

International
Progress Report

IPR-00-01

Äspö Hard Rock Laboratory

Test plan for

**Sampling of Matrix fluids from low
conductive bedrock**

John Smellie
Conterra AB

January 1999

Svensk Kärnbränslehantering AB

Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19



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Laboratory**

Report no.

IPR-00-01

Author

John Smellie

Checked by

Peter Wikberg

Approved

Olle Olsson

No.

F80K

Date

Date

2000-01-14

Date

2000-01-17

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John A T Smellie

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Keywords: Matrix fluid chemistry, groundwater sampling, chemical analyses, saline groundwater

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

Abstract

This report presents the plans for sampling analyses and evaluation of the chemistry of groundwater in the pores and micro fractures of the rock mass in the Äspö tunnel.

The aim of the investigations is to find out whether or not the chemical composition of the stagnant water in the rock matrix is similar to that of the water conductive fractures.

A review of international work in the field is also included.

Sammanfattning

Rapporten innehåller planer för provtagning analys och utvärdering av kemin hos vatten som finns i bergets porer och mikrosprickor i Äspölaboratoriet.

Syftet med undersökningarna är att ta reda på om det stillastående vattnet i berget skiljer sig kemiskt från det vatten som finns i de vattenledande sprickorna.

En överblick av de kunskapsläget internationellt inom området ingår.

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1 BACKGROUND

Much of the groundwater sampled from the Äspö site at depths greater than 500 m is saline in character, and salinity continues to increase with depth. These groundwaters have been collected from water-conducting fracture zones with hydraulic conductivities greater than $K = 10^{-9} \text{ms}^{-1}$. The salinity of these groundwaters probably obtain their character mostly through mixing along fairly rapid conductive flow paths, being mainly determined by the hydraulic gradient, rather than by chemical water/rock interaction. In contrast, little is known about groundwater compositions from low conductive parts ($K < 10^{-10} \text{ms}^{-1}$) of the bedrock (i.e. matrix fluids), which are determined mainly by the mineralogical composition of the rock and the result of water/rock reactions. As rock of low hydraulic activity constitutes the major volume of the bedrock mass in any granite body, matrix fluids are suspected to contribute significantly to the salinity of deep formation groundwaters. It is considered expedient therefore to sample and quantify such fluids and to understand their chemistry and origin.

Migration of matrix fluids will be facilitated by small-scale fractures and fissures. It is important therefore to relate the matrix fluid chemistry to the chemistry of groundwaters present in hydraulically-conducting minor fractures ($K = 10^{-12} - 10^{-9} \text{ms}^{-1}$), since it will be these groundwaters that may initially saturate the bentonite buffer material.

Such knowledge of matrix fluids and groundwaters from rocks of low hydraulic conductivity will complement the hydrogeochemical studies already conducted at Äspö, and also provide a more realistic chemical input to near-field performance and safety assessment calculations, since deposition of spent fuel will be restricted to rock volumes of similar hydraulic character.

2 OBJECTIVES

The main objectives of the task are:

- to determine the origin and age of the matrix fluids,
- to establish whether present or past diffusion processes have influenced the composition of the matrix fluids, either by dilution or increased concentration,
- to derive a range of groundwater compositions as suitable input for near-field model calculations, and
- to establish the influence of fissures and small-scale fractures on fluid chemistry in the bedrock.

3 RATIONALE

3.1 Relevance to Repository Performance

Modelling near-field processes requires specific knowledge of the near-field input groundwater compositions. Hydrochemical data sets used in near-field calculations cover the range of compositions (fresh to saline) characteristic of the candidate site under investigation. So far groundwater sampling has been restricted to those water-bearing fracture zones of intermediate to high hydraulic conductivity. The groundwaters collected therefore tend to be more uniform in composition within these zones, probably obtaining their character mainly through rapid mixing and dilution rather than by chemical water/rock interaction.

The actual groundwater compositions likely to interact with the engineered barrier system of a repository will probably reflect more the matrix fluids characteristic of the low conductive bedrock volume selected to host the repository. Evidence to date indicates that such matrix fluids may be more saline than what is observed during the normal sampling campaign in a candidate site area. The engineered barrier system may not be particularly sensitive to high salinity, but there are limits set, and the expected near-field salinities need to be quantified.

3.2 Current State of Knowledge

Chloride contents of up to 200 gL⁻¹ (Canadian Shield; Frapé and Fritz, 1987), 93 gL⁻¹ (Siljan Sweden; Aldahan et al., 1993), 45 gL⁻¹ (Laxemar, Sweden; Laaksoharju et al., 1995), 40 gL⁻¹ (Kotalahti, Finland; Blomqvist et al., 1989), 43 gL⁻¹ (Olkiluoto, Finland, Ruotsalainen and Alhoniemi-Aalonen, 1997; Helenius et al., 1998), and 12 gL⁻¹ (Äspö, Sweden; Smellie and Laaksoharju, 1992) have been recorded from Precambrian Shield areas. These values relate mostly to borehole samples collected from fracture zones of intermediate to high hydraulic conductivity located at different depths. It is therefore reasonable to expect that highly saline compositions are more widespread, to the extent of being generally characteristic of low permeable crystalline bedrock ($K < 10^{-10}$ ms⁻¹). Groundwater compositions at repository depths of brine character have been confirmed recently from the Whiteshell Underground Rock Laboratory (URL) in Manitoba, Canada, by Gascoyne et al. (1996). Here, pore fluid compositions approaching brine composition (TDS ~90 gL⁻¹) were successfully extracted from the matrix of granitic rocks over long time periods.

The origin of saline groundwaters has been recently reviewed by Lampén (1992) and Raven and Clark (1993). To explain the occurrence of saline waters several questions need to be answered. What is the origin of the salinity? Was it introduced into the bedrock (e.g. marine-derived waters)? Does it represent relict, ancient fluids in the bedrock (e.g. metamorphic fluids)? Does it derive from bedrock reactions with meteoric-derived waters? What role does bedrock geochemistry play in determining the groundwater chemistry? Furthermore, what is the mean groundwater residence time, and how old are the saline waters?

Several hypothesis have been proposed to explain these salinity levels. Nordstrom et al. (1989) referred to 'allochthonous' and 'autochthonous' origins. The former, as summarised by Lampén (1992), comprises those saline constituents that may be introduced into the bedrock groundwater system. These include:

- Palaeozoic (older than ~ 240 Ma) basinal brines which have undergone metamorphism and extensive interaction with the bedrock,
- Palaeozoic seawater which has undergone chemical alteration during surface evaporation followed by extensive interaction with the bedrock,
- Dissolution of Palaeozoic evaporites followed by infiltration into the bedrock,
- Proterozoic (older than ~ 570 Ma) seawater or basinal brines,
- Holocene (10-0 ka) brackish water.

Autochthonous sources are from within the bedrock and include:

- Hydrolysis of silicate minerals,
- Release of salts from the rupture of fluid inclusions (Note: these fluids may originally have been allochthonous in origin),
- Radiolytic decomposition of groundwater.

It is generally accepted that no one process or source can account for the observed salinities in basement shield areas (see Kelley et al., 1986; Kamineni, 1987; Nurmi et al., 1988; Herut et al., 1990; Kamineni et al., 1992; Bottomley et al., 1994; Frape et al., 1996, and references therein). Most reported samples seem to represent mixtures of meteoric water with a highly concentrated brine (Pearson, 1987), which may be an ancient relict seawater or fluids genetically linked to geochemical processes occurring from elevated temperature water/rock interactions over long periods of geological time in the bedrock.

As pointed out by Raven and Clark (1993), hydrochemical and isotopic data show the basement brines in Canada to be highly modified by low temperature alteration such that many of the primary chemical and isotopic signatures (e.g. stable isotopes) have been lost, thus making it impossible to differentiate whether the brines are meteoric in origin or syngenetic with the rocks themselves. The solutes in the brines may thus be as old as the rocks themselves, giving ages of 10^6 to 10^9 years for the most concentrated brines.

An interesting and highly relevant conclusion from studies of deep mines in the Canadian Shield, and the Posiva studies in Finland, is that there is no clear correlation between major rock type and the brine chemistry. With respect to the Canadian Shield: "In all cases, the brines and brackish groundwater are dominated by a Ca-Na-Cl facies, with similar maximum concentrations of specific species in the most concentrated brines" (Raven and Clark, 1993). Other other Finnish studies (e.g. Ruskeeniemi et al., 1996), however, suggest some bedrock geochemical control differentiating between

4 EXPERIMENTAL CONCEPT

4.1 Background

The experiment is designed to extract representative matrix fluid volumes from low conductive crystalline rock, and relate the composition of these fluids to the detailed mineralogy and geochemistry of the host rock. Since very small volumes of fluid are expected, it is necessary to reduce the 'dead space' in the borehole section being sampled to a minimum. Furthermore, the hydraulic head differential between the rock mass and the borehole section being sampled should be kept to a level whereupon fluids can enter the section. Changes in composition (e.g. isotopic fractionation) and matrix clogging (e.g. due to a build-up of gas bubbles) may occur in the fluid if the pressure differential maintained in the borehole section is too great.

To extract matrix fluids therefore requires considerable care and planning since sampling of adequate volumes for analysis may take months to years. The experimental configuration described below (Section 4.2) has been designed to accomplish this objective.

There is little earlier experience to draw upon. The extraction of pore waters at the URL facility in Canada (Gascoyne et al., 1996) was carried out in bedrock with an average hydraulic conductivity of around 10^{-14}ms^{-1} . The method used was simple; three upwardly inclined boreholes were drilled to lengths of 100 m and packers were used to isolate a total of 6 borehole sections. The selection of the sections was based on rock type, general absence of fractures, and orientation with respect to bedrock foliation. After removing the standing water from the borehole, the test zones were filled with deionised water. At three monthly intervals, during which time there was a build-up of pressure in the packed off sections, samples were collected. Following a period of only 700 days, the chloride content of the deionised water due to diffusion from the bedrock in some sections had increased to 5gL^{-1} . However, no attempt was made to control the hydraulic head differential between the borehole and the rock mass. Fluid extraction may therefore have been on occasions too rapid, and may have contributed to the contrasting fractionating behaviour of, for example the ^{35}Cl and ^{37}Cl isotopes (S. K. Frape, per. comm., 1998).

Previous studies at Äspö to study trace element contents in waters derived from low permeable bedrock were reported by Wikström and Björklund (1994). Two borehole sites were chosen in the access tunnel on the basis of rock type and paucity of fractures. Following drilling, suitable borehole sections were chosen from drillcore evidence and packed off. The resulting waters, collected over a period of three months under nitrogen to prevent oxidation, and using teflon-coated packer parts to minimise trace element contamination, were analysed and compared with the mineralogy and chemistry of the corresponding drillcore material. The experiment was partly successful in relating trace element variations to lithology type and measuring increasing trace element contents with time from low conductive bedrock. However, many of the borehole sections studied would appear to have been characterised by hydraulic conductivities much in excess (e.g. extraction rates of $2.5\text{-}30 \text{mL min}^{-1}$) to that preferred for the collection of matrix fluids.

The present Äspö experiment offers the unique possibility of quantifying the sampling and analysis of matrix fluids from specific sections of known hydrology, and relating these data to the detailed mineralogy and geochemistry of the rock. Such data should be adequate to:

- test the various hypothesis listed above to explain the presence and origin of highly saline deep waters in crystalline rock environments, and in particular in low permeable bedrock of the type that is expected to constitute the immediate near-field environment of an intended repository,
- compare matrix fluid and dissolved gas compositions from contrasting lithologies to determine the extent of bedrock geochemical control, and
- better understand the influence of low hydraulically-conducting fissures and small-scale fractures on the distribution and chemistry of fluids in a near-field repository environment.

4.2 Experimental Configuration

The experiment has been designed to sample matrix fluids from predetermined, isolated borehole sections. The borehole will be selected and drilled on the basis of: a) rock type, b) mineral and geochemical homogeneity, c) major rock foliation, d) depth, e) presence and absence of fractures, and f) existing groundwater data from other completed and on-going experiments at Äspö. Special equipment has been designed to sample the matrix fluids ensuring: a) an anaerobic environment, b) minimal contamination from the installation, c) minimal dead space in the sample section, d) the possibility to control the hydraulic head differential between the sampling section and the surrounding bedrock, e) in-line monitoring of electrical conductivity and uranine content, f) the collection of fluids (and gases) under pressure, and g) convenient sample holder to facilitate rapid transport to the laboratory for analysis.

The borehole will be gently inclined upwards (~ 30-40°). The reasons for this include:

- the removal of rock flour and flushing water, and the removal of microbial populations during sterilisation, will be facilitated further by an upward inclined borehole.
- as only small amounts of matrix fluids are expected, sampling will be relatively continuous from the sampling sections since the accumulation of fluids in the sampling section will be minimal. For a downward inclined borehole, longer times are required to suitably fill the sampling section before initiating 'continuous flow' conditions to the sample cylinder.
- since sampling will be relatively continuous, contamination effects from earlier borehole activities (e.g. flushing water) will be more efficiently removed and 'representative' fluids more quickly established. For the downward inclined borehole, the initial accumulation of water in the sampling section will be a mixture of contaminated water and representative matrix fluids. This will necessitate a much longer time to ensure adequate flushing out of contaminated water prior to sampling
- since sampling will be relatively continuous, in-line monitoring of the groundwater composition (e.g. by electrical conductivity) will be thus possible, ensuring the collection of 'representative' samples.

- the borehole has been designed to enable all borehole activities to be conducted under N₂ pressure, including the installation of the long-term sampling equipment. This is important to minimise the possibility of O₂ incursion into the borehole. A downward inclined borehole will allow any O₂ in the system to ventilate upwards along the borehole and escape. This may have an obvious advantage over an upward inclined borehole over long timescales. Both borehole types, however, cannot avoid the possibility of some oxygen entering the system during drilling.
- hydraulic testing of the borehole following sampling will not be seriously influenced by the inclination of the borehole. A downward inclined borehole is preferable, but since the main onus is on sampling fluids, rather than intensive hydraulic testing, then an upward inclined borehole is favoured.

The equipment for the experiment will comprise the following:

Drilling

The borehole length will be 10-12 m, 76 mm in diameter, and core drilled using the triple-tube method (Leif Berglund, Hagby-Asahi AB, per. comm., 1998) to ensure good core recovery and minimise groundwater contamination in the bedrock adjacent to the borehole. Since drilling will be carried out under N₂ pressure (to minimise O₂ incursion), a N₂ source is required.

To ensure that drilling operations are carried out under N₂ pressure, there are two main prerequisites. First the formation water used for flushing will be kept in plastic containers continually flushed with N₂ prior to, and during, drilling. Secondly, the design of the casing (see Quality Plan) allows N₂ to enter directly into the borehole during drilling at the casing termination (some 2 m into the borehole). This greatly facilitates maintaining N₂ pressure during drilling.

TV-Imaging (BIPS)

This will be employed to document the boreholes (Strähle, 1995), and will be conducted also under N₂ pressure to avoid unnecessary contamination. The borehole will also be documented following the experiment for comparison.

Sterilisation

Although impossible to fully irradiate, sterilisation will be used to minimise bacterial activity in the borehole and the external surfaces of the sampling equipment (Winberg et al., 1996). The internal components of the sampling equipment will be sterilised using formalin, rinsed with deionised water, and finally flushed with N₂. The external parts of the equipment and the borehole itself will be sterilised using a 30% ethanol solution under N₂ pressure (essentially a high pressure spray technique), rinsed with deionised water, and then flushed with N₂.

Long-Term Sampling Equipment

See Appendix 1 for configuration. For further details, including installation protocol, see Quality Plan: 'Drilling of a 76 mm TT cored borehole (KF0051A01) into a specified tunnel section' (1998-05-22).

Hydraulic Testing

Standard double packer system with adjustable straddle length to measure 0.2-1.2 m borehole sections.

Matrix Fluid/Gas Analysis

Fluid analysis: Standard laboratory equipment; Inductively-Coupled Plasma (ICP) for major and trace elements. Specialised equipment; mass spectrometry for isotopic analysis.

Gas analysis: Standard gas chromatography injection techniques; gas chromatograph mass spectrometry for isotopes (GC-RIMS).

Rock and Mineral Analysis

Standard laboratory equipment; optical microscopy (+ fluid inclusion stage) for mineral phases; Microthermometry and Raman Microspectrometry for fluid inclusion analysis; Inductively-Coupled Plasma (ICP) techniques for whole-rock and mineral separate analysis; standard techniques to measure hydraulic conductivity, permeability, porosity and diffusivity.

4.3 Problem Areas and Alternative Solutions

The preference of conducting the experiment with an upward inclined borehole has been discussed in Section 4.2. In addition, the following problems may arise during the execution of the experiment:

1. Introduction of oxidation conditions during drilling. This will be minimised by using nearby reducing formation water (tagged with uranine) as the flushing medium, maintained under nitrogen gas to prevent oxidation. If not available, reducing water will have to be transported from elsewhere in the Äspö HRL complex and stored under nitrogen pressure.
2. Compared to other core drilling techniques, the planned triple tube method is expected to result in: 1) better drillcore samples, and 2) a general reduction of contamination of the bedrock adjacent to the borehole since contact with the flushing water is minimised. Most flushing water is returned between the inner tubes and not between the outer tube and the borehole walls.
3. Following drilling, residual flushing water contained in small microfissures in the rock, may not be totally removed by water and nitrogen gas flushing. The absence of a flushing water tracer (e.g. uranine), combined with stable chemistry (from in-line

measurement of electrical conductivity) during the initial monitoring stage, should indicate when the collected fluids are free of major contamination.

4. TV-imaging along the boreholes may also introduce oxidising conditions. This can be minimised by keeping the open borehole under nitrogen pressure during logging.

5. Correlation between the TV data and preliminary drillcore mapping should be carried out as soon as possible to minimise oxidation in the open borehole prior to installation of the sampling equipment. Continuous flushing with nitrogen is recommended.

6. Sterilisation of the borehole surfaces and the sampling equipment to minimise bacterial activity is a necessary precaution, but may well introduce oxidising conditions. The process should be carried out as swiftly as possible using a 30% ethanol mixture under N₂ pressure, immediately followed by flushing out the borehole with nitrogen.

7. Installation of the sampling equipment should be carried out swiftly, and under high purity nitrogen to avoid unnecessary oxidation. This procedure should be practiced beforehand at another locality.

8. Potential long-term contamination from the sampling equipment has been minimised by the use of PEEK (i.e. polyetheretherketone, which is extremely chemically inert, flexible, and capable of withstanding high pressures and temperatures) and teflon coatings in its construction. In addition, the packer sleeves are composed of polyurethane (Shore A 90), a suitably durable and chemical stable material for the purpose.

9. Sampling is expected to take several months, if not years. There is the possibility that leakages will develop around the various inflated packers. Careful, long-term monitoring of the installation is necessary to ensure that constant packer pressure and nitrogen pressure is maintained in the boreholes being sampled. Long-term incursion of O₂ can be further minimised by sealing the end of the borehole at the tunnel face.

10. Even though prior precautions will have been taken (see Section 5), the potentially long sampling times involved may lead to small changes in the matrix fluid chemistry - in particular redox changes due to small oxygen leakages around the packers, diffusion of oxygen into the system through the various seals, anaerobic microbial activity, and isotopic fractionation. For example, oxidation from incursion of oxygen and/or microbial activity may lead to the precipitation of iron and perhaps clogging of the narrow PEEK transport tubes (1.5 mm inner diameter) to the sample holder. Other than ensuring point (6) above, little more can be done.

11. High pressure behind the packer compresses the residual gas in the borehole sections and may influence the discharge of matrix fluids. Gas compression in the innermost borehole section can also exert pressure in the installed equipment. This possibility can be minimised by securely anchoring the equipment to the tunnel wall.

12. Potential contamination of the samples during transport from the borehole site to the laboratory should be avoided since the sampling device will be disconnected under pressure and used for transport.

4.4 Expected Outcome

By sampling fluids from low conductive bedrock ($K < 10^{-10} \text{ms}^{-1}$) it is hoped to provide some insight into the distribution and origin of saline groundwaters and deep brines in

general, and at Äspö in particular, and also to provide a more realistic input groundwater composition for near-field repository performance and safety assessment calculations. Comparison of fluids from different lithologies (if present in the borehole), and from fractures/fissures of variable hydraulic properties, will test the hypothesis of bedrock geochemical control on the fluid chemistry.

4.5 Supplementary Activities

It is important to try and relate the matrix fluid chemistry to the chemistry of groundwaters present in nearby minor fracture zone(s) of low hydraulic conductivity ($K=10^{-12}$ - 10^{-9} ms⁻¹), since it will be these groundwaters that will come in contact eventually with the bentonite buffer material. The fracture zones, representing variations in hydraulic conductivity, may reflect different hydrochemical signatures. Do these signatures indicate an evolution of groundwater chemistry from the matrix out into fracture zones, or vice versa, and is evidence of this evolution mainly restricted to within or around fractures of low hydraulic conductivity? These are important questions to be answered, and to address them adequately a reliable hydraulic and hydrochemical database is required. To build up such a database of fracture groundwater chemistry, related to hydraulic conductivity and at equivalent depths to the matrix fluid experiment, three possibilities exist:

- sample groundwaters from hydraulically characterised fractures present in the near- vicinity of the matrix fluid chemistry experiment borehole,
- use existing and future data from the TRUE Experiment programme, and
- sample from boreholes used to hydraulically characterise the deposition holes (and their surroundings) which will form the basis to the Prototype Repository Experiment.

Boreholes in the Near- vicinity of the Matrix Fluid Chemistry Experiment

The matrix fluid chemistry experiment borehole is to be located in a massive, fracture- poor, section of Äspö diorite in Tunnel F. This massive block, in two dimensions, is bounded on both sides by a series of parallel fracture zones trending approximately NW-SE. Further west and east along the tunnel are other zones of similarly trending fractures. An integral part of the matrix fluid chemistry programme, budget constraints allowing, will include drilling an array of short boreholes (3-5 m length; diameter 56 mm) around the tunnel circumference (including the floor), angled to intercept the fracture zones. Selection of the fracture zones will be based partly on different water seepage rates observed on the tunnel walls, which should reflect a range of transmissivity and possibly a variation in groundwater chemistry.

The boreholes will be first documented by TV-imaging (BIPS) and drillcore mapping. Using this information, suitable fractures sections will be selected for sampling and subsequently packed-off for hydrochemical characterisation. In situ monitoring of pH, Eh and electrical conductivity will be carried out for the duration of the sampling, initially indicating when representative groundwaters should be sampled. To facilitate integration of hydrochemical data, the range of chemical and isotopic parameters to be analysed will be similar to those measured for the matrix fluids.

Diffusion profile drillcore

At least one of the boreholes, drilled to intercept hydraulically active fracture zones, should be extended for some 3-4 metres into the massive, fracture-poor block which hosts the matrix fluid borehole. The drillcore should be at least 76 mm in diameter, and oriented perpendicular to the fracture face, since it will be used to measure chemical and isotopic diffusion profiles (e.g. U-decay series; helium; ^{37}Cl). These measurements will help to identify the presence (and possible rates) of chemical in/out-diffusion in the rock matrix adjacent to the fracture zone.

TRUE Experiment Programme

Careful sampling and characterisation of groundwater from hydraulically tested isolated fracture zones selected for tracer studies has been a feature of the TRUE-1 Experiment (Nilsson, 1997 a,b; Laaksoharju and Skårman, 1997). The drilling and sampling protocols employed are similar to those planned for the Tunnel F sampling programme outlined above. Additional hydrochemical characterisation of new boreholes is planned within the TRUE Block Scale Project (Winberg, 1998). Collectively, these studies should result in very useful hydraulic and hydrochemical information which can be integrated with the proposed Tunnel F studies.

To facilitate comparison. future studies will stress that the groundwaters should be analysed for the same parameters as those planned for the Tunnel F and matrix fluid samples.

Long Term Diffusion Experiments (LTDE)

These also form part of the TRUE Experiment programme and are intended to focus on the diffusion of selected tracers into the microfractures of the rock matrix. Requirements include the hydraulic and hydrochemical characterisation of suitable fractures intercepted by the experimental boreholes. The duration of this experiment will be over a similar timescale as that envisaged for the matrix fluid chemistry experiment.

Prototype Repository Experiment

The Prototype Repository experiment is being carried out at approximately the same level as the Matrix Fluid Experiment (~450 m), and only some 120 m to the west (Dahlström, 1998). Two types of sampling will be possible: 1) sampling during the characterisation phase, and 2) sampling during post-closure conditions as part of the long-term monitoring hydrochemical programme (Pedersen and Puigdoménech, 1998). Close collaboration is required.

For the characterisation phase, a series of boreholes have been hydraulically tested already (Rhén and Forsmark, 1998 a,b) and some have been sampled for groundwater. Future sampling will be carried out in parallel with interference tests, mostly confined to selected boreholes close to the planned deposition holes. In this case care will be taken to extract groundwater from individual fracture zones, and the analytical protocol will be in accordance with that mentioned above.

5 SCOPE

The main emphasis of the experiment is:

- to sample matrix fluids and dissolved gases from a selected area of low conductive bedrock typical for Äspö,
- to characterise the matrix fluids and dissolved gases hydrochemically and isotopically,
- to hydraulically characterise the sampled sections,
- to mineralogically and geochemically characterise the corresponding drillcore material from the borehole sections sampled,
- to sample matrix fluids and dissolved gases from contrasting rock types (if present) to establish the degree of bedrock geochemical control on matrix fluid and gas compositions, and
- to sample groundwaters from near-vicinity fracture zone(s) of low hydraulic conductivity to establish their hydrochemical character.

5.1 Main Project Tasks

Several prerequisites are necessary to carry out the planned experiment at the Äspö HRL. These are:

- access to selected tunnel sections which have been determined as being of low permeability
- access to HRL personnel for further characterisation of the selected tunnel sections to precisely locate the most suitable drilling locations
- prior discussion and agreement with personnel responsible for on-going projects in the near-vicinity of the planned tasks (e.g. TRUE Experiment Programme)
- access to drilling equipment and drilling personnel
- access to sources of formation water for flushing purposes in the vicinity of the planned drilling programme
- access to responsible personnel within the Äspö HRL to help supervise and execute the planned tasks.

Only one borehole will be drilled and completed in rock of low hydraulic conductivity. The following major tasks are foreseen:

Task 1: Site Selection

On the basis of available geological, hydrological and tunnel construction data (e.g. HRL-96-19; HRL-97-20), and reconnaissance of the Äspö HRL, five potential locations were considered from tunnel sections characterised by:

- low fracture frequency; very few water-conducting fractures
- homogeneous and similar rock-types (Äspö Diorite and Småland Granite)
- low transmissivity in probe holes
- absence of grouting
- possible access to tunnel niches to facilitate drilling
- additional information, e.g. in the vicinity of earlier (or on-going) studies (e.g. TRUE and Prototype Repository Experiments) where groundwater sampling has been carried out and there exist available hydrochemical data.

The selection of a first preference borehole location was based on several criteria:

- that the experiment should be conducted at repository depths (~ 500 m)
- that the tunnel section chosen should be dry and free from water-conducting fractures
- that the rock be homogeneous, i.e. minimum potential influence from variations in composition
- that there should be minimum future disturbance from tunnel activities
- that drilling could be carried out with minimum disturbance to tunnel activities

Five locations were considered, and their respective priorities are summarised below:

<i>Tunnel Section (m)</i>	<i>Vertical Depth (m)</i>	<i>Rock-type</i>	<i>Comments</i>	<i>Priority</i>
2375	~ 320	Äspö Diorite	Niche at 2375 m	3
2520	~ 345	Äspö Diorite	Tunnel curve location	2
3010	~ 415	Småland Granite	Near-vicinity of True Project	4
3375	~ 445	Småland Granite	Vicinity of lift	5
L=51	~ 450	Äspö Diorite	Tunnel F	1

Priority (1) fulfilled most of the criteria listed above.

Task 2: Drilling/Orientation of Boreholes

One borehole will be drilled and completed; the preferred location for the borehole is indicated in the table above at L=51 m in Tunnel F, and at a vertical depth of 450 m. Core drilling (triple tube) will be carried out and formation groundwater (under nitrogen pressure) will be used as the flushing medium to minimise contamination. The borehole

diameter will be 76 mm to conform with the equipment designed to complete the boreholes for sampling.

The foreseen sequence of borehole activities is as follows:

- identification of a near-vicinity formation groundwater source to serve as a flushing water medium during drilling
- the boreholes will be gently angled upwards ($\sim 30/40^\circ$) to facilitate long-term sampling
- triple-tube cored drilling is recommended to: a) ensure maximum drillcore recovery, and b) minimise host-rock contamination
- sterilisation of drilling equipment
- borehole drilling using tagged (uranine) flushing water under N_2 pressure is recommended to reduce the risk of excess O_2 contamination
- drilling will commence with an approximately 10 m long borehole. Metal casing (2.5 m in length) will be secured then at the tunnel face to ensure correct alignment of the borehole prior to any further drilling.
- regular monitoring and analysis of the formation water will be carried out to ensure a homogeneous chemistry during drilling; these data will be used to correct for any contamination of the sampled matrix fluids that may ensue
- controlled monitoring of flushing water loss (or gain) during drilling
- preliminary drillcore mapping
- on completion, the boreholes will be rinsed to remove accumulated debris, sterilised to minimise bacterial activity, and finally flushed with N_2
- TV-imaging (BIPS) of the boreholes under N_2 circulation
- based on drillcore logging in combination with the results of the TV-imaging, suitable borehole sections for study will be selected
- installation of sampling equipment suitably sterilised to minimise microbial activity
- sampling of matrix fluids and dissolved gases
- hydraulic testing at selected intervals following sampling

Task 3: Borehole Completion

Based on the TV-imaging and drillcore logging, borehole sections suitable for sampling will be identified; care will be taken to avoid the excavation damage zone (EDZ) which may lead to short-circuiting around the packer systems if they are placed too close to the tunnel face. Provision has been made to sample from up to three borehole sections in the borehole using two double packer systems.

The sampling packer systems will be installed as soon as possible to avoid undue perturbation of the borehole. During installation the borehole will be purged with N_2 , and each section subsequently pressurised with N_2 to establish the correct hydraulic head pressure differential between the sampling section and the surrounding rockmass.

Task 4: Pre-sampling

Following completion it will be necessary to remove all traces of contamination (flushing water etc.). This will require a monitoring period when uranine (i.e. indicative of drilling water contamination) and electrical conductivity (i.e. total TDS) will be regularly measured from small volumes of extracted fluid (0.2 - 0.5 mL). When uranine has decreased to an acceptable level (< 1%) and the electrical conductivity measurements have stabilised, sampling will commence.

Task 5: Hydraulic Pressure Build-up Tests

At the initial stage of Task 4 (i.e. prior to monitoring) the valve at the sampling outlet will be closed to allow a hydraulic pressure build-up in the borehole sections being studied. This will be recorded by a data logger for a duration of some months to allow adequate pressure to build up; it should be possible following Tasks 2 and 3 to estimate a more precise time period for pressure build up. This is the only hydrotest planned before completion of the sampling programme to keep perturbation of the borehole to a minimum.

Task 6: Sampling of Matrix Fluid and Gases

Matrix sampling will be conducted over time periods necessary to collect adequate volumes of water. The time required will vary between borehole sections, being dependent on the transmissivity of the isolated sections. A minimum of 0.5 L (volume of sampling cylinder is 0.6 L) is required to carry out the necessary major element and isotopic analysis, and this volume will be collected only when the amount (if any) of residual flushing water is at an insignificant level (i.e. < 1% uranine). Monitoring carried out under Task 4 during the initial stages of the sampling procedure will be therefore important to evaluate the suitability of the water for final collection.

Based on present knowledge, it is expected that with a transmissivity of 10^{-11} - 10^{-12} m²s⁻¹ and a pressure of 10 bars lower than the undisturbed pressure in the sampling section, the flow rate will be in the order of 0.01 to 0.1 L/day. A lower conductivity gives a proportionally lower flow rate.

Fluid sampling from the various borehole sections will continue until the chemical composition is constant. The time interval between the sampling occasions will depend on the hydraulic conductivity.

Task 7: Analysis of Matrix Fluid and Gases

Preliminary analysis of the collected water will include major ions (plus Br, I), stable isotopes (¹⁸O, ²H) and radioactive isotopes of carbon (¹⁴C/¹³C) and tritium (³H) to characterise the groundwaters; tritium and carbon are required as a check on the possible presence or absence of any modern water input, e.g. through contamination caused by short-circuiting. Analysis will be supplemented by trace element analysis (standard suite of elements provided by ICP methods plus U, Th and REEs), and determination of more exotic isotopes such as ³⁷Cl/³⁵Cl and δ ³⁴S (in SO₄), Sr and δ ⁸⁷Sr, and ¹¹B, ⁶Li etc. Gas analysis will include the hydrocarbon gases, C1-C6 (plus ¹³C/¹²C ratio of CH₄ and CO₂) and He, Ne, Ar, N₂, H₂, O₂, CO₂, CO and H₂S.

To safeguard against potential microbial activity influencing the matrix fluid chemistry, the collected samples will be tested for the presence of microbes.

Task 8: TV-Imaging and Drillcore Evaluation

Preliminary evaluation of the drillcore material already forms part of Task 3. Task 8 will comprise a quantitative study as a necessary prerequisite to selecting samples for Task 9 studies.

Task 9: Mineralogical and Geochemical Studies

Also important for the hydrochemical interpretation is a thorough understanding of the mineralogy, geochemistry and petrophysical properties of the rockmass. In particular, the study of fluid inclusions and intergranular fluids, and measuring the pore volume, porosity/permeability and diffusivity. These studies may be possible through SKB collaboration with the University of Berne, Switzerland, Nagra, Switzerland, Posiva, Finland, the University of Waterloo, Canada, and Stockholm University, Sweden.

Because of the expected time-lag to collect adequate amounts of matrix fluid, the mineralogical studies will commence following drilling even prior to knowing the composition of the matrix fluid. Until geochemical studies are carried out, the drillcores (following detailed mapping) will be preserved and stored. Preservation may be required to minimise fluid evaporation (which may also give rise to isotopic fractionation), accentuated by stress-release fissures in the drillcore. It is recommended that the drillcores be wrapped in aluminium foil and sealed with wax following documentation.

Parameters to be analysed will be similar to those outlined under Task 7.

Task 10: Hydraulic Testing

On completion of the matrix water sampling (1-2 years?), the following sequence of events are planned: a) repeat Task 5, i.e. pressure build-up measurements, combined this time with water-filled sections, b) remove installed equipment, and c) systematic 0.3-1.0 m hydraulic testing of the complete borehole. This is essential for the full interpretation of the hydrochemical data.

5.2 Supporting Project Tasks

- 1) A major supporting task relates to the design, construction and testing of the sampling equipment illustrated in Appendix 1.
- 2) A further task will be to assess the results of the matrix fluid chemical analyses with respect to the function of the engineered barriers. A potentially high saline concentration in the matrix fluids ($>100 \text{ gL}^{-1}$ TDS), and adequate accessible volume of fluid, requires further assessment of the long-term integrity of the bentonite buffer material (Ström et al., 1998).

5.3 Time Schedule

Construction and testing of the sampling equipment has been completed. Drilling and installation of the equipment will be carried out during May/June 1998. Long-term monitoring of the equipment will commence following installation, and water sampling will be periodically carried out when adequate volumes ($\sim 0.5 \text{ L}$) have been removed

from the borehole sections selected for study. The accumulation time will probably vary from one borehole section to the other. Chemical and isotopic analysis will be carried out as soon as possible following sampling. The duration of the project is estimated to 2 years (to the end of 2000).

6 PROJECT ORGANISATION AND RESOURCE REQUIREMENTS

6.1 Organisation

Project Manager :	John Smellie (Conterra)
Responsible Hydrogeochemist:	John Smellie (Conterra)
Responsible Hydrogeologist:	Erik Gustafsson (Geosigma)
Äspö HRL Coordinator:	Anna Säfvestad (Äspö HRL)

6.2 Documentation

Each of the above-described tasks will generate data that will be systematically documented. This will take the form of preliminary reports of type: 1) TD: Technical Document, and 2) PR: Progress Reports. The entire work will be synthesised and summarised in the reporting of the Matrix Fluid Experiment as a TR: Technical Report. Furthermore, all chemical and isotopic analyses will be added to the Äspö HRL database.

The main title for all reports will be "Groundwater sampling from low-conductive bedrock", and major sub-titles will be: A. Selection of Sampling Locality: Drilling and Characterisation of Borehole KF0051A01; B. Borehole KF0051A01: Installation of Equipment, Hydraulic Pressure Testing and Pre-sampling Protocol; C. Borehole KF0051A01: Sampling and Analysis of Matrix Fluids; D. Borehole KF0051A01: Hydraulic Testing; E. Borehole KF0051A01: Mineralogical, Geochemical and Petrophysical Studies of Drillcore Material; F. Low-conducting Fractures at Depth 415-450 m: Hydraulic and Hydrochemical Database. G. In- and Out-diffusion Rock Profile Studies. H. Synthesis and Summary of the Project Results.

A. Selection of Sampling Locality: Drilling and Characterisation of Borehole KF0051A01

- Results of drilling and monitoring of flushing water (1st TD)
- Results from TV-logging (2nd TD)
- Results from drillcore mapping (3rd TD)
- Summary of results of drilling, TV-logging and drillcore mapping, and selection of sampling locations (PR)

B. Borehole KF0051A01: Installation of Equipment, Hydraulic Pressure Testing and Pre-sampling Protocol

- Installation of sampling equipment (1st TD)
- Results from hydraulic pressure build-up testing (2nd TD)
- Results from pre-sampling of borehole sections (3rd TD)
- Summary of borehole completion and pre-sampling results (PR)

C. Borehole KF0051A01: Sampling and Analysis of Matrix Fluids

- Results from matrix water analysis (1st TD)
- Summary of results from matrix fluid analysis (PR)

D. Borehole KF0051A01: Hydraulic Testing

- Results from borehole hydraulic testing (1st TD)
- Summary of results from hydraulic testing (PR)

E. Borehole KF0051A01: Mineralogical, Geochemical and Petrophysical Studies of Drillcore Material

- Results from mineralogy and geochemistry (1st TD)
- Results from fluid inclusion and intergranular fluid studies (2nd TD)
- Results from petrophysical measurements (3rd TD)
- Summary of results from mineralogy, geochemistry, fluid inclusion and petrophysical measurements (PR)

F. Low-conducting Fractures at Depth 415-450 m: Hydraulic and Hydrochemical Database.

- Selection, drilling and completion of tunnel boreholes in the near-vicinity of the matrix fluid experiment (1st TD)
- Results from groundwater sampling and chemistry from the tunnel boreholes in the near-vicinity of the matrix fluid experiment (2nd TD)
- Compilation of relevant hydraulic and hydrochemical data from the TRUE experiment (3rd TD)
- Compilation of relevant hydraulic and hydrochemical data from the Prototype Repository experiment (4th TD)

- Low-conducting fractures at depth 415-450 m: Hydraulic and hydrochemical database (PR)

G. In- and Out-diffusion Rock Profile Studies

- Selection and mineralogical characterisation of suitable water-conducting fracture zone (1st TD)
- Petrophysical, chemical and isotopic analysis of drillcore profile (2nd TD)
- Summary of results of rock diffusion studies (PR)

H. Synthesis and Summary of the Project Results (TR).

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APPENDIX 1

CONFIGURATION OF SAMPLING EQUIPMENT

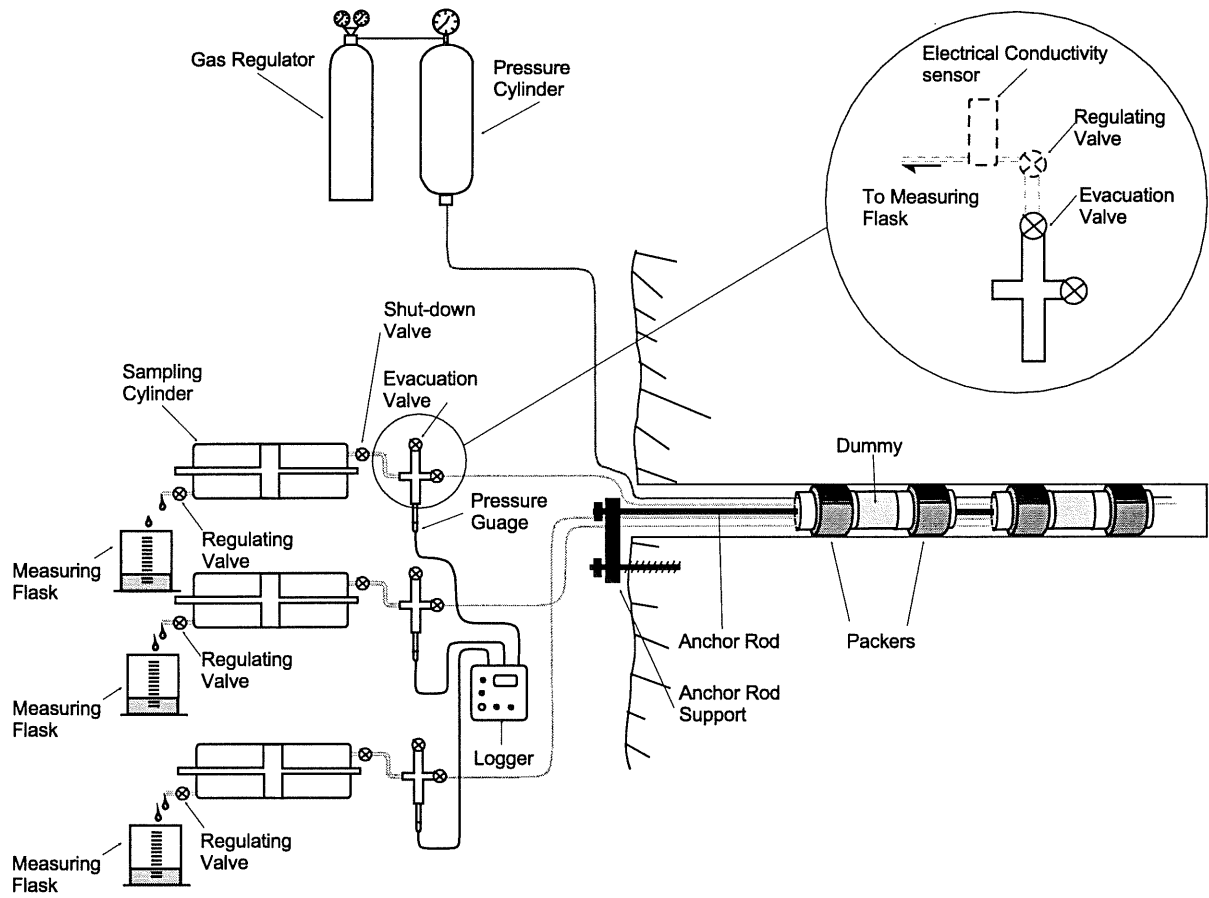


Figure A-1: Proposed experiment configuration for sampling matrix fluids. Note that the casing has not been included.