frape, S.K., Ruskeeniemi, T., Pitkänen, P. & Blowes, D.W. 2012. The interglacial–glacial cycle and geochemical evolution of Canadian and Fennoscandian Shield groundwaters. Geochimica et Cosmochimica Acta, 76, pp. 45–67.

Suikki, M. 2011. Canister transfer trolley and canister transfer corridor equipment. Working Report 2011-57. Posiva Oy, Eurajoki.

Suikki, M. 2012a. The fuel handling machine and the auxiliary systems of the fuel handling cell. Working Report 2012-54. Posiva Oy, Eurajoki. (in print)

Suikki, M. 2012b. Remote controlled mover for disposal canister transfer. Working Report 2012-53. Posiva Oy, Eurajoki. (in print)

Suolanen, V. & Rossi, J. 2012. Käytetyn ydinpolttoaineen kuljetusten riskienhallinta. Working Report 2012-67. Posiva Oy, Eurajoki. (in Finnish) (in print)

Söderlund, M. & Lehto, J. 2012. Sorption of Molybdenum, Niobium and Selenium in Soils. Working Report 2012-38. Posiva Oy, Eurajoki.

Söderlund, M., Lusa, M., Lehto, J., Hakanen, M., Vaaramaa, K. & Lahdenperä, A-M. 2011. Sorption of Iodine, Chlorine, Technetium and Cesium in Soil. Working Report 2011-04. Posiva Oy, Eurajoki. 130 s.

Söderlund, M., Lusa, M., Virtanen, S., Välimaa, I., Hakanen, M., Lehto, J. & Lahdenperä, A-M. 2012. Distribution coefficients of cesium, chlorine, iodine, niobium, selenium and technetium on Olkiluoto soils. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Tammisto, E. & Palmen, J. 2011. Database for Hydraulically Conductive fractures - Update 2010. Working Report 2011. Posiva Oy, Eurajoki. (in print)

Tammisto, E., Palmen, J. & Ahokas, H. 2009. Database for Hydraulically Conductive Fractures. Working Report 2009-30. Posiva Oy, Eurajoki. 110 p.

Tarvainen, A-M. 2012. Geophysical logging and imaging of shallow drillholes ONK-PP318, 319, 320, 323, 324, 326 and 327 in the ONKALO investigation niche 5. Working report 2012. Posiva Oy, Eurajoki. (in print)

Tarvainen, A-M. & Heikkinen, E. 2011. Geophysical Drillhole Logging and Imaging of Drillholes OL-KR54, OL-KR55 and OL-KR55B at Olkiluoto in 2010 and 2011. Working report 2011-58. Posiva Oy, Eurajoki. 132 p.

Tarvainen, A-M. 2011a. Geophysical logging and imaging of characterisation drillholes ONK-KR13, ONK-KR14 and ONK-KR15. Working report 2011-59. Posiva Oy, Eurajoki. 86 p.

Tarvainen, A-M. 2011b. ONKALO Pose experiment- Geophysical logging and imaging of drillholes ONK-PP223, ONK-PP226, ONK-PP254, ONK-PP259-261. Working report 2011-60. Posiva Oy, Eurajoki. 140 p.

Tarvainen, A-M. 2011c. Geophysical logging and imaging of shallow drillholes ONK-PP262 and ONK-PP274 at Olkiluoto in 2010. Working report 2011-74. Posiva Oy, Eurajoki. 140 p.

Tarvainen, A-M. 2010a. Geophysical Drillhole Logging and Optical Imaging of the Drillholes OL-KR49, OL-KR49B, OL-KR50, OL-KR50B and complement of OL-KR45 at Olkiluoto 2009. Working report 2010-23. Posiva Oy, Eurajoki. 138 p.

Tarvainen, A-M. 2010b. Geophysical Drillhole Logging and Imaging of Drillholes OL-KR51, OL-KR52, OL-KR52B, OL-KR53 and OL-KR53B at Olkiluoto in 2009 and 2010. Working Report 2010-74. Posiva Oy, Eurajoki. 108 p.

Tarvainen, A-M. 2010c. Mise-à-la-masse measurements at Olkiluoto in 2010. Working report 2010-76, Posiva Oy, Eurajoki. 92 p.

TKS-2009. Nuclear Waste Management at Olkiluoto and Loviisa Power Plants: Review of Current Status and Future Plans for 2010–2012. Posiva Oy, Eurajoki.

Tohidi, B., Chapoy, A., Smellie, J. & Puigdomenech, I. 2010. The potential for methane hydrate formation in deep repositories of spent nuclear fuel in granitic rock. Report R-10-58. Swedish Nuclear Fuel and Waste Management Co. (SKB). Stockholm, Sweden. 26 p. ISSN 1402-3091

Toropainen, V. 2012. Core drilling of HYDCO drillholes ONK-PP262 and ONK-PP274 in ONKALO at Olkiluoto. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Trinchero, P., Román-Ross, G., Maia, F. & Molinero, J. 2012a. Hydrogeochemical evolution of the Olkiluoto Site. (in print)

Trinchero, P., Molinero, J., Luna, M., Jimenez, S. & Ruiz, E. 2012b. Coupled groundwater flow and reactive transport modeling of the Infiltration Experiment. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Tsutomu, S., Takashi, M., Hiroshi, I. & Toshihiko, O. 1995. Effect of crystallochemistry of starting materials on the rate of smectite to illite reaction. Mater. Res. Soc. Symp. roc. 353, 239– 246.

Tuisku, P. & Kärki, A. 2010. Metamorphic Petrology of Olkiluoto. Working Report 2010-54. Posiva Oy, Eurajoki. 76 s.

Tuominen, J. 2012. Kapselointi- ja loppusijoituslaitoksen sähköjärjestelmät. Working Report 2012-24. Posiva Oy, Eurajoki. (in Finnish)

TVO 2008. Olkiluodon ydinvoimalaitoksen käytöstäpoiston suunnitelma 2008. TVO-1/08. Teollisuuden Voima Oyj, Fortum Nuclear Services Oy, Safram Oy. ISSN 1465-1514. (in Finnish)

Vainio, J. 2011. Coordinate Measuring of Wire-Cut Surfaces. Tampere University of Technology. Working Report 2011-93. Posiva Oy, Eurajoki.

Vaittinen, T. & Pentti, E. 2012. Compilation and analysis of hydrogeological responses to field activities in Olkiluoto during 2006–2009. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Vaittinen, T., Ahokas, H. & Nummela, J. 2010a. Hydrogeological Analysis of Pressure Responses During Excavation Through HZ20 Zones. Working Report 2010-12. Posiva Oy, Eurajoki. 74 p.

Vaittinen, T., Ahokas, H., Klockars, J., Nummela, J., Pentti, E., Penttinen, T., Tammisto, E., Karvonen, T. & Lindgren, S. 2010b. Results of Monitoring at Olkiluoto in 2009, Hydrology. Working Report 2010-43. Posiva Oy, Eurajoki. 272 p.

Vaittinen, T., Ahokas, H., Klockars, J., Nummela, J., Pentti, E., Penttinen, T., Pöllänen, J., Karvonen, T. & Lindgren, S. 2012a. Results of Monitoring at Olkiluoto in 2010 – Hydrology. Working Report 2011-43. Posiva Oy, Eurajoki. 378 p.

Vaittinen, T., Ahokas, H., Klockars, J., Nummela, J., Pentti, E., Penttinen, T., Pöllänen, J., Karvonen, T. & Lindgren, S. 2012b. Results of Monitoring at Olkiluoto in 2011 – Hydrology. Working Report 2012-43. Posiva Oy, Eurajoki. (in print)

Vaittinen, T., Ahokas, H., Nummela, J. & Paulamäki, S. 2011. Hydrogeological Structure Model of the Olkiluoto Site - Update in 2010. Working Report 2011-65. Posiva Oy, Eurajoki. 329 p.

Vaittinen, T., Nummela, J. & Ahokas, H. 2008. Compilation and analysis of hydrogeological responses to field activities in Olkiluoto. Working Report 2008-03. Posiva Oy, Eurajoki. 213 p.

Valkiainen, M., Aalto, H., Lindberg, A., Olin, M. & Siitari-Kauppi, M. 1995. Diffusion in the matrix of rocks from Olkiluoto – the effect of anion exclusion. Report YJT-95-20. Nuclear waste commission of Finnish power companies. 38 p.

Valli, J., Kuula, H. & Hakala, M. 2011. Modelling of the in situ Stress State at Olkiluoto. Working Report 2011-34. Posiva Oy, Eurajoki.

Valtioneuvosto 2000. Valtioneuvoston periaatepäätös 21. päivänä joulukuuta 2000 Posiva Oy:n hakemukseen Suomessa tuotetun käytetyn ydinpolttoaineen loppusijoituslaitoksen rakentamisesta. Valtioneuvosto, Helsinki.

Valtioneuvosto 2002. Valtioneuvoston periaatepäätös 17. päivänä tammikuuta 2002 Posiva Oy:n hakemukseen käytetyn ydinpolttoaineen loppusijoituslaitoksen rakentamisesta laajennettuna. Valtioneuvosto, Helsinki.

Valtioneuvosto 2010. Valtioneuvoston periaatepäätös 6. päivänä toukokuuta 2010 Posiva Oy:n hakemukseen käytetyn ydinpolttoaineen loppusijoituslaitoksen rakentamisesta laajennettuna. Valtioneuvosto, Helsinki.

Vesikari, E. & Koskinen, P. 2012. Durability of Concrete Barriers in Final Depositories of Nuclear Waste. VTT-R-01185-12. VTT, Espoo.

Vieno, T., Lehikoinen, J., Löfman, J., Nordman, H. & Mészáros, F. 2003. Assessment of Disturbances Caused by Construction and Operation of ONKALO. POSIVA 2003-6. Posiva Oy, Eurajoki.

Virtanen, S. 2011. Luonnon radionuklidien fraktiointi vaiheittaisten uuttojen avulla maaperä- ja sedimenttinäytteistä. Working Report 2011-55. Posiva Oy, Eurajoki. 98 s. (in Finnish)

Vuorela, A., Penttinen, T. & Lahdenperä, A-M. 2009. Review of Bothnian Sea Shore-Level Displacement Data and Use of a GIS Tool to Estimate Isostatic Uplift. Working Report 2009-17. Posiva Oy, Eurajoki.

Väisäsvaara, J. 2010. Difference Flow and Electrical Conductivity Measurements at the Olkiluoto Site in Eurajoki, Drillholes OL-KR49, OL-KR50 and OL-KR50B. Working Report 2010-16. Posiva Oy, Eurajoki.

Wersin, P., Kiczka, M. & Rosch, D. 2012a. Safety case for a spent nuclear fuel repository at Olkiluoto: Radionuclide solubility limits and migration parameters for the canister and buffer. POSIVA 2012. Posiva Oy, Eurajoki. (in print)

Wersin, P., Pitkänen, P., Snellman, M., Román-Ross, G., Smith, P., Filby, A. & Kiczka, M. 2012b. Sulphide fluxes in the spent nuclear fuel repository at Olkiluoto. Working Report 2012. Posiva Oy, Eurajoki. (in print)

Åkesson, U. 2012. Laboratory Measurements of the Coefficient of Thermal Expansion of Olkiluoto Drill Core Samples. Working Report 2012-14. Posiva Oy, Eurajoki. 31 p.