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**Keywords:** nuclear safeguards, spent nuclear fuel, final disposal, monitoring, seismicity, hydrogeology

# Summary

In relation to the construction of a disposal facility for spent nuclear fuel in Olkiluoto, Posiva Oy runs a multidisciplinary monitoring programme targeted at studying the environmental impact of the project, improving the understanding of the natural properties of the site, verifying favourable conditions for long-term safety, and developing methods for monitoring the performance of engineered barriers. The aim of this report is to assess the usability of the data produced by the monitoring programme for the implementation of nuclear safeguards, which in the case of a disposal facility under construction primarily involves detecting the excavation of any undeclared underground rooms or surface construction.

Among the measurements included in the programme, microseismic monitoring is currently the only one whose results, located seismic events in Olkiluoto and surroundings are already used in implementing national safeguards. An examination of the monitoring programme leads to the conclusion that, in addition to microseismic monitoring, automatic hydraulic head measurements in deep drillholes and land use monitoring produce relevant data for safeguards.

Hydraulic head (in other words, groundwater pressure) is monitored in several drillholes that penetrate the rock volume where the disposal facility is going to be excavated. The monitored drillholes are divided into sections, so that head can be measured separately at different depths. The monitored sections are often situated in hydrogeological zones, where a fault in the crystalline bedrock allows groundwater to flow significantly more freely than elsewhere. Experience has shown that, in some of these zones, a groundwater leak into a new tunnel or drillhole at one point gives rise to a significant decrease of hydraulic head at such a large distance that it can be readily detected in several monitoring sections.

Monitoring of land use is based on aerial photographs taken every other year and maintaining a land use record. These sources are used to regularly update a land use grid covering the whole of Olkiluoto. The aerial photographs and land use grid can supplement other imagery used to verify the declaration of surface constructions.

The inclusion of the results of hydraulic head and land use monitoring in the input for the implementation of safeguards could apparently be achieved by examining material that Posiva already delivers for other purposes. The estimated work load would be of the order of a week per year for hydraulic head monitoring and a few days per year for land use monitoring.

*PENTTI Elias, HEIKKINEN Eero (Pöyry Finland Oy). Olkiluodon monitorointiohjelman käytettävyys ydinmateriaalivalvonnassa. STUK-TR 28. Helsinki 2017. 31 pp.*

**Avainsanat:** ydinmateriaalivalvonta, käytetty ydinpolttoaine, loppusijoitus, monitorointi, seismiikka, hydrogeologia

# Tiivistelmä

Posiva Oy ylläpitää käytetyn ydinpolttoaineen loppusijoituslaitoksen rakentamisen aikana monialaista monitorointiohjelmaa, jonka tavoitteina on seurata hankkeen ympäristövaikutuksia, hankkia lisää tietoa Olkiluodon laitospaikan luonnollisista ominaisuuksista, varmistua pitkäaikaisturvallisuuden kannalta otollisten olosuhteiden säilymisestä ja kehittää menetelmiä laitoksen teknisten vapautumisesteiden toiminnan seurantaan. Tässä raportissa arvioidaan monitorointiohjelman tuottamien tulosten käyttökelpoisuutta ydinmateriaalivalvonnassa, joka rakenteilla olevan loppusijoituslaitoksen tapauksessa merkitsee ensisijaisesti ilmoittamattomien maanalaisten tai maanpäällisen tilojen rakentamisen havaitsemista.

Mikroseisminen monitorointi tuottaa tulkintoja Olkiluodon ympäristöön paikannetuista seismisistä tapahtumista. Tämä on raporttia kirjoitettaessa ainoa ohjelmaan kuuluva monitorointimenetelmä, jonka tuloksia jo käytetään kansallisessa ydinmateriaalivalvonnassa. Monitorointiohjelman tarkastelun johtopäätöksenä on, että mikroseismisen monitoroinnin lisäksi hydraulisen painekorkeuden automaattinen seuranta syvissä kairarei'issä ja maankäytön monitorointi tuottavat tuloksia, jotka ovat käyttökelpoisia ydinmateriaalivalvonnan kannalta.

Hydraulista painekorkeutta (eli kalliopohjaveden painetta) monitoroidaan useissa kairarei'issä, jotka lävistävät kalliotilavuutta, johon loppusijoitustilat aiotaan louhia. Monitoroitavat reiät on jaettu hydraulisesti eristetyiksi tulppaväleiksi, jotta painekorkeutta voidaan mitata samanaikaisesti ja riippumattomasti eri syvyyksiltä. Monitoroitavat tulppavälit sijaitsevat usein hydrogeologisissa vyöhykkeissä, joissa kiteisen peruskallion rakoilu sallii pohjaveden virtaavan selvästi vapaammin kuin muualla. Kokemus on osoittanut, että joissakin vyöhykkeissä pistemäinen pohjaveden vuoto uuteen tunneliin tai reikään aiheuttaa merkittävän painekorkeuden aleneman niin kaukana, että se on helposti havaittavissa useissa monitoroiduissa tulppaväleissä.

Maankäytön monitorointi perustuu ilmakuviin, joita otetaan joka toinen vuosi, ja maankäyttörekisterin ylläpitoon. Näiden lähteiden perusteella Posiva päivittää säännöllisesti koko Olkiluodon kattavan maankäyttöruudukon. Sekä ilmakuvat että maankäyttöruudukko ovat sopivia täydentämään muuta kuvamateriaalia, jota käytetään laitosalueen rakennuksista tehdyn vuosi-ilmoituksen todentamiseen.

Painekorkeuden ja maankäytön monitorointitulokset saadaan tarvittaessa ydinmateriaalivalvonnan käyttöön dokumenteista, jotka Posiva toimittaa säännöllisesti Säteilyturvakeskukselle muita tarkoituksia varten. Arvioitu vuotuinen työmäärä olisi noin viikko hydraulisen painekorkeuden monitoroinnin ja muutamia päiviä maankäytön monitorointia osalta.

# Contents

# 1 Introduction

It has been decided that spent nuclear fuel produced in the currently operational nuclear power plants in Finland will be disposed of in a geological repository in Olkiluoto, an island on the south-western coast of Finland and also the location of a nuclear power plant – see map in Figure 1. Posiva Oy, a company founded and jointly owned by two operators of nuclear power plants, Teollisuuden Voima Oyj and Fortum Power and Heat Oy, is responsible for the construction of the disposal facility and projects to begin the deposition in the early 2020s.

The construction of the actual repository was preceded by the excavation of an underground rock characterisation facility, called the ONKALO, which will eventually become the access route to the deposition galleries. Figure 2 shows the location of the ONKALO in Olkiluoto and a 3D view of it at the end of 2016. It consists of an access ramp, shafts for ventilation and hoists, and various niches, tunnels and halls for technical and research purposes, but no actual disposal galleries yet. The disposal facility will also include buildings at ground level near the entrance to the ONKALO, such as an encapsulation plant and ventilation and hoist buildings, some of which are already complete and some under construction.

The final disposal project involves an extensive research programme, which started with geological site characterisation at several candidate sites before the selection of Olkiluoto, and has progressively widened to include, for example, the development of disposal and excavation techniques, studies of surface ecology (summarised in Posiva 2013), and long-term experiments on groundwater chemistry


**Figure 1.** The location of Olkiluoto.

(Käpyaho et al. 2012). On the basis of the Nuclear Energy Act (Council of State 1987), STUK has issued Regulatory Guides that determine the legal requirements for the nuclear safety of the disposal facility and also to the related research. Regulatory Guide YVL D.5: Disposal of Nuclear Waste (STUK 2013b), issued in 2013, states in paragraph 506:

*During the construction and operation of the disposal facility, a research, testing and monitoring programme shall be executed to ensure that the*

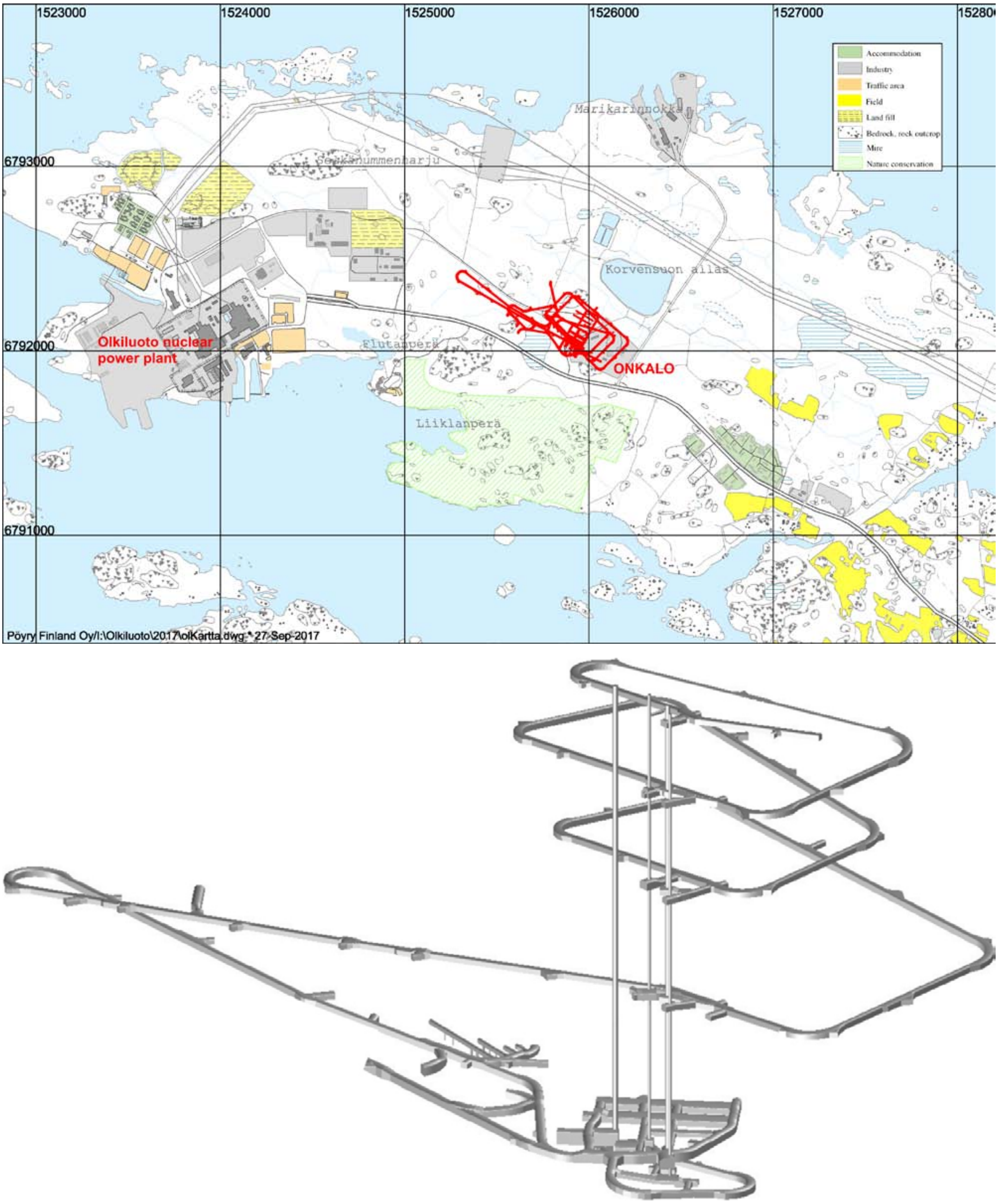


**Figure 2.** Above: map of Olkiluoto with the horizontal projection of the ONKALO shown in red. Grid size 1 km. Below: 3D illustration of the ONKALO at the end of 2016 (Haapalehto et al. 2017). The deepest parts are about 460 m below ground, and the length of the spiralling access ramp is about 5 km. View from the south.

*site and the rock to be excavated are suitable for disposal and to collect supplementary information the safety-relevant characteristics of the host rock and the performance of the barriers.*

To fulfil this requirement, Posiva runs a multidisciplinary Olkiluoto Monitoring Programme, whose aims include studying the impact of the repository project on the environment, improving the understanding of the conditions at the site, and supporting the analysis of the long-term safety of the repository. At present, monitoring is based on a programme presented by Posiva (2012), intended to cover the period of the construction of the repository before operation. Preparation of an updated monitoring programme for the operational phase is in process.

This report discusses the usability of Posiva's monitoring programme for implementing nuclear safeguards at the Olkiluoto site – during the current construction phase and, as regards detecting undeclared excavation, also during the operational phase. Nuclear safeguards are based on international treaties, agreements and protocols (IAEA 1970, 1972, 1997) that oblige Finland as a state to ensure for its part that the use of nuclear energy and nuclear materials remains strictly limited to peaceful purposes without the risk of proliferation of nuclear weapons. European Commission Regulation (Euratom) No 302/2005 (EC 2005) and STUK Regulatory Guide YVL D.1: Regulatory Control of Nuclear Safeguards (STUK 2013a) give the framework for Posiva's reporting to the international inspectorates. This includes the design information including maps in area layout in BTC (Basic Technical Characteristics) and those in the site declaration according to the Additional Protocol. In Finland, the implementation of nuclear safeguards at state level is the responsibility of the Radiation and Nuclear Safety Authority (STUK), and as regards the disposal facility in Olkiluoto, of Posiva Oy as the construction licence holder. Section 3.7 of Guide YVL D.1: Regulatory Control of Nuclear Safeguards (STUK 2013a), entitled "Specific requirements related to the disposal of spent nuclear fuel", states in paragraph 355 that:

*The operator shall also ensure that no undeclared activities of nuclear safeguards relevance take place in the disposal area (area delimited in the decision-in-principle).*

The next paragraph reads:

*The operator shall demonstrate during the construction of the nuclear waste facility and the associated underground facilities that the facility is being constructed in compliance with the notifications filed.*

And paragraph 359:

*The operator shall design the nuclear waste facility and its operations in such a way that the continuity of control data after the verification of the fuel items can be assured every step of the way. If the continuity is lost, it shall be possible to re-verify the fuel items.*

Therefore, from the point of view of the final deposition of spent nuclear fuel in the geological repository in Olkiluoto, nuclear safeguards most importantly concern the verification of two issues: first, that the construction of underground facilities corresponds to the reported and licenced design, and second, that full accountability for all nuclear material is maintained in the process of transport, encapsulation and final deposition of spent nuclear fuel (or any other nuclear material). Of these two safeguards issues, the monitoring programme mainly contributes to the first one, because the surveillance of the operation of the facility is not within its scope.

Posiva has had a safeguards programme since the early stages of the excavation of the ONKALO. Under that programme, detected microseismic events in Olkiluoto have been regularly reported to STUK as the only contribution of the monitoring programme to safeguards implementation.

# 2 Monitoring programme

Olkiluoto Monitoring Programme (in Finnish: Olkiluodon monitorointiohjelma, OMO) has formally existed since 2004 (Posiva 2003), the year when Posiva started the excavation of the ONKALO. However, in some of the subjects now included in the monitoring programme, repeated long-term measurements have been carried out for several years before launching the actual programme.

The present Monitoring Programme (Posiva 2012) defines monitoring as "Continuous or periodic observations and measurements of engineering, environmental or radiological parameters, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment, and to help in making decisions on the implementation of successive phases of the disposal concept." In comparison with otherwise similar EC and IAEA definitions (EC 2004 and IAEA 2001), the definition adopted by Posiva excludes issues like observing the societal impact of and public attitudes towards the project, and focuses solely on technical and scientific measurements motivated by long-term safety and environmental impact. Moreover, the programme does not intend to cover monitoring related to operational and occupational safety, technical maintenance and ageing management, or nuclear safeguards, but states that these issues are covered by other programmes and guides of Posiva.

In 2016, Posiva made some adjustments to the Monitoring Programme on the basis of experience gathered and changes in the needs for research. Its duration was extended to include the years 2017–2019. The next update of the programme will thus take place in 2019 at the latest and, after that, a monitoring programme for the operational phase of the repository will be compiled and released before submitting the application for the operational licence for the disposal facility. The adjustments were published in the form of memos, separately for each discipline (document numbers POS-023621–POS-023626).

Olkiluoto Monitoring Programme is organised into five sub-programmes or disciplines:

- rock mechanics
- hydrology and hydrogeology
- hydrogeochemistry
- surface environment
- engineered barrier system (EBS).

In the 2012 programme, there also was a separate discipline for foreign materials, but in the update and reorganisation of 2016, the subject was separated from the Monitoring Programme.

A summary of results is published annually as a Posiva Working Report for each discipline, available in digital format at www.posiva.fi/en/databank/workreports. For most recent published results, see Haapalehto et al. (2017) for rock mechanics, Vaittinen et al. (2016) for hydrology and hydrogeology, Lamminmäki et al. (2017) for hydrogeochemistry, Pere et al. (2017) for surface environment, and Sacklén (2016) for foreign materials. In contrast to the other monitoring disciplines, EBS monitoring is still at the stage of research and development, so annual reports of its results are not yet compiled.

## 2.1 Rock mechanics monitoring

Rock mechanics monitoring concentrates on the assessment of tectonic movements in Olkiluoto and the surrounding area, and the stability of the bedrock. Table 1 presents the rock mechanics monitoring programme according to the update of 2016 (POS-023623) and comments on the relevance of the monitoring measurements to safeguards.

Microseismic monitoring aims at detecting seismic events in the "ONKALO block", a 2 km × 2 km × 2 km cube surrounding the ONKALO, and in a

Table 1. Updated rock mechanics monitoring programme for 2017–19. Modified from Table 2 in POS-023623.

| Process | Target/method | Location | Frequency | Relevance to safeguards |
|---|---|---|---|---|
| Seismicity, reactivation of bedrock structures | Microseismic monitoring | 18 automatic stations | Continuous | Located seismic events indicate excavation by blasting; data already used for safeguards |
| Tectonic movement of bedrock | GPS measurements | 17 automatic stations | Continuous | none |
| | | 1 manual station | Twice a year | |
| | Control marker measurements | Carried out as a part of GPS and levelling measurements near GPS stations if necessary (suspected pillar damage) | | none |
| Isostatic land uplift | Precise levelling | Levelling loops: ONKALO, VLJ (low and intermediate-level radioactive waste repository), Olkiluoto line | Once a year | none |
| | | GPS network | Once in 2018 | |
| | | Olkiluoto–Lapijoki line | Every fourth year; not during 2017–19 | |
| Redistribution of rock stress | Extensometry | Selected locations in the ONKALO | Continuous | none |
| Reactivation of bedrock structures | Surface extensometry | Selected intersections of tunnels and bedrock structures | Continuous | |
| Thermal evolution | Monitoring of temperature | Temperature profiles in drillholes | During flow and geophysical loggings | Anomaly in temperature profile may indicate open space near the drillhole |
| | | Tunnel air, (surface) extensometers | Continuous | none |
| Spalling | Visual monitoring | All underground spaces | Continuous | none |

wider semi-regional area within a radius of about 10 km. The main purpose of microseismic monitoring is to improve understanding of the structure, behaviour and long-term stability of the bedrock. At the beginning of 2017, Posiva's permanent seismic network consisted of 17 seismic stations, seven of which were at ground level inside the ONKALO block and four further away, one in a borehole next to the ONKALO at a depth of 139 m, and five in the ONKALO at depths of 276, 293, 369, 420, and 428 m. During the excavation of the disposal facility, the microseismic network is likely to be expanded, probably with new measuring stations in the central tunnels.

Seismic events can be located with sufficient spatial accuracy to determine whether they result from excavation by blasting or other reasons such as natural or excavation-induced displacements in the bedrock. Therefore, microseismic monitoring is currently the part of the Monitoring Programme that also produces data for Posiva's safeguards programme. Saari & Malm (2015) show in their report that, in addition to blasting, microseismic monitoring can also be applied to detect and monitor excavation by tunnel boring. However, because of the large amount of data gathered, microseismic data is not permanently stored as a continuous time series. Instead, the measurement system applies automatic triggering based on certain pre-defined criteria, and saves only the data from the time of detected seismic event for further analysis.

*GPS measurements* and surface levelling are performed to monitor relative crustal movements in Olkiluoto and the surrounding region. Measurements of the relative positions of the 18 GPS stations mainly provide data on horizontal deformations, whereas surface levelling between a network of 87 fixed measuring points measures vertical changes. To exclude systematic error in the GPS measurements, the distance between two of the GPS stations was previously also monitored by electronic distance measurements (EDM), but this has been ended as it is redundant.

Rock mechanic monitoring also includes measurements of *rock displacements* and *temperatures* in the ONKALO. Displacements are monitored by extensometers installed in boreholes to detect the response of the rock mass to the stress redistribution that results from excavation. Some of the measurement locations are in known brittle fault zones so that possible displacements in these zones could be detected. The Monitoring Programme of 2012 also mentions monitoring rock creep with load cells in rock bolts and rock displacements with convergence measurements, but these methods have been abandoned as unfeasible.

## 2.2 Hydrological and hydrogeological monitoring

Figure 3 shows the hydrogeological measuring points in central Olkiluoto, drawn on an aerial photograph of the area. One deep drillhole (OL-KR58) has been drilled below the sea from a smaller island west of Olkiluoto and is shown in the embedded pane in the lower left-hand-side corner. The embedded pane in the upper right-hand-side corner shows the densely located drillholes and observation tubes in an area north of the ONKALO entrance used for field studies on groundwater infiltration.

Table 2 presents the monitoring programme of hydrology and hydrogeology according to the update of 2016 (POS-023622) and comments on the relevance of the monitoring measurements to safeguards.

*Groundwater table* is monitored by regular measurements of water level in several shallow drillholes and groundwater observation tubes. The results are used to assess the impact of the excavation of the disposal facility and other human activities on shallow groundwater and to study its natural behaviour.

*Groundwater flow* in the bedrock is studied by drillhole measurements with the Posiva Flow Log (PFL) tool. The tool is able to detect groundwater flow between a drillhole and a single intersecting fracture or a fracture zone. Flow logging with different drillhole pressures yields information on the *hydraulic conductivity* of the rock mass, because the transmissivities of the intersecting fractures or deformation zones can be calculated from the data.

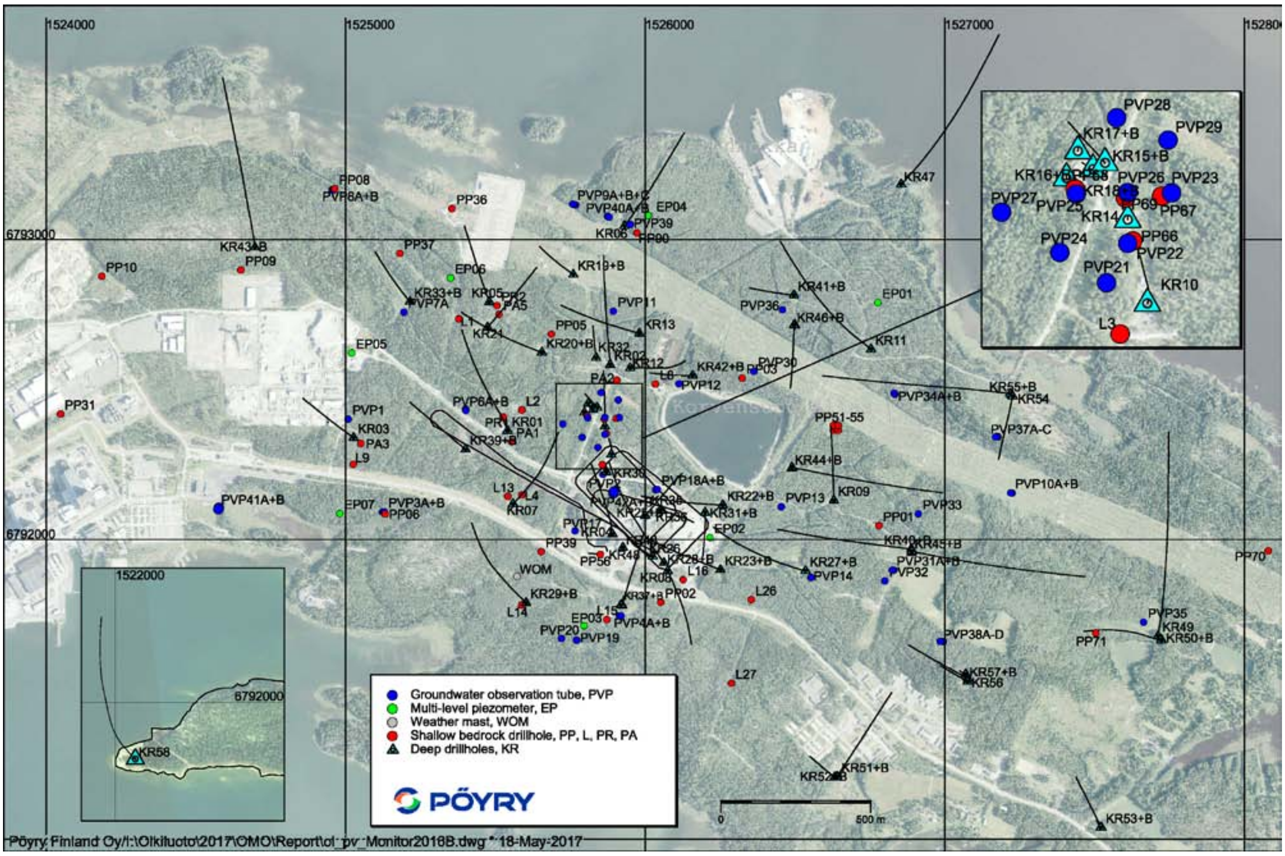


**Figure 3.** Drillholes and other measuring points used for hydrological and hydrogeological monitoring in Olkiluoto. Deep core-drilled holes are marked with a triangle at the mouth and a black line representing the surface projection. The access ramp of the ONKALO is marked by the winding black line in the middle of the image. The nuclear power plant, with two reactor units in operation and one under construction, and related facilities, are situated in the lighter area west of the ONKALO.

**Table 2.** Updated hydrological and hydrogeological monitoring programme for 2017–19. Modified from Table 1 in POS-023622.

| Process | Target/method | Location | Frequency | Relevance to safeguards |
|---|---|---|---|---|
| Evolution of groundwater table | Groundwater level measurements | Observation tubes, manual | Monthly | In principle, a possibility of detecting undeclared earthwork or tunnelling, but at such a short range that it would probably also be detected visually by field personnel. |
| | | Observation tubes, automatic | Hourly | |
| | | Shallow bedrock holes, manual | Monthly | Sampling rate too low for reliably detecting and distinguishing underground activities. |
| | | Shallow bedrock holes, automatic | Hourly | Potentially detects tunnel excavation if a suitable hydraulic connection exists. |
| Evolution of groundwater flow | Flow conditions in open drillholes | Selected holes | Once a year | Potentially detects tunnel excavation if a suitable hydraulic connection exists. No systematic monitoring of all holes. |
| | Transverse flow in drillholes | Selected holes | Once a year | Theoretically detects tunnel excavation if a suitable hydraulic connection exists. Only a few fractures are monitored. |
| Evolution of hydraulic properties in the bedrock and the overburden | Hydraulic conductivity/ transmissivity of structures | Flow logging of drillholes | Once a year | see previous process |
| | | Slug tests in groundwater observation tubes | Once a year | none |
| Evolution of hydraulic head | Hydraulic head monitoring | Deep open bedrock holes | Weekly | Sampling rate too low for reliably detecting and distinguishing underground activities |
| | | Packed-off surface drillholes | Hourly | Detects tunnel excavation in case it causes a change in the flow of groundwater from a monitored hydrogeological structure. |
| | | Packed-off ONKALO drillholes | At least hourly | |
| | Analysis of pressure responses | Hydraulic head data | | |
| Inflow into tunnels | Total inflow | | Monthly | Undeclared tunnelling or additional excavation is highly unlikely to affect the inflow into existing, declared tunnels to a detectable extent. |
| | Inflow at measuring weirs | manual weirs | Monthly | |
| | | automatic weirs | 4 times / hour | |
| | Individual leakage points | | Monthly | |
| | Leakages in shafts | | Monthly | |
| | Visual mapping of leakages | | Once a year | |
| | Air flow and humidity | | Daily | |
| | Amount of process water used | | Weekly | |
| Influence of Korvensuo reservoir | Korvensuo water level | | Weekly | none |
| | Hydraulic conductivity at the dam seepage tubes | | Every other year | |

With the PFL TRANS version of the tool, the rate and direction of transverse flow across a drillhole can be measured. This method is used to monitor flow in a few fractures near the ONKALO where the rate is sufficiently large for measurement.

Most of the almost 60 deep characterisation drillholes in Olkiluoto are packed-off, in other words equipped with a set of inflatable packers that divide the drillhole into hydraulically isolated sections. Hydraulic head is monitored automatically in selected packer sections, typically once in an hour. In open drillholes, fracture-specific head data is obtained from PFL flow logging measurements. In addition to the deep drillholes, hydraulic head is also monitored in multi-level piezometers, which are drillholes about 100 metres deep and divided into four monitoring sections with permanent cement plugs. Hydraulic head data together with results on groundwater flow and hydraulic conductivity are used in the assessment of the effect of the disposal facility, hydrogeological modelling of Olkiluoto, and interpretation of hydrogeochemical observations. Flow logging with the PFL tool also produces data on hydraulic head in the deep drillhole studied. That data has a better spatial resolution than the continuous monitoring of a multi-packered drillhole, but as only a fraction of holes are logged each year, the acquired time series are so sparse that they do not usually allow observing variation in time.

*Inflow into tunnels* and the water balance of the ONKALO in monitored with automatic and manual measuring weirs along the ONKALO access tunnel, inflow measurements in the shafts, visual mapping of tunnel walls, flow and humidity measurements of the ventilation air of the ONKALO, and measurement of the usage of process water.

*Influence of Korvensuo reservoir* is a special issue because of the vicinity of this artificial volume of surface water near the ONKALO. Water level in the reservoir and its effects on groundwater chemistry are monitored.

Monitoring of *surface hydrology* gathers data on, among other things, the variation of sea level, surface water runoff, precipitation, snow depth and water content, ground frost and infiltration of surface water into the groundwater system. These issues partly overlap with the monitoring of surface environment.

According to the programme update memo of 2016, hydrological monitoring has remained essentially unchanged throughout the construction of the ONKALO, and no significant changes are expected to occur in the operational phase of the disposal facility either. Drillhole measurements with the Hydraulic Testing Unit (HTU) were, however, discontinued. One possible new issue in the discipline is the research and development of methods and effects of permanently sealing the deep drillholes drilled from ground surface.

## 2.3 Hydrogeochemical monitoring

Table 3 presents the updated hydrogeochemical monitoring programme (POS-023621). It is based on the analysis of water samples, either taken to the laboratory from various locations in Olkiluoto or examined *in situ*. Understanding the composition of groundwater and processes affecting it is crucial for the long-term safety of the disposal project as it has a great influence on the performance of the engineered barriers (copper canister, bentonite buffer, and tunnel backfill) and on the migration and retention of radionuclides both in the geosphere and in the biosphere. Therefore, the target properties set for the conditions in the disposal tunnels and holes include a number of requirements for groundwater chemistry, and systematic hydrogeochemical monitoring is expected to continue throughout the construction and operation of the facility. Changes in groundwater chemistry, especially close to the surface, are also monitored to detect any environmental effects of the project (or other human activity) in Olkiluoto.

## 2.4 Monitoring of the surface environment

The two main reasons for the monitoring of the surface environment in Olkiluoto are to observe the *environmental impact* of the repository project and to acquire *input data for biosphere modelling* used in the assessment of the long-term safety of final disposal. In the 2016 update of the Monitoring Programme (POS-023624), the studies motivated by the biosphere modelling were significantly reduced, as no additional input is required in the present stage of preparing the next Safety Case (aiming at the application of the nuclear operational licence in 2020). Therefore, the present monitoring programme for surface environment mainly focuses on the conventional (non-nuclear) environmental effects of the disposal project that resemble those of a mine or an industrial construction. Monitoring targets include noise, water in the ditches that flow into the sea from the ONKALO and from the rock piling area, and yield and quality of household water in drilled wells in eastern Olkiluoto. Some biological and ecological issues that were earlier

**Table 3.** Updated hydrogeochemical monitoring programme for 2017–19. Modified from Table 1 in POS-023621.

| Process | Target/method | Location | Frequency | Relevance to safeguards |
|---|---|---|---|---|
| Evolution of groundwater properties and salinity distribution in shallow groundwater | Groundwater sampling and chemical analysis | Groundwater observation tubes and shallow surface drillholes | 2–3 sampling campaigns per year | In principle, a possibility of detecting undeclared earthwork or construction on ground surface, but at such a short range that it would probably also be detected visually by field personnel. Monitoring of radioactivity not part of the programme. |
| Evolution of groundwater properties and salinity distribution in deep groundwater | Groundwater sampling and chemical analysis | Deep surface drillholes, drillholes in the ONKALO | According to an annual plan | Undeclared tunnelling or additional excavation is highly unlikely to affect groundwater chemistry to a detectable extent. |
| | On-line measurement of pH, EC, $O_2$, $E_h$, T | Deep surface drillholes, drillholes in the ONKALO | During groundwater sampling or continuously | |
| | Microbe and gas sampling | Deep surface drillholes, drillholes in the ONKALO | According to an annual plan | |
| Influence of Korvensuo reservoir | Stable isotope samples ($\delta^2H$ and $\delta^{18}O$) | Shallow and deep surface drillholes, drillholes in the ONKALO | According to an annual plan | none |
| Influence of foreign materials | Sampling and analysis of defined parameters | Drillholes in the ONKALO | According to an annual plan | Foreign materials from undeclared tunnelling or additional excavation are highly unlikely to affect groundwater chemistry to a detectable extent. |
| | | Leaking structures in the ONKALO | Once or twice a year | |
| Inflow into the ONKALO | Automatic observations | Measuring weirs | Continuous | Potentially detects undeclared excavation in the ONKALO itself on the basis of increased flow of technical water in the access ramp. |
| | Chemical analyses of samples | Measuring weirs | Once a year | Sampling rate too low for reliably detecting and distinguishing underground activities. |
| | | Leaking structures in the ONKALO | Once or twice a year | |

studied to support the biosphere modelling now belong to a biodiversity study, planned to be done every 10 years.

The determination of a *baseline for monitoring radioactive releases* previously belonged to the surface environment monitoring programme, but has now been reorganised into a separate project outside the Monitoring Programme. In the operational phase of the disposal facility, monitoring of radioactive substances in its surroundings could also serve safeguards control by, for example, detecting the handling of nuclear materials on the surface somewhere else than inside the encapsulation plant. The subject of environmental monitoring that also has some relevance for safeguards, *changes in land use*, is based on aerial photographs taken every other year, keeping record of changes in infrastructure and other land use, and maintaining a land use grid (division of Olkiluoto into 50 m × 50 m squares). The latest reported update of the land use grid describes the situation in 2013 (Pere et al. 2015).

## 2.5 Monitoring of the engineered barrier system

In the KBS-3H concept of final deposition that Posiva's plans are based on, the engineered barrier system (EBS) includes four components: 1) the copper canister into which the spent fuel in

Table 4. Updated monitoring programme of the surface environment for 2017–19. Modified from Table 2 in POS-023624.

| Motivation | Subject | Target/method | Frequency | Relevance to safeguards |
|---|---|---|---|---|
| Input data for modelling, aquatic ecosystems | Sea water quality | Hydrogeochemical characterisation | A campaign in 2017 | none |
| | | Sea water quality | Three samples a year | |
| | | Background data on water quality | Provided by TVO | |
| | River discharge and water quality | Water quality monitoring | Provided by TVO | none |
| | | River discharge, by environmental authorities | Continuous | |
| | | Background data | Provided by TVO | |
| | | Bottom fauna background data | Provided by TVO | |
| | | Test and account fishing, interviews | Provided by TVO | |
| Interaction between surface environment and groundwater in bedrock | Land use | Aerial photographs | Every other year | Can supplement present satellite imaging |
| | | Records of changes in infrastructure and other land use | Continuous | Can supplement present accounting of surface facilities (if not already used) |
| | | Update of land use grid | in 2018 | Can supplement present accounting of surface facilities (if not already used) |
| | | Records of forest and aquatic management | Continuous | none |
| | Surface hydrology and meteorology | Surface water discharge (automatic weirs) | Continuous | none |
| | | Weather observations | Continuous | none |
| | | Precipitation | Continuous | |
| | | Snow cover | Continuous during winter | |
| | | Ground frost | Continuous during winter | |

encapsulated before deposition, 2) a bentonite buffer that surrounds the canister in the deposition hole, 3) deposition tunnel backfill, and 4) auxiliary components such as various plugs and seals for closing tunnels and holes and backfill of other excavated spaces besides deposition tunnels.

Monitoring of the EBS is still in the development stage rather than a subject of regular monitoring. The Monitoring Programme of 2012 presented a description of preliminary ideas and the ongoing tests of possible techniques. Posiva plans to develop the first version of an EBS monitoring programme before submitting the operational licence application.

## 2.6 Monitoring of foreign materials

Before 2016, the Monitoring Programme included a discipline for monitoring foreign materials. Its purpose was to register all materials used in the construction of the ONKALO, estimate the amounts of materials that have ended up in the ONKALO unintentionally, maintain Posiva's Material Handbook

| Motivation | Subject | Target/method | Frequency | Relevance to safeguards |
|---|---|---|---|---|
| Environmental impact of the final disposal project | Noise | | Twice a year | Sampling rate too low for reliably detecting and distinguishing undeclared activities, unless on such a remarkable scale that it would also be detected visually by field personnel. |
| | Effluent water | On-line measurements of surface runoff | Continuous | In principle, a possibility of detecting undeclared earthwork or construction on ground surface, but the scale of the activity would need be so large that it would probably also be detected visually by field personnel. Monitoring of radioactivity not part of the programme. |
| | | Quality of drainage water (in weirs) | Three samples per year | Sampling rate too low for reliably detecting and distinguishing undeclared activities. |
| | | ONKALO outlet waters (in ditch) | Continuous monitoring of basic parameters + four samples per year for analysis | In principle, a possibility of detecting undeclared excavation in the ONKALO, but the scale of the activity would need to be so large that it would probably also be detected visually by field personnel. Monitoring of radioactivity not part of the programme. |
| | | ONKALO process water (in sedimentation pool) | Continuous monitoring of basic parameters + four samples per year for analysis | |
| | | Leaching from rock spoil | Three samples per year for analysis | In principle, a possibility of detecting undeclared excavation, if the rock spoil would end up in the monitored piling area. |
| | Impact on natural resources | Game statistics | Once a year | none |
| | | Fishing conditions | Provided by TVO | |
| | | Household water quality in drilled wells | One sample per year | |

that defines the materials approved for use in the ONKALO, and produce calculations of the amounts of different kinds of foreign materials that are expected to remain underground as a result of the construction of the repository. These activities are no longer considered a part of the Monitoring Programme. The effect of the use of foreign materials is studied within hydrogeochemical monitoring by taking water samples from fractures and structures in the ONKALO, and within the monitoring of the surface environment by sampling the process water pumped out of the ONKALO into the sedimentation pool and outlet ditch on the surface.

# 3 Potential of monitoring in safeguards implementation

## 3.1 Rock mechanics

Microseismic monitoring is currently the only part of the monitoring programme whose results Posiva submits for safeguard purposes. Each observed seismic event is analysed to determine the location of its source. Figure 4 presents the located seismic events in 2010 within the seismic “ONKALO block”. Most of the events were blasts related to the excavation of the lowest straight section of the ONKALO access ramp; the marks are coloured on the basis of time, so that the progress of excavation is clearly visible. There were also detected seismic events on or near the ground surface above the ONKALO that could be associated with construction of pipelines and buildings. Experience from the time of the excavation of ONKALO has proven that microseismic monitoring is able to detect tunnelling by blasting reliably and accurately in Olkiluoto. Sensitivity to excavation by boring has also been demonstrated, as well as the ability to distinguish simultaneous blasting at an undeclared location from declared excavation. The obvious advantages of microseismic monitoring in detecting clandestine tunnelling are that, firstly, it covers the entire volume of host rock between and beyond the network of drillholes and other monitoring locations, and secondly, that blasts are detected immediately. On the other hand, because of the large sampling frequency of seismic sensors, the measurement data cannot be stored as a continuous time series, but the measuring stations are programmed to store and transmit only the sequences of data where a seismic event occurs according to certain triggering criteria.

One of the methods of thermal monitoring is measuring the temperature of drillhole water when the PFL flow logging equipment is lowered into a drillhole before the flow measurement. Figure 5 presents temperature profiles measured in drillhole OL-KR7 at the beginning of six flow logging measurements (Johansson et al. 2017). With its two

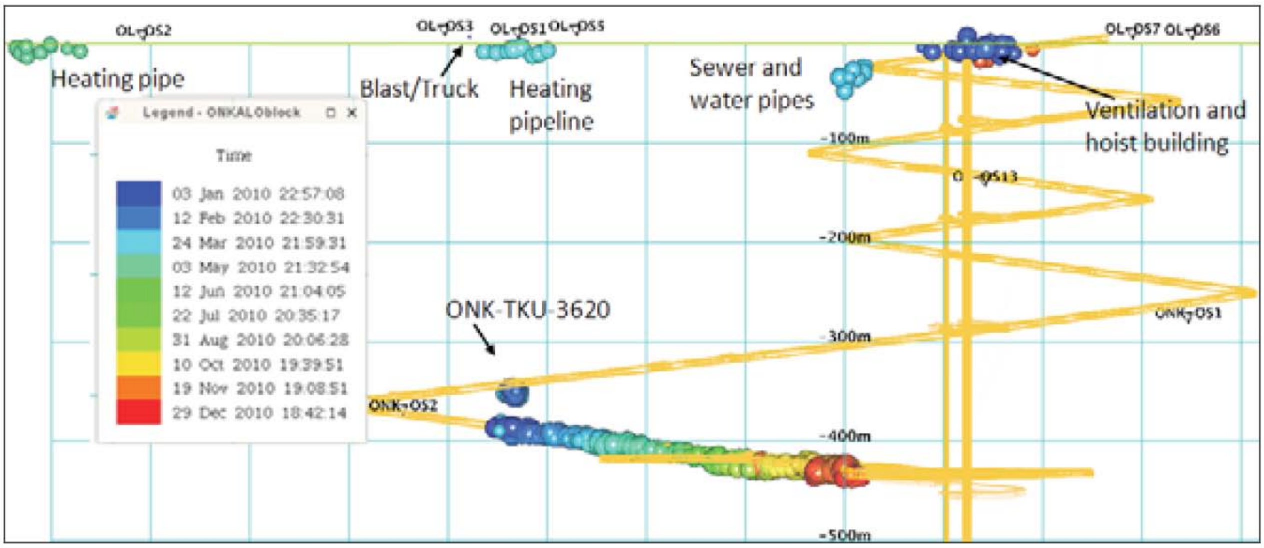


**Figure 4.** Microseismic events detected in the ONKALO block in 2010. Colour scale indicates time from January (blue) to December (red). ONKALO access ramp and shafts are shown in orange (Lahti & Siren 2011).

temperature peaks around depths of 320 m and 400 m, the latest data from 2015 differs notably from the regular temperature gradients observed in all previous measurements. The increase of temperature results from the vicinity of the ONKALO access ramp, which passes the drillhole at distances of about 20 m at the depth of the upper temperature anomaly and about 35 m at the depth of the lower one (see Figure 6). Excavation reached the upper point in March 2009 and the lower point in May 2010, so that the observed temperature effect has taken 5–6 years to develop. The 2015 data also indicates a decrease of temperature at depth range 200–260 m where the drillhole intersects a major sub-horizontal hydrogeological system named HZ20 (see Section 3.2). This result demonstrates that it is, at least in principle, possible to detect clandestine tunnelling by means of thermal monitoring. However, the method is very slow and uncertain for the following reasons: the tunnel has to pass a drillhole relatively closely, it takes a long time before the existence of the tunnel alters the temperature of the surrounding rock mass sufficiently for detection (depends on distance but typically order of years), and temperature profile measurements are not carried out systematically in all drillholes but only in those that are selected, by other criteria from the drillholes without a packer system installed, for groundwater flow logging.

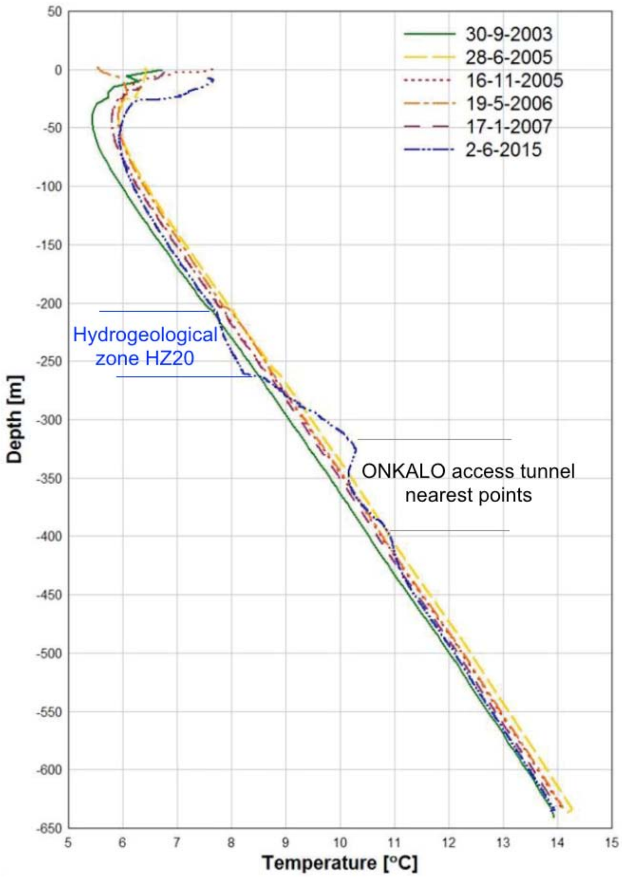


**Figure 5.** Temperature profiles of drillhole OL-KR7 from flow logging during 2003–2015 (Johansson et al. 2017). The closest points to the ONKALO access tunnel are marked in black and the depth range of the intersection with hydrogeological zone HZ20 in blue.

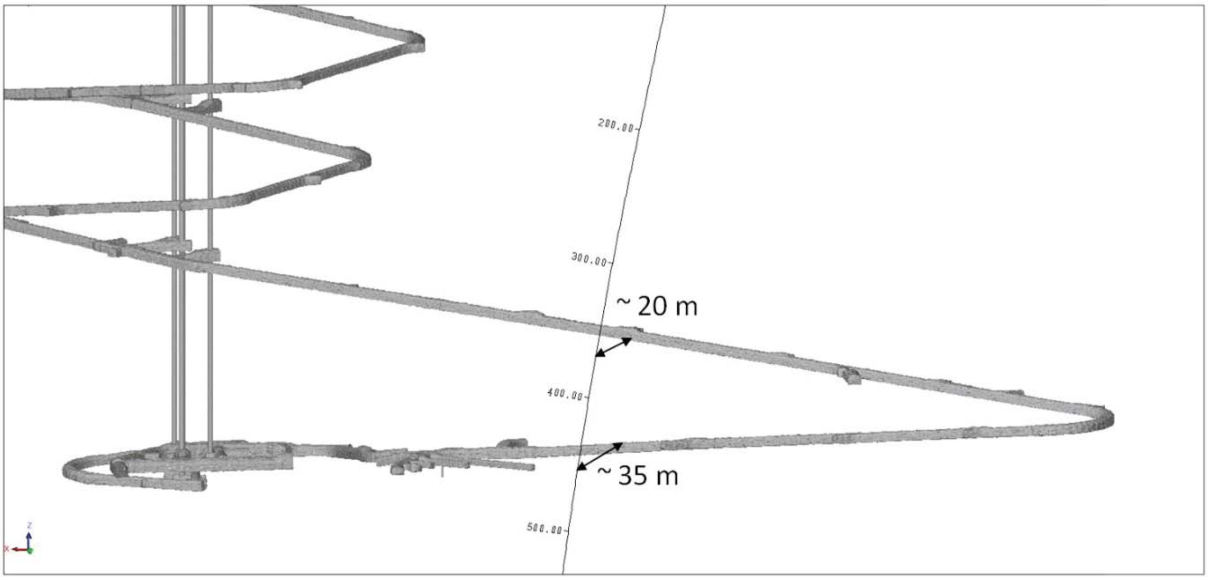


**Figure 6.** The relative positions of drillhole OL-KR7 and the ONKALO (Johansson et al. 2017). View from the north.

## 3.2 Hydrology and hydrogeology

The data on the geology and hydrogeology of Olkiluoto, gathered by various methods including monitoring measurements, has been used to compile a hydrogeological structure model of the site (Vaittinen et al. 2017). It describes the hydraulic properties of the bedrock with approximately planar hydrogeological zones, along which groundwater is able to flow significantly more easily than in the rock volumes in between. The zones coincide with bedrock faults and fractures that have formed during the geological evolution of Olkiluoto. Monitoring of hydraulic head mostly concentrates on the modelled zones, and increasingly on transmissive fractures at the disposal depth, because they are essential for both the planning and the long-term safety analysis of the repository. Figure 7 presents a 3D visualisation of the current hydrogeological structure model showing almost the whole Olkiluoto area, and Figure 8 a close-up around the ONKALO, where the model is more detailed than elsewhere because of denser observations.

Figures 9, 11 and 12 present hydraulic head data from three example cases in which the construction of the ONKALO has caused clear effects in the monitoring results. In the first case in April 2006, the excavation of the access ramp was just reaching the intersection with the HZ19 zone (cyan ellipse in Figure 8 and red circle in Figure 10). As usual, probe holes were drilled from the end of the tunnel towards the direction of excavation to examine the rock ahead. One of the probe holes penetrated the conductive fractures belonging to the HZ19 zone, triggering groundwater inflow and a decrease in groundwater pressure. As Figure 9 shows, the leak lasted for about 18 hours and made the head (groundwater pressure expressed as the height of the water column in an open drillhole) fall by five metres in the nearest monitored drillhole section in HZ19, L3 of drillhole OL-KR23 (about 300 m to the east from the leaking probe hole), and three metres in section L7 of OL-KR29 (about 400 m to the south-west). In monitoring sections further away from the leak, the effect was smaller and smoother, but still observable as far as in section L5 of OL-KR9 (750 m to the east). Figure 10 presents a 3D visualisation of the ONKALO (shown in the 2017 extent for reference), zone HZ19C (the widest part of the HZ19 system according to the hydrogeological model), and the affected drillholes and monitoring sections mentioned above and referred to in the preceding data plot.

The second example of a response of hydraulic head to the construction of the ONKALO is from

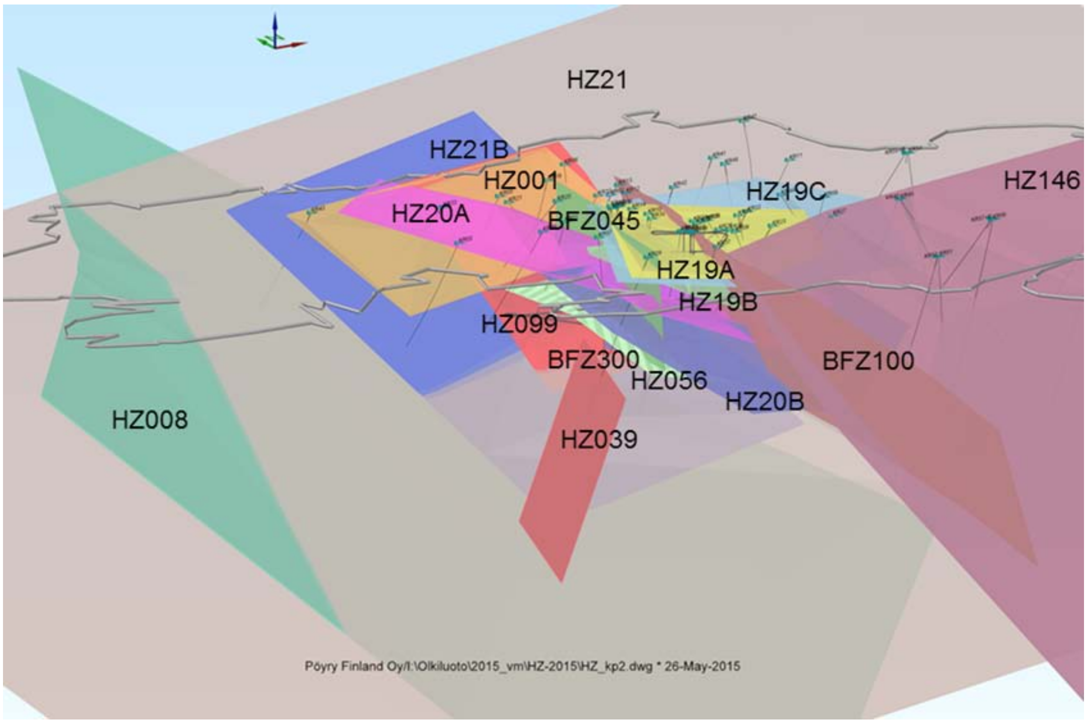


Figure 7. Visualisation of the hydrogeological structure model of Olkiluoto. Coloured polygons represent hydrogeolgical zones (HZ+number) or brittle deformation zones (BFZ+number), the thick grey line the shoreline of Olkiluoto, and thin black lines deep drillholes. View from the south-west.

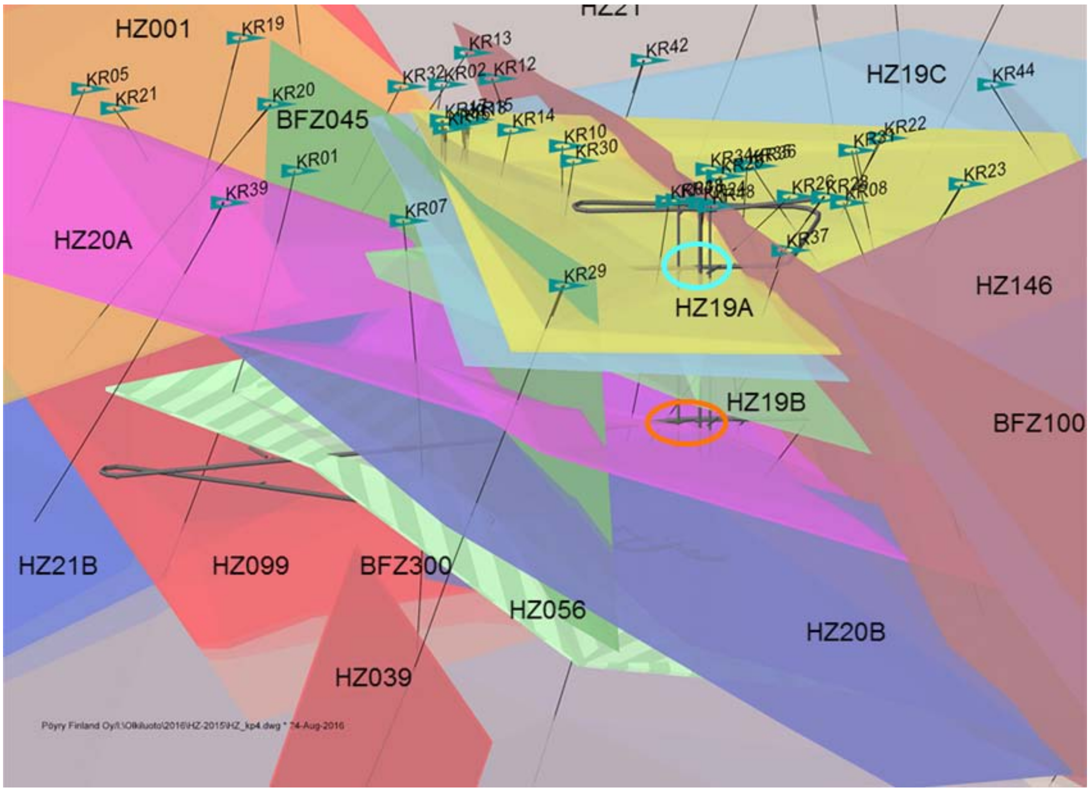


**Figure 8.** Visualisation of the hydrogeological structure model in the surroundings of the ONKALO. The dark grey line represents the ONKALO access ramp and shafts. The cyan and orange ellipses show where the ONKALO intersection with the HZ19 and HZ20 systems, respectively, caused remarkable effects in the hydraulic head.

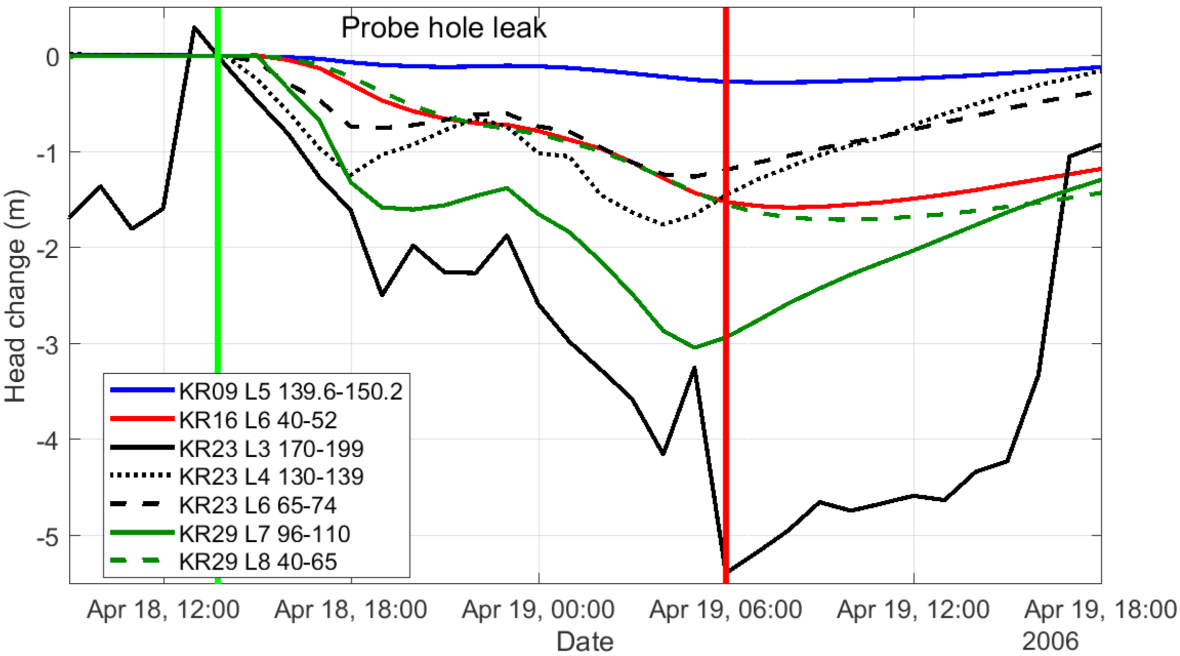


**Figure 9.** Change of head in some monitored drillhole sections during a leak from a probe hole intersecting the HZ19 system. The vertical green and red lines mark the beginning and end of the leak, respectively. Drillhole section labels consist of drillhole code (KR+number), section code (L+number), and range of drillhole length in metres.

July 2008. At that time, the access ramp was approaching the intersection with zone HZ20 (orange ellipse in Figure 8). Before excavating through the zone, a core-drilled pilot hole, longer than the routine probe holes, was made into the planned tunnel profile for investigations. The pilot hole penetrated the HZ20 zone, and a leak that lasted for over two weeks started. The largest head response in the head monitoring data occurred in section L4 of drillhole OL-KR4, which lies only a few dozen metres from the leaking point. The interruption in the data from that section, as well as the almost as strongly affected L2 of OL-KR22, results from the water level in the measuring hoses in the drillholes falling below the pressure sensor. Uninterrupted data exists from section L2 of OL-KR25 (230 m from the leaking point), where the head decreased by about 8.5 m before the leak stopped. In other monitored drillhole sections in the HZ20 zone, the response decreases with distance still being about 1 m in section L8 of OL-KR5, which lies about 900 m to the north-west of the leak point, and 1.6 m in L1 of OL-KR44, 1,000 m to the east.

The third example is also related to zone HZ20. In July 2009, as a preparation for the raise boring of one of the vertical shafts in the ONKALO, grouting holes were drilled at the level of zone HZ20. During a leak from one of the holes, head decreased by almost 20 m in about 12 hours in drillhole sections L3 of OL-KR4, L2 of OL-KR25, and L1 of OL-KR22. The response was much smaller or zero in other sections of the same drillholes, demonstrating how hydraulic effects propagate significantly better along the hydrogeological zones than in other directions.

Figure 13 presents a 3D visualisation of the ONKALO (shown in the 2017 extent for reference), zones HZ20A and HZ20B (nearly parallel parts of the HZ20 system according to the hydrogeological model), and the affected drillholes and monitoring sections mentioned above and referred to in the data plots.

During the excavation of the ONKALO, dozens of responses to temporary groundwater leaks, similar to the three examples presented here, have occurred in the monitoring data. Most of them have been mediated by zones HZ19 and HZ20. Moreover, in a

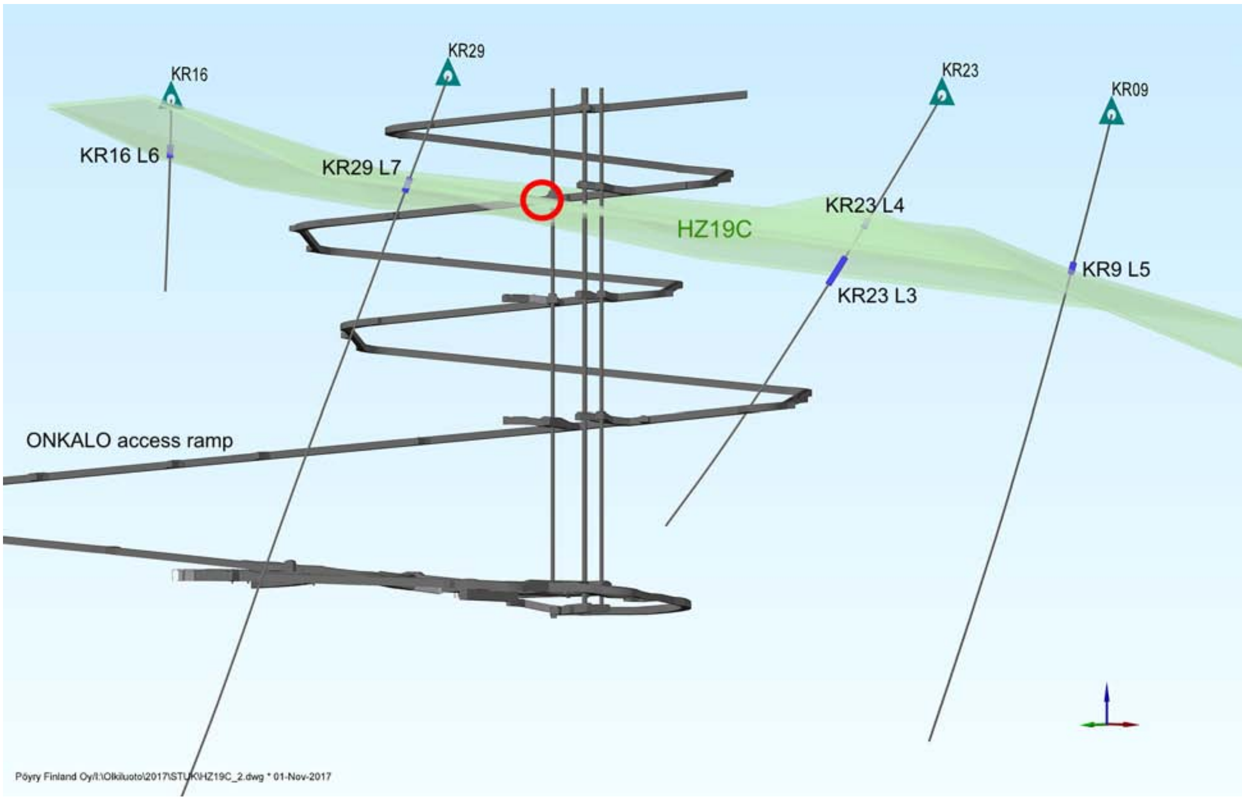


**Figure 10.** 3D visualisation of the ONKALO, hydrogeological zone HZ19C, and some head monitoring sections of drillholes where a response to the probe hole leak in April 2006 was detected. The leak occurred when the excavation of the ONKALO was proceeding to the area marked with the red circle. The drillholes are presented with black lines and the selected monitoring sections with thick blue lines. View from the south-west.

number of monitored drillhole sections, a long-term drawdown (decrease of head) has developed due to hydraulic connections to the ONKALO. On the basis of this experience, hydraulic head monitoring data is sensitive to tunnelling in the repository site. When excavation or drilling intersects a major hydrogeological zone or a local hydraulically conductive feature, groundwater pressure is inevitably affected, and the effect propagates to distances of a few hundred meters in a matter of hours. Advan-

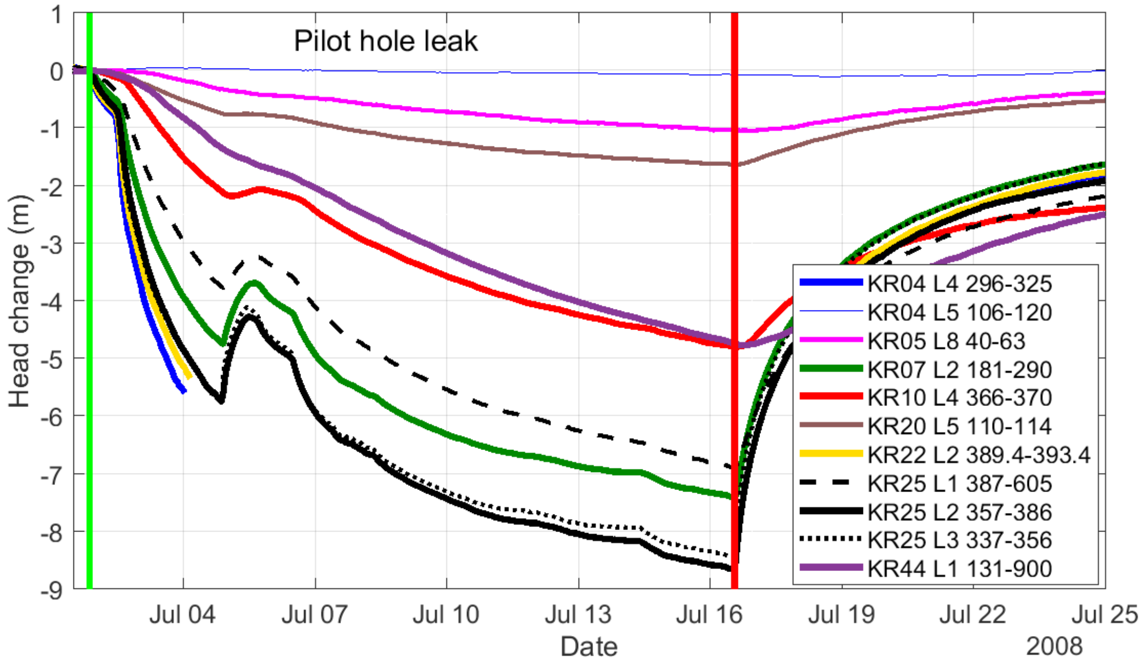


**Figure 11.** Change of head in some monitored drillhole sections during a leak from a pilot hole intersecting the HZ20 structure. The vertical green and red lines mark the beginning and end of the leak, respectively. Drillhole section labels consist of drillhole code (KR+number), section code (L+number), and range of drillhole length in metres.

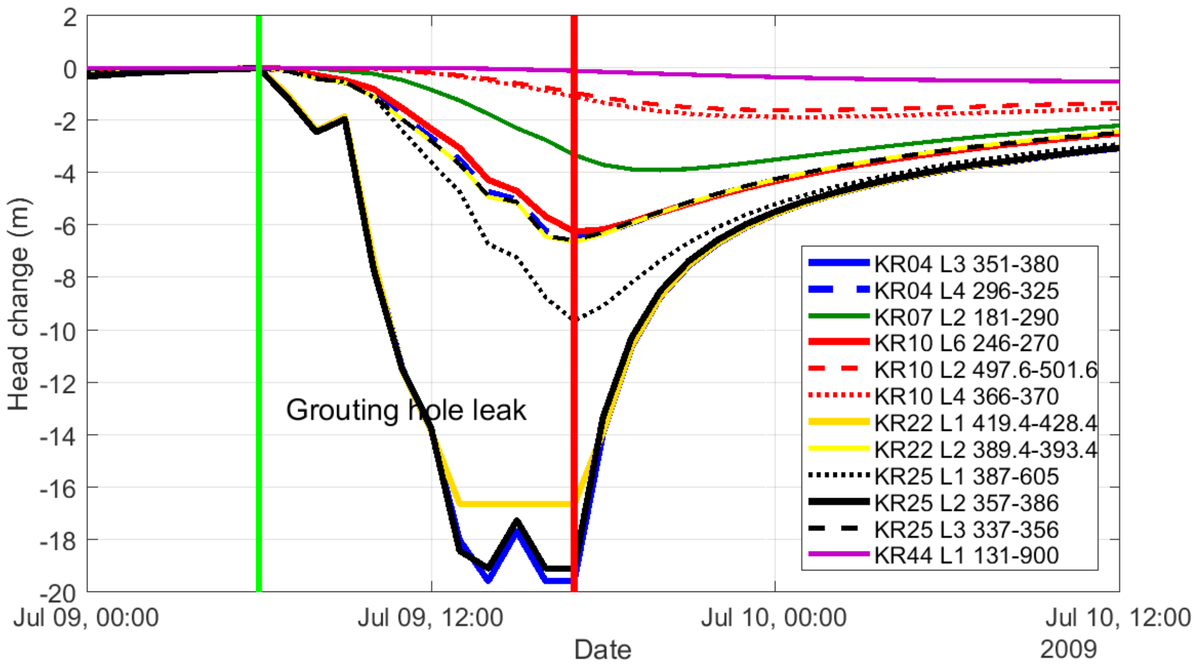


**Figure 12.** Change of head in some monitored drillhole sections during a leak from a shaft grouting hole intersecting the HZ20 structure. The vertical green and red lines mark the beginning and end of the leak, respectively. Drillhole section labels consist of drillhole code (KR+number), section code (L+number), and range of drillhole length in metres.

tages in comparison with microseismic monitoring are that continuous monitoring data is automatically stored from all operational sensors and that the effect of excavation is not instantaneous but usually lasts for at least a couple of days even if the leak itself is quickly stopped. Therefore, missing a signal because of failed triggering of the measurement system is not possible. On the other hand, there are the evident limitations that, firstly, a response can usually only be observed if the tunnel or drillhole penetrates a hydrogeological zone that has intersections in monitored drillhole sections, and secondly, the exact location of the leak causing the head decrease cannot be determined from the data because of the heterogeneity of the structures mediating the effect. A rough estimate of the location can, however, be deduced if the same effect is observed in more than one monitoring sections.

Water table monitoring has in some cases detected effects of surface activity involving substantial excavation of the overburden or continuous pumping of groundwater. Examples include digging research trenches for studies of the bedrock surface and laying the foundations of new buildings. However, these effects have only been observable with a delay and at a short distance from the source, so that the cause has obviously been known to any field personnel before the monitoring measurements.

## 3.3 Hydrogeochemistry

Hydrogeochemical monitoring in general cannot be thought to produce data relevant for the implementation of nuclear safeguards, unless radiological monitoring is included in the programme in the future. However, monitoring of the water flowing in the ditch in the ONKALO access ramp is sensitive to excavation in the ONKALO because of the water used in drilling. As an example of this, Figure 14 and Figure 15 present flow and electric conductivity data from automatic measuring weir ONK-MPL3125 on 6 and 7 February 2017. On both days, a flow peak occurred because of the drilling of grouting holes in the ONKALO at a distance

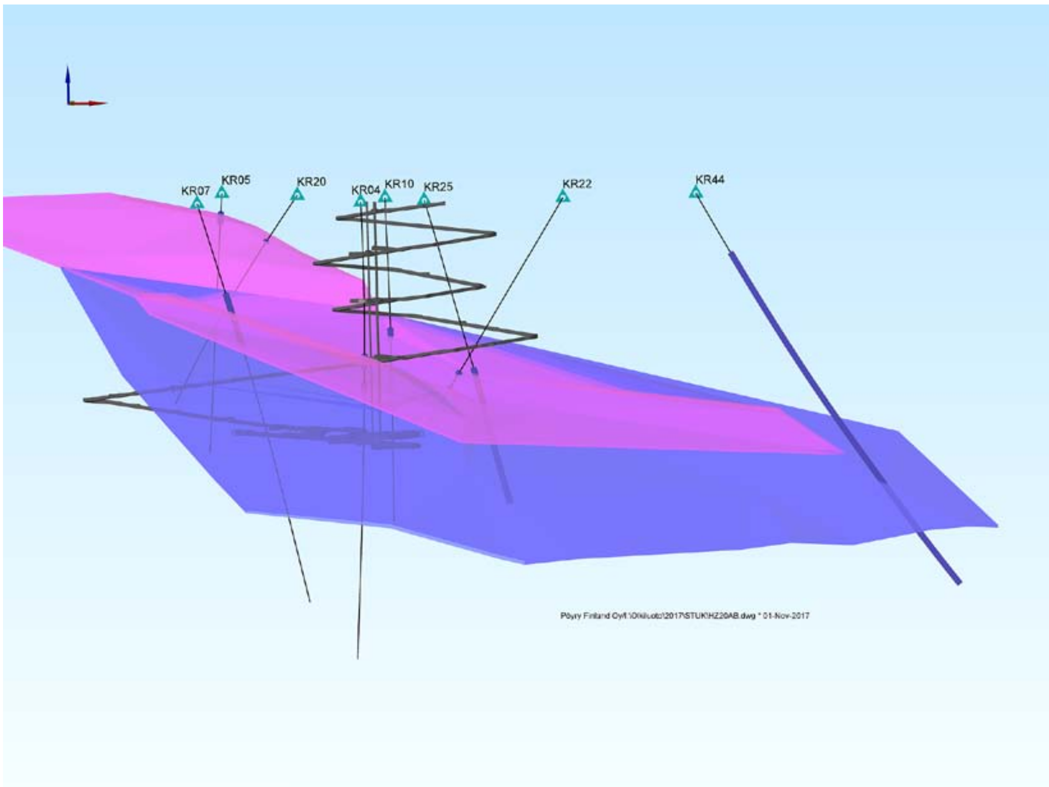


**Figure 13.** 3D illustration of the ONKALO, hydrogeological zones HZ20A (purple) and HZ20B (blue), and some head monitoring sections of drillholes where responses to the leaks discussed in the text were detected. The drillholes are presented with black lines and the selected monitoring sections with thick blue lines. View from the south.

upwards from the weir. Since the process water used in the drilling is more diluted than the groundwater leaking into the tunnel from the bedrock, there also occurred coinciding dips in electrical conductivity. Careless excavation of undeclared rooms connected to the ONKALO could, hypothetically, also produce this kind of results.

## 3.4 Surface environment

The monitoring of land use within the programme for the surface environment is based on aerial photography, registering construction projects and other activities at Olkiluoto that affect the use of land, and on maintaining an interpreted 50 m × 50 m land

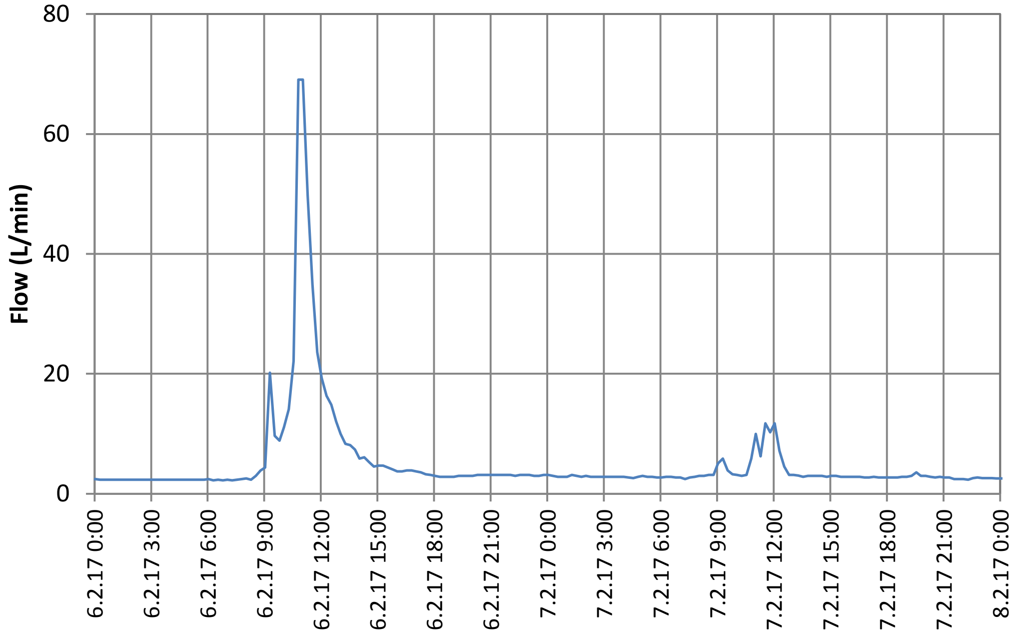


**Figure 14.** Flow of water in a measuring weir in the ONKALO during Feb. 6–7, 2017.

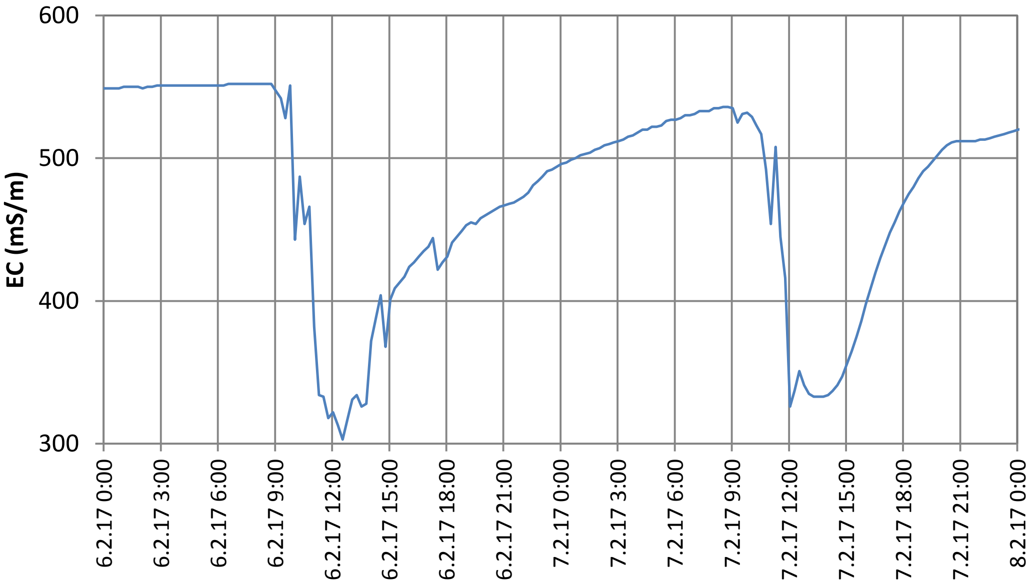


**Figure 15.** Electric conductivity of water in a measuring weir in the ONKALO during Feb. 6–7, 2017.

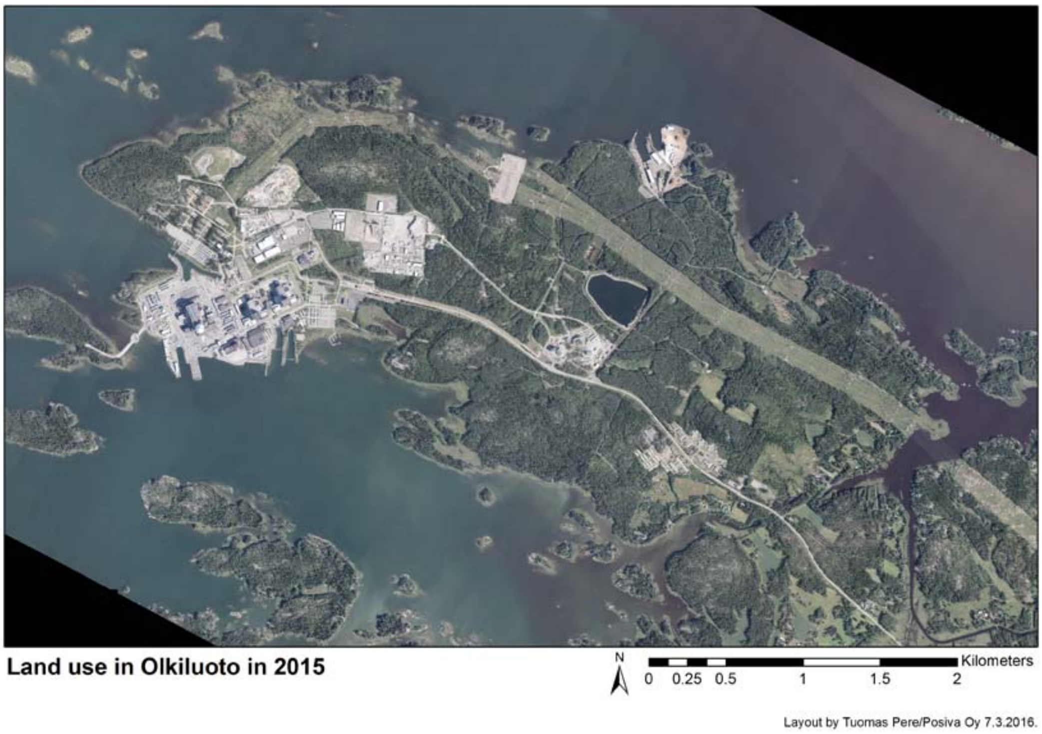


**Figure 16.** Aerial photograph of Olkiluoto, taken in 2015 for land use monitoring.

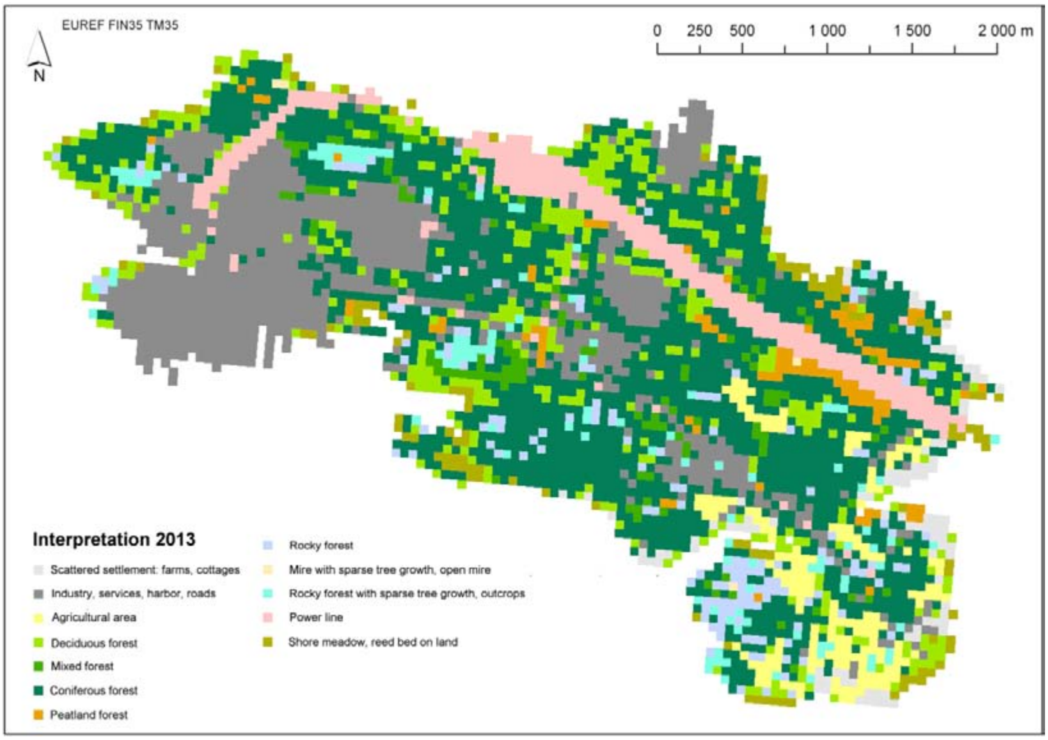


**Figure 17.** Land use grid for 2013 (Pere et al. 2015).

use grid. Figure 16 presents an aerial photograph taken for this purpose in 2015, and Figure 17 the latest published version of the land use grid for 2013 (Pere et al. 2015). As a part of the implementation of safeguards, the aerial photograph could be used to detect buildings on the surface, tunnel openings and the piling of excavated rock and soil.

## 3.5 Monitoring of radioactivity

Although not a part of the present monitoring programme, monitoring of radioactivity in the repository, encapsulation plant, and their environment will start together with the final disposal.

# 4 Resources needed for using monitoring for implementing safeguards

According to the above analysis, three monitoring methods yield data that is reasonable to use for safeguards implementation: microseismic monitoring, automatic hydraulic head monitoring in deep packed-off drillholes, and the monitoring of land use.

## 4.1 Microseismic monitoring

The results of microseismic monitoring have already been submitted according to Posiva's safeguards programme, and taken into account in the safeguards implementation. The contractor responsible for the microseismic measurements presents the detected seismic events in a monthly report, which is saved in Posiva's electronic archive and made available to STUK. The results are also summarised in the annual monitoring report of the discipline of rock mechanics. The examination of these documents can be continued with the current resources.

## 4.2 Hydraulic head monitoring

Hydraulic head in the deep drillholes in Olkiluoto appears to be the most obvious subject with which the monitoring-based implementation of safeguards could be widened. Posiva reports the results of head monitoring in the form of quarterly memos that present the data from each three-month period, preliminary analysis on the causes of observed changes, changes in the monitoring system, known technical issues, etc. The results are also presented and further discussed in the annual reports of hydrological and hydrogeological monitoring together with other data of the discipline. Currently, these documents are communicated to STUK in relation to its role as the supervisor of the construction and long-term safety of the disposal facility, but not directly for safeguards purposes.

The use of the hydraulic head monitoring data in the implementation of safeguards would not necessarily require new reporting from Posiva, but the examination of the already regularly submitted material for safeguards-relevant matters would provide STUK with the essential information. Special attention should be paid to changes of hydraulic head in hydrogeological zones HZ19 and HZ20, which cover a large area above the projected repository, are both intersected by several monitored drillhole sections, and have proven to be rather sensitive to any drilling or excavation through the zone. The required work would consist of examining the quarterly memos on head monitoring as soon as they become available, the applicable sections of the annual monitoring report, and, possibly, other treatments of hydraulic head observations. The estimated work load in a year would be of the order of a week.

Even though STUK's approach to implementing nuclear safeguards is to rely on data and reporting provided by the operator of the facility under supervision, it may also be useful to comment here on the possibility of using independent monitoring equipment to ensure the authenticity of the data. In the case of monitoring hydraulic head in the bedrock, this would mean either drilling one or more new drillholes for the purpose, installing separate pressure sensors and data acquisition equipment in selected packer sections of existing drillholes, or reserving one or more of the existing drillholes exclusively for independent monitoring. However, none of these options can be considered realistic for the following reasons. First, drilling new holes through the major hydrogeological zones would increase the risk of mixing chemically different groundwater types naturally occurring at different depths, and other disturbances regarded as disadvantageous for the long-term safety of the final disposal. Moreover, it would reduce the volume of intact rock without artificial vertical hydraulic connections available for the excavation of disposal tunnels. Second, drillhole dimensions have been designed so that the sensors and measurement hoses for the currently monitored sections barely fit in, leaving no room for extra sensors. The sensors must be installed inside the holes at depths of tens of metres because they have to be located below the water level. Third, it would unnecessarily hamper other studies, such as chemical sampling, flow logging and geophysical investigations in the drillholes, if Posiva lost control of some of them.

## 4.3 Land use monitoring

Posiva regularly orders aerial photographs of Olkiluoto (every other year according to the present programme), and maintains a land use record and a land use grid on the basis of the photographs as well as information gathered on the site and other available sources. The results of Posiva's land use monitoring could be used by STUK in the implementation of nuclear safeguards, for example by checking that they are consistent with the site declaration. Because both the aerial photography and the update of the land use grid are carried out only once every two years, the required resource in terms of working time would only amount to at most a few days per year.

# 5 Conclusions

This report discusses the Olkiluoto Monitoring Programme and its potential in implementing nuclear safeguards on the disposal facility for spent nuclear fuel that Posiva Oy is constructing. A systematic assessment of the relevance of each monitoring method for safeguards leads to the conclusion that three of them produce usable results: microseismic monitoring, automatic hydraulic head monitoring in deep drillholes, and land use monitoring. In addition, some methods can, in principle, indicate surface excavation or tunnelling, but only at a short distance (if at all) and after the activity would already have been detected visually. Therefore, it is not reasonable to use them for implementing safeguards.

The results of microseismic monitoring, i.e., the detected and located seismic events in Olkiluoto and the surrounding region, have been reported to STUK for safeguards supervision since the early stages of the excavation of ONKALO, an underground rock characterisation facility now becoming the central part and access route to the disposal facility. This method of monitoring has proven to accurately detect blasts from underground excavation as well as on the surface.

Automatic hydraulic head (groundwater pressure) monitoring acquires hourly data on groundwater pressure in over 200 packer sections of deep drillholes in Olkiluoto. A significant share of the monitored packer sections have been positioned in sub-horizontal hydrogeological zones, where pressure variations, caused by groundwater leaking from the zone into drilled holes or excavated spaces, have been observed to spread over long distances. Therefore, hydraulic head monitoring, especially in the HZ20 system of the hydrogeological model of Olkiluoto, has potential to reveal clandestine tunnelling or drilling from the ground surface towards the depth of the disposal facility. Its advantages include sensitivity to all methods of excavation, in contrast to microseismic monitoring that can reliably only detect blasting. Another advantage is that the effects on head that can reveal underground activity are long-lasting or even irreversible, so the probability of missing a significant signal is low. The most obvious disadvantages are that the source of the signal cannot be located with the same accuracy as in microseismic monitoring, and the method is sensitive only to activities within the hydraulically conductive zones. Posiva already reports the results of hydraulic head monitoring with interpreted explanations to detected variations regularly for the supervision of the construction and long-term safety of the disposal facility.

The monitoring of land use in Olkiluoto involves aerial photography and updating a land use grid every second year. These results, if reported to STUK for safeguards purposes, can be used to supplement other aerial or satellite imagery of the Olkiluoto site in verifying the declared surface constructions and activities.

The required resources for widening the use of monitoring data in the implementation of safeguards consist of working time needed for the examination of reported results. For the hydraulic head results, the estimated work load is of the order of one week per year, and for the results of land use monitoring, a few days per year.

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**Internal Posiva memos on updated plans of monitoring programme (2016, in Finnish):**

POS-023621: Hydrogeochemistry

POS-023622: Hydrology and Hydrogeology

POS-023623: Rock Mechanics

POS-023624: Surface Environment

POS-023625: Engineered Barrier System

POS-023626: Foreign Materials