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Task description of Task 9C – Modelling of REPRO experiment TDE

Task 9 of SKB Task Force GWFTS – Increasing the realism in solute transport modelling based on the field experiments REPRO and LTDE-SD

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Keywords: Taskforce GWFTS, REPRO, Matrix diffusion, Sorption, Rock matrix, Through-diffusion experiment.

Abstract

This report concerns Task 9 of the SKB Task Force GWFTS – Increasing the realism in solute transport modelling – Modelling the field experiments of REPRO and LTDE-SD. The purpose of this report is to publish the Task 9C description, as well as accompanying data deliveries, in the open literature. These documents have previously been distributed to the modelling groups of Task 9.

Task 9C concerns the combined predictive (earlier stage) and inverse (later stage) modelling of tracer breakthrough curves of the Through-Diffusion Experiment (TDE). This in situ tracer test has been carried out within the REPRO programme at about 400 m depth at the ONKALO underground rock characterisation facility in Olkiluoto, Finland, by Posiva. The Task 9C description gives the prerequisites of the experiments; accompanying laboratory data on rock matrix retention properties; and guidance on the predictive modelling of the breakthrough curves. The actual modelling within Task 9C is not presented here but in separate papers and/or reports.

Sammanfattning

Den här rapporten rör Task 9 inom ramen för SKB Task Force GWFTS – Förbättring av realismen vid transportmodellering av lösta ämnen – Modellering av fältexperimenten REPRO och LTDE-SD. Syftet med denna rapport är att publicera modelleringsbeskrivningen för Task 9C, samt de medföljande dataleveranserna, i den öppna litteraturen. Dessa dokument har tidigare distribuerats till modelleringsgrupperna i Task 9.

Task 9C rör prediktiv (före experimentet) och analyserande (efter experimentet) modellering av genombrottskurvor för spårämnen i experimentet Through Diffusion Experiments (TDE – diffusionsexperiment i vattenfas). Detta spårämnesförsök har utförts in situ på ca 400 m djup i underjordslaboratoriet ONKALO i Olkiluoto, Finland. Detta har utförts av Posiva inom ramen för undersökningsprogrammet REPRO. Modelleringsbeskrivningen för Task 9C ger förutsättningarna för experimenten, kompletterande laborativa data gällande matrisbergets retentionsegenskaper, samt vägledning angående den prediktiva och analyserande modelleringen av genombrottskurvorna. Den faktiska modelleringen inom Task 9C presenteras inte här utan i artiklar och/eller rapporter.

Contents

1 Introduction

1.1 SKB Task Force GWFTS – Task 9

Task 9 is part of the SKB Task Force on Modelling of Groundwater Flow and Transport of Solutes (Task Force GWFTS), which focuses on the fractured crystalline host rock surrounding present and future repositories for spent fuel and other radioactive waste. Special interest is taken in work on fracture flow and solute transport made by the Äspö Hard Rock Laboratory (HRL), Sweden.

The title of Task 9 is "Increasing the realism in solute transport modelling – Modelling the field experiments of REPRO and LTDE-SD". The task focuses on the realistic modelling of coupled matrix diffusion and sorption in the heterogeneous crystalline rock matrix at depth. This is done in the context of inverse and predictive modelling of tracer concentrations of the in situ experiments performed within LTDE-SD at the Äspö HRL in Sweden, as well as within the REPRO project at ONKALO in Finland, focusing on sorption and diffusion. The aim is to develop models that in a more realistic way represent retardation in the natural rock matrix at depth. The following waste management organisations are part of Task 9:

- Svensk Kärnbränslehantering AB, SKB, Sweden.
- Bundesministerium für Wirtschaft und Technologie, BMWi, Germany.
- Japan Atomic Energy Agency, JAEA, Japan.
- Korea Atomic Energy Research Institute. KAERI, South Korea.
- Posiva Oy, Finland.
- Department of Energy, DOE, USA.
- Radioactive Waste Repository Authority (RAWRA), SURAO, Czech Republic.

These waste management organisations assign modelling groups that perform the actual modelling within Task 9.

1.2 Organisation of Task 9C

Task 9 is divided into subtasks that model different in situ tracer tests. The framework of Task 9C was first established by the Technical Committee of Task 9, including:

- Jan-Olof Selroos, Svensk Kärnbränslehantering AB.
- Björn Gylling, Svensk Kärnbränslehantering AB/Gylling Geosolutions.
- Lasse Koskinen/Maarit Yli-Kaila/Kalle Rahkola, Posiva Oy.
- Martin Löfgren, Niressa AB.
- Kersti Nilsson, Geosigma AB.
- Antti Poteri, VTT Technical Research Centre of Finland/Posiva.

The Scientific Chairman of Task 9:

- Bill Lanyon, Fracture Systems Ltd.

was also included in the discussion when setting up the framework of Task 9C. The subtask was thereafter detailed in the Task 9C description, primarily authored by the Principal Investigators Martin Löfgren and Kersti Nilsson but with valuable input from the technical committee and also Bill Lanyon. Task 9C was initiated in 2017. The setup of Task 9C, and the modelling groups' work on the subtask, is evaluated by the Task 9 Evaluator.

- Josep Maria Soler Matamala, IDAEA-CSIC.

The outcome of Task 9C (predictive and inverse modelling) will be reported as papers and/or reports.

1.3 REPRO Through-Diffusion Experiment (TDE)

This section gives an overview of the in situ tracer test in focus of Task 9C, i.e. the Through-Diffusion Experiment (TDE) that is ongoing, most probably until the end of 2019, at the ONKALO underground rock characterisation facility in Olkiluoto, Finland. Details of the experiments are given in the task definition in Chapter 2.

This subtask, Task 9C, is focused on predictive modelling of the ongoing *in situ* Through-Diffusion Experiment, TDE, which is a part of the REPRO project carried out by Posiva at ONKALO in Olkiluoto, Finland. The location of REPRO niche (ONK-TKU-4219) is shown in Figure 1-1.

The experiment was initiated in November 2015 and is still ongoing (planned to be ongoing through 2019). It is carried out between three parallel drillholes arranged as a right-angled triangle. Drillhole ONK-PP326 is used as the injection hole and drillholes ONK-PP324 and ONK-PP327 as observation holes (see Figure 1-2). This facilitates tracer migration along, and across, the rock foliation. The experiment is carried out in 1 m long packed-off intervals, at about 12 m from the tunnel wall. The distances between the drillhole walls are a little more than one decimetre. Any advective flow between the drillholes was foreseen to be insignificant at the stage of initiation of the experiment, as the pressures in the test intervals and surrounding guard intervals were kept constant and equal in all three drillholes. However, due to some unforeseen experimental conditions, after three months the control of the experiment pressures had to be released and ambient pressures were applied. The REPRO site contains very tight rock, locally lacking water-bearing fractures, which is normally not the case in transport experiments. This condition has turned out to cause quite large pressure differences between the experiment intervals, even though the distances are only about 0.1 m. Therefore, presence of advective flow might have to be taken into consideration.

The tracers HTO, Na-22, Cl-36, Ba-133, and Cs-134 have been injected into the source interval in ONK-PP324 and then recirculated. The decreasing tracer concentrations in the injection interval and (foreseen) increasing tracer concentrations in the observation holes are analysed in ongoing measurements. This is done on extracted water samples in the laboratory; for HTO and Cl-36 by liquid scintillation counting and for Na-22, Ba-133 and Cs-134 by High Resolution GXRS (gamma measurements), in most cases after chemical separation. Furthermore, from the start online measurements of Na-22, Ba-133 and Cs-134 were performed for the injection interval and simultaneously for the two observation holes by a High Performance Germanium detector and a Na(Tl)I-scintillation detector, respectively. Tracer concentrations in the injection interval were measured at a higher frequency during the first part of the experiment. In February 2017, focus was shifted towards analysing breakthrough concentrations in the observation holes and for ONK-PP324 the High Performance Germanium detector is used. For ONK-PP327, the Na(Tl)I-scintillation detector is used. From February 2017, only sample collection and subsequent analysis is applied for the injection hole ONK-PP326. Tracer concentrations are not measured in adjacent drillholes ONK-PP321 and ONK-PP322 (see Figure 1-2). Breakthroughs of non-sorbing tracers are foreseen within the time frame of Task 9, although unexpectedly low pore diffusivities may prevent this from happening. For tracers that do not break through within the time frame of Task 9, TDE can be modelled as an in-diffusion experiment similar to that in the small-diameter borehole of LTDE-SD (cf. Task 9B). The tracers were chosen to make overcoring of TDE and analysis of tracer penetration profiles possible, although this option is presently not included in the REPRO planning.

The predictive modelling of Task 9C concerns both the declining tracer concentrations in the injection drillhole and the increasing concentration in the two observation drillholes. The concentration evolutions of all five tracers used in the experiment should be predicted. In Chapters 2.1 to 2.3, the setup and performance of TDE is described together with the environmental monitoring. In Chapter 2.4, supporting geological and retention data obtained within the REPRO laboratory programme are provided. The expected outcome of Task 9C is discussed in Chapter 2.5.

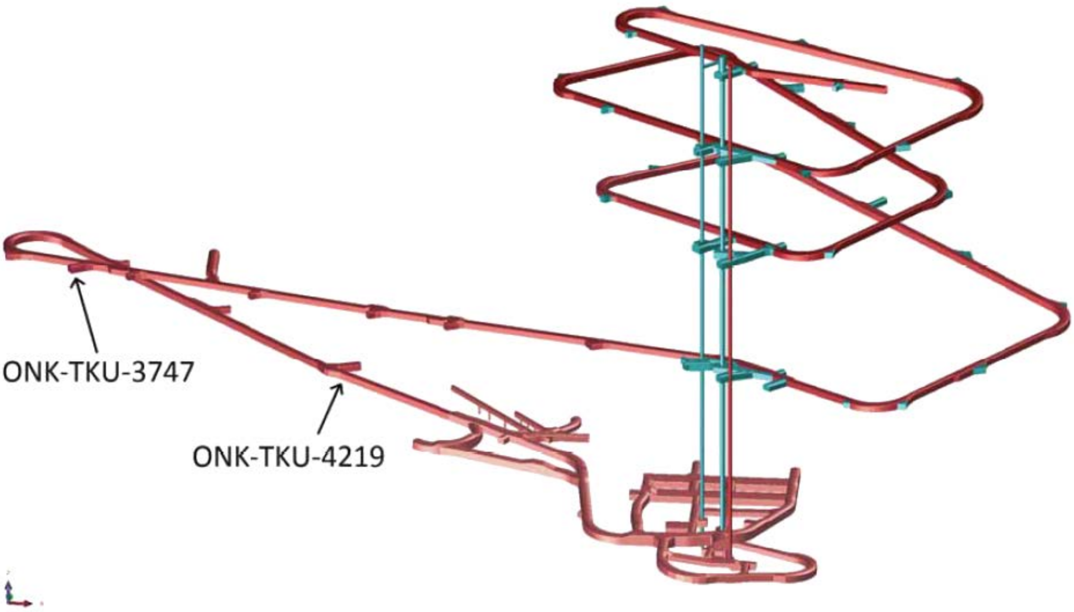

Figure 1-1. *Location of the REPRO niche (ONK-TKU-4219) at ONKALO. Reproduced from Toropainen (2012, Figure 1).*

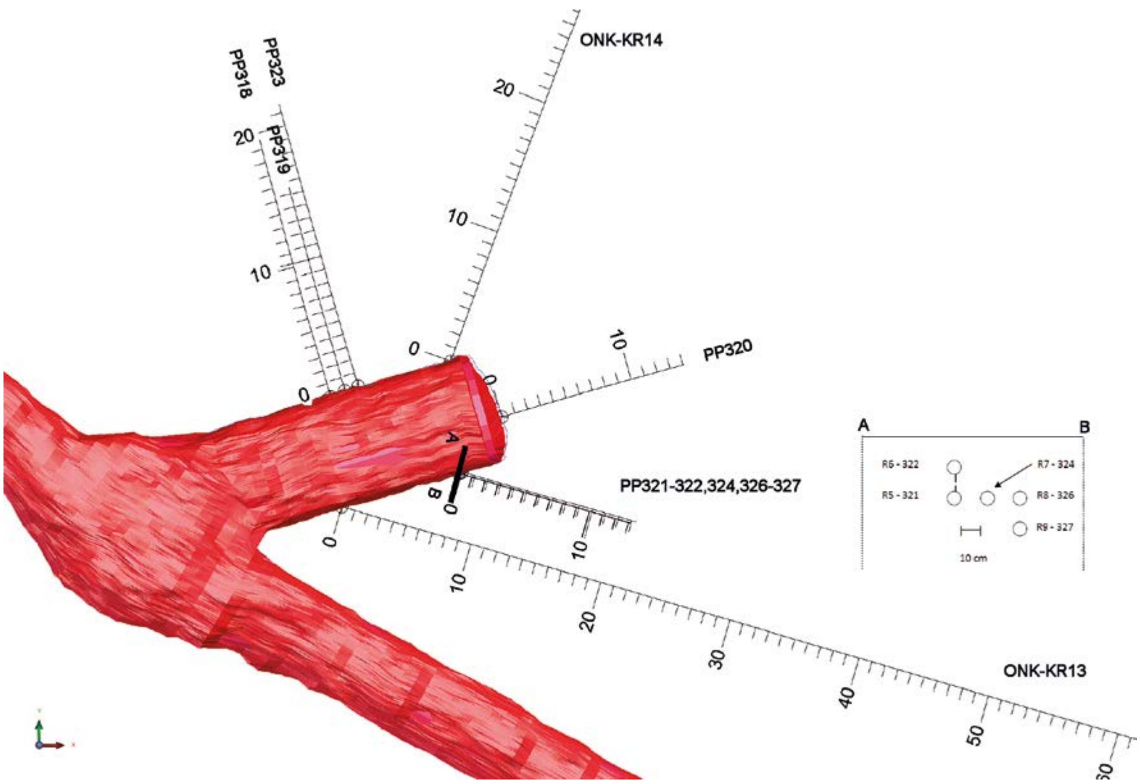

Figure 1-2. *REPRO niche ONK-TKU-4219 and TDE drillholes ONK-PP318 to PP327, provided by Posiva Oy.*

1.4 Task description and data deliveries of Task 9C

The main purpose of this report is to publish the Task 9C description, as well as accompanying data deliveries, in the open literature. These documents have been provided to the modelling groups during the course of Task 9C. The final task description for Task 9C was sent out to the modellers in the later part of 2017, and is dated 14th of November, 2017. In addition to the task description, there are several accompanying data deliveries. These are tabulated in Table 1-1, where also the data delivery number relating to the SKB Task Force website is provided. These data deliveries are appended to this report and the rightmost column of Table 1-1 provides the link to the corresponding section or appendix. The first few rows concern the task description, and links to where the different chapters and appendices are found in this present report.

Table 1-1. Mapping of task description and data deliveries to this report.

Delivery number	Description of data delivery	Link to location in this report
18	^{14}C-PMMA autoradiography and X-ray tomography data	Section 2.4.8
22	Task description of Task 9C	This report
23	Update on pressure gradients in REPRO TDE	Section 2.3.4
25	Additional updated pressure data of REPRO TDE, and clarifications	Section 2.3.3
30	Updated caliper volumes	Table 2-3
31	Experimental activity and pressure values	Appendix 3 to 7
34	Updated experimental values for REPRO TDE	Appendix 3 to 7

Modification to the original text is avoided and instead clarifications and comments are inserted in grey text boxes below the concerned paragraphs. An example of such a text box is provided below.

Clarification or comment
Text providing a brief clarification of comment.

2 Task definition of Task 9C

2.1 Experimental setup and geometries

2.1.1 Drill-hole geometry data

The TDE campaign is carried out between the three parallel drillholes ONK-PP326 (injection), ONK-PP324 (observation), and ONK-PP327 (observation) drilled from the right-hand wall of the REPRO niche. The drillholes have a dip of about −8°, meaning that they are drilled almost horizontally but with a slight dip downwards. In addition, there are two nearby observation drillholes, ONK-PP321 and ONK-PP322, where pressures are measured (cf. Figure 1-2). These holes were originally intended as test holes but they were unfortunately interconnected during drilling, at about 9 m depth. Start coordinates; lengths; dips and directions (at the start coordinates) of the drillholes are given in Table 2-1. Further results from surveys on the drillhole directions are presented in Toropainen (2012, Appendix 4). Calculations of the distances between the drillhole walls have been performed in 3D, and the results are reported in Table 2-3.

Table 2-1. Geometric data of the TDE drillholes in terms of start coordinates; length; and dip and azimuth at the drillhole mouth. Data reproduced from Toropainen (2012, Appendix 4).

Drillhole	X (m)	Y (m)	Z (m)	Length (m)	Azimuth (°)	Dip (°)
ONK-PP324	6 792 242.43	1 525 593.48	−401.31	13.30	106.1*	−8.1
ONK-PP326	6 792 242.34	1 525 593.23	−401.29	13.22	106.0*	−8.2*
ONK-PP327	6 792 242.33	1 525 593.27	−401.45	13.15	106.1*	−8.5
ONK-PP321	6 792 242.54	1 525 593.68	−401.33	13.34	105.0	−7.4
ONK-PP322	6 792 242.53	1 525 593.71	−401.18	12.57	105.0	−7.9

* Value updated since Toropainen (2012) and saved to Posiva's research database POTTI.

2.1.2 Experimental setup

The experimental setup consists of installations in the drillhole (installations performed on January 15th, 2015); equipment in two containers in the REPRO niche, one for injection and one for observation; and connecting tubing. Figure 2-1 shows a side view illustration of one of the experiment intervals utilised in the campaign. The equipment is identical to the one used in the WPDE tests (cf. Task 9A) except for the length of the isolated interval. A 1 000 m long drillhole interval has been packed off by using inflatable packers. The ends of the packers, facing the experiment interval, have been teflonized to avoid interactions with the tracers. An inert and non-porous 54 mm dummy of PEEK (PolyEtherEtherKetone) has been placed within the packed-off drillhole section, with the aim to reduce the water volume of the test intervals. The measures are given in Table 2-3. Locally the drillhole diameter may change, due to surface roughness and minor irregularities of the drillhole wall.

Clarification

The measure of the annular slot for the three sections was earlier given in the section above. The three drillhole section diameters have been revised and are different. The updated section diameters are given in Table 2-3.

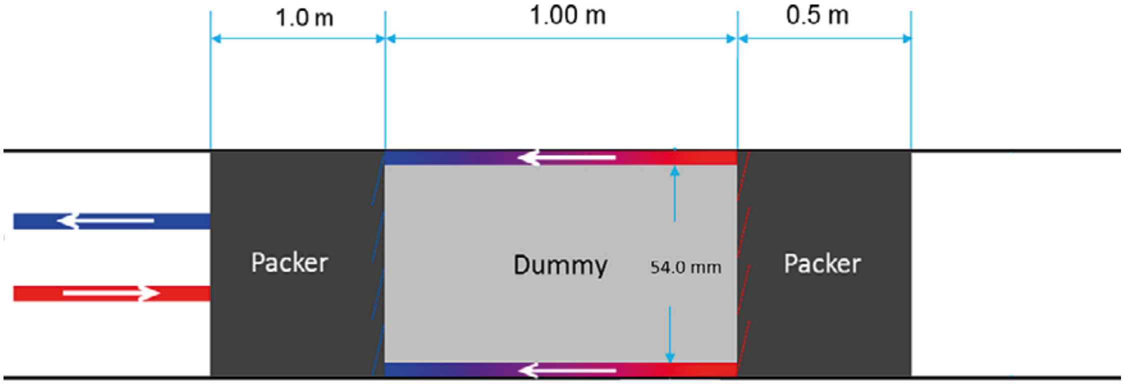

Figure 2-1*. The experimental setup of the TDE in situ campaign. Side view of the experimental section. Red colour signifies ingoing circulating water and blue colour outgoing water. The measures of the drillhole diameters are different for the three sections and are given in Table 2-3.*

The bedrock surrounding the drillhole test intervals is veined gneiss (VGN), as further described in Section 2.4.2. The veined gneiss shows a weak to moderate banded foliation but locally also irregular foliation. The general orientation of the foliation is almost parallel to the drilling direction. The drillholes also intersect a skarn lens (or layer). Only few fractures intersect the drillholes (Toropainen 2012) but there is only one part of the local rock volume, with a length of 1 m or more, that is completely free from fractures in all three drillholes (cf. Section 2.4.2). This local rock volume was chosen for the experiment and the upper and lower drillhole positions for test intervals are given in Table 2-2.

The orientation of the drillholes was chosen to study diffusion along and perpendicular to the foliation. Using drillhole ONK-PP326 as injection drillhole and ONK-PP324 as observation hole allows for diffusion along the foliation. Diffusion from the injection hole towards observation hole ONK-PP327 is perpendicular to the foliation.

Drillholes ONK-PP321 and ONK-PP322 are located very close to the three experimental drillholes (about 0.1 m from PP324). These holes were therefore plugged with packers in order to avoid creating a hydraulic sink. All holes are also equipped with an extra guard packer closer to the drillhole mouth to diminish hydraulic gradient towards the REPRO niche. Pressures are monitored in the holes, which may give an indication of hydraulic gradients during the experiment. Table 2-2 shows all intervals monitored.

Clarification
The section below has been moved from next page for clarity.

The experiment intervals are connected to various pieces of equipment fitted in two containers that are placed next to the drillholes in the REPRO niche. The reason to use two containers is to avoid contamination during sampling and on-line detection from the highly active injection drillhole to the low-active observation drillholes. The inside of the injection container, which is placed close to the drillhole mouths, is partly displayed in Figure 2-2. The second container is placed about 8 meters from the drillholes and from the start only contained the on-line gamma detector and 6-way sampling valves for the two observation drillholes. From February 2017, both detectors are placed in this container. The lengths, dimensions and volumes of the tubing and drillholes in the TDE experiment are summarised in Table 2-3. Note that a discussion on the distance between the drillholes is given in Section 2.1.3.

Comment
The text section below has been added since the first version of the Task description 9C.

During the REPRO Through-Diffusion Experiment, there have been some problems with the circulation in observation hole PP324, which has caused problems with collecting representative samples from the experiment water volume. From December 2017, 90 mL samples instead of 10 mL samples were collected to increase the probability of representative samples. However, this procedure has increased the uncertainty of the results, both due to less representative samples due to incomplete mixing (the inlet and outlet from the section are situated close to each other) and unwanted dilution of the tracer concentrations. Therefore, it was decided to restore the circulation in PP324 by removing the packer system and changing the PEEK tubing to 2 mm inner diameter instead of 1 mm diameter. During the two weeks operation, the drillhole was packed off and the pressure was kept the same as the guard pressures (about 0.95 MPa). On September 12th 2018, the re-installation of packers was made, and the circulation in PP324 worked successfully again. The new, larger volume for the tubing is reported in Table 2-3.

Table 2-2. Experimental drillhole intervals with measured parameters.

Drillhole	Interval (m)	Comment	Measured parameters
ONK-PP324	0.00–6.13	Open to atm.	None
(Obs. hole)	7.13–10.38	Outer guard	Pressure
	11.38–12.38	Test interval	Pressure, circulation flow, gamma activity
	12.88–13.30	Inner guard	Pressure (interconnected with outer guard)
ONK-PP326	0.00–6.35	Open to atm.	None
(Inj. hole)	7.35–10.60	Outer guard	Pressure
	11.60–12.60	Test interval	Pressure, circulation flow, gamma activity until February 2017
	13.10–13.22	Inner guard	Pressure (interconnected with outer guard)
ONK-PP327	0.00–6.28	Open to atm.	None
(Obs. hole)	7.28–10.53	Outer guard	Pressure
	11.53–12.53	Test interval	Pressure, circulation flow, gamma activity
	13.03–13.15	Inner guard	Pressure (interconnected with outer guard)
ONK-PP321	0.00–6.28	Open to atm.	None
(Obs. hole)	7.28–8.53	Outer guard	Pressure
	9.53–13.34	Inner guard	Pressure (interconnected with ONK-PP322)
ONK-PP322	0.00–6.28	Open to atm.	None
(Obs. hole)	7.28–8.57	Outer guard	Pressure
	9.57–12.57	Inner guard	Pressure (interconnected with ONK-PP321)

Comment
Table 2-3 below was updated as delivery #30. Caliper data from the REPRO drillholes had been available for some time (received after distribution of the 9C Task Description) but had not yet been delivered to the modellers. Caliper data show that the diameters (and volumes) are larger than reported before, and that the volumes differ between the three experiment sections. Also tubing diameter after 2018-09-12 in ONK-PP324 was updated. See the section above.

Table 2-3. Geometries and volumes of the TDE experiment.

Description	Measure	Unit
Drillhole diameter of 1 m experiment section in ONK-PP324 (± 2σ)	56.76 ± 0.07	mm
Drillhole diameter of 1 m experiment section in ONK-PP326 (± 2σ)	56.92 ± 0.14	mm
Drillhole diameter of 1 m experiment section in ONK-PP327 (± 2σ)	57.00 ± 0.16	mm
Outer diameter of dummy in ONK-PP324, 326, and 327	54.0	mm
Length of annular slot in ONK-PP324, 326, and 327 (also distance between inlet and outlet)	1.00	m
PEEK tubing – inner diameter	1.02	mm
PEEK tubing – inner diameter in ONK-PP324 from 2018-09-12	2.03	mm
Distance of intact rock between test intervals ONK-PP326 to ONK-PP324 [a]	0.115	m
Distance of intact rock between test intervals ONK-PP326 to ONK-PP327 [a]	0.15	m
Total length of PEEK tubing ONK-PP324 (including 9 m detector tubing, 1 mm)	63.4	m
Total length of PEEK tubing ONK-PP326	43.4	m
Total length of PEEK tubing ONK-PP327	63.4	m
Volume of water in test interval ONK-PP324	240	mL
Volume of water in test interval ONK-PP326	254	mL
Volume of water in test interval ONK-PP327	262	mL
Total volume of water in ONK-PP324 test interval (including tubing)	291	mL
Total volume of water in ONK-PP324 test interval (including tubing from 2018-09-12)	424	mL
Total volume of water in ONK-PP326 test interval (including tubing)	290	mL
Total volume of water in ONK-PP327 test interval (including tubing)	313	mL

[a] Calculated by Posiva from drillhole deviation measurements at drillhole length 12.0 m. Data are saved to Posiva's research database POTTI. The measure signifies the shortest distance between the drillhole walls, and not the drillhole axis to axis distance.

Figure 2-2. *Parts of TDE injection container in the REPRO niche, containing equipment such as data acquisition (A), pressure transducers (B), pressure regulation vessels (C), and circulation pumps (D).*

The injection and observation drillholes were originally interconnected with all guard intervals, creating a pressure common for all guard intervals as well as test intervals in order not to create any pressure gradients between the drillholes. The common pressure was maintained through individual pressure regulation vessels (Figure 2-2) However, after a period of pressure stabilisation it was decided to stop the regulation as natural pressures were decreasing and thereby creating an excess pressure in the experimental volume. Instead, the experiment is carried out during ambient pressure situation. A schematic illustration (Figure 2-3) shows the experimental setup.

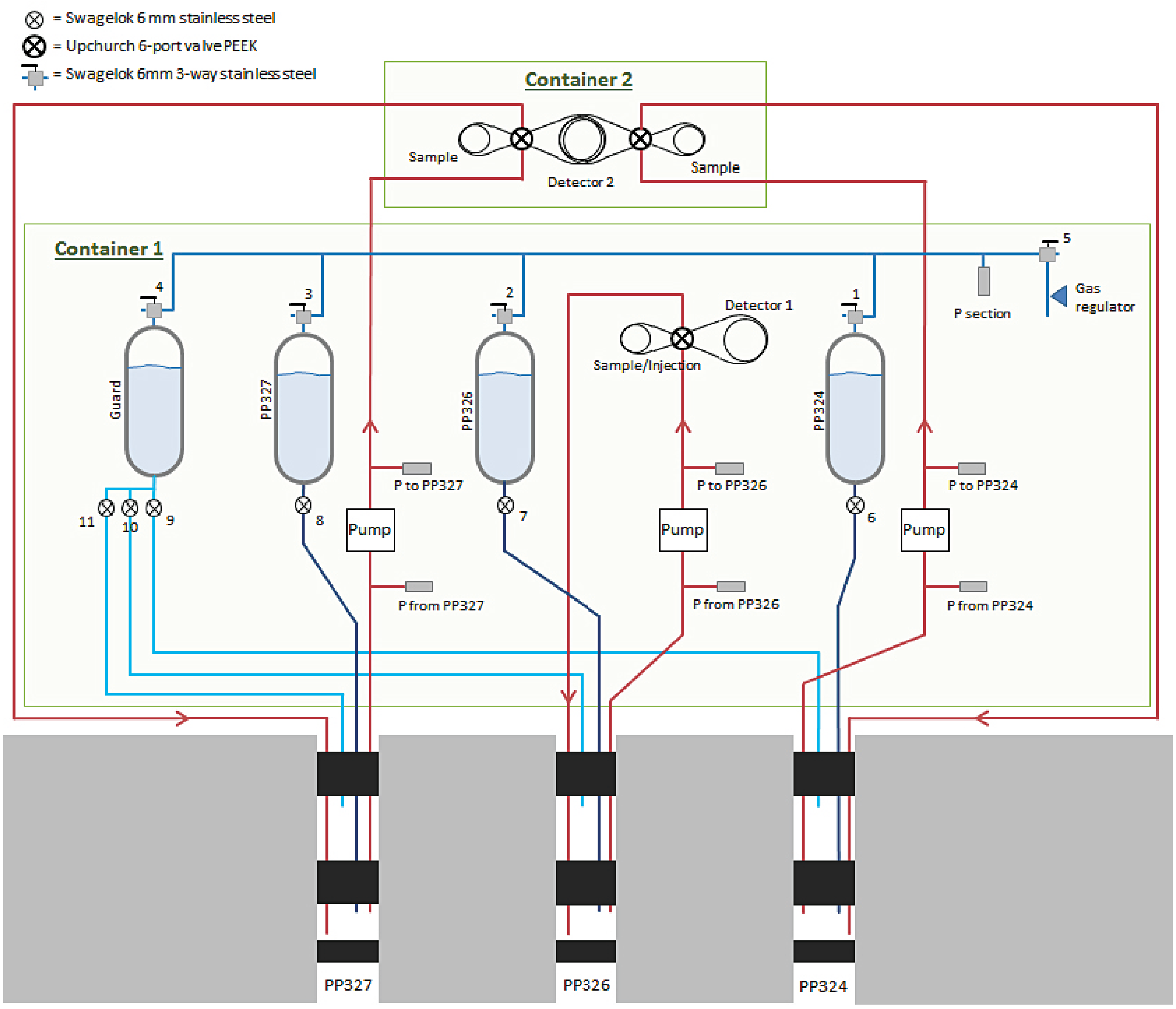

Figure 2-3. Schematic illustration of the flow and pressure regulation unit including tracer sampling, injection and on-line detectors.

2.1.3 Distance between drillholes

The values of the distance between the drillholes have been calculated at three different positions in the drillholes (start, middle and end), and the results are 11.5 cm (ONK-PP326 to ONK-PP324) and 15 cm (ONK-PP326 to ONK-PP327). These values signify the minimum thicknesses of the rock matrix between the drillholes and not the drillhole axis to axis distances. Due to difficulties in drilling absolutely straight drillholes and accurately measuring the deviations of the drillholes, these distances are associated with uncertainty. One prominent uncertainty relates to the general placements of the drillhole axes, giving a general shift in the drillhole to drillhole distance. The other relates to differences in, and uncertainty of, the dip and azimuth of the drillholes. However, the measured and calculated difference between the drillhole to drillhole distances (general placement of the drillhole axes) at the inlets and outlets of the test intervals is much smaller than the uncertainty in the borehole deviation measurement. At the moment no estimation of the uncertainty of the geometric data has been possible to perform.

2.1.4 Tracer injection and sampling setup

Tracer solution was added to ONK-PP326 on November 19, 2015, by switching the 6-way valve to a tube containing 5 mL of concentrated tracer solution and circulating the entire drillhole volume with a circulation pump, see Figure 2-3. Circulation pumps with PEEK material in contact with the water are used for water circulation in all three drillholes. The pumps run continuously with a flow rate of 2 mL/min – 4 mL/min. The flow rate was increased to 10 mL/minute during the mixing phase of the tracer injection.

Comment

In the original Task Description 9C, a sampling schedule was provided in a Table 2-4. However, adjustments have been made, and the performed sample collections are instead presented in Appendix 5.

Sampling is done through the 6-way valves at regular intervals. The original plan was to extract each time a volume of 0.2 mL from ONK-PP326 and 10 mL from ONK-PP324 and 327, respectively, via the 6-way valve into a sampling loop, by pumping. The extracted volume is replaced with the same volume of tracer free synthetic groundwater. The performed sample collections are presented in Appendix 5.

A complement to the manual sampling is the on-line measurements, performed by a NaI(Tl)-detector in the observation holes (initially both holes together) and a High Purity Germanium (HPGe) detector in the injection hole. These detectors only measure gamma activity of the tracers. From February 2017, no on-line detection is performed for the injection hole, only sample collection and subsequent analyses. The two observation holes are since then measured separately using the two different detectors.

Circulation flow rates are not explicitly measured. Instead, the pressure difference created by the pumping, before and after the pump ("P to" and "P from" in Figure 2-3), are used to calculate a theoretical flow rate and also to indicate that the pumps work.

Comment

During the course of the Through Diffusion Experiment, there have been questions whether the circulation of the water in the observation sections ONK-PP324 and ONK-PP327 has been ongoing or not. Therefore, a flow indicator was installed in ONK-PP327 in October 2017. However, the construction of the flow indicator led to very long periods of pressure recovery, see Figure 2-6 and Figure 2-7. The flow indicator was removed at the same occasion as the change to 2 mm tubings in ONK-PP324.

2.2 Tracers and water chemistry

2.2.1 Tracers

The injected TDE tracer cocktail contained the radionuclides ^{3}H, $^{22}Na^{+}$, $^{36}Cl^{-}$, ^{133}Ba, and ^{134}Cs. Table 2-4 lists the radioactive elements used and the injected decay-corrected activities. The reference date for decay correction is the tracer injection date; 2015-11-19. In addition, the measurement method is given for each radionuclide. Selected radionuclides represent non-sorptive elements and sorptive elements with a wide range of sorption distribution coefficients (Na < Ba < Cs).

Comment

Results from analyses of collected samples from ONK-PP324, ONK-PP326 and ONK-PP327 are shown in Appendix 3 and results from on-line gamma measurements of ONK-PP324, ONK-PP326 and ONK-PP327 are shown in Appendix 4.

Table 2-4. List of tracers for TDE experiment.

Isotope	Activity (MBq)	Decay mode*	Half-life (yr)	Special issues	Measurement method
^{3}H	198 ± 2	β^{-}	12.3	After gamma's chemical separation	Liquid scintillation counting, Hidex
^{36}Cl	5.5 ± 0.2	β^{-}	3.0E+5	After chemical separation, AgCl precipitation	Liquid scintillation counting, Hidex
^{22}Na	22.4 ± 0.2	$\varepsilon + \beta^{+}$	2.6		Gamma measurement, Canberra High resolution GXRS
^{133}Ba	1.92 ± 0.06	ε	10.5	Chemical separation needed, Sulfate precipitation	Gamma measurement, Canberra High resolution GXRS
^{134}Cs	2.09 ± 0.04	β^{-}, ε	2.1	Chemical separation needed, Ion exchange with Cs-treat	Gamma measurement, Canberra High resolution GXRS

* ε signifies Electron Capture.

2.2.2 Water chemistry

Synthetic groundwater has been slowly circulated in the experimental drillhole intervals throughout the TDE experiment. The recipe of this synthetic groundwater has been designed to match the groundwater composition in the rock surrounding the ONKALO tunnel. The recipe was initially made to match groundwater composition data from a flowing fracture in drillhole ONK-PP319, which is also drilled from the REPRO niche (Figure 1-2). The recipe of the synthetic groundwater is provided in Table 2-5, together with measured groundwater compositions in drillholes ONK-KR14 and ONK-PP319. The locations of the drillholes are shown in Figure 1-2. Table 2-5 also contains data on five water samples collected from the TDE intervals of drillholes ONK-PP324, ONK-PP326 and ONK-PP327 after drillhole installations and filling of the drillholes with synthetic groundwater prior to tracer injection.

It should be noted that the redox conditions in the experimental intervals likely deviate from the natural redox conditions at the site. This is because the redox conditions of the synthetic groundwater are not controlled, or measured, prior to injection. Given the handling of the synthetic groundwater it is judged, by the personnel performing the experiments, to be oxic in nature.

Table 2-5. Groundwater compositions in nearby drillholes; recipe of synthetic groundwater; and results from analyses of water samples from the TDE intervals filled with synthetic groundwater prior to tracer injection. The samples were analysed at two different laboratories; TVO and Labtium Oy. Blank entries indicate not analysed.

ACTIVITY_ID	57518	72108							Unit
HOLE_ID	ONK-KR14[1)]	ONK-PP319[1)]	Synthetic ground-water, recipe	ONK-PP324[2)] 2015-07-08	ONK-PP324[1)] 2015-10-13	ONK-PP327[2)] 2015-07-23	ONK-PP326[2)] 2015-06-17	ONK-PP326[1)] 2015-10-21	
DATE_START	20.6.2011	21.2.2013							
LENGTH_FROM	28.1		-						
LENGTH_TO	29.6		-						
SAMPLE_ID	1964	72108	-						
WATER_TYPE	Na-Cl	Na-Cl	-						
Sodium fluorescein	1.2	< 1	-						µg/l
pH	7.0	7.9	7.0		7.4			6.1	
Conductivity	15.33	17.27	-		16.21			16.50	mS/cm
Iron, Fe^{2+}	-	< 0.02	-						mg/l
Total acidity, NaOH uptake	0.06	-	-						mmol/l
Total dissolved solids	8601	9559	-		9161			9104	mg/l
Bromide, Br	33	34	33		34			35	mg/l
Calcium, Ca	520	690	520	650	640	712	708	680	mg/l
Carbonate alkalinity, HCl uptake	< 0.05	< 0.05	-						mmol/l
Dissolved inorg. Carbon	2	8.9	-		8.8			6.9	mg/l
Iron, Fe	11	-	-	< 0.05	< 0.02	2.29	0.58	0.67	µg/l
Nitrogen, N total	6	-	-						mg/l
Non Purgeable Organic Carbon	50	2.1	-						mg/l
Potassium, K	7.9	14	7.9	17.4	14	20.9	21.1	20	mg/l
Strontium, Sr	4.5	5.7	4.5	5.85		6.04	5.95		mg/l
Sulphide, S^{2-}	-	< 0.02	-						mg/l
Magnesium, Mg	35	34	35	37.4	33	41.3	41.8	38	mg/l
Sulphur, S total	1.4	-	-						mg/l
Total alkalinity, HCl uptake	0.2	0.73	-						mmol/l
Bicarbonate, HCO_3	12.2	45	12.2						mg/l
Fluoride, F	1.5	-	1.5						mg/l
Nitrite, NO_2	0.035	-	-						mg/l
Silicate, SiO_2	6.2	5.4	13	4.0[3)]		3.91[3)]	4.63[3)]		mg/l
Sodium, Na	2770	2840	2670	(1860)*	2760	(1830)*	(1810)*	2700	mg/l

Sulphate, SO_4	0.3	1.1	0.3		0.4			< 0.2	mg/l
Charge balance, calculated from HCO_3	0.66	−1.85	-						%
Ammonium, NH_4	0.10	-	-						mg/l
Chloride, Cl	5 210	5 890	5 130	5 400	5 680	5 500	5 500	5 630	mg/l
Nitrate, NO_3	0.086	-	-						mg/l
Uranium, U	0.14	-	-						µg/l
Colour	< 5	-	-						mg/l Pt
Turbidity	< 5	-	-						FTU
Deuterium, H-2	-	−56.5	-						‰ VSMOW
Oxygen-18, O-18	-	−10.19	-						‰ VSMOW

[1)] Analysed by TVO's lab.
[2)] Analysed by Labtium Oy.
[3)] Reported as Si.
* (Unreliable value).

2.3 Environmental monitoring and experimental artefacts

Comment

The field protocol for REPRO TDE is reported in Appendix 6 and tracer concentrations versus time with major events displayed are shown in Appendix 7.

2.3.1 Pressure monitoring

The pressures have been monitored in test and guard intervals (cf. Table 2-2) of the TDE drillholes. As stated in Section 2.1.2, at the early phase of the experiment the pressures were controlled. As the experiment progressed it was decided to instead allow the pressures in the individual intervals to reach their ambient pressures. This change was implemented on the 11th of February 2016. The resulting pressures are plotted in Figure 2-4 to Figure 2-7.

Clarification

One complementary diagram with pressures results has been added since the first version of the Task Description 9C, present in Figure 2-7.

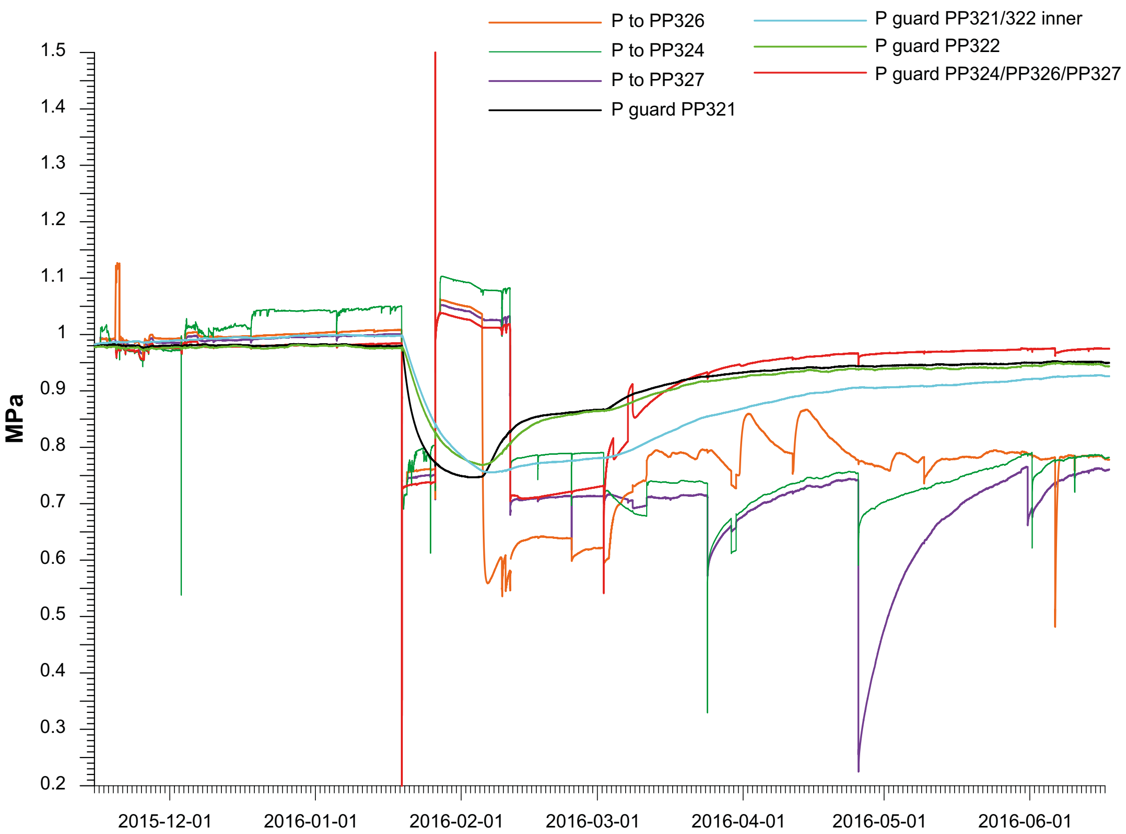

Figure 2-4. *Pressures in all monitored intervals as measured from 2015-11-15 to 2016-06-17. The pressures in the test interval of PP324, PP326 and PP327 are not exact, since they are influenced by the continuous flow rates and therefore show only the pressures in the lines directed into the experiment intervals (cf. "P to" in Figure 2-3). Before 2016-02-11 the pressures were controlled, and after that the pressures are ambient.*

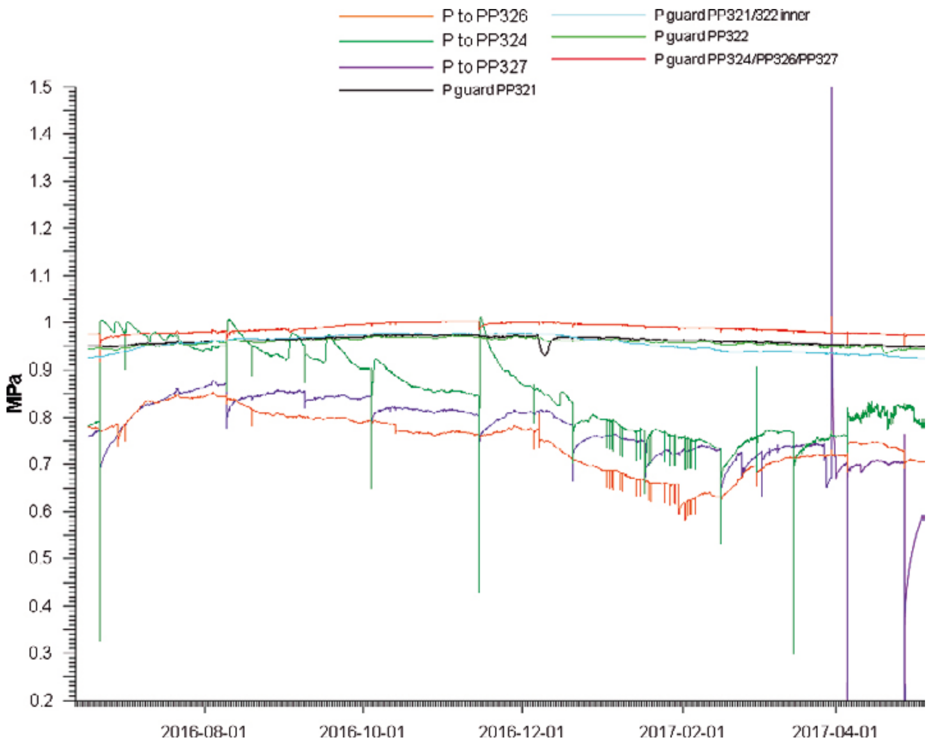

Figure 2-5. *Pressures in all monitored intervals as measured from 2016-06-17 to 2017-05-05. The pressures in the test intervals of PP324, PP326 and PP327 are not exact, since they are influenced by the continuous flow rates and therefore show only the pressures in the lines directed into the experiment intervals (cf. "P to" in Figure 2-3).*

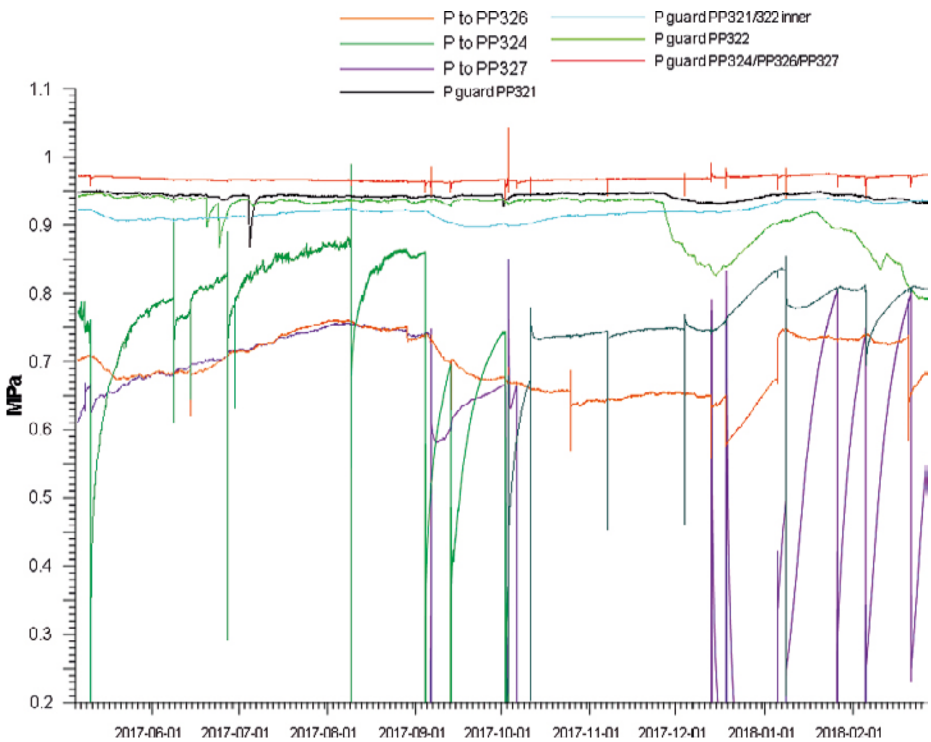

Figure 2-6. *Pressures in all monitored intervals as measured from 2017-05-06 to 2018-01-26. The pressures in the test intervals of PP324, PP326 and PP327 are not exact, since they are influenced by the continuous flow rates and therefore show only the pressures in the lines directed into the experiment intervals (cf. "P to" in Figure 2-3).*

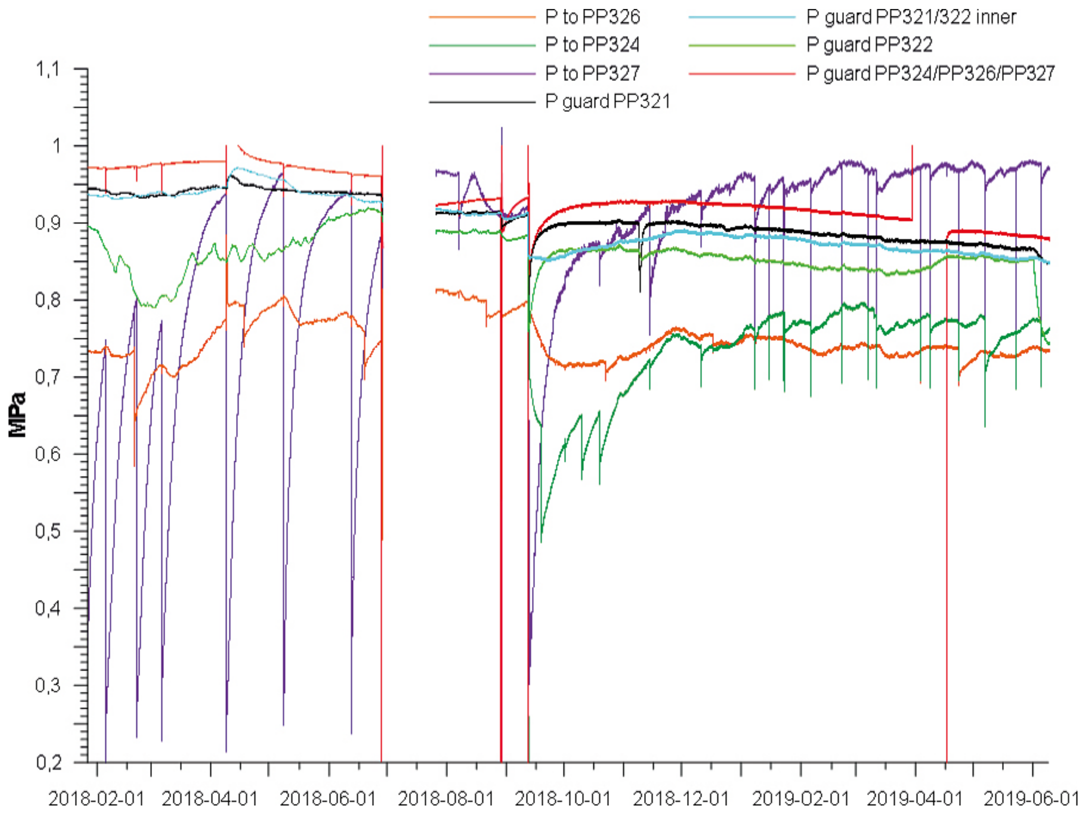

Figure 2-7. *Pressures in all monitored intervals as measured from 2018-01-26 to 2019-06-04. The pressures in the test intervals of PP324, PP326 and PP327 are not exact, since they are influenced by the continuous flow rates and therefore show only the pressures in the lines directed into the experiment intervals (cf. "P to" in Figure 2-3).*

2.3.2 Temperature

The temperature of the TDE experiments should coincide with the ambient in situ temperature, given the low flowrates of the circulating water. The *in situ* temperature at the Olkiluoto site is in general between 10 and 11 °C at the −400 m level (Sedighi et al. 2014, Section 3.1). The temperature in the REPRO niche (i.e. at the experimental containers) has not been measured but the somewhat elevated temperature in the tunnel should have limited impact on the experiment intervals that are shielded by more than 10 m of rock.

2.3.3 Known experimental artefacts

In January 2016, a leakage from the injection interval (ONK-PP326) was detected, which resulted in a dilution of the tracer cocktail with loss of 47.7 ± 0.2 mL of synthetic groundwater. The leakage is suspected to have occurred due to sudden pressure changes (human mistake) in the system (see pressure spikes in January 2016 in Figure 2-4). The leaked activity is believed to be contained within the inner and outer guard intervals of ONK-PP326.

In observation hole ONK-PP327, a contamination occurred at about the same time as the sudden leakage from PP326. This was initially interpreted as an early breakthrough, but later discovered to be a human error (in connection with sample collection) causing the contamination.

It was also recently (March 2017) discovered that the flow lines in the observation holes were partly clogged during spring 2016 (which was not noted due to the contamination) and representative samples were not collected with certainty until after about 1.5 years after the beginning of tracer circulation.

2.3.4 Complementary information concerning the pressure situation, not present in the original Task Description

Comment

During Task 9C, two updates/clarifications (#23 and #25) concerning the pressure situation have been delivered. The aim of the update was to clarify the known gradients to facilitate considerations in modelling of the prediction of tracer breakthrough. The updates are presented below in the added Section 2.3.4. Further, new data from Appendix 2 has been added in Figures 2-8 and 2-9 since the #23 and #25 deliveries.

Pressure gradients in TDE

The pressures for the three experiment sections shown in Figure 2-4 to Figure 2-7 are influenced by the continuous circulation of water, as pressures are measured through the flow lines. The actual pressures in the experiment sections, measured at times when the pumps were off, are displayed in Figure 2-8. Pressures are varying quite a lot, partly due to experimental artefacts, in particular a leakage in PP327 during late 2017, but there is also a tendency of a general decrease in pressures over time. Figure 2-9 shows that both magnitude as well as direction of the hydraulic gradient between the drillholes vary significantly over time. Hydraulic gradients in the order of 100 (0.1 MPa/0.1 m) or more seem to prevail during long periods of time and the dominating gradient from summer 2016 until spring 2017 is towards the injection section.

It should also be noted that pressures in the guard sections (Figures 2-4 to 2-7) are much more stable and undisturbed with the exception of Pguard PP322 which varies quite a lot during and after blastings that have taken place beneath the REPRO niche. The pressures are also higher than in the experiment sections although guard sections are closer to the tunnel interface. The reason for this may be that all guard sections are intersected by a low transmissive flowing fracture set (2–3 fractures) which is interpreted not to intersect the tunnel and thereby keeping a higher pressure. The hydraulic gradient along the drillholes, between guard sections and experimental sections is in the order of 20–30 m/m (0.2–0.3 MPa/1 m), always directed towards the experimental sections.

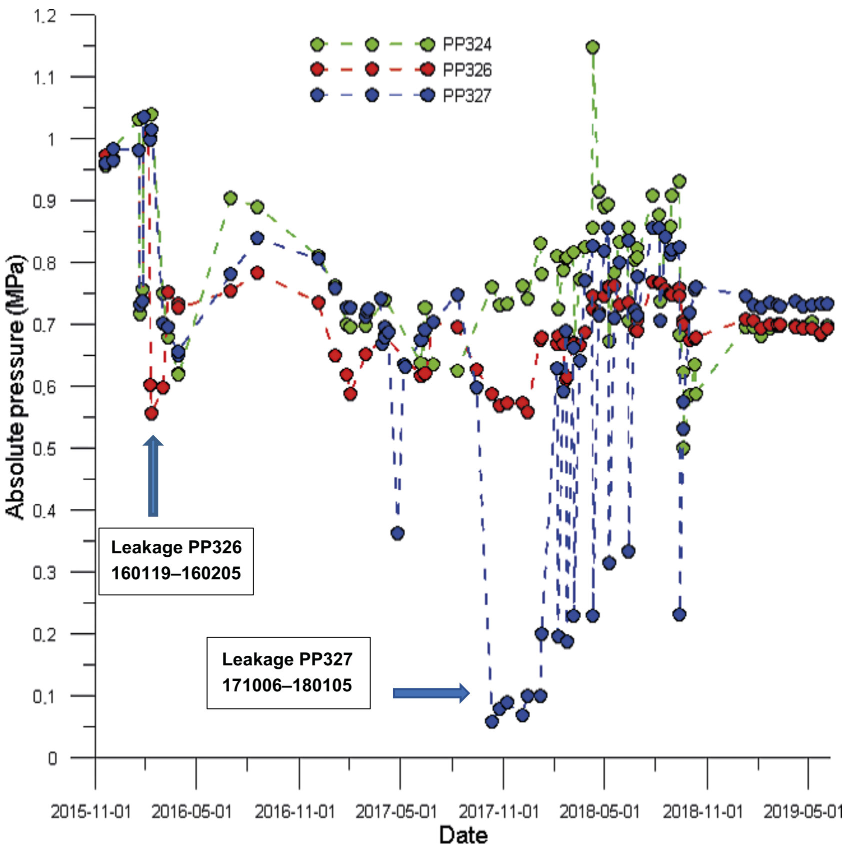

Figure 2-8. *Pressures in the three experimental intervals as measured from 2015-11-15 to 2019-05-16. The dots represent actual measurements, lines in between are interpolations.*

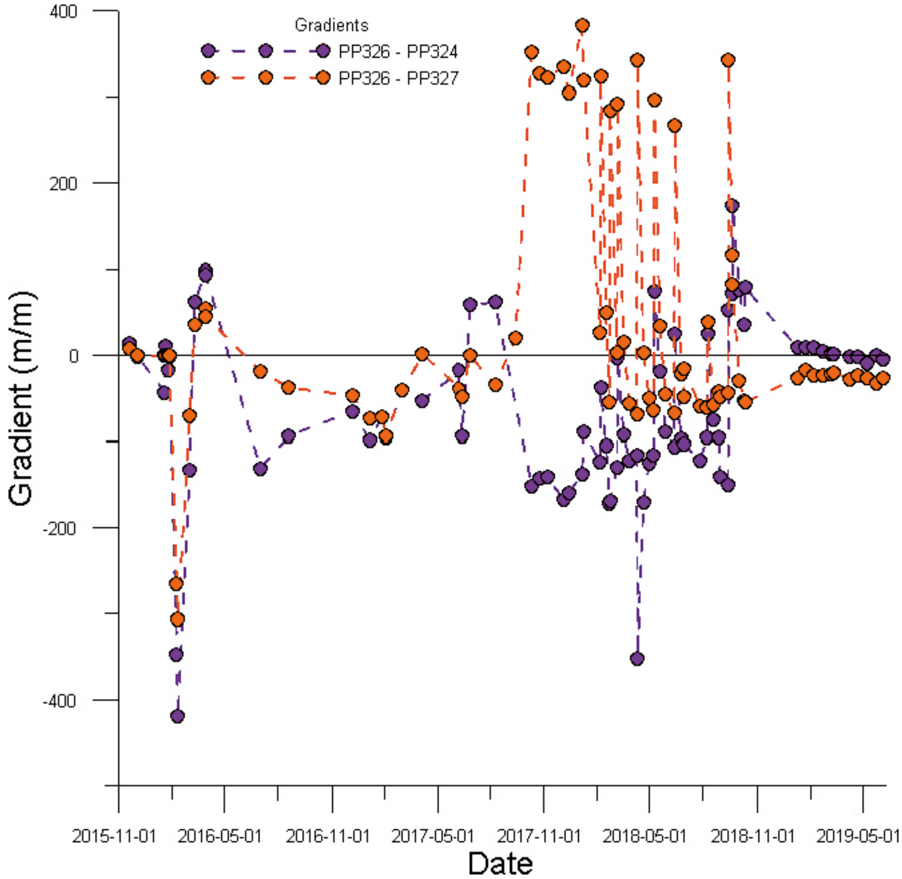

***Figure 2-9.** Hydraulic gradients between PP326 and the two observation drillholes PP324 and PP327. The two leakages shown in Figure 2-8 are clearly visible as extremes. The dots represent actual measurements, lines in between are interpolations.*

Hydraulic conductivity

In addition to the pressure gradients, the risk for advective flow also depends on the hydraulic conductivity of the rock. The hydraulic conductivity of the experimental intervals has been determined in the field for drillholes PP323 (REPRO WPDE), PP324 and PP326.

Field measurements were made by measuring the inflow to the experimental sections during several weeks prior to the TDE experiment. The measurements were made by installing a double-packer with the test section open to the atmosphere (1.0 m long test section in TDE holes and 1.9 m test section in PP323). The section was initially filled with water and inflow was measured at the borehole mouth by collecting the water coming out of the drillhole in a bottle which was weighed and emptied once a week. The bottle was covered to avoid evaporation.

Inflow was found to vary quite much from week to week (especially in PP326), which may be an effect of gas release due to pressure release of water entering the drillhole at atmospheric pressure. By experience, small gas bubbles aggregate to larger bubbles rising through the outlet tubing, and the release of them was unevenly distributed in time. Therefore, it is assumed that the best value to use would be the total outflow over the entire measurement period.

The transmissivity (or hydraulic conductivity for the 1 m section) was then estimated as specific capacity, Q/s (m^2/s). Here Q (m^3/s) is the mean inflow over the measurement period and s (m) is the pressure drop between rock and atmosphere. In this case s was set to 100 m based on measured pressures during TDE and 200 m for ONK-PP323. The data are given in Table 2-6 below.

Table 2-6. Results of inflow measurements in TDE drillholes.

Drillhole	Measurement period (days)	Specific Capacity, *Q/s* (m^2/s)
PP323 (WPDE)	5	3E−14
PP324	38	5E−15
PP326	64	3E−14

Laboratory measurements of permeability have also been made using the He-gas method, and the results are presented in Table 2-14. These measurements are performed on a few rather small pieces (about 2 cm thick) of the core and give values of permeabilities between 0.2E−19 to 9.5E−19 m^2 which would suggest a somewhat higher hydraulic conductivity. However, samples have been released from confining pressure and they are cut so that test are made in parallel to the foliation which may influence the measurements.

Summary

Pressures

The typical pressure in the three main intervals is ~ 750 kPa with various superposed trends:

1. Equilibration to boundary condition changes (e.g. after switch to ambient pressure after first leak).
2. The response to the 2 leaks (19/01/16–05/02/16, 06/10/17–05/01/18).
3. Sampling responses (small volume changes). Note the smaller sample volumes in PP326 (0.2 mL rather than 10 mL).
4. Seasonal responses most clearly seen in PP326 (~ 80 kPa over a year).

The stability of the guard zone pressures (no sampling) argue for a relatively steady hydraulic situation and pressure changes in PP324, PP327 and to a lesser extent PP326, probably reflect small volume changes (e.g. due to sampling). These small volume changes cause relatively large pressure disturbances because:

1. The packer systems and associated surface equipment are stiff with an interval compressibility of ~ 10^{-11} m^3/Pa.
2. Permeability in the intervals is very low.

Permeability/Hydraulic conductivity

It is possible from the Thiem equation to estimate the interval hydraulic conductivity K (m/s) from the specific capacity Q/s by assuming steady-state uniform radial flow and guessing the distance to a fixed head boundary (r_{bc}). K values range from 10^{-15} to 2×10^{-14} m/s (see Table 2-7).

The hydraulic conductivity measured in core tests is significantly higher in the range 2×10^{-13} to 10^{-11} m/s. The core samples were small and likely to have undergone sample disturbance (stress relief) so the inflow measurements are thought to be more representative of the in situ conditions.

If we assume an interval hydraulic conductivity of 10^{-14} m/s then interval pressure will be sensitive to very small net flows. For example, a steady withdrawal (or injection) of 30 µL/day (~ 4×10^{-13} m^3/s) would result in a pressure change of ~ 0.1 MPa. Transient responses to sampling will be a function of the interval compressibility (~ 10^{-11} m^3/Pa) resulting in instantaneous responses ~ 0.1 MPa for a net volume change of 1 mL.

Comment

The K (m/s) values for hole PP323 in Table 2-7 have been revised, number of digits for Q/s (m^2/s) have been decreased and a comment on the equation used has been added in the section above.

Table 2-7. Estimates of interval hydraulic conductivity for rbc = 0.15 and 1 m.

Hole	Test length days	r_{bc} (m)	0.15	1
		Q/s (m^2/s)	K (m/s)	K (m/s)
PP323	5	3E−14	4E−15	9E−15
PP324	38	5E−15	1E−15	3E−15
PP326	64	3E−14	8E−15	2E−14

2.4 The REPRO laboratory campaign and other supporting data for TDE

2.4.1 Introduction

The outline of this chapter intentionally resembles the outline of the corresponding chapter in the Task 9A description, with the difference that rock samples from the TDE drillholes are focused upon. Concerning the drillhole length associated with drill core samples, length zero is at the start coordinates of Table 2-1. Focus is on characterisation data considered relevant for the modelling task.

2.4.2 Rock type, lithology, and fractures

The drill cores of the concerned drillholes at the REPRO niche have been subjected to geological core logging. This is detailed in Toropainen (2012) where a multitude of quantitative core logging data is tabulated. Concerning the intact rock matrix, the rock type, lithology, foliation and degree of weathering have been documented. In addition, a few fracture related indicators, as well as other indicators, have been logged. Toropainen (2012) also provides photos of the concerned drill cores, which in part are reproduced in Figure 2-10.

Figure 2-11 to Figure 2-13 present close-up photos of the drill cores (roughly) corresponding to the injection and observation intervals of TDE. Additional close-ups and optical drillhole images are given in Appendix 1.

Table 2-8. Lithology of the lower part of the TDE drillholes. Data and descriptions are reproduced from Toropainen (2012, Appendix 6), where additional information is found.

Drillhole	Drillhole interval (m)	Rock type	Leucosome (%)	Description
PP324	7.57–13.30	Veined gneiss	30	Moderately banded quite homogeneous VGN. Sillimanite in melanosome, locally cordierite. K-feldspar porphyroblasts in thin leucosome veins. Unweathered/unaltered.
PP326	7.80–13.22	Veined gneiss	20	Weakly to moderately banded quite homogeneous VGN. Sillimanite in melanosome, locally cordierite. K-feldspar porphyroblasts in thin leucosome veins. Unweathered/unaltered.
PP327	7.80–13.15	Veined gneiss	30	Weakly to moderately banded quite homogeneous VGN. Sillimanite in melanosome, locally cordierite. K-feldspar porphyroblasts in thin leucosome veins. Unweathered/unaltered.

Figure 2-10. *Photos of extracted drill cores of the lower parts of the TDE drillholes, where the tracer test is carried out. Upper photo = ONK-PP324, middle photo = ONK-PP326, and lower photo = ONK-PP327. The drill cores are wetted. Reproduced from Toropainen (2012).*

Figure 2-11. *Photos of* extracted *drill core of ONK-PP324, interval 11.29–11.81 (dry sample). Reproduced from Ikonen et al. (2015, Appendix 3).*

Figure 2-12. *Photos of extracted drill core of ONK-PP326, interval 11.22–11.78 (dry sample). Reproduced from Ikonen et al. (2015, Appendix 3).*

Figure 2-13. *Photos of extracted drill core of ONK-PP327, interval 11.82–12.12 (dry sample). Reproduced from Ikonen et al. (2015, Appendix 3).*

Table 2-9. Fractures in the TDE drillholes that are closest to the test intervals. Data and description are based on Toropainen (2012, Appendix 8), where additional information is found.

Drillhole	Drillhole length (m)	Fracture type	Fracture filling
PP324	11.30	Tight, no filling material	
PP324	12.94	Filled	0.3 mm chlorite, clay mineral, and pyrite
PP326	11.02	Tight, no filling material	Clay mineral
PP326	13.18	Filled	0.2 mm calcite
PP327	11.24	Tight, no filling material	calcite

The general lithology of the lower parts of the TDE drillholes, where the tracer test is carried out, is provided in Table 2-8. The foliations of different intervals of the TDE drillholes are provided in Toropainen (2012, Appendix 7). In the lower parts of the drillholes, the foliation is banded with weak to moderate foliation intensity. No (recorded) fracture intersects the packed off injection and observation intervals of the TDE drillholes. However, the intervals are surrounded by fractures as shown in Table 2-9.

2.4.3 Rock samples of the TDE drillholes

Rock samples have been collected from drill core intervals that roughly correspond to the TDE experiment intervals.

ONK-PP324, 326 and 327

For each drillhole, numerous cylindrical rock samples between 1 and 10 cm in length have been sawed for subsequent drill core analysis in the laboratory. One of the samples, from each drillhole, has been cut into equal parts, A and B, by sawing a straight cut along the drillhole axis. These A and B samples have been used for ^{14}C-PMMA autoradiography for porosity characterisation of the rock matrix, porosity measurements by water gravimetry, and thin sections for mineralogical analysis. The remaining cylindrical samples have been used for:

- ^{14}C-PMMA autoradiography for porosity characterisation.
- Water phase through-diffusion experiments.
- Electromigration experiments.
- Gas phase measurements of porosity, effective diffusivity, and permeability.

For drillhole ONK-PP324, the sampled drill core in part corresponds to the TDE test interval of the drillhole (cf. Table 2-1). For drillhole ONK-PP326, the sampled drill core does not correspond to the test interval but is collected slightly closer to the REPRO niche. The sampled drill core of ONK-PP327 is fully included in the test interval. The partitioning of the drill cores, and in addition the analysis that the individual samples have been subjected to, are provided in Table 2-10.

Table 2-10. Partition of drill cores ONK-PP324, 326, and 327 into rock samples, based on partition diagrams in Ikonen et al. (2015, Appendix 3) and Kuva et al. (2015, Table 1).

Drillhole	Drillhole lengths (m)	Cylindrical sample	Parted A sample	Parted B sample
PP324	11.29–11.39	^{14}C-PMMA		
	11.39–11.42	Water gravimetry ^{14}C-PMMA, mineralogy	Autoradiography	Water gravimetry Thin section
	11.42–11.44	Water phase through diffusion		
	11.44–11.49	Water gravimetry Electromigration		
	11.49–11.51	Gas phase methods		
PP326	11.22–11.32	^{14}C-PMMA		
	11.32–11.35	Water gravimetry ^{14}C-PMMA, mineralogy	Autoradiography	Water gravimetry Thin section
	11.35–11.37	Water phase through diffusion		
	11.37–11.42	Water gravimetry Electromigration		
	11.42–11.44	Gas phase methods		
	11.72–11.74	Gas phase methods		
PP237	11.82–11.92	^{14}C-PMMA		
	11.92–11.95	Water gravimetry ^{14}C-PMMA, mineralogy	Autoradiography	Water gravimetry Thin section
	11.95–11.97	Water phase through diffusion		
	12.00–12.05	Water gravimetry Electromigration		
	12.05–12.07	Gas phase methods		

2.4.4 Mineralogy of the rock matrix

One thin section from each of the three TDE drillholes has been analysed by using polarized microscopy and point counting; with 500 points per sample. All thin sections were classified as veined gneiss and resulting mineral compositions are provided in Figure 2-14 to Figure 2-16.

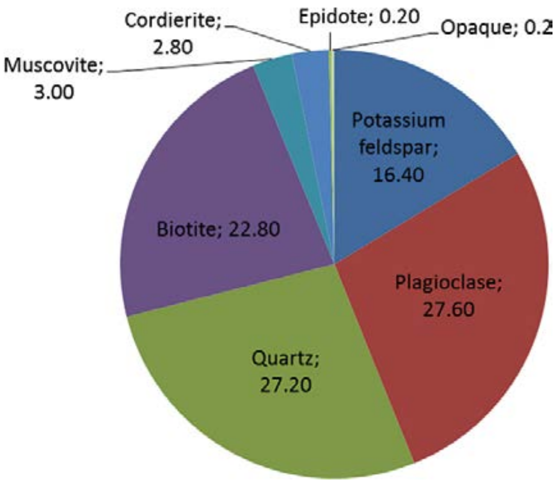

***Figure 2-14.** Mineral composition of drill core ONK-PP324, at drillhole length 11.39 m (just within the test interval). Reproduced from Ikonen et al. (2015, Figure 73).*

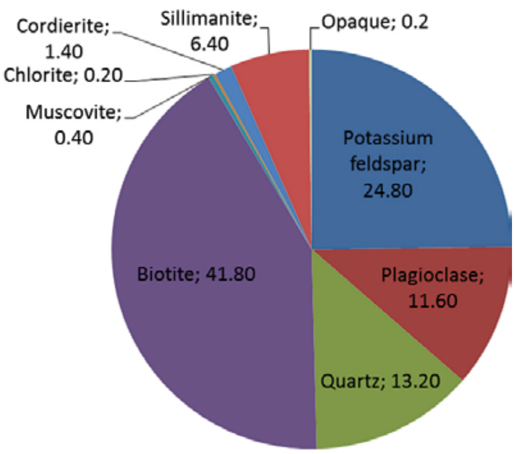

***Figure 2-15.** Mineral composition of drill core ONK-PP326, at drillhole length 11.32 m (just outside the test interval). Reproduced from Ikonen et al. (2015, Figure 79).*

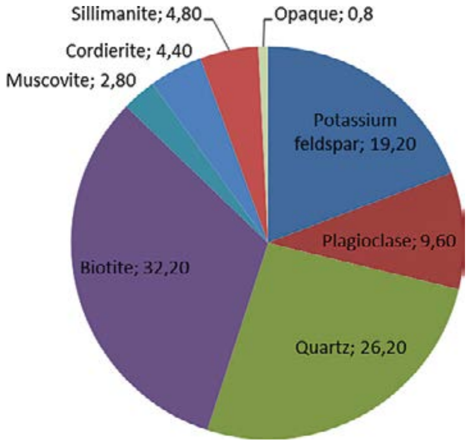

Figure 2-16. *Mineral composition of drill core ONK-PP327, at drillhole length 11.92 m (within the test interval). Diagram provided by Voutilainen M (2017, personal communication). Note that the reported mineral composition in Ikonen et al. (2015, Figure 84) for the corresponding sample is erroneous.*

2.4.5 Porosity

Porosities have been obtained by water gravimetry, argon pycnometry (which is a gas phase method) and ^{14}C-PMMA autoradiography (Kuva et al. 2015, Ikonen et al. 2015). The resulting porosity data are tabulated in Table 2-11.

Table 2-11. Rock matrix porosities obtained in the REPRO laboratory campaign. Data are reproduced from Ikonen et al. (2015, Tables 2, 3 and 4) and, where noted, from Kuva et al. (2015).

Drillhole	Drillhole lengths (m)	Porosity (%)	Method
ONK-PP324	11.39–11.42	0.61 ± 0.15 0.50 ± 0.05	Water gravimetry Autoradiography
ONK-PP324	11.44–11.49	0.48 ± 0.14	Water gravimetry
ONK-PP324	11.49–11.51	1.02 ± 0.05	Ar-pycnometry
ONK-PP326	11.32–11.35	1.05 ± 0.22 1.40 ± 0.14	Water gravimetry Autoradiography
ONK-PP326	11.37–11.42	1.08 ± 0.29	Water gravimetry
ONK-PP326	11.42–11.44	2.9 ± 0.1	Ar-pycnometry
ONK-PP326	11.72–11.74	0.68 ± 0.08	Ar-pycnometry (Kuva et al. 2015)
ONK-PP327	11.92–11.95	0.67 ± 0.16 0.80 ± 0.08	Water gravimetry Autoradiography
ONK-PP327	12.00–12.05	0.81 ± 0.22	Water gravimetry
ONK-PP327	12.05–12.07	0.7 ± 0.1	Ar-pycnometry

Moreover, for the three autoradiographs targeting the intact rock matrix, the porosity distributions shown in Figure 2-17 to Figure 2-19 were obtained.

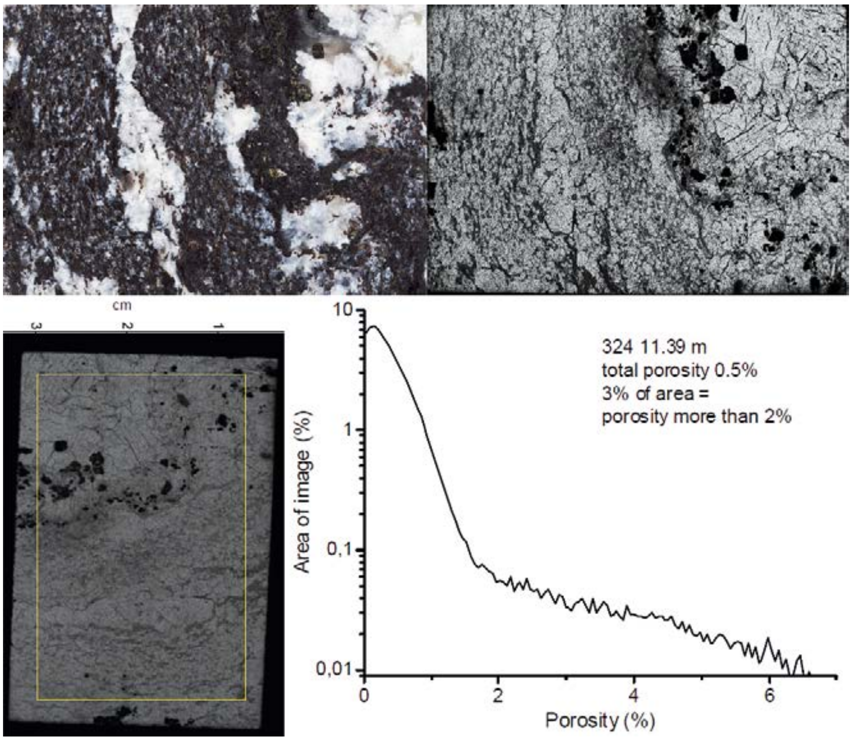

__Figure 2-17.__ Upper left: Photo of the 11.39 surface of sample ONK-PP324, 11.39–11.42 m. Upper right: Corresponding autoradiograph. Lower left: Area of interest highlighted. Lower right: Corresponding porosity histogram. Reproduced from Ikonen et al. (2015, Figures 71 and 72).

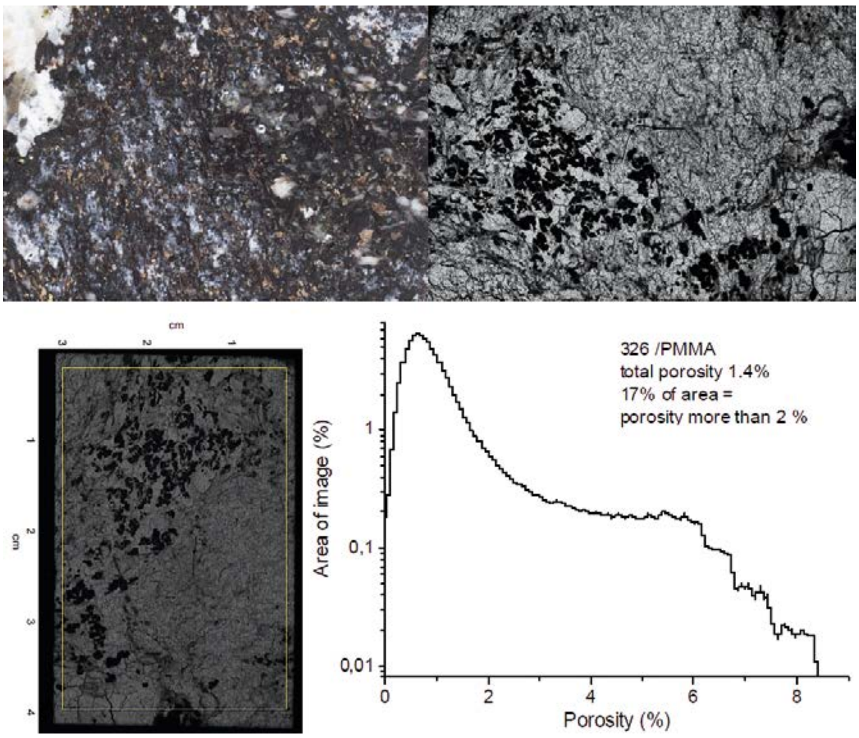

__Figure 2-18.__ Upper left: Photo of the 11.32 surface of sample ONK-PP326, 11.32–11.35 m. Upper right: Corresponding autoradiograph. Lower left: Area of interest highlighted. Lower right: Corresponding porosity histogram. Reproduced from Ikonen et al. (2015, Figures 77 and 78).

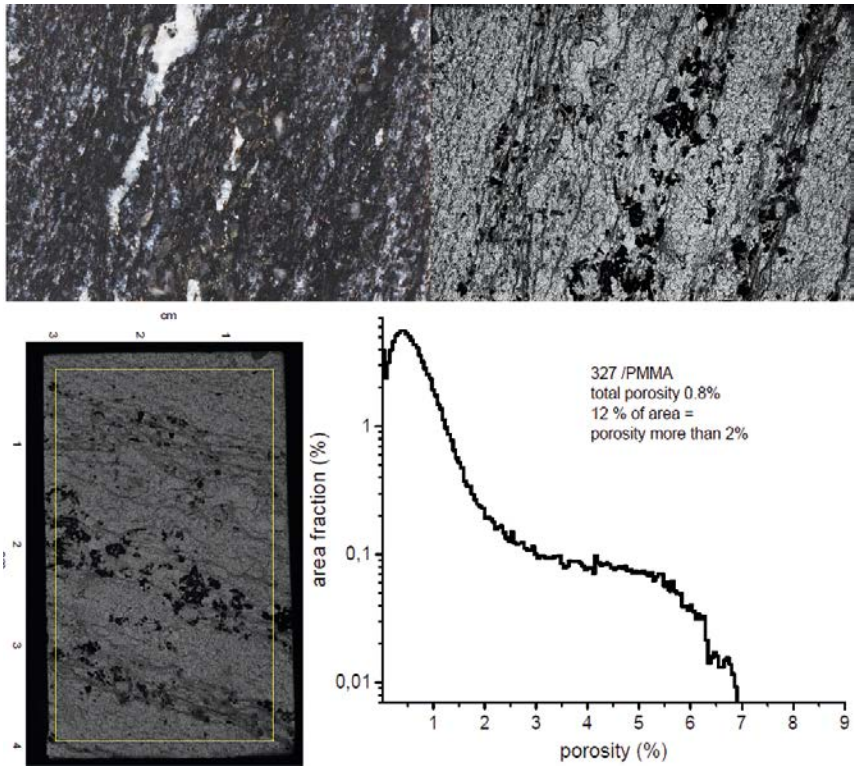

Figure 2-19. Upper left: Photo of the 11.92 surface of sample ONK-PP327, 11.92–11.95 m. Upper right: Corresponding autoradiograph. Lower left: Area of interest highlighted. Lower right: Corresponding porosity histogram. Reproduced from Ikonen et al. (2015, Figures 82 and 83).

2.4.6 Rock matrix effective diffusivity and permeability

The effective diffusivity and permeability of the rock matrix have been measured on numerous of samples from ONKALO and the REPRO niche (Voutilainen et al. 2018, Kuva et al. 2015). Here only samples from the TDE drillholes are discussed.

Water phase through-diffusion measurements

The effective diffusivity has been measured in traditional water phase through-diffusion experiments in the laboratory using HTO and Cl-36 as active tracers. Measurements have been performed on 3 cm long samples, one from each drillhole. The experimental time has been on the order of one year and the experiments have been carried out at room temperature. In the fitting of the effective diffusivity, both the transient and steady state part of the breakthrough curve have been used together with Fick's second law. The resulting effective diffusivities are provided in Table 2-12.

In addition, the effective diffusivity of caesium has been measured in an in-diffusion experiment at the laboratory as detailed in Muuri et al. (2017). The rock samples used are from the Olkiluoto site but not necessarily from the TDE drillholes. The data are shown in Table 2-13. The effective diffusivity of caesium in veined gneiss is of the same magnitude as the effective diffusivity of HTO and Cl-36 in Table 2-12.

Table 2-12. Effective diffusion coefficients (D_e) determined in water phase (through-diffusion) using HTO and Cl-36 as tracers. Uncertainties are given as ± 1σ. The determinations were performed parallel to the foliation. Reproduced from Voutilainen et al. (2018).

Sample	HTO D_e (m^2/s)	Cl D_e(m^2/s)
ONK-PP324, 11.42–11.44	$(3.4 \pm 0.6)\cdot 10^{-13}$	$(3.4 \pm 0.8) \times 10^{-13}$
ONK-PP326, 11.35–11.37	$(4.8 \pm 0.6)\cdot 10^{-13}$	$(3.4 \pm 0.7) \times 10^{-13}$
ONK-PP327, 11.95–11.97	$(3.5 \pm 0.6)\cdot 10^{-13}$	$(3.4 \pm 0.7) \times 10^{-13}$

Table 2-13. Effective diffusion coefficients (D_e) determined in water phase (in diffusion) using Cs-134 as tracer. Uncertainties are not given, but large, since the values are derived as side results. Reproduced from Muuri et al. (2017, Table 3).

Rock type	Cs D_e(m^2/s)
Veined gneiss	3.0×10^{-13}
Pegmatitic rock (not present in TDE)	4.0×10^{-13}

Gas phase through-diffusion measurements

The effective diffusivity has also been measured with helium gas as the tracer, using nitrogen gas as the carrier (Kuva et al. 2015). In addition, the permeability of the intact rock samples has been measured. The rock type of all samples is veined gneiss (VGN) and measurements have been made in parallel with the foliation. The resulting effective diffusivities and permeabilities of the TDE samples are provided in Table 2-14. Note that the provided diffusivity data applies for gas phase diffusion. In order to convert the data to water phase diffusivities Kuva et al. (2015) recommends a reduction factor of 11 600.

Table 2-14. Measured porosities, effective gas diffusion coefficients, and permeabilities, as well as rock types of the REPRO samples. Error estimates are given as ± 1σ. Data are reproduced from Kuva et al. (2015, Table 2) but sample foliation is added.

Sample	Gas diffusion $D_e \times 10^{-9}$ (m^2/s)	Permeability $k \times 10^{-19}$ (m^2)	Rock type	Foliation
ONK-PP324 11.49–11.51	0.8 ± 0.1	3.6 ± 0.4	VGN	||
ONK-PP326 11.42–11.44	1.4 ± 0.1	2.0 ± 0.2	VGN	||
ONK-PP326 11.72–11.74	1.1 ± 0.1	9.5 ± 0.2	VGN	||
ONK-PP327 12.05–12.07	1.2 ± 0.1	0.2 ± 0.1	VGN	||

Electromigration measurements

Electromigration is an analogue to diffusion and the relation between the diffusivity and ionic mobility is described by the Einstein relation. This analogue has been assumed to be valid also in the porous system of crystalline rock (e.g. Skagius and Neretnieks 1986). Within the REPRO laboratory campaign, electromigration has been utilised in two methods. One method, the so called through-electromigration method where a tracer electromigrates through a sample (e.g. Löfgren and Neretnieks 2006), has so far not provided any published or finally evaluated data.

In the other method, the sample is placed in a direct electric field and the electrical current running through the sample is measured in short-term experiments. As the current relates to the electrical conductivity of the pore water, the sample's pore water is exchanged for an electrolyte of known composition prior to the measurements. The rock sample's formation factor is evaluated by

$$\kappa_r = F_f \kappa_w + \kappa_s \qquad \text{Equation 2-1}$$

where κ_r (S/m) is the electrical conductivity of the rock sample, F_f (–) is the formation factor, κ_w (S/m) is the electrical conductivity of the electrolyte in the porous system, and κ_s (S/m) is the rock's surface conductivity. This approach is detailed in (e.g. Löfgren 2015). Noteworthy is that for other rock types, the surface conductivity is reported to relate to the cation exchange capacity of the rock (e.g. Waxman and Smits 1968).

A series of electromigration measurements have been obtained for the TDE samples as saturated, in sequence, by five different electrolytes of different ionic strength (Voutilainen et al. 2018). Each sample is 5 cm long. By plotting the measured κ_r versus the κ_w of the electrolyte, the formation factor and surface conductivity can be obtained by linear regression (cf. Equation 2-1). The resulting data are tabulated in Table 2-15 for the TDE samples.

In Voutilainen et al. (2018) the effective diffusivity is obtained from the formation factor by multiplying it by the diffusivity in unconstrained pore water, which is assumed to be 1.7×10^{-9} m²/s.

Table 2-15. Formation factor and surface conductivity obtained for TDE samples. Based on Voutilainen et al. (2018). The determinations were performed parallel to the foliation.

Sample	F_f	κ_s
ONK-PP324, 11.44–11.49	2.2×10^{-4}	8.5×10^{-5}
ONK-PP326, 11.37–11.42	5.9×10^{-4}	9.1×10^{-4}
ONK-PP327, 12.00–12.05	4.0×10^{-4}	2.4×10^{-4}

2.4.7 Sorption partitioning coefficients

Within the REPRO laboratory programme, sorption partitioning coefficients have been measured on a few crushed samples for Na-22 and Ba-133. What can be said is that multiple samples that were either classified as "pure" veined gneiss or "pure" pegmatitic granite were collected from different drill core locations. The samples were crushed/ground and sieved and the size fraction < 0.3 mm was used for batch experiments using synthetic groundwater as background. Table 2-16 presents the obtained data, which in part are the same as in the Task 9A description. The data are still unpublished. The coefficient of the cubic pegmatitic rock sample is very small, due to the very small biotite content in pegmatitic rock and the small surface area of the cube.

Sorption data for Cs-134 are also available in Muuri et al. (2017), both from batch experiments and in-diffusion experiments into monolithic rock cubes from Olkiluoto. That publication also gives mineral specific sorption data and other interesting information and is recommended reading.

Table 2-16. Sorption partitioning coefficients obtained in batch experiments on crushed rock of different size fractions or intact rock cubes at Helsinki University. Uncertainty estimates, if available, represent one standard deviation.

Radionuclide	Rock type	Sorption partitioning coefficients (m³/kg)	Source
Na-22	Veined gneiss Pegmatitic granite	0.0013 ± 0.0003 0.0008 ± 0.0003	Unpublished data
Ba-133	Veined gneiss Pegmatitic granite	0.06 ± 0.02 0.08 ± 0.02	Unpublished data
Cs-134 (cube)	Veined gneiss Pegmatitic rock	0.031 0.0041	(Muuri et al. 2017, Table 3)
Cs-134 (batch)	Veined gneiss Pegmatitic rock	0.092 0.033	(Muuri et al. 2017, Table 3)

2.4.8 X-ray micro-tomography and PMMA-characterisation

During Task 9, new data has been acquired on rock samples from REPRO and LTDE-SD, which have been subjected to ^{14}C-PMMA autoradiography and X-ray tomography. These data are available for download at the Task Force member area under Task 9, as data delivery #18.

2.5 Expected outcome and reporting

2.5.1 Deliverables

In Task 9C, predictive modelling is performed of the through-diffusion experiment TDE. Increasing tracer activities in the observation drillholes and decreasing activities in the injection drillhole should be modelled.

> **Comment**
> After the TDE data delivery 2019-03-06, also inverse modelling is an option in Task 9C.

Breakthrough curves

The breakthrough curves of all five tracers (cf. Table 2-4) should be modelled in observation drillholes ONK-PP324 and 327, even though breakthrough of ^{133}Ba and ^{134}Cs is not expected at detectable levels during the time frame of TDE. The simulation should be done in terms of decay corrected activities (Bq/g water), simulating a (hypothetical) experimental time period of 10 years.

It is encouraged to model alternative breakthrough curves and, where possible, to tie them to conceptual understanding or alternative experimental data. For example, in-diffusion experiments (Muuri et al. 2017) suggest faster diffusion of Cs-134 than expected, possibly attributed to surface enhanced diffusion. In WPDE-1, there was some indication of sorption (or other retention) of iodide, although that we chose not to include iodide modelling in Task 9A.

Modellers are encouraged to model the breakthrough:

- As a central case at a first stage, ignoring artefacts, e.g.:
  - No loss of tracers or leakages.
  - No effect of sampling.
  - Drillhole separation specified.
- Including uncertainty analyses at a later stage, exploring the impact of artefacts, e.g.:
  - Loss of tracers due to leakages and other artefacts.
  - Effect of sample collection.
  - Pressure gradients.
  - Estimated uncertainty in drillhole separation.

Declining activities in the injection hole

The evolution of the decay corrected activities (Bq/g water) should be modelled in the injection hole ONK-PP326 for all five tracers, simulating a (hypothetical) experimental time period of 10 years. The modelling of alternative evolutions of decreasing tracer activities is encouraged, preferably tied to the alternative breakthrough curves discussed above.

At a first stage, modellers are encouraged to model declining activities in a simplified system, ignoring artefacts such as leakages as well as the effect of sampling. In a later stage the impact of artefacts etc can be included in the model.

Mass balances

In preparing the above requested results, at least in a later stage of the modelling, the modelling groups should keep track of the mass balance of the tracers. Tracers may:

- Remain in the tracer cocktail in the injection hole and associated tubing.
- Be within the rock matrix of the local rock volume.
- Be in the water volume of the observation holes and associated tubing.
- Have been removed from the system by sampling.
- Have been removed from the system through leakages and other artefacts.
- Have been removed from the local rock volume through advective flow (although less likely), electromigration, or other processes.

2.5.2 Reporting

Comment

This section has been re-written, although the content is the same, completed with the succeeding workshops and meetings.

Oral presentations of Task 9C results have been requested for the following occasions:

- Task 9 Workshop in Barcelona, Spain, on September 18–19, 2017. About two weeks prior to the workshop the numerical results were due to be sent to the Task 9 Evaluator Josep Soler. If possible, some explanatory text should have accompanied the numerical results.
- Task Force meeting #36 in Mizunami, Japan, June 5–7, 2018. It was decided that evaluation of modelling results and explanatory text should be sent to the Task 9 Evaluator by 15 May 2018, prior to the Task Force GWFTS meeting.
- Task 9 Workshop in Solna, Sweden, on October 23–24, 2018. To enable prepare the evaluation session, updated results were asked to be sent to Pep Soler before October 8. This was also the last chance for predictive modelling, since existing data were presented on this occasion.
- Task Force meeting in Solna, Sweden, on March 19–21, 2019. To enable the evaluation, updated results were asked to be sent to Pep Soler March 1.

The subtask will likely carry over to the autumn of 2018 (and even through 2019), and the preferred form of reporting will have to be decided at a later time (e.g. at the Task Force meeting in June, 2018/ Task Force workshop in October 2019). The limited scope of the task may facilitate reporting in the form of papers in scientific journals rather than in reports, which is encouraged by the SKB Task Force.

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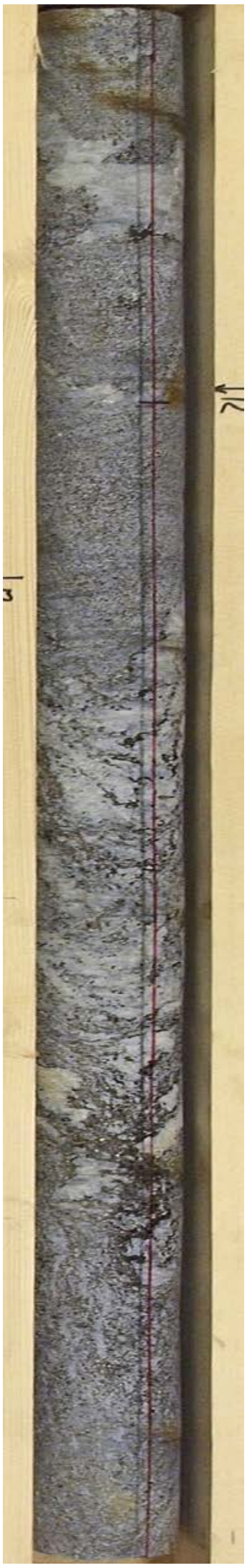
Appendix 1

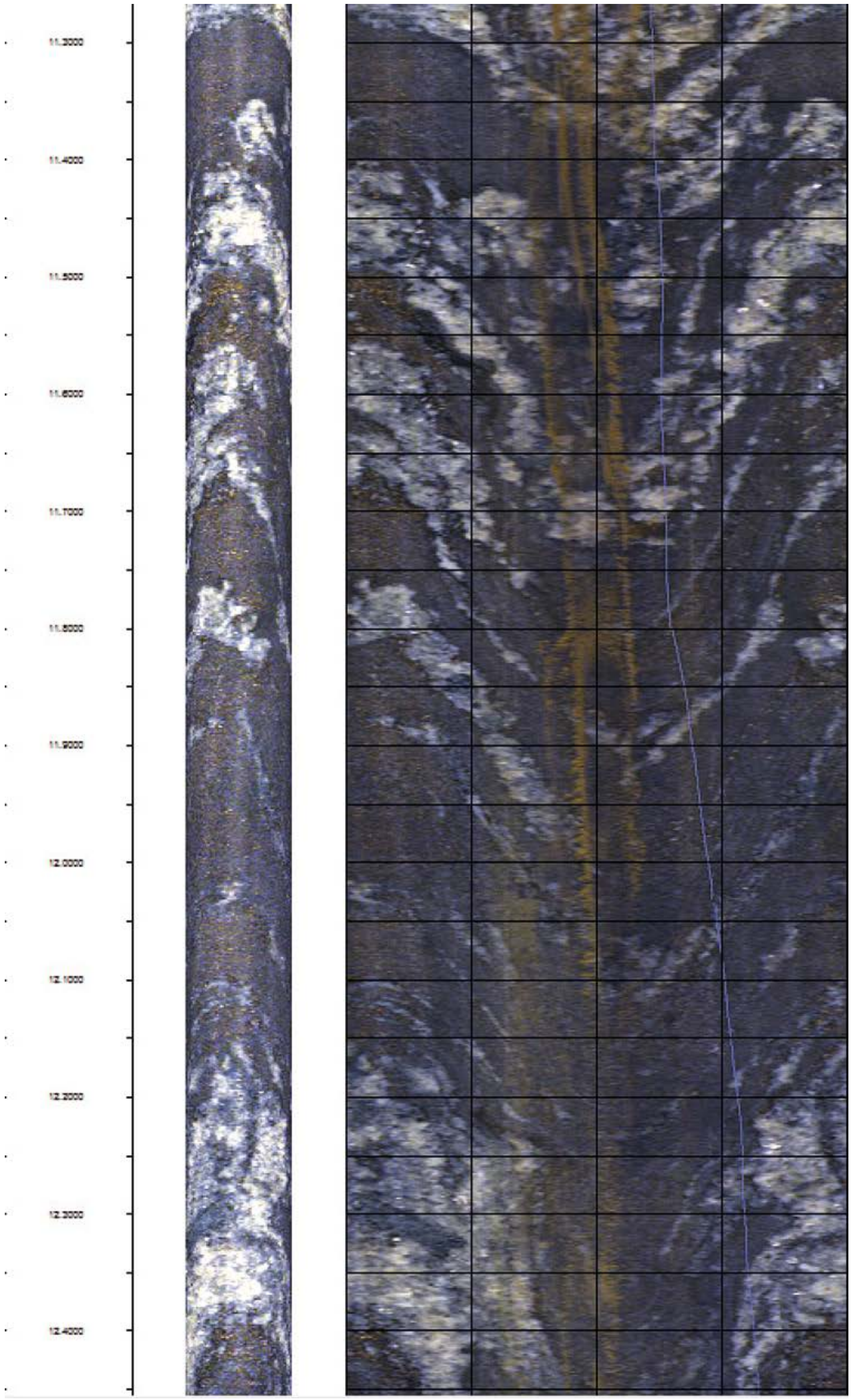
Close-up and optical drillhole images of drill cores at test intervals



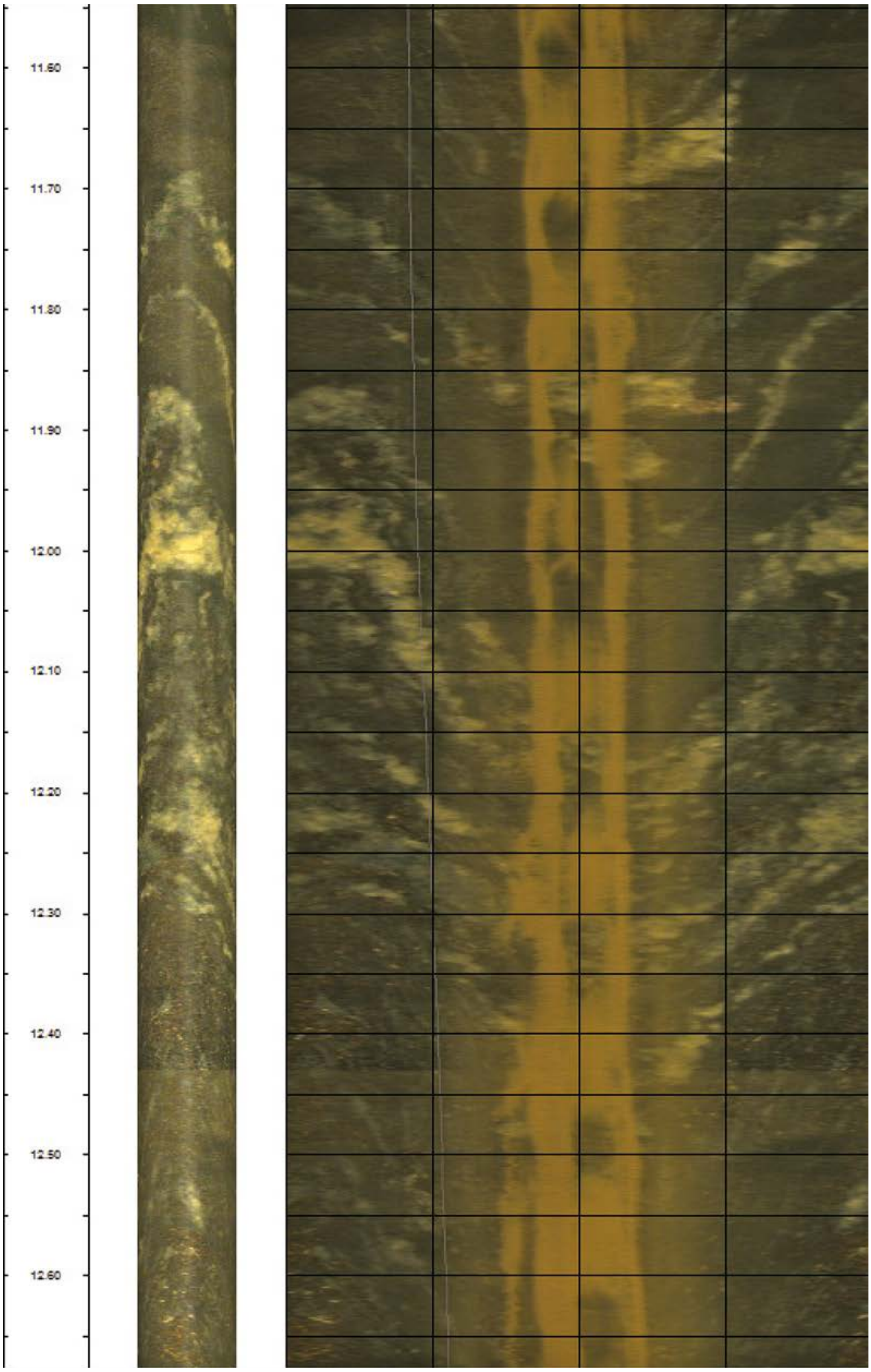
ONK-PP326 11.8−12.6 m
Dry rock

ONK-PP324 11.4−12.4 m
Dry rock

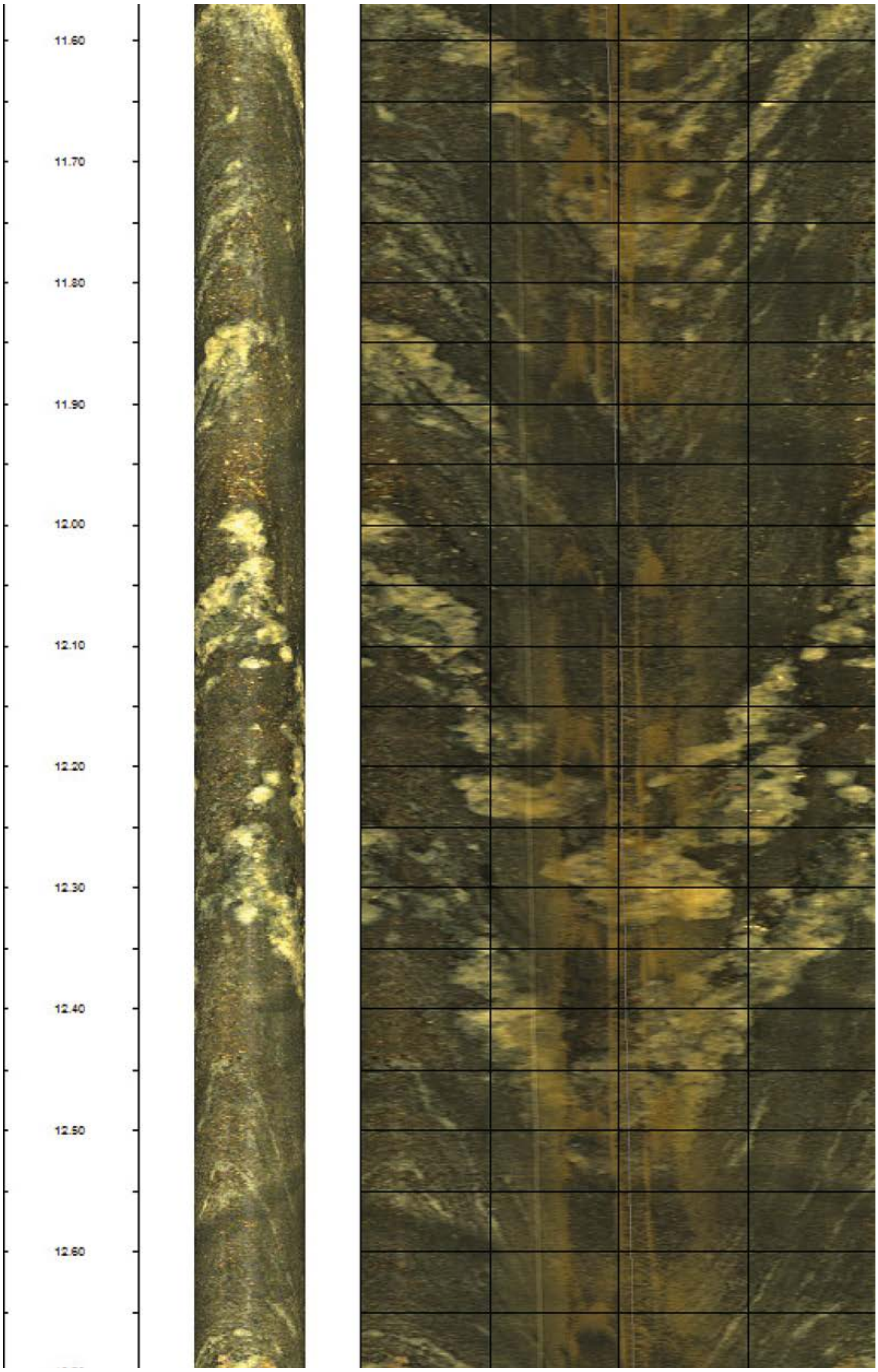
ONK-PP327 11.0−12.3 m
Dry rock



ONK-PP324, 11.3−12.4 m



ONK-PP326, 11.6–12.6 m



ONK-PP327, 11.6–12.6 m

Appendix 2

Actual pressures in the TDE drillholes at times when pumps were off

Table A2-1. Pressures in ONK-PP324, ONK-PP326 and ONK-PP327 displaying the actual pressures at times when pumps have been turned off. Also, the calculated gradients between PP326 and PP324 as well as between PP326 and PP327 are reported.

Date	Time (days)	Pressure (MPa) ONK-PP324	Pressure (MPa) ONK-PP326	Pressure (MPa) ONK-PP327	Gradient 326–324 (m/m)	Gradient 326–327 (m/m)
2015-11-20	1	0.957	0.973	0.961	14	8
2015-12-03	14	0.967	0.965	0.965	−1.7	0
2015-12-04	15	0.985	0.984	0.984	−0.9	0
2016-01-19	61	1.032	0.983	0.983	−43	0
2016-01-20	62	0.717	0.731	0.731	12	0
2016-01-26	68	0.757	0.738	0.738	−17	0
2016-01-27	69	1.037	1.036	1.036	−0.9	0
2016-02-05	78		1.009			
2016-02-09	82	1.000	0.602	0.999	−346	−265
2016-02-11	84	1.040	0.558	1.016	−419	−305
2016-03-02	104	0.750	0.598	0.703	−132	−70
2016-03-11	113	0.680	0.752	0.697	63	37
2016-03-29	131	0.621	0.734	0.651	98	55
2016-03-30	132	0.619	0.727	0.658	94	46
2016-07-01	225	0.904	0.754	0.781	−130	−18
2016-08-19	274	0.891	0.784	0.840	−93	−37
2016-12-05	382	0.811	0.736	0.806	−65	−47
2017-01-04	412	0.763	0.651	0.760	−97	−73
2017-01-26	434	0.701	0.619	0.727	−71	−72
2017-02-01	440	0.697	0.588	0.727	−95	−93
2017-03-01	468	0.699	0.653	0.714	−40	−41
2017-03-03	470			0.722		
2017-03-06	473			0.725		
2017-03-27	494			0.742		
2017-03-30	497			0.670		
2017-04-05	503			0.696		
2017-04-05	503	0.741	0.681	0.679	−52	1.3
2017-04-10	508			0.688		
2017-04-27	525			0.364		
2017-05-08	536			0.637		
2017-05-10	538			0.632		
2017-06-08	567	0.638	0.618	0.676	−17	−39
2017-06-14	573	0.728	0.621	0.692	−93	−47
2017-06-27	586	0.637	0.705	0.704	59	0.7
2017-08-09	629	0.625	0.697	0.749	63	−35
2017-09-13	664		0.628	0.598		20
2017-10-11	692	0.762	0.588	0.060	−151	352
2017-10-25	706	0.733	0.570	0.080	−142	327
2017-11-07	719	0.735	0.573	0.090	−141	322
2017-12-04	746	0.764	0.573	0.070	−166	335
2017-12-13	755	0.742	0.559	0.100	−159	306
2018-01-05	778	0.833	0.676	0.100	−137	384
2018-01-08	781	0.782	0.680	0.200	−89	320
2018-02-05	809	0.811	0.670	0.63	−123	27
2018-02-06	810	0.726	0.682	0.196	−38	324
2018-02-15	819	0.789	0.669	0.593	−104	50

Date	Time (days)	Pressure (MPa) ONK-PP324	Pressure (MPa) ONK-PP326	Pressure (MPa) ONK-PP327	Gradient 326–324 (m/m)	Gradient 326–327 (m/m)
2018-02-21	825	0.807	0.611	0.691	−171	−54
2018-02-22	826	0.810	0.616	0.189	−169	285
2018-03-06	838	0.818	0.669	0.664	−129	3.6
2018-03-07	839	0.672	0.669	0.229	−2	293
2018-03-17	849	0.773	0.668	0.643	−91	17
2018-03-27	859	0.827	0.688	0.772	−121	−56
2018-04-09	872	0.858	0.725	0.827	−115	−68
2018-04-10	873	1.15	0.746	0.231	−351	344
2018-04-20	883	0.915	0.720	0.715	−170	3.3
2018-04-30	893	0.891	0.747	0.820	−125	−49
2018-05-08	901	0.894	0.762	0.858	−115	−64
2018-05-09	902	0.674	0.761	0.316	75	297
2018-05-18	911	0.785	0.763	0.711	−19	35
2018-05-28	921	0.834	0.732	0.800	−89	−46
2018-06-12	936	0.857	0.735	0.837	−106	−68
2018-06-13	937	0.706	0.735	0.334	25	268
2018-06-23	947	0.804	0.693	0.724	−97	−21
2018-06-28	952	0.825	0.707	0.778	−102	−47
2018-06-29	953	0.808	0.691	0.714	−102	−16
2018-07-26	980	0.909	0.769	0.858	−122	−59
2018-08-07	992	0.878	0.768	0.858	−96	−60
2018-08-08	993	0.739	0.768	0.708	26	40
2018-08-18	1 003	0.844	0.758	0.843	−75	−57
2018-08-28	1 013	0.859	0.751	0.813	−94	−41
2018-08-29	1 014	0.910	0.749	0.822	−140	−48
2018-09-12	1 028	0.933	0.760	0.825	−150	−44
2018-09-13	1 029	0.685	0.746	0.232	54	342
2018-09-19	1 035	0.623	0.706	0.531	73	117
2018-09-20	1 036	0.501	0.701	0.575	173	84
2018-10-01	1 047	0.586	0.675	0.719	78	−29
2018-10-10	1 056	0.637	0.678	0.757	36	−53
2018-10-11	1 057	0.588	0.680	0.762	80	−55
2019-01-08	1 146	0.697	0.708	0.747	10	−26
2019-01-23	1 161	0.697	0.708	0.733	9.6	−17
2019-02-05	1 174	0.683	0.694	0.729	9.6	−23
2019-02-21	1 190	0.695	0.701	0.736	5.2	−23
2019-03-07	1 203	0.698	0.700	0.732	1.7	−21
2019-03-11	1 207	0.699	0.701	0.730	1.7	−19
2019-04-08	1 235	0.699	0.697	0.738	−1.7	−27
2019-04-23	1 250	0.696	0.695	0.730	−0.9	−23
2019-05-07	1 264	0.705	0.694	0.733	−9.6	−26
2019-05-23	1 280	0.685	0.686	0.735	0.9	−33
2019-06-05	1 293	0.698	0.694	0.734	−3.5	−27
2019-06-18	1 306	0.702	0.699	0.741	−2.3	−28
2019-07-09	1 327	0.715	0.708	0.744	−5.4	−24
2019-08-08	1 357	0.713	0.703	0.739	−8.7	−23
2019-08-14	1 363	0.697	0.695	0.731	−1.4	−24
2019-09-05	1 385	0.722	0.706	0.743	−14	−24
2019-10-09	1 419	0.692		0.713		
2019-10-17	1 427	0.671	0.675	0.713	3.1	−25

Appendix 3

Tracer sample data from ONK-PP324, ONK-PP326 and ONK-PP327

Table A3-1. Hole ONK-PP326, activity versus time in collected samples.

Time (days)	^{133}Ba Bq/g	Uncer-tainty	^{134}Cs Bq/g	Uncer-tainty	^{22}Na Bq/g	Uncer-tainty	HTO Bq/g	Uncer-tainty	^{36}Cl Bq/g	Uncer-tainty
0.279	1770	43	488	6.7	58900	370	637000	6900	19900	430
0.751	1540	37	308	5.4	57900	360	640000	6900	19600	430
1.05	1420	35	273	4.8	56700	360	608000	6600	19100	420
2.02	1070	26	187	3.7	58400	370	651000	7000	19900	440
3.94	1070	27	170	4.3	58800	370	651000	7000	20100	440
5.01	921	22	149	1.7	56900	350	650959	7000	19400	430
6.93	835	21	124	3.1	58200	350	642000	6900	18800	410
14.0	683	17	101	3.0	53800	340	649000	7000	18800	410
28.7	755	20	112	3.4	68000	410	625000	6800	22600	680
40.0	721	19	107	3.0	66600	400	590000	6400	22200	670
54.9	712	19	111	3.4	73800	450	607000	6600	24800	740
66.9	577	15	79.5	2.6	63700	380	573000	6200	21500	650
82.9	519	13	108	2.3	48000	290	511000	5500	16300	490
96.9	475	12	72.0	1.8	46300	280	526000	5700	15900	480
144	397	10	53.0	2.6	45600	290	516000	5600	16300	490
171	251	8.3	38.5	3.9	42100	320	484000	5200	16100	480
200	213	9.9	40.1	5.4	45200	350	485000	5200	16500	500
222	318	8.8	41.8	3.0	44000	280	460000	5000	15400	460
264	308	8.3	37.2	1.8	41700	250	466000	5000	15600	470
329	264	6.6	43.2	1.6	46800	350	447000	4800	16900	510
384	280	6.7	39.1	0.70	43200	270	429000	4600	15300	460
438	264	6.8	34.7	1.9	41900	260	422000	4600	15200	460
524	259	7.3	38.0	1.8	42100	320	408000	4400	15800	480
573	251	7.1	63.3	3.3	40500	260	375000	4100	15000	450
648	221	7.1	61.7	4.5	39900	300	354000	3800	15100	450
706	218	6.9	65.4	4.1	38800	250	346000	3700	15300	461
755	230	5.7	70.4	1.8	37800	240	334000	3600	14700	440
824	240	6.0	77.5	2.3	43400	330	326000	3500	16200	490
881	198	4.8	57.4	2.2	39400	300	307000	3300	14900	450
943	206	5.1	49.4	2.5	37600	280	296000	3200	14400	430
1006	194	5.2	67.4	3.1	38600	290	282000	3000	14600	440
1068	194	5.1	77.0	2.4	37400	280	264000	2800	12300	370
1124	196	5.1	76.8	2.9	38700	290	263000	2800	14900	450
1190	203	4.8	69.0	0.7	34800	210	239000	2600	13800	414
1251	192	4.7	58.6	1.1	33200	200	227000	2500	13800	413
1307	183	4.7	61.8	2.4	34900	220	232000	2500	14000	420
1364	189	4.7	50.3	2.3	34000	210	224000	2400	13700	412
1428	190	4.6	56.9	1.2	32900	200	217000	2300	13800	414

Table A3-2. Hole ONK-PP324, activity versus time in collected samples.

Time (days)	^{133}Ba Bq/g	^{134}Cs Bq/g	Uncer-tainty	^{22}Na Bq/g	Uncer-tainty	HTO Bq/g	Uncer-tainty	^{36}Cl Bq/g	Uncer-tainty
13.9									
28.7									
46.9									
66.9									
82.1									
89.7									
96.9									
126									
158									
195									
215									
264									
294	< 0.0013	< 0.0012		0.0038	8.0E−04	0.147	0.032	< 0.006	
320	< 0.0013	< 0.0012		< 0.0012		0.275	0.034	< 0.006	
361	< 0.0013	< 0.0012		< 0.0012		0.111	0.033	< 0.006	
397	< 0.0013	0.0010	3.00E−04	< 0.0012		0.468	0.034	< 0.006	
425	< 0.0013	0.0013	3.00E−04	0.0024	4.0E−04	0.346	0.11	< 0.006	
482	< 0.0013	< 0.0012		0.0014	5.0E−04	0.832	0.025	< 0.006	
537	< 0.0013	< 0.0012		< 0.0012		0.873	0.026	< 0.006	
567	< 0.0013	< 0.0012		0.012	8.8E−04	1.87	0.033	0.00856	0.0074
585	< 0.0013	< 0.0012		0.0029	6.0E−04	1.69	0.032	0.0124	0.0073
629	< 0.0013	< 0.0012		< 0.0012		1.60	0.031	0.00967	0.0073
664	< 0.0013	< 0.0012		0.0015	3.9E−04	6.69	0.080	0.0479	0.0075
683	< 0.0013	< 0.0012		< 0.0012		18.9	0.21	< 0.006	
691	< 0.0013	< 0.0012		< 0.0012		16.9	0.19	< 0.006	
719	< 0.0013	< 0.0012		< 0.0012		15.6	0.17	< 0.006	
746	< 0.0013	< 0.0012		< 0.0012		5.52	0.068	0.0175	0.0074
781	< 0.0013	< 0.0012		< 0.0012		5.07	0.064	0.0266	0.0074
809	< 0.0013	< 0.0012		< 0.0012		4.10	0.054	0.0157	0.0074
838	< 0.0013	< 0.0012		< 0.0012		4.66	0.059	0.0299	0.0075
872	< 0.0013	< 0.0012		< 0.0012		4.62	0.059	0.0222	0.0074
901	< 0.0013	< 0.0012		< 0.0012		4.29	0.056	0.0125	0.0074
936	< 0.0013	< 0.0012		< 0.0012		4.72	0.060	0.0174	0.0074
965	< 0.0013	< 0.0012		< 0.0012		4.80	0.061	0.0248	0.0074
992	< 0.0013	< 0.0012		< 0.0012		4.54	0.059	0.0296	0.0075
1028	< 0.0013	< 0.0012		< 0.0012		0.203	0.025	< 0.006	
1035	< 0.0013	< 0.0012		< 0.0012		0.198	0.026	< 0.006	
1047	< 0.0013	< 0.0012		< 0.0012		0.276	0.025	< 0.006	
1056	< 0.0013	< 0.0012		< 0.0012		0.380	0.025	< 0.006	
1065	< 0.0013	1065		< 0.0012		0.464	0.025	< 0.006	
1091	< 0.0013	1091		< 0.0012		0.847	0.028	0.0124	0.0073
1118	< 0.0013	1118		< 0.0012		1.13	0.029	0.0224	0.0074
1146	< 0.0013	1146		< 0.0012		1.52	0.032	0.0282	0.0075
1161	< 0.0013	< 0.0012		< 0.0012		1.63	0.032	0.0451	0.0088
1174	< 0.0013	< 0.0012		< 0.0012		1.88	0.038	0.0523	0.0077
1208	< 0.0013	< 0.0012		< 0.0012		2.49	0.040	0.0577	0.0076
1236	< 0.0013	< 0.0012		< 0.0012		2.72	0.042	0.0729	0.0078
1265	< 0.0013	< 0.0012		< 0.0012		3.14	0.046	0.0885	0.0080
1294	< 0.0013	< 0.0012		< 0.0012		3.51	0.050	0.108	0.0082
1328	< 0.0013	< 0.0012		< 0.0012		3.96	0.054	0.132	0.0085
1358	< 0.0013	< 0.0012		< 0.0012		4.26	0.057	0.149	0.0089
1386	< 0.0013	< 0.0012		< 0.0012		4.53	0.059	0.207	0.0096
1420	< 0.0013	< 0.0012		< 0.0012		4.89	0.063	0.208	0.0096

Table A3-3. Hole ONK-PP327, activity versus time in collected samples.

Time (days)	^{133}Ba Bq/g	^{134}Cs Bq/g	^{22}Na Bq/g	Uncer-tainty	HTO Bq/g	Uncer-tainty	^{36}Cl Bq/g	Uncer-tainty
13.9								
28.7								
46.9								
66.9								
82.0								
89.7								
96.9								
126								
158								
195								
215								
264								
294	< 0.0013	< 0.0012	< 0.0012		< 0.012		< 0.006	
320	< 0.0013	< 0.0012	0.00351	0.00056	< 0.012		< 0.006	
361	< 0.0013	< 0.0012	< 0.0012		< 0.012		< 0.006	
397	< 0.0013	< 0.0012	< 0.0012		< 0.012		< 0.006	
425	< 0.0013	< 0.0012	0.00177	0.00042	0.0137	0.022	< 0.006	
462	< 0.0013	< 0.0012	0.00288	0.00056	0.0528	0.022	< 0.006	
537	< 0.0013	< 0.0012	< 0.0012		< 0.012		< 0.006	
691	< 0.0013	< 0.0012	0.0247	0.0015	1.54	0.031	0.0186	0.0074
719	< 0.0013	< 0.0012	0.0334	0.0018	1.82	0.033	0.0345	0.0074
746	< 0.0013	< 0.0012	0.0282	0.0019	2.06	0.035	0.0552	0.0076
781	< 0.0013	< 0.0012	0.0157	0.0010	2.24	0.037	0.0670	0.0077
809	< 0.0013	< 0.0012	0.0165	0.0023	2.36	0.038	0.0803	0.0079
838	< 0.0013	< 0.0012	0.0183	0.00086	2.81	0.042	0.104	0.0081
872	< 0.0013	< 0.0012	0.0122	0.0012	2.89	0.042	0.122	0.0084
902	< 0.0013	< 0.0012	0.0108	0.0013	3.35	0.047	0.139	0.0087
936	< 0.0013	< 0.0012	0.0250	0.0012	3.52	0.049	0.161	0.0090
965	< 0.0013	< 0.0012	0.0220	0.0023	3.91	0.052	0.175	0.0093
992	< 0.0013	< 0.0012	0.0128	0.0022	3.74	0.051	0.186	0.0095
1 029	< 0.0013	< 0.0012	0.0116	0.0014	4.30	0.059	0.198	0.0107
1 065	< 0.0013	< 0.0012	0.0212	0.0023	4.59	0.059	0.230	0.010
1 091	< 0.0013	< 0.0012	0.0152	0.0031	4.80	0.061	0.228	0.010
1 118	< 0.0013	< 0.0012	0.0265	0.0024	5.08	0.064	0.238	0.011
1 146	< 0.0013	< 0.0012	0.0262	0.0035	5.18	0.065	0.245	0.011
1 161	< 0.0013	< 0.0012	0.0236	0.0036	5.06	0.063	0.239	0.026
1 174	< 0.0013	< 0.0012	0.0235	0.0023	5.26	0.066	0.260	0.015
1 208	< 0.0013	< 0.0012	0.0226	0.0024	5.71	0.071	0.252	0.011
1 236	< 0.0013	< 0.0012	0.0143	0.0014	5.56	0.07	0.253	0.011
1 265	< 0.0013	< 0.0012	0.0148	0.0016	5.96	0.074	0.272	0.011
1 294	< 0.0013	< 0.0012	0.0222	0.00018	6.24	0.077	0.280	0.012
1 328	< 0.0013	< 0.0012	< 0.0012		6.39	0.078	0.288	0.012
1 358	< 0.0013	< 0.0012	0.0142	0.0010	6.57	0.080	0.297	0.012
1 386	< 0.0013	< 0.0012	0.0289	0.0024	6.70	0.081	0.305	0.012
1 420	< 0.0013	< 0.0012	0.0196	0.0014	7.16	0.086	0.309	0.012

Appendix 4

Tracer on-line data from ONK-PP324, ONK-PP326 and ONK-PP327

Table A4-1. Hole ONK-PP326, activity versus time. Time for injection was 2015-11-19 14:40.

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{133}Ba Bq/g	Uncertainty	^{134}Cs Bq/g	Uncertainty
2015-03-25 4:05 PM	−239	< 2.3	< 0.9		< 0.9		
2015-03-28 4:06 PM	−236	< 2.1	< 0.9		< 0.9		
2015-03-31 5:07 PM	−233	< 2.1	< 0.9		< 0.9		
2015-04-03 6:07 PM	−230	< 2.2	< 0.9		< 0.9		
2015-04-06 6:08 PM	−227	< 2.2	< 0.9		< 0.8		
2015-04-09 6:08 PM	−224	< 2.1	< 0.9		< 0.9		
2015-04-12 6:09 PM	−221	< 2.1	< 0.9		< 0.9		
2015-04-15 6:10 PM	−218	< 2.2	< 0.9		< 0.9		
2015-04-18 6:10 PM	−215	< 2.1	< 0.9		0.952	0.68	
2015-11-19 3:08 PM	0.0200	14 243	936	828	248	205	195
2015-11-19 3:13 PM	0.0235	62 673	1 930	1 285	557	1 451	409
2015-11-19 3:18 PM	0.0270	71 652	2 106	1 509	604	1 558	467
2015-11-19 3:24 PM	0.0306	53 213	1 755	1 455	511	1 276	390
2015-11-19 3:29 PM	0.0342	36 411	1 521	1 416	449	984	331
2015-11-19 3:34 PM	0.0377	27 637	1 316	1 091	356	984	292
2015-11-19 3:39 PM	0.0413	31 820	1 404	1 045	402	935	292
2015-11-19 3:44 PM	0.0448	44 820	1 609	1 285	480	1 023	331
2015-11-19 3:49 PM	0.0483	54 968	1 843	1 385	511	1 013	312
2015-11-19 3:54 PM	0.0519	56 606	1 872	1 331	542	1 091	351
2015-11-19 3:59 PM	0.0555	50 684	1 726	1 509	495	886	331
2015-11-19 4:04 PM	0.0590	42 407	1 609	1 339	480	1 081	273
2015-11-19 4:10 PM	0.0625	40 360	1 609	1 478	433	701	312
2015-11-19 4:15 PM	0.0661	44 469	1 638	1 370	464	769	273
2015-11-19 4:20 PM	0.0696	49 222	1 726	2 043	480	750	331
2015-11-19 4:25 PM	0.0732	52 366	1 755	1 772	480	984	292
2015-11-19 4:30 PM	0.0767	50 758	1 726	1 439	511	721	331
2015-11-19 4:35 PM	0.0803	49 427	1 696	1 254	495	380	370
2015-11-19 4:40 PM	0.0839	48 652	1 696	1 633	464	662	331
2015-11-19 4:45 PM	0.0874	46 020	1 667	1 795	449	740	312
2015-11-19 4:50 PM	0.0910	48 535	1 726	1 176	511	760	312
2015-11-19 4:56 PM	0.0945	48 813	1 726	1 215	495	555	331
2015-11-19 5:01 PM	0.0981	50 846	1 755	1 571	480	750	312
2015-11-19 5:06 PM	0.102	50 525	1 755	1 261	511	984	312
2015-11-19 5:11 PM	0.105	48 477	1 726	1 261	464	682	370
2015-11-19 5:16 PM	0.109	48 054	1 696	1 416	495	545	351
2015-11-19 5:21 PM	0.112	46 811	1 667	882	480	711	331
2015-11-19 5:26 PM	0.116	47 644	1 696	1 300	480	438	370
2015-11-19 5:31 PM	0.119	49 750	1 726	1 231	480	614	331
2015-11-19 5:37 PM	0.123	49 721	1 726	1 447	480	692	292
2015-11-19 5:42 PM	0.126	49 107	1 697	1 277	511	545	292
2015-11-19 5:47 PM	0.130	48 829	1 726	1 571	480	594	331
2015-11-19 5:52 PM	0.134	48 230	1 726	1 099	495	633	312
2015-11-19 5:57 PM	0.137	48 171	1 755	1 378	464	516	292
2015-11-19 6:02 PM	0.141	47 908	1 755	1 718	480	507	331
2015-11-19 6:07 PM	0.144	49 137	1 726	936	495	516	312
2015-11-19 6:12 PM	0.148	48 742	1 755	1 176	511	390	370
2015-11-19 6:17 PM	0.151	49 825	1 784	1 919	464	594	312
2015-11-19 6:23 PM	0.155	49 795	1 726	1 122	495	545	273
2015-11-19 6:28 PM	0.158	49 679	1 755	1 354	464	711	312

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{133}Ba Bq/g	Uncertainty	^{134}Cs Bq/g	Uncertainty
2015-11-19 6:33 PM	0.162	48465	1697	1494	480	682	292
2015-11-19 6:38 PM	0.166	50556	1726	1393	464	623	292
2015-11-19 6:43 PM	0.169	48714	1697	1068	480	< 331	
2015-11-19 6:48 PM	0.173	50981	1755	1331	480	438	312
2015-11-19 6:53 PM	0.176	47778	1726	1409	480	409	312
2015-11-19 6:58 PM	0.180	48539	1726	1323	480	555	292
2015-11-19 7:03 PM	0.183	47939	1697	789	480	390	331
2015-11-19 7:09 PM	0.187	49285	1726	960	480	< 331	
2015-11-19 7:14 PM	0.190	47925	1755	1354	495	614	312
2015-11-19 7:19 PM	0.194	49446	1755	1169	480	< 351	
2015-11-19 7:24 PM	0.198	49110	1667	1006	480	516	312
2015-11-19 7:29 PM	0.201	49431	1755	1292	464	545	312
2015-11-19 7:34 PM	0.205	50060	1726	1440	464	458	292
2015-11-19 7:39 PM	0.208	47969	1697	1161	480	614	292
2015-11-19 7:44 PM	0.212	48759	1697	936	495	< 370	
2015-11-19 7:59 PM	0.222	48845	702	1113	199	494	133
2015-11-19 8:29 PM	0.243	48643	707	1251	196	534	133
2015-11-19 8:59 PM	0.264	48566	707	1139	199	463	130
2015-11-19 9:30 PM	0.285	48589	707	1051	196	485	123
2015-11-19 10:00 PM	0.306	48548	702	1179	193	383	130
2015-11-19 10:30 PM	0.327	49136	712	1032	199	375	130
2015-11-19 11:01 PM	0.348	49337	707	1176	196	409	127
2015-11-19 11:31 PM	0.369	47819	707	1171	194	463	127
2015-11-20 12:01 AM	0.390	48173	707	1300	191	372	123
2015-11-20 12:32 AM	0.411	48371	697	1121	196	292	133
2015-11-20 1:02 AM	0.432	48340	707	1098	196	339	127
2015-11-20 1:33 AM	0.453	48851	702	1149	196	357	127
2015-11-20 2:03 AM	0.475	48493	707	1107	196	289	123
2015-11-20 2:33 AM	0.496	48550	702	1173	196	424	127
2015-11-20 3:04 AM	0.517	48760	702	1100	196	393	127
2015-11-20 3:34 AM	0.538	48532	707	1054	199	281	127
2015-11-20 4:04 AM	0.559	48681	702	1049	199	218	133
2015-11-20 4:35 AM	0.580	48626	707	1120	194	291	130
2015-11-20 5:05 AM	0.601	48185	698	1004	196	255	127
2015-11-20 5:35 AM	0.622	48247	707	1116	199	289	127
2015-11-20 6:06 AM	0.643	48592	698	1129	196	351	120
2015-11-20 6:36 AM	0.664	48114	698	1232	191	351	127
2015-11-20 7:06 AM	0.685	48727	707	1238	194	260	130
2015-11-20 7:37 AM	0.706	47865	703	1124	196	326	120
2015-11-20 8:07 AM	0.728	48158	698	983	194	187	130
2015-11-20 8:38 AM	0.749	47937	708	1053	196	257	130
2015-11-20 9:08 AM	0.770	47865	703	928	199	289	127
2015-11-20 9:38 AM	0.791	48290	703	913	199	224	133
2015-11-20 10:09 AM	0.812	47832	698	1058	196	180	127
2015-11-20 10:39 AM	0.833	48142	703	809	196	310	120
2015-11-20 11:09 AM	0.854	48748	698	1037	191	288	124
2015-11-20 11:40 AM	0.875	48641	708	846	196	242	120
2015-11-20 12:10 PM	0.896	48457	698	987	194	283	124
2015-11-20 12:40 PM	0.917	48609	703	1147	191	253	127
2015-11-20 1:11 PM	0.938	47919	708	1001	194	210	130
2015-11-20 1:41 PM	0.960	47908	703	1188	191	153	130
2015-11-20 2:12 PM	0.981	48369	708	942	194	275	127
2015-11-20 2:42 PM	1.00	48770	708	993	191	146	133
2015-11-20 3:12 PM	1.02	48159	703	973	191	252	124
2015-11-20 3:43 PM	1.04	48350	698	1077	194	265	124
2015-11-20 4:13 PM	1.06	48107	698	953	191	289	120

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{133}Ba Bq/g	Uncertainty	^{134}Cs Bq/g	Uncertainty
2015-11-20 4:43 PM	1.09	47490	698	997	194	185	127
2015-11-20 5:14 PM	1.11	48910	698	898	191	292	120
2015-11-20 5:44 PM	1.13	47789	698	946	194	146	130
2015-11-20 6:14 PM	1.15	47861	703	1064	191	200	124
2015-11-20 6:45 PM	1.17	47620	713	969	191	216	130
2015-11-20 7:15 PM	1.19	47911	698	986	191	198	127
2015-11-20 7:45 PM	1.21	48465	713	953	194	341	124
2015-11-20 8:16 PM	1.23	48122	703	912	196	263	127
2015-11-20 8:46 PM	1.25	47989	708	827	194	206	127
2015-11-20 9:17 PM	1.28	48704	708	830	191	296	120
2015-11-20 9:47 PM	1.30	48190	698	805	191	249	130
2015-11-20 10:17 PM	1.32	48140	708	842	191	310	117
2015-11-20 10:48 PM	1.34	47260	698	1026	191	234	117
2015-11-20 11:18 PM	1.36	48666	698	968	191	254	127
2015-11-20 11:48 PM	1.38	48393	708	939	194	348	124
2015-11-21 12:19 AM	1.40	48314	703	959	194	250	120
2015-11-21 12:49 AM	1.42	48292	708	863	194	< 133	
2015-11-21 1:19 AM	1.44	48449	703	930	186	206	127
2015-11-21 1:50 AM	1.47	48040	703	962	188	258	124
2015-11-21 2:20 AM	1.49	48038	708	711	196	323	120
2015-11-21 2:50 AM	1.51	48159	699	840	191	276	124
2015-11-21 3:21 AM	1.53	48045	699	957	191	< 130	
2015-11-21 3:51 AM	1.55	47723	703	792	194	215	127
2015-11-21 4:22 AM	1.57	47710	703	890	191	166	124
2015-11-21 4:52 AM	1.59	47622	699	852	194	254	120
2015-11-21 5:22 AM	1.61	48277	708	793	194	211	124
2015-11-21 5:53 AM	1.63	48017	708	938	191	205	124
2015-11-21 6:23 AM	1.66	47759	708	875	194	< 133	
2015-11-21 6:53 AM	1.68	47694	704	800	191	280	124
2015-11-21 7:24 AM	1.70	47785	699	784	194	190	124
2015-11-21 7:54 AM	1.72	48147	694	810	194	166	120
2015-11-21 8:24 AM	1.74	48594	704	853	194	132	124
2015-11-21 8:55 AM	1.76	48304	704	957	191	< 127	
2015-11-21 9:25 AM	1.78	47522	709	850	194	234	124
2015-11-21 9:55 AM	1.80	48074	699	826	194	296	124
2015-11-21 10:26 AM	1.82	48204	704	937	188	145	127
2015-11-21 10:56 AM	1.84	48422	704	1041	191	210	121
2015-11-21 11:27 AM	1.87	48247	699	804	194	257	117
2015-11-21 11:57 AM	1.89	47906	699	983	191	< 133	
2015-11-21 12:27 PM	1.91	48151	929	906	250	< 171	
2015-11-21 1:03 PM	1.93	47852	203	849	56	212	36
2015-11-21 7:06 PM	2.19	47774	203	780	55	188	36
2015-11-22 1:10 AM	2.44	47885	203	792	55	180	36
2015-11-22 7:14 AM	2.69	47648	203	833	55	196	36
2015-11-22 1:17 PM	2.94	47913	203	763	55	191	36
2015-11-22 7:21 PM	3.20	47779	204	787	54	187	36
2015-11-23 1:24 AM	3.45	47638	202	747	54	176	36
2015-11-23 7:28 AM	3.70	47627	203	741	55	176	36
2015-11-23 1:31 PM	3.95	47669	203	714	55	164	35
2015-11-26 11:06 AM	6.85	47312	102	636	27	130	18
2015-11-27 11:20 AM	7.86	47080	101	607	27	144	18
2015-11-28 11:34 AM	8.87	47063	101	594	27	121	18
2015-11-29 11:48 AM	9.88	46975	102	582	27	125	18
2015-11-30 12:02 PM	10.9	46923	102	549	27	115	18
2015-12-01 12:15 PM	11.9	46803	101	566	27	104	18
2015-12-02 12:29 PM	12.9	46727	102	526	27	124	18

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{133}Ba Bq/g	Uncertainty	^{134}Cs Bq/g	Uncertainty
2015-12-03 12:43 PM	13.9	46782	102	519	27	116	18
2015-12-04 12:56 PM	14.9	46624	102	530	27	130	18
2015-12-05 1:10 PM	15.9	46491	102	514	26	115	18
2015-12-06 1:23 PM	16.9	46661	102	499	26	104	18
2015-12-07 1:37 PM	18.0	46523	102	534	26	95.9	18
2015-12-08 1:50 PM	19.0	46439	102	484	26	98.2	18
2015-12-09 2:04 PM	20.0	46433	102	476	26	96.7	18
2015-12-10 2:17 PM	21.0	46207	102	487	26	105	18
2015-12-11 2:31 PM	22.0	46191	102	472	26	96.1	18
2015-12-12 2:44 PM	23.0	46180	102	458	26	95.1	18
2015-12-13 2:57 PM	24.0	46138	102	479	26	93.5	18
2015-12-14 3:11 PM	25.0	46162	102	467	26	102	18
2015-12-15 3:24 PM	26.0	46005	102	460	26	98.9	18
2015-12-16 3:37 PM	27.0	46055	103	455	26	108	18
2015-12-17 3:51 PM	28.0	45989	102	448	26	84.2	18
2015-12-18 4:04 PM	29.1	45916	103	452	26	72.7	18
2015-12-19 4:17 PM	30.1	45833	103	421	26	97.5	18
2015-12-20 4:30 PM	31.1	45666	103	433	26	83.7	18
2015-12-21 4:43 PM	32.1	45770	103	437	26	79.9	18
2015-12-22 4:57 PM	33.1	45732	103	414	26	84.3	18
2015-12-23 5:10 PM	34.1	45696	103	409	26	98.7	18
2015-12-24 5:23 PM	35.1	45755	103	428	26	87.7	18
2015-12-25 5:36 PM	36.1	45683	103	385	26	79.8	18
2015-12-26 5:49 PM	37.1	45609	103	409	26	88.9	18
2015-12-27 6:02 PM	38.1	45572	103	405	26	77.9	18
2015-12-28 6:15 PM	39.1	45487	103	422	26	68.8	18
2015-12-29 6:28 PM	40.2	45414	103	406	26	89.8	18
2015-12-30 6:41 PM	41.2	45454	103	412	26	89.1	18
2015-12-31 6:54 PM	42.2	45415	104	386	26	95.3	18
2016-01-01 7:07 PM	43.2	45493	104	392	26	77.8	18
2016-01-02 7:20 PM	44.2	45387	104	386	26	84.0	18
2016-01-03 7:33 PM	45.2	45348	104	376	26	74.6	18
2016-01-05 12:32 PM	46.9	45240	104	396	26	88.0	18
2016-01-06 12:45 PM	47.9	45253	104	380	26	81.3	18
2016-01-07 12:58 PM	48.9	45172	104	370	26	74.3	18
2016-01-08 1:11 PM	49.9	45208	104	370	26	78.9	18
2016-01-09 1:24 PM	50.9	45134	104	390	26	72.7	18
2016-01-10 1:36 PM	52.0	45116	104	382	26	79.3	18
2016-01-11 1:49 PM	53.0	45022	104	372	26	79.9	18
2016-01-12 2:02 PM	54.0	44977	104	352	26	68.3	18
2016-01-13 2:15 PM	55.0	44960	104	351	26	73.7	18
2016-01-14 2:27 PM	56.0	44872	104	364	26	60.0	19
2016-01-15 2:40 PM	57.0	44871	104	368	26	57.5	19
2016-01-16 2:53 PM	58.0	44873	104	353	26	72.5	18
2016-01-17 3:05 PM	59.0	44842	105	351	26	63.1	19
2016-01-18 3:18 PM	60.0	44782	105	354	26	71.1	19
2016-01-19 3:30 PM	61.0	44723	105	344	26	80.6	18
2016-01-20 3:43 PM	62.0	44276	104	358	26	68.7	18
2016-01-22 11:18 AM	63.9	43754	104	317	26	60.2	18
2016-01-23 11:30 AM	64.9	43706	104	330	25	68.7	18
2016-01-24 11:42 AM	65.9	43531	104	318	25	72.8	18
2016-01-25 11:54 AM	66.9	43313	104	331	25	61.6	18
2016-01-26 12:06 PM	67.9	43391	104	330	25	74.1	18
2016-01-27 12:19 PM	68.9	42536	103	337	25	73.9	18
2016-01-28 12:30 PM	69.9	42159	103	319	25	78.6	18

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{133}Ba Bq/g	Uncertainty	^{134}Cs Bq/g	Uncertainty
2016-01-29 12:42 PM	70.9	41921	102	345	25	63.4	18
2016-01-30 12:54 PM	71.9	41631	102	313	25	65.3	18
2016-01-31 1:06 PM	72.9	41376	102	306	25	83.3	18
2016-02-01 1:17 PM	73.9	41177	102	302	25	62.3	18
2016-02-02 1:29 PM	75.0	40713	101	334	25	71.9	18
2016-02-03 1:40 PM	76.0	39503	100	313	24	55.2	18
2016-02-04 1:51 PM	77.0	38314	99	319	24	49.4	18
2016-02-05 2:02 PM	78.0	37984	98	297	24	65.7	17
2016-02-06 2:12 PM	79.0	38080	98	310	24	60.6	18
2016-02-07 2:23 PM	80.0	38196	99	308	24	71.2	17
2016-02-08 2:33 PM	81.0	38253	99	293	24	49.8	18
2016-02-09 2:44 PM	82.0	38294	99	299	24	62.8	18
2016-02-10 2:54 PM	83.0	38142	99	316	24	72.9	18
2016-02-11 3:05 PM	84.0	38117	99	299	24	70.7	18
2016-02-12 3:16 PM	85.0	38136	99	308	24	65.8	18
2016-02-13 3:26 PM	86.0	38062	99	295	24	73.3	18
2016-02-14 3:37 PM	87.0	38176	100	312	24	71.4	18
2016-02-15 3:47 PM	88.0	38166	100	318	24	60.1	18
2016-02-16 3:58 PM	89.1	38149	100	301	24	68.2	18
2016-02-17 4:08 PM	90.1	38147	100	302	24	80.2	18
2016-02-18 4:19 PM	91.1	38167	100	306	24	65.0	18
2016-02-19 4:29 PM	92.1	38047	100	292	24	60.6	18
2016-02-20 4:40 PM	93.1	38142	100	316	24	78.3	18
2016-02-21 4:50 PM	94.1	38032	100	285	24	70.6	18
2016-02-22 5:01 PM	95.1	38039	100	290	24	75.0	18
2016-02-23 5:11 PM	96.1	38043	100	311	24	73.2	18
2016-02-24 5:21 PM	97.1	38067	101	309	24	65.6	18
2016-02-25 5:32 PM	98.1	38096	101	314	24	77.0	18
2016-02-26 5:42 PM	99.1	38073	101	297	24	83.5	18
2016-02-27 5:53 PM	100	38067	101	297	24	72.0	18
2016-02-28 6:03 PM	101	37965	101	295	24	66.1	18
2016-02-29 6:13 PM	102	37981	101	306	24	51.8	18
2016-03-01 6:24 PM	103	37988	101	299	24	82.3	18
2016-03-02 6:34 PM	104	38079	101	294	24	68.9	18
2016-03-03 6:44 PM	105	38131	102	302	24	56.3	18
2016-03-04 7:55 PM	106	38219	102	297	24	66.2	18
2016-03-05 7:05 PM	107	38352	102	306	24	63.0	18
2016-03-06 7:16 PM	108	38347	102	313	24	75.0	18
2016-03-07 7:26 PM	109	38509	102	297	24	61.8	18
2016-03-08 7:37 PM	110	38627	103	296	24	70.0	18
2016-03-09 7:47 PM	111	38604	103	276	24	64.9	18
2016-03-16 11:56 AM	118	37562	59	292	14	72.8	11
2016-03-19 12:26 PM	121	37439	59	282	14	63.8	11
2016-03-22 12:56 PM	124	37449	59	274	14	53.1	11
2016-03-25 1:26 PM	127	37424	59	285	14	57.4	11
2016-03-28 2:56 PM	130	37439	60	278	14	58.0	11
2016-03-31 3:26 PM	133	37296	60	276	14	59.0	11
2016-04-03 3:56 PM	136	37255	60	258	14	51.6	11
2016-04-19 10:26 AM	152	37020	61	243	13	39.9	11
2016-04-22 10:55 AM	155	36971	61	263	13	47.5	11
2016-04-25 11:24 AM	158	36999	61	251	13	38.9	11
2016-04-28 11:53 AM	161	36850	61	237	13	40.0	11
2016-05-01 12:22 PM	164	36860	61	240	13	46.6	11
2016-05-04 12:51 PM	167	36809	62	250	13	42.9	11
2016-05-07 1:19 PM	170	36772	62	242	13	49.6	11

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{133}Ba Bq/g	Uncertainty	^{134}Cs Bq/g	Uncertainty
2016-05-10 1:48 PM	173	36680	62	236	13	41.5	11
2016-05-13 2:16 PM	176	36642	62	244	13	50.8	11
2016-05-16 2:44 PM	179	36582	62	239	13	48.2	11
2016-05-19 3:13 PM	182	36569	63	230	13	42.8	12
2016-05-22 3:41 PM	185	36500	63	237	13	36.3	12
2016-05-25 4:09 PM	188	36443	63	247	13	40.5	12
2016-05-28 4:37 PM	191	36379	63	228	13	43.1	12
2016-05-31 5:04 PM	194	36389	63	233	13	53.1	12
2016-06-03 5:32 PM	197	36357	63	235	13	36.0	12
2016-06-14 1:22 PM	208	35979	42	235	8.7	35.7	7.8
2016-06-21 2:25 PM	215	35893	42	223	8.7	42.0	7.8
2016-06-28 3:28 PM	222	35799	42	223	8.7	42.1	7.9
2016-08-12 10:30 AM	267	35302	59	213	12	36.5	11
2016-08-24 2:31 PM	279	35144	45	210	8.6	28.3	8.5
2016-08-31 3:29 PM	286	35070	45	212	8.6	40.1	8.6
2016-09-07 4:27 PM	293	34992	45	222	8.6	31.2	8.7
2016-09-14 5:25 PM	300	34961	45	212	8.6	39.4	8.7
2016-09-21 6:22 PM	307	34841	46	214	8.6	35.7	8.8
2016-09-28 6:19 PM	314	34828	46	212	8.6	36.9	8.9
2016-10-05 8:16 PM	321	34710	46	217	8.5	30.4	9.0
2016-10-12 9:12 PM	328	34629	47	213	8.6	35.6	9.1
2016-10-19 10:07 PM	335	34571	47	214	8.5	32.9	9.2
2016-10-26 11:03 PM	342	34463	47	217	8.5	35.2	9.2
2016-11-02 10:57 PM	349	34366	48	222	8.5	38.4	9.3
2016-11-09 11:52 PM	356	34354	48	218	8.5	32.1	9.4
2016-11-17 12:46 AM	363	34202	48	217	8.5	37.5	9.5
2016-11-24 1:40 AM	370	34130	49	206	8.5	36.1	9.6
2016-12-13 8:00 AM	390	33952	49	210	8.5	34.0	9.9
2016-12-20 8:52 AM	397	33948	50	207	8.5	34.8	10
2017-01-17 10:23 AM	425	33762	137	213	23	29.8	28
2017-01-30 10:36 AM	438	33663	97	208	16	28.4	20
2017-02-07 8:46 AM	446	33475	52	196	8.4	33.9	11

Table A4-2. Hole ONK-PP324, activity versus time. Time for injection was 2015-11-19 14:40.

Time	Time (days)	^{22}Na Bq/g	Uncer-tainty	^{133}Ba Bq/g	Uncer-tainty	^{134}Cs Bq/g	Uncer-tainty
2017-04-06 11:56 AM	504	0.0236	0.0080	< 0.001		0.00550	0.0041
2017-04-13 11:56 AM	511	0.0226	0.0080	< 0.004		0.00547	0.0042
2017-04-20 11:57 AM	518	0.0293	0.0078	< 0.002		< 0.0069	
2017-04-27 11:57 AM	525	0.0371	0.0080	< 0.003		< 0.0054	
2017-05-09 2:15 PM	537	0.0244	0.0082	< 0.004		< 0.0087	
2017-05-16 2:15 PM	544	0.0264	0.0082	< 0.005		0.00674	0.0044
2017-05-23 2:15 PM	551	0.0261	0.0080	< 0.003		0.00446	0.0045
2017-05-30 2:16 PM	558	0.0309	0.0081	< 0.005		0.00515	0.0046
2017-06-06 2:16 PM	565	0.0280	0.0082	< 0.005		< 0.0077	
2017-06-13 2:16 PM	572	0.0215	0.0083	< 0.004		< 0.0077	
2017-06-20 2:17 PM	579	0.0345	0.0080	< 0.003		< 0.0035	
2017-06-27 2:17 PM	586	0.0302	0.0081	< 0.004		0.00557	0.0045
2017-07-04 2:17 PM	593	0.0330	0.0084	< 0.002		0.00608	0.0046
2017-07-11 2:19 PM	600	0.0240	0.0084	< 0.002		0.0111	0.0046
2017-07-18 2:19 PM	607	0.0275	0.0084	< 0.003		< 0.0088	
2017-07-25 2:19 PM	614	< 0.023		< 0.002		0.0106	0.0045
2017-08-01 2:20 PM	621	0.0247	0.0085	< 0.003		0.00852	0.0048
2017-08-08 2:20 PM	628	0.0304	0.0084	< 0.003		0.00758	0.0047

Time	Time (days)	^{22}Na Bq/g	Uncer-tainty	^{133}Ba Bq/g	Uncer-tainty	^{134}Cs Bq/g	Uncer-tainty
2017-08-15 2:20 PM	635	0.0239	0.0088	< 0.0027		< 0.0093	
2017-08-22 2:21 PM	642	0.0289	0.0085	< 0.004		< 0.0091	
2017-08-29 2:21 PM	649	0.0321	0.0085	< 0.003		< 0.0088	
2017-09-05 2:21 PM	656	0.0310	0.0084	< 0.003		0.00785	0.0049
2017-09-12 2:22 PM	663	0.0279	0.0086	< 0.004		0.00832	0.0048
2017-09-19 2:22 PM	670	0.0216	0.0088	< 0.002		0.00977*	0.0050
2018-11-29 11:56 AM	1 106	< 0.028		< 0.003		< 0.013	
2018-12-06 11:57 AM	1 113	< 0.025		< 0.003		< 0.013	
2018-12-12 11:58 AM	1 119	< 0.032		< 0.001		< 0.005	
2018-12-19 11:59 AM	1 126	0.0275	0.011	< 0.004		< 0.020	
2018-12-26 12:00 PM	1 133	0.0229	0.011	< 0.003		< 0.014	
2019-01-02 12:01 PM	1 140	< 0.030		< 0.002		< 0.011	
2019-01-09 12:02 PM	1 147	< 0.032		< 0.002		< 0.019	
2019-01-16 12:03 PM	1 154	< 0.030		< 0.003		< 0.012	
2019-01-23 12:04 PM	1 161	< 0.023		< 0.001		< 0.016	
2019-01-30 12:05 PM	1 168	0.0307	0.011	< 0.002		< 0.016	
2019-02-06 12:07 PM	1 175	0.0311	0.011	< 0.003		< 0.017	
2019-02-13 12:08 PM	1 182	< 0.029		< 0.005		< 0.011	
2019-02-20 12:09 PM	1 189	0.0297	0.012	< 0.002		0.0154	0.0078
2019-02-27 12:10 PM	1 196	0.0269	0.011	< 0.002		< 0.022	
2019-03-06 12:11 PM	1 203	< 0.033		< 0.003		< 0.019	
2019-03-13 12:12 PM	1 210	< 0.029		< 0.004		< 0.012	
2019-03-20 12:13 PM	1 217	< 0.030		< 0.005		< 0.015	
2019-03-27 12:14 PM	1 224	0.0268	0.012	< 0.003		< 0.020	
2019-04-03 1:15 PM	1 231	< 0.031		< 0.003		< 0.015	
2019-04-10 1:16 PM	1 238	< 0.032		< 0.004		0.0174	0.0080
2019-04-17 1:17 PM	1 245	< 0.032		< 0.003		< 0.020	
2019-04-24 1:18 PM	1 252	< 0.025		< 0.002		< 0.016	
2019-05-01 1:19 PM	1 259	0.0277	0.012	< 0.004		< 0.016	
2019-05-08 1:20 PM	1 266	< 0.024		< 0.002		< 0.018	
2019-05-15 1:21 PM	1 273	< 0.035		< 0.004		< 0.011	
2019-05-22 1:23 PM	1 280	< 0.029		< 0.001		< 0.016	
2019-05-29 1:24 PM	1 287	< 0.030		< 0.002		< 0.023	
2019-06-05 1:25 PM	1 294	< 0.032		< 0.002		< 0.021	
2019-08-16 1:43 PM	1 366	< 0.031		< 0.002		< 0.017	
2019-08-23 1:44 PM	1 373	< 0.029		< 0.004		< 0.016	
2019-10-04 11:55 PM	1 415	< 0.033		< 0.002		< 0.022	
2019-10-12 12:06 AM	1 422	< 0.036		< 0.003		< 0.014	
2019-10-19 12:16 AM	1 429	< 0.019		< 0.001		< 0.016	
2019-10-26 12:27 AM	1 436	< 0.039		< 0.002		< 0.018	
2019-11-01 11:38 PM	1 443	0.0299	0.014	< 0.004		< 0.022	
2019-11-08 11:49 PM	1 450	0.0350	0.013	< 0.004		< 0.023	
2019-11-15 11:59 PM	1 457	< 0.035		< 0.003		0.0219	0.0097
2019-11-23 12:10 AM	1 464	< 0.0340		< 0.004		< 0.017	
2019-12-13 3:08 PM	1 485	< 0.026		< 0.003		0.0202	0.0100
2019-12-20 3:09 PM	1 492	< 0.028		< 0.004		< 0.019	

* Blockage discovered.

Table A4-3. Hole ONK-PP327, activity versus time. Time for injection was 2015-11-19 14:40. Ba-133 and Cs-134 are not possible to measure using the NaI scintillation device.

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{122}Ba Bq/g	^{134}Cs Bq/g	Comments
2017-04-10 11:49	508	0.101	0.015	< 0.006	< 0.011	No circulation
2017-04-17 11:49	515	0.102	0.015	< 0.006	< 0.010	
2017-04-24 11:49	522	0.0990	0.015	< 0.006	< 0.010	
2017-05-02 11:49	530	0.0875	0.015	< 0.006	< 0.010	
2017-05-09 14:25	537	0.0882	0.015	< 0.006	< 0.010	
2017-05-16 14:25	544	0.0858	0.015	< 0.006	< 0.010	
2017-05-23 14:25	551	0.0877	0.015	< 0.006	< 0.011	
2017-05-30 14:24	558	0.0870	0.015	< 0.006	< 0.011	
2017-06-06 14:24	565	0.0930	0.015	< 0.006	< 0.011	
2017-06-13 14:24	572	0.0900	0.015	< 0.006	< 0.011	
2017-06-20 14:24	579	0.0971	0.015	< 0.006	< 0.011	
2017-06-27 14:24	586	0.0965	0.015	< 0.006	< 0.011	
2017-07-04 14:24	593	0.101	0.015	< 0.006	< 0.011	
2017-07-11 14:24	600	0.100	0.015	< 0.006	< 0.011	
2017-07-18 14:24	607	0.106	0.016	< 0.006	< 0.011	
2017-07-25 14:24	614	0.108	0.016	< 0.006	< 0.011	
2017-08-07 14:24	627	0.114	0.016	< 0.006	< 0.011	
2017-08-14 14:24	634	0.240	0.016	< 0.006	< 0.012	
2017-08-21 14:24	641	0.121	0.016	< 0.006	< 0.011	
2017-08-28 14:24	648	0.122	0.016	< 0.006	< 0.012	
2017-09-04 14:24	655	< 0.016		< 0.006	< 0.011	Emptying the lines
2017-09-11 14:23	662	< 0.015		< 0.006	< 0.011	
2017-09-18 14:23	669	< 0.016		< 0.006	< 0.012	
2017-10-11 10:49	692	< 0.016		< 0.006	< 0.012	
2017-10-18 10:48	699	< 0.016		< 0.006	< 0.012	Circulation restored
2017-10-25 10:48	706	< 0.016		< 0.006	< 0.012	
2017-11-01 09:48	713	< 0.016		< 0.006	< 0.012	
2017-11-08 09:47	720	< 0.016		< 0.006	< 0.012	
2017-11-15 09:47	727	< 0.016		< 0.006	< 0.012	
2017-11-22 09:47	734	< 0.016		< 0.006	< 0.012	
2017-11-29 09:46	741	< 0.017		< 0.006	< 0.012	
2017-12-06 09:46	748	< 0.017		< 0.006	< 0.012	
2017-12-13 09:46	755	< 0.017		< 0.006	< 0.012	
2017-12-20 09:46	762	< 0.017		< 0.006	< 0.013	
2017-12-27 09:45	769	< 0.017		< 0.006	< 0.013	
2018-01-03 09:45	776	< 0.017		< 0.006	< 0.013	
2018-01-10 09:45	783	< 0.017		< 0.006	< 0.013	
2018-01-17 09:44	790	< 0.017		< 0.006	< 0.013	
2018-01-24 09:44	797	< 0.017		< 0.006	< 0.013	
2018-01-31 09:44	804	< 0.017		< 0.006	< 0.013	
2018-02-07 09:43	811	< 0.017		< 0.006	< 0.013	
2018-02-14 09:43	818	< 0.017		< 0.006	< 0.013	
2018-02-21 09:43	825	< 0.018		< 0.006	< 0.013	
2018-02-28 09:43	832	< 0.018		< 0.006	< 0.013	
2018-03-16 09:02	848	< 0.018		< 0.006	< 0.014	
2018-05-18 09:59	911	< 0.019		< 0.006	< 0.014	
2018-11-21 13:46	1 098	< 0.021		< 0.006	< 0.017	
2018-11-28 13:45	1 105	< 0.021		< 0.006	< 0.017	
2018-12-05 13:45	1 112	< 0.021		< 0.006	< 0.017	
2018-12-12 13:45	1 119	< 0.022		< 0.006	< 0.017	
2018-12-19 13:45	1 126	< 0.022		< 0.006	< 0.017	
2018-12-26 13:45	1 133	< 0.022		< 0.006	< 0.017	
2019-01-02 13:45	1 140	< 0.022		< 0.006	< 0.018	

Time	Time (days)	^{22}Na Bq/g	Uncertainty	^{122}Ba Bq/g	^{134}Cs Bq/g	Comments
2019-01-09 13:44	1147	< 0.022		< 0.006	< 0.018	
2019-01-16 13:44	1154	< 0.022		< 0.006	< 0.018	
2019-01-23 13:44	1161	< 0.022		< 0.006	< 0.018	
2019-01-30 13:44	1168	< 0.022		< 0.006	< 0.018	
2019-02-06 13:44	1175	< 0.022		< 0.006	< 0.018	
2019-02-13 13:43	1182	< 0.023		< 0.006	< 0.018	
2019-02-20 13:43	1189	< 0.023		< 0.006	< 0.018	
2019-02-27 13:43	1196	< 0.023		< 0.006	< 0.018	
2019-03-06 13:43	1203	< 0.023		< 0.006	< 0.019	
2019-03-13 13:43	1210	< 0.023		< 0.006	< 0.019	
2019-03-20 13:42	1217	< 0.023		< 0.006	< 0.019	
2019-03-27 13:42	1224	< 0.023		< 0.006	< 0.019	
2019-04-03 14:42	1231	< 0.023		< 0.006	< 0.019	
2019-04-10 14:42	1238	< 0.023		< 0.006	< 0.019	
2019-04-17 14:42	1245	< 0.024		< 0.006	< 0.019	
2019-04-24 14:41	1252	< 0.024		< 0.006	< 0.019	
2019-05-01 14:41	1259	< 0.024		< 0.006	< 0.020	
2019-05-08 14:41	1266	< 0.024		< 0.006	< 0.020	
2019-05-15 14:41	1273	< 0.024		< 0.006	< 0.020	
2019-05-22 14:41	1280	< 0.024		< 0.006	< 0.020	
2019-05-29 14:40	1287	< 0.024		< 0.006	< 0.020	
2019-06-05 14:40	1294	< 0.024		< 0.006	< 0.020	
2019-10-09 11:46	1420	< 0.027		< 0.006	< 0.023	
2019-10-16 11:46	1427	< 0.027		< 0.006	< 0.023	
2019-10-23 11:46	1434	< 0.027		< 0.006	< 0.023	
2019-10-30 10:46	1441	< 0.027		< 0.006	< 0.023	
2019-11-06 10:45	1448	< 0.027		< 0.006	< 0.023	
2019-11-13 10:45	1455	< 0.027		< 0.006	< 0.023	
2019-11-20 10:45	1462	< 0.028		< 0.006	< 0.024	
2019-11-27 10:45	1469	< 0.028		< 0.006	< 0.024	
2019-12-04 10:45	1476	< 0.028		< 0.006	< 0.024	
2019-12-11 10:44	1483	< 0.028		< 0.006	< 0.024	
2019-12-18 10:44	1490	< 0.028		< 0.006	< 0.024	

Appendix 5

Performed sample collections in ONK-PP326, ONK-PP324 and ONK-PP327

Table A5-1. Hole ONK-PP326, dates and extracted volumes.

Sample	Date	Time/d	Volume	Comment
326:001	2015-11-19	0.28	0.2 mL	
326:002	2015-11-20	0.75	0.2 mL	
326:003	2015-11-20	1.0	0.2 mL	
326:004.1	2015-11-21	2.0	0.2 mL	
326:004.2	2015-11-23	3.9	0.2 mL	
326:005	2015-11-24	5.0	0.2 mL	
326:006	2015-11-26	6.9	0.2 mL	
326:007	2015-12-03	14	0.2 mL	
326:008	2015-12-10	21	0.2 mL	
326:009	2015-12-18	29	0.2 mL	
326:010	2015-12-29	40	0.2 mL	
326:011	2016-01-13	55	0.2 mL	
326:012	2016-01-25	67	0.2 mL	
326:013	2016-02-10	83	0.2 mL	
326:014	2016-02-24	97	0.2 mL	
326:015	2016-04-11	144	0.2 mL	
326:016	2016-05-09	171	0.2 mL	
326:017	2016-06-06	200	0.2 mL	Sampling failed, leakage valve of sampling loop
326:018	2016-06-06	200	0.2 mL	
326:019	2016-06-28	222	0.2 mL	
326:020	2016-08-09	264	0.2 mL	
326:021	2016-10-13	329	0.2 mL	
326:022	2016-12-07	384	0.2 mL	
362:023	2017-01-30	438	0.2 mL	
326:024	2017-04-27	524	0.2 mL	
326:025	2017-06-14	573	0.2 mL	
326:026	2017-08-29	648	0.2 mL	Pumping speed was increased in the beginning of the sampling
326:027	2017-10-25	706	0.2 mL	
326:028	2017-12-13	755	0.2 mL	
326:029	2018-02-20	824	0.2 mL	
326:030	2018-04-18	881	0.2 mL	
326:031	2018-06-19	943	0.2 mL	
326:032	2018-08-21	1 006	0.2 mL	
326:033	2018-10-22	1 068	0.2 mL	
326:034	2018-12-17	1 124	0.2 mL	
326:035	2019-02-21	1 190	0.2 mL	
326:036	2019-04-23	1 251	0.2 mL	
326:037	2019-06-18	1 307	0.2 mL	
326:038	2019-08-14	1 364	0.2 mL	
326:039	2019-10-17	1 428	0.2 mL	

Table A5-2. Hole ONK-PP324, dates and extracted volumes.

Sample	Date	Time/d	Volume	Comment
324:001	2015-12-03	14	10 mL	No data delivered due to contamination
324:002	2015-12-18	29	10 mL	No data delivered due to contamination
324:003	2016-01-05	47	10 mL	No data delivered due to contamination
324:004	2016-01-25	67	10 mL	No data delivered due to contamination
324:005	2016-02-09	82	10 mL	No data delivered due to contamination
324:006	2016-02-17	90	10 mL	No data delivered due to contamination
324:007	2016-02-24	97	10 mL	No data delivered due to contamination
324:008	2016-03-24	126	10 mL	No data delivered due to contamination
324:009	2016-04-25	158	10 mL	No data delivered due to contamination
324:010	2016-06-01	195	10 mL	No data delivered due to contamination
324:011	2016-06-21	215	10 mL	Leakage in the first loop valve. No data delivered due to contamination.
324:012	2016-08-09	264	10 mL	No data delivered due to contamination
324:013	2016-09-08	294	10 mL	
324:014	2016-10-04	320	10 mL	
324:015	2016-11-14	361	10 mL	Leakage in sampling tube (connector after valve)
324:016	2016-12-20	397	10 mL	
324:017	2017-01-17	425	10 mL	
324:018	2017-02-15	454	10 mL	Not analysed
324:019	2017-03-15	482	10 mL	
324:020	2017-05-10	537	10 mL	
324:021	2017-06-08	567	10 mL	
324:022	2017-06-27	585	10 mL	
324:023	2017-08-09	629	10 mL	
324:024	2017-09-13	664	10 mL	Flow increased during sampling from 1.1 to 1.6 mL/min
324:025	2017-10-03	683	10 mL	Sample collected to a bottle (about 10 mL), using manual pump
324:026	2017-10-11	691	10 mL	Sample collected to a bottle (about 10 mL), using manual pump
324:027	2017-11-07	719	10 mL	Sample collected to a bottle (about 10 mL), using manual pump
324:028	2017-12-04	746	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:029	2018-01-08	781	90 mL	Sampling failed because of a broken pump (water leakage in pump)
324:030	2018-02-05	809	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:031	2018-03-06	838	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:032	2018-04-09	872	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:033	2018-05-08	901	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:034	2018-06-12	936	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:034	2018-06-12	936	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:035	2018-07-11	965	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:035	2018-07-11	965	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:036	2018-08-07	992	90 mL	Sample collected to a bottle (about 90 mL), using manual pump
324:037	2018-09-12	1 028	10 mL	First sample with the new equipment. Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:038	2018-09-19	1 035	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:039	2018-10-01	1 047	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:040	2018-10-10	1 056	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:041	2018-10-19	1 065	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:042	2018-11-14	1 091	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:043	2018-12-11	1 118	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:044	2019-01-08	1 146	10 mL	
324:045	2019-01-23	1 160	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling.

Sample	Date	Time/d	Volume	Comment
324:046	2019-02-05	1174	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:047	2019-03-11	1208	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:048	2019-04-08	1236	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:049	2019-05-07	1265	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling
324:050	2019-06-05	1294	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling.
324:051	2019-07-09	1328	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling.
324:052	2019-08-08	1358	10 mL	Flow setting increased from 0.6 mL/min to 1.0 mL/min during sampling.
324:053	2019-09-05	1386	10 mL	Radon injection
324:054	2019-09-06	1387	10 mL	Radon test
324:055	2019-10-09	1420	10 mL	Problems with the sample loop, slightly larger pressure drop than usually.

Table A5-3. Hole ONK-PP327, dates and extracted volumes.

Sample	Date	Time/d	Volume	Comment
327:001	2015-12-03	14	10 mL	No data delivered due to contamination
327:002	2015-12-18	29	10 mL	No data delivered due to contamination
327:003	2016-01-05	47	10 mL	No data delivered due to contamination
327:004	2016-01-25	67	10 mL	No data delivered due to contamination
327:005	2016-02-09	82	10 mL	No data delivered due to contamination
327:006	2016-02-17	90	10 mL	No data delivered due to contamination
327:007	2016-02-24	97	10 mL	No data delivered due to contamination
327:008	2016-03-24	126	10 mL	No data delivered due to contamination
327:009	2016-04-25	158	10 mL	Leakage, sampling failed. No data delivered due to contamination
327:010	2016-06-01	195	10 mL	No data delivered due to contamination
327:011	2016-06-21	215	10 mL	No data delivered due to contamination
327:012	2016-08-09	264	10 mL	No data delivered due to contamination
327:013	2016-09-08	294	10 mL	
327:014	2016-10-04	320	10 mL	
327:015	2016-11-14	361	10 mL	
327:016	2016-12-20	397	10 mL	
327:017	2017-01-17	425	10 mL	
327:018	2017-02-15	454	10 mL	Not analysed
327:019	2017-02-23	462	10 mL	
327:020	2017-05-10	537	10 mL	
327:021	2017-10-11	691	10 mL	First sample after changing the lines
327:022	2017-11-07	719	10 mL	Flow setting increased from 2 mL/min to 4 mL/min during sampling
327:023	2017-12-04	746	10 mL	
327:024	2018-01-08	781	10 mL	Flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling
327:025	2018-02-05	809	10 mL	
327:026	2018-02-21		10 mL	Ra/Rn sample. No other radionuclides analysed
327:027	2018-03-06	838	10 mL	
327:028	2018-04-09	872	10 mL	
327:029	2018-05-08	902	10 mL	Flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling
327:030	2018-06-12	936	10 mL	Flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling

Sample	Date	Time/d	Volume	Comment
327:031	2018-06-28		10 mL	Ra/Rn sample; flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling. No other radionuclides analysed
327:032	2018-07-11	965	10 mL	
327:033	2018-08-07	992	10 mL	Flow setting increased from 1.7 mL/min to 2.1 mL/min during sampling
327:034	2018-09-13	1029	10 mL	Flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling
327:035	2018-10-19	1065	10 mL	Flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling
327:036	2018-11-14	1091	10 mL	Flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling
327:037	2018-12-11	1118	10 mL	Flow setting increased from 1.7 mL/min to 2.2 mL/min during sampling
327:038	2019-01-08	1146	10 mL	
327:039	2019-01-23	1161	10 mL	Ra/Rn-sample. Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling. No other radionuclides analysed
327:040	2019-02-05	1174	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:041	2019-03-11	1208	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:042	2019-04-08	1236	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:043	2019-05-07	1265	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:044	2019-06-05	1294	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:045	2019-07-09	1328	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:046	2019-08-08	1358	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:047	2019-09-05	1386	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling
327:048	2019-10-09	1420	10 mL	Flow setting increased from 1.7 ml/min to 2.2 ml/min during sampling

Appendix 6

Field protocol for REPRO TDE

Table A6-1. Events during the Through Diffusion Experiment. All sample collections are given in Appendix 5.

Date	Time	Time/days after injection	Event
2016-01-19	08:24	61	Pumps turned off
2016-09-08	09:12	294	Sampling system was modified (tubes changed)
2016-09-12	10:35	298	Valves 10 and 11 opened
2016-12-05		382	Power cut in ONKALO
2016-12-07		384	Computers in error mode, wipe samples were taken
2016-12-09		386	Computers restarted, new files added
2016-12-13		390	High Voltage measurement started
2017-01-17	09:50	425	Computers restarted, old files were used because there were not new spectrums in directory. Measuring time was changed from 604800s to 84600s
2017-01-30	10:00	438	Computers restarted, new files added. Sampling from dehumidifier. Wipe samples were taken
2017-02-07	08:30	446	Computers restarted
2017-02-15	10:20	454	HPGe measurement switched off
2017-02-21	whole day	460	Turned off the detector systems. Moved the HPGe detector to the observation container. Changed the UPS connection so that both loads are available in the observation container and only the computer in the injection container. Cleaned the observation container
2017-02-22	whole day	461	Cleaned the injection container
2017-02-22	09:40	461	Test of the UPS, with all detector electronics connected, including the X-cooler. X-cooler with initial cooling, so the power is probably large. Backup time 25 min. Changed an put the X-cooler to the ordinary net
2017-02-22	13:28	461	Test of the UPS, with all detector electronics connected, exept for the X-cooler. Backup time approx 75 min
2017-02-22	14:00	461	Connect a field computer with a RS232 cable (from TVO). Possible to run LocalView but not possible to set-up by Socomec program. Logging with power cut off (at 15:00). 0 % load with 3 computers and Digibase-E, 8 % load with DiSpec 50 connected. Computers restarted, new files added
2017-02-23	13:22	462	Testing the circulation loop
2017-04-27	09:20	525	Wipe samples were taken. Flow test to PP327
2017-05-08		536	UPS installed to electric center, detector measurements stopped during the installation
2017-05-09	09:25	537	New jobfiles added, detector measurements started again. Short pump test was done to PP327
2017-05-10		538	For some reason PP324 pressure dropped in the beginning of the sampling, no leakages occurred
2017-08-24		644	PP327 on-line tubing emptied and filled with new synthetic groundwater
2017-09-13	07:46	664	Computer in TDE container was crashed, re-started. Tried to install flow indicator to PP324, but it didn't work. PP324 and PP326 pumps switched off for a while after sampling
2017-10-02 to 2017-10-03		683	Flow indicator installed to PP327. New line opened for sampling and circulation in PP324. New line worked well, and circulation was started after long break. Noticed that both old lines of PP324 are blocked. New line opened, but circulation is not possible with one line. PP324 pump stopped. Pressure in test section can be monitored, but online detector measurement is not possible. Samples need to be collected with a hand-operated pump

Date	Time	Time/days after injection	Event
2017-10-05		686	PP327 Pressure lost due to leakage
2017-10-11		692	Computer in monitoring container was crashed, PP327 online detector measurement restarted. Six-way valve was turned to detector position after sampling
2017-10-25	10:00	706	Wipe samples were taken. PP326 and PP327 pumps switched off for a while after sampling. Tried to check the connections of PP327, because pressure is low
2017-12-13	08:30	755	PP326 and PP327 pumps were switched off for a while after sampling. Wipe samples were taken. Test to PP327, because the pressure is still low. Leakage noticed in the connectors between PP327 pump and valves C and D
2018-01-05	12:58	778	Pump head of PP327 changed and pump started again
2018-01-26	12:00	799	Pump and flow test to PP327, PP327 pressure restored
2018-02-20	10:01	824	Wipe samples
2018-02-21	08:30	825	Ra/Rn-sample to HYRL
2018-02-26	12:30	830	Computer in TDE container was crashed, re-started
2018-03-08	08:10	840	Logging frequency from 30 s to 10 min
2018-04-18	12:35	881	Wipe samples
2018-06-12	09:50	936	The computer in the injection container was crashed, re-started
2018-06-19	09:05	943	Wipe samples
2018-06-28	10:00	952	Sampling from PP323 and PP327 (Ra/Rn-sampling). Detector out of use in the monitoring container. PP327 pressure stable
2018-07-11	09:00	965	All pressure values were jammed – problem is probably not in the REPRO-logger, because the same problem is seen in all ONKALO pressure data
2018-07-18	13:30	972	The PLC-computer is still jammed, although other ONKALO-pressure data is up and running. The PLC-computer was restarted, but the data is still frozen
2018-07-23	16:00	977	The PLC-computer was restarted again twice, with longer reboot times. The data is still frozen
2018-07-26	15:00	980	A blown fuse was replaced from PLC-computer. The pressure data is now collected again. The pressures were ok, only a little higher values than before the jamm
2018-08-21	13:30	1006	Wipe samples
2018-08-29	10:00	1014	PP324 restoration: the experiment equipment was carried out of the hole, guard packer was reinstalled
2018-09-10	12:00	1026	PP326 loop in the injection container: a surface contamination meter was installed inside of the lead shielding
2018-09-12	09:00	1028	PP324 restoration: the experiment equipment reinstallation. The flow meters were removed from monitoring container. Sampling from PP324 after the reinstallation
2018-10-10	12:30	1056	The computer in the injection container was crashed, re-started
2018-10-19	08:50	1065	The computer in the injection container was crashed, re-started
2018-10-22	12:30	1068	Wipe samples
2018-11-12	12:30	1089	Detector reassembly on the monitoring container, shielding of the detectors
2018-11-14	13:30	1091	Detector cooling started in the monitoring container
2018-11-16	14:00	1093	Detectors started in the monitoring container
2018-11-21	14:00	1098	Detectors restarted in the monitoring container
2018-11-27	13:00	1104	Detector 1 restarted in the monitoring container
2018-11-29	12:00	1106	Detector 1 restarted in the monitoring container
2018-12-17	10:00	1124	Wipe samples
2019-01-08	09:50	1146	Blocking test in detector loops
2019-01-23	08:00	1161	Four Ra/Rn-samples

Date	Time	Time/days after injection	Event
2019-02-21	12:05	1190	The computer in the injection container was crashed, re-started. Wipe samples
2019-04-03	13:20	1231	Psect transducer (Ch3) behaving oddly: the pressure has risen to about 4 MPa, and goes down to 0 MPa occasionally. The pressure data is also not going to POTTI, although the logger and the computer are otherwise working normally. The computer was re-started and the Ch3-cord was unplugged from the logger
2019-04-17	08:10	1245	Psect transducer (Ch3) changed to a new one
2019-04-26	12:00	1254	Wipe sampling due odd results from previous sampling
2019-06-18	09:10	1307	Power cut in ONKALO 15.6.2019 – turning up the computers and detectors. Wipe samples
2019-06-28	09:30	1317	Detector 1 counting restarted in the monitoring container
2019-07-01	13:45	1320	Both detectors restarted in the monitoring container
2019-07-09	12:00	1328	Detector 1 counting restarted in the monitoring container
2019-08-14	08:00	1364	Internet connection failure with the detectors – net switch failure (broken cooler fan). Service ordered
2019-08-16	12:00	1366	Booting everything after internet switch replacement. Both detectors restarted and working now
2019-09-05	08:00	1386	Measurement time in detectors to 30 min
2019-10-04	12:00	1415	PLC-computer was down – restarted. Pump C is making odd noises after the restart. Dehumidifier is not working in the monitoring container

Appendix 7

Tracer concentrations and events in ONK-PP326, ONK-PP324 and ONK-PP327

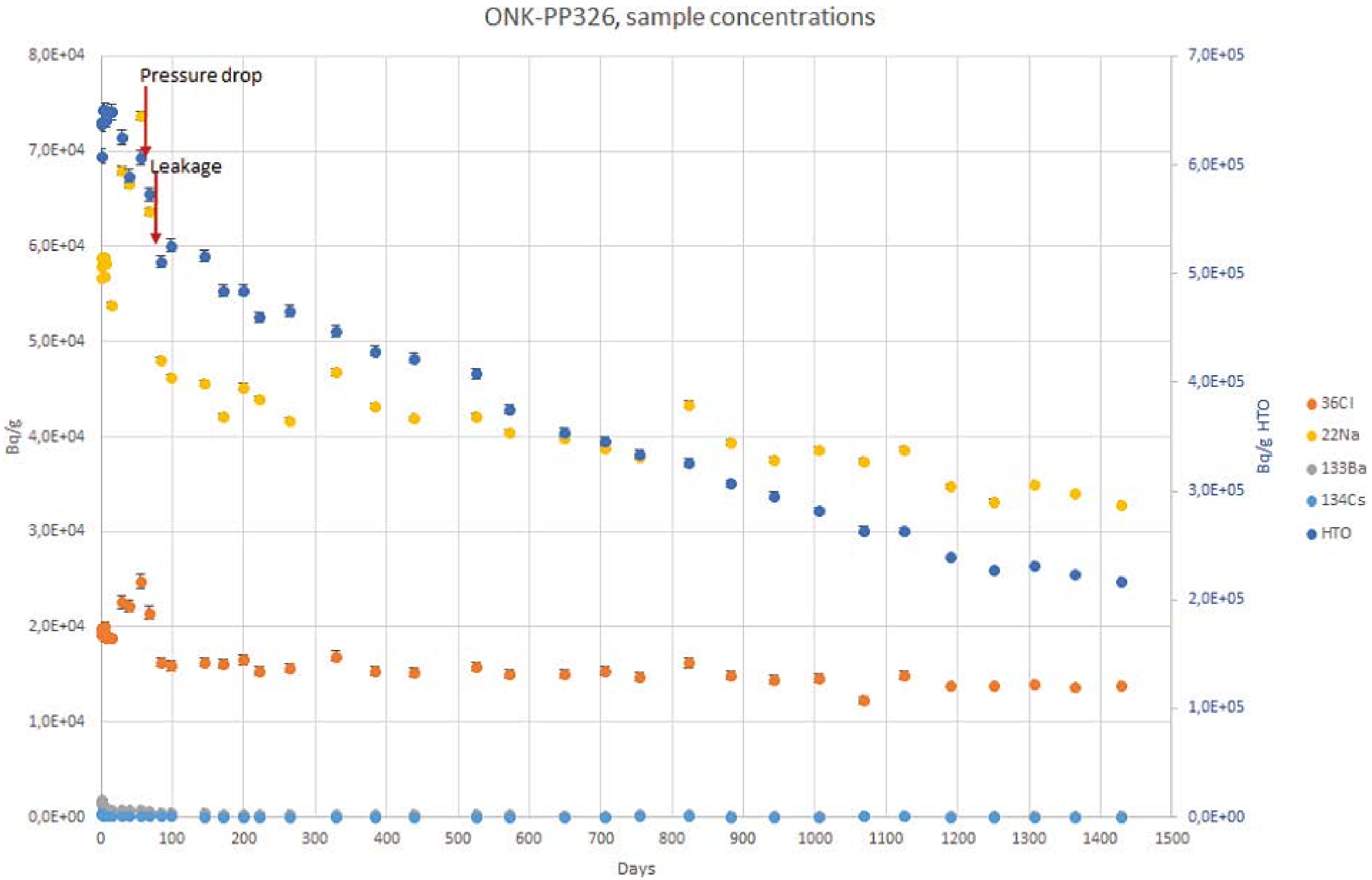


Figure A7-1. *Tracer concentrations in injection section ONK-PP326 during the first 1 428 days of the experiment from analyses of extracted samples. Major events are indicated with red arrows. HTO values (dark blue) refer to the right-hand axis.*

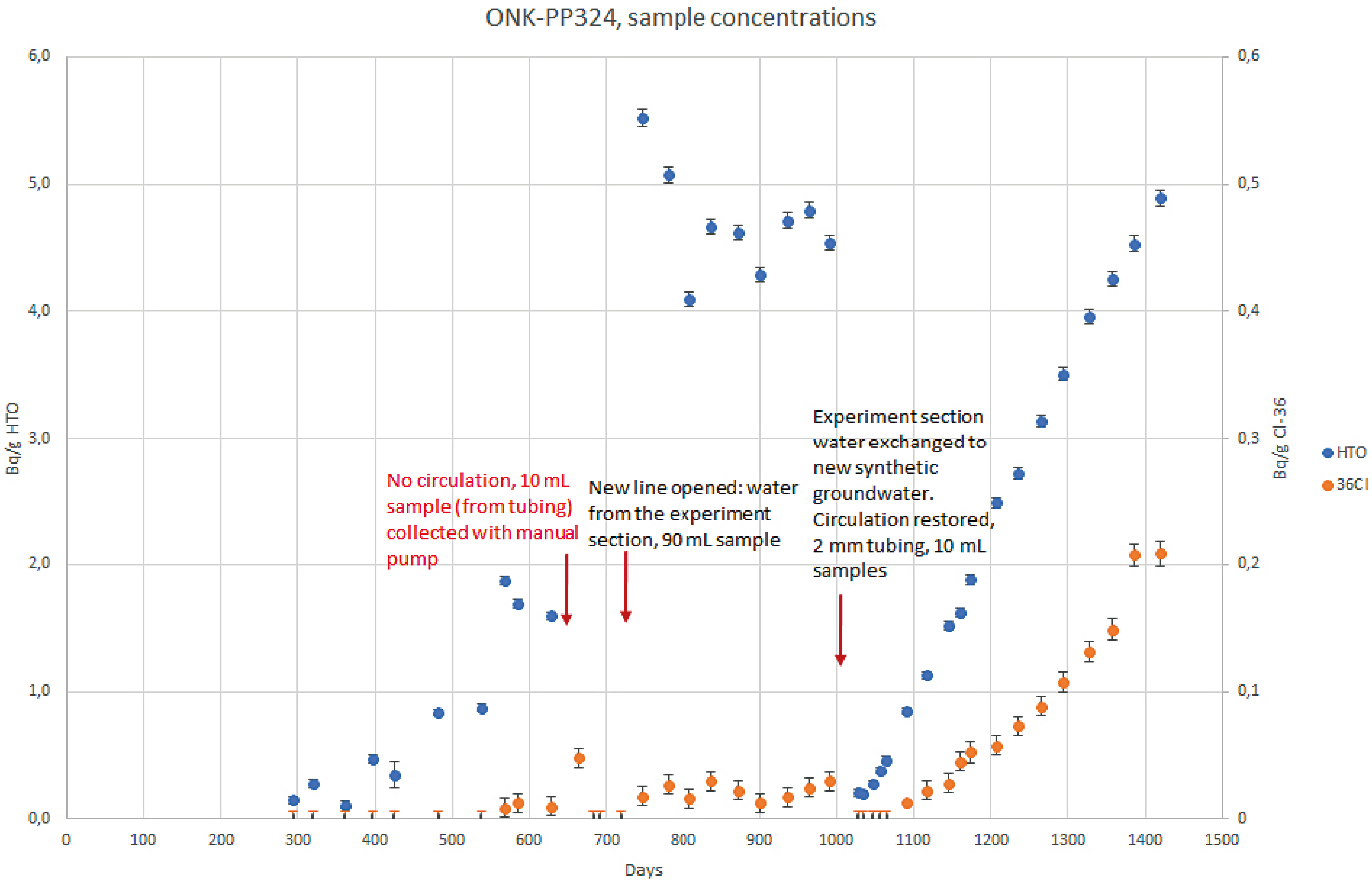


Figure A7-2. *Tracer concentrations experiment from analyses of HTO and Cl-36 in extracted samples in observation section ONK-PP324 (parallel to the foliation) during the first 1 420 days of the experiment. Major events are indicated with red arrows.*

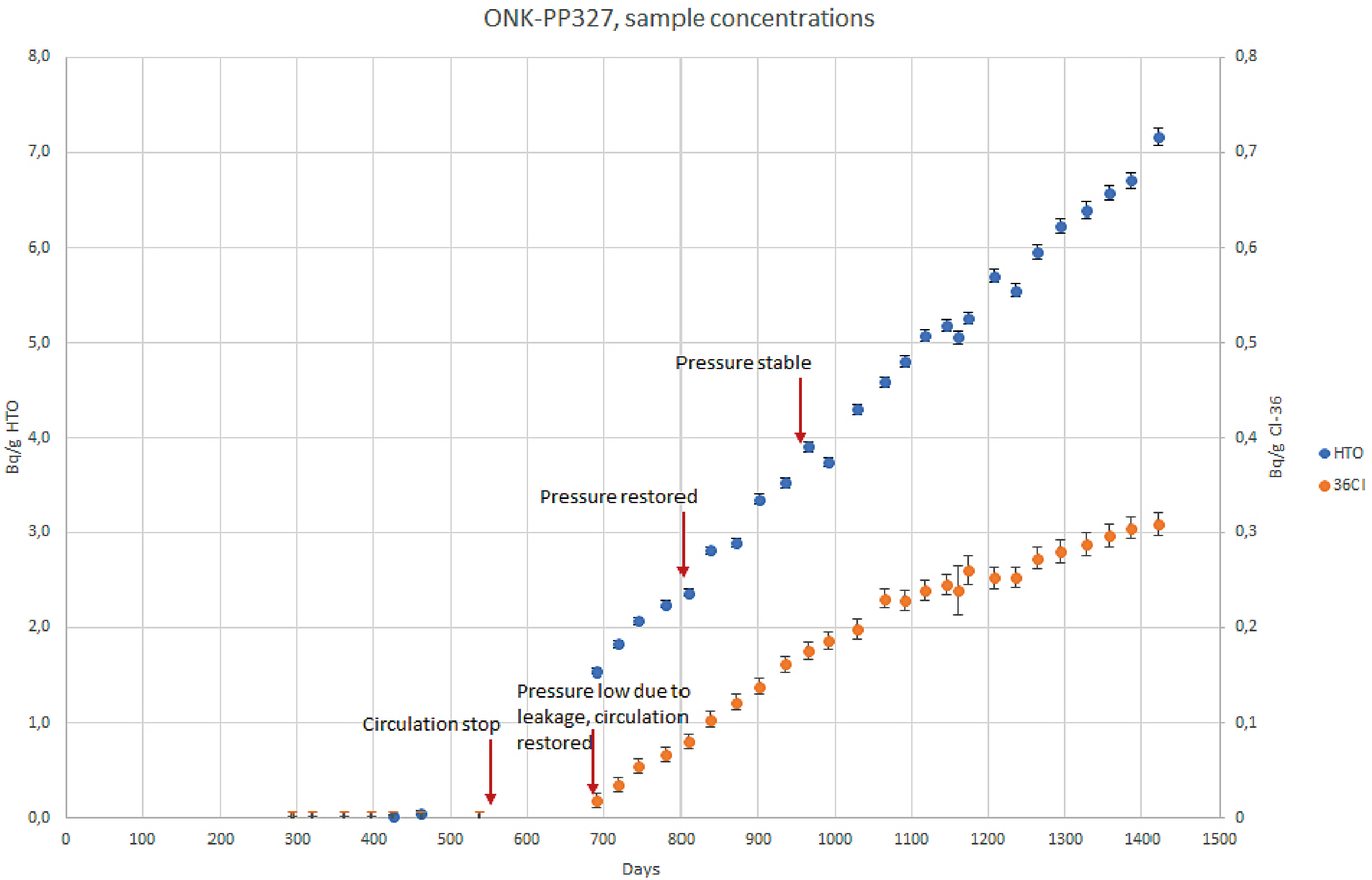


***Figure A7-3.** Tracer concentrations experiment from analyses of HTO and Cl-36 in extracted samples in observation section ONK-PP327 (perpendicular to the foliation) during the first 1 420 days of the experiment. Major events are indicated with red arrows.*

Arkitektkopia AB, Bromma, 2020

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