International
Progress Report

IPR-99-01

Äspö Hard Rock Laboratory

Test plan

Long term test of buffer material

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November 1998

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Keywords: Alteration, Aspo, Bacteria, Bentonite, Copper, Diffusion, Field-test, Gas, Heater, Repository.

CONTENTS

1 BACKGROUND

Bentonite clay has been proposed as buffer material in several concepts for HLW repositories. In the Swedish KBS3 concept the demands on the bentonite buffer are to serve as a mechanical support for the canister, reduce the effects on the canister of a possible rock displacement, and minimize water flow over the deposition holes. The transport through the buffer is expected to be reduced principally to diffusion, both with respect to corrosive components in the ground water and to escaping radionuclides in case of a canister failure.

The decaying power from the spent fuel in the HLW canisters will give rise to a thermal gradient over the bentonite buffer by which original water will be redistributed parallel to an uptake of water from the surrounding rock. A number of laboratory test series, made by different research groups, have resulted in various buffer alteration models. According to these models no significant alteration of the buffer is expected to take place at the prevailing physico-chemical conditions in a KBS3 repository neither during nor after water saturation. The models may to a certain degree be validated in long term field tests. Former large scale field tests in Sweden, Canada, Switzerland and Japan have in some respects deviated from possible KBS3 repository conditions and the testing periods have generally been dominated by initial processes, i.e. water uptake and temperature increase.

The present test series is consequently focused on the long term performance of the bentonite buffer, i.e. the conditions after water saturation, and on buffer related processes concerning microbiology, radionuclide transport, copper corrosion and gas transport.

2 OBJECTIVES

The test series aims at validate models and hypotheses concerning physical properties in a bentonite buffer material and of related processes regarding microbiology, radionuclide transport, copper corrosion and gas transport under conditions similar to those in a KBS3 repository. The expression "long term" refers to a time span long enough to study the buffer performance at full water saturation, but obviously not "long term" compared to the life time of a repository. The objectives may be summarized in the following items:

- Data for validation of models concerning buffer performance under quasi-steady state conditions after water saturation, e.g. swelling pressure, cation transport and gas penetration.

- Check of existing models concerning buffer degrading processes, e.g. illitization and salt enrichment.

- Information concerning survival, activity and migration of bacteria in the buffer.

- Check of calculation data concerning copper corrosion, and information regarding type of corrosion.

- Data concerning gas penetration pressure and gas transport capacity.

- Information which may facilitate the realization of the full scale test series with respect to clay preparation, instrumentation, data handling and evaluation.

3 RATIONALE

3.1 RELEVANCE TO REPOSITORY PERFORMANCE, CONSTRUCTION OR LICENSING?

Bentonite material is a natural mixture of smectite and several common minerals e.g. quartz, feldspar, calcite, siderite and pyrite. The desirable physico-chemical properties of a bentonite buffer, e.g. low hydraulic conductivity, swelling ability and suitable rheological behavior, are determined by the interaction between water and the smectite component, which usually is montmorillonite. The clay/water system is generally not in chemical equilibrium with the surrounding groundwater in crystalline rock. This non-equilibrium and the thermal conditions in the buffer may on certain buffer conditions result in cementation or clay mineral alteration, which in turn may result in changes in the physical properties of the buffer. The understanding of involved processes is consequently of vital importance in predicting the function of a bentonite buffer in a long term perspective. In addition, the test layout makes it possible to study other important processes in the canister-buffer-rock system such as bacteria activity, radionuclide transport, copper corrosion and gas transport.

3.2 CURRENT STATE OF KNOWLEDGE

3.2.1 Unaltered buffer performance

Comprehensive research and development work have been carry out during the last twenty years in order to determine the basic behavior of unaltered bentonite material. The results have been reported in a number of technical reports, and tentative computer codes concerning both unsaturated and saturated buffer conditions are at hand (Börgesson et al. 1995). The present models are believed to well describe the function of an unaltered MX-80 bentonite buffer after water saturation with respect to physical properties, e.g. swelling pressure, hydraulic conductivity and rheological behavior. Further, techniques for bentonite block production and application have been developed in order to fulfill the requirements concerning density, homogeneity, handling etc. (Johannesson 1995).

3.2.2 Buffer alteration

The concept of buffer alteration may be divided in three quite different categories; clay mineral (montmorillonite) alteration, clay surface reactions and accessory mineral alteration. Depending on the overall conditions all three types of alteration may result in changed physical properties. The clay mineral reactions in a KBS3-repository system are generally considered to be slow and to lead to irreversible changes. The clay surface reactions may take place rather fast and are in general reversible. The accessory mineral alteration may be fast or slow, reversible or not, depending on the involved minerals. According to buffer alteration models and hypotheses no significant changes are expected in physical properties or in clay mineral structure within the time span of the proposed tests at repository conditions. The following possible alteration processes have been of special interest and have been studied in various laboratory tests.

Smectite-to-illite conversion

Depending on the conditions, alteration of minerals in the smectite group may take place and form a number of related minerals, e.g. illite, chlorite or zeolites. In nature the most common smectite alteration at elevated temperature is transformation into illite. This type of conversion has also been considered as the most probable, or rather least improbable, under repository conditions. Fortunately the smectite-to-illite reaction has been extensively studied for several decades because of its relevance to oil prospecting. Different parameters have been proposed as kinetic controlling factors but there is no basic consensus on the reactions involved in the conversion. Based on geological analogs and laboratory experiments i.a. the following factors have been proposed as kinetic controlling factors (no ranking):

- overburden pressure,
- temperature,
- potassium availability,
- aluminum availability,
- pH,
- dehydration,
- silica activity.

According to the Huang, Longo and Pevear model (1993), the overall kinetics of the smectite-to-illite reaction can be described by the equation:

$$-dS/dt = A \cdot [K^+] \cdot S^2 \cdot \exp(-E_a / RT) \,, \qquad 1$$

where S is the smectite fraction in the illite/smectite material, A is frequency factor, E_a is activation energy and R is the universal gas constant, and T is temperature. From this equation the smectite content at a certain time may be calculated if the temperature and potassium concentration in the pore water are known (figure 3.1). According to the model, only minor clay conversion is possible in a KBS3-type repository. However, the reaction relationship and the constants are determined from short term laboratory experiments at relatively high temperatures (250-325°C) and from geological analogs which differ from repository conditions in several aspects. The uncertainty in calculated conversion increases with the difference in temperature between test condition and calculated condition (Karnland 1995). It is therefore vital to validate the model relationship and to determine the model constants (activation energy and frequency factor) in experiments performed at "as repository like conditions" as possible. It is obviously not possible to fully use repository conditions because of the very slow reaction rate (Figure 3.1). However, it is possible to check the constants at a moderate temperature increase (proposed 130°C) at high potassium concentrations, and especially to ensure that the reaction is not substantially faster than predicted by the model.

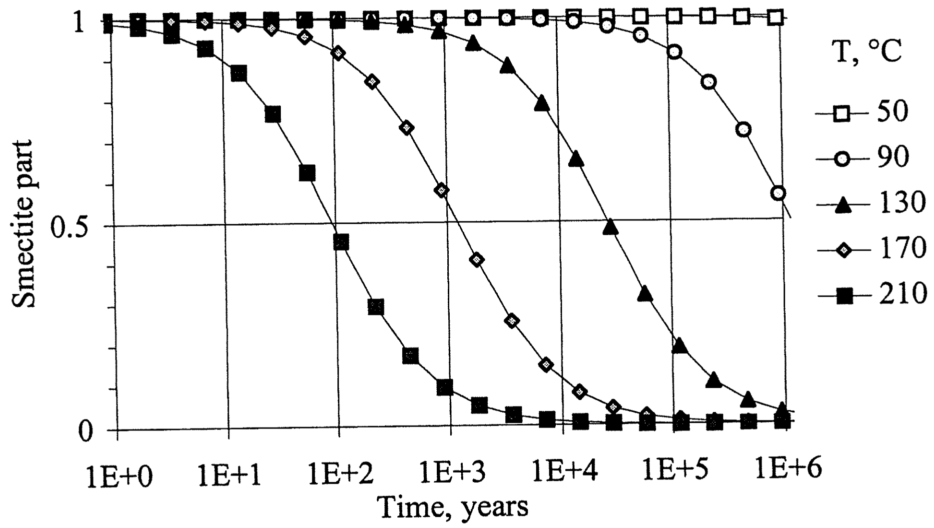

Figure 3.1 Remaining smectite part for different temperatures in a hydrothermal system with $[K^+]$ = 0.01 mole/liter according to the Huang et al. kinetic model and laboratory determined constants (E_a = 27.4 kcal/mole and A = 8.5E4.)

Salt enrichment

The temperature gradient, which prevails over the buffer during the first part of the deposition period, may affect the buffer functions by different enrichment processes of dissolved substances, with e.g. cementation as a consequence (Karnland 1995:2). One such process is ion transport parallel to water uptake from the outer cooler parts of the bentonite, or from the surrounding groundwater, to the wetting front in the originally unsaturated bentonite. The transport is assumed to take place by a cyclic evaporation/condensation process in which water is sucked in from cooler parts, evaporates at the wetting front, and is partly redistributed in the form of steam. Dissolved salts will thereby be deposited at the wetting front. A second possible process is precipitation of specimens which have lower solubility at higher temperature, e.g. calcium sulfate (gypsum) and calcium carbonate (calcite). If the buffer material is the source of the original pore water concentration, the process will come to a standstill after a limited enrichment, which is easily calculated. On the other hand, if the surrounding ground water is the cause of the pore water concentration the enrichment process may continue until a major part of the pore volume is filled by the neoformed mineral.

According to laboratory experiments the following conditions will minimize enrichment of easily dissolved minerals in a bentonite buffer.

- high buffer density, at least 2.0 g/cm^3,
- low content of accessory minerals in the buffer,
- low electrolyte content in the surrounding water,
- high water pressure.

The use of pre-saturated bentonite blocks, supply of low electrolyte water in open slots, and a fast restoration of the hydrostatic pressure are consequently considered in order to reduce the enrichment of salt.

Effects of cement pore-water

The pore-water of fresh, unaltered Portland cement is basically a strong alkali hydroxide solution saturated with calcium hydroxide, leading to high pH. Depending on the type of cement the pH vary considerably in fresh cement due to the concentrations of the alkali hydroxides. In aged cement the more easily dissolved alkali hydroxide will be removed from the system and pH will drop to a value of about 12.

Geochemical modeling of cement in contact with bentonite have predicted dissolution of the montmorillonite in bentonite and neoformation of K-feldspar and Ca-zeolites, as a consequence of the high pH. Several independent laboratory investigations have not shown evidence of this neoformation. On the other hand, other bentonite degradation processes, such as minor illitization and cementation, have been found. Cement hydrates have been identified between the montmorillonite stacks leading to restricted swelling and strengthening of the bentonite. A relative increase of Fe and Mg in relation to Al in octahedral positions in the montmorillonite lattice have been observed (Milodowski et al. 1991). The resulting increase in net negative charge has led to an increase in cation exchange capacity. Different laboratory investigations have shown an increase in 10 Å minerals (illite) also at relatively low temperatures (35°C), (Eberl et al. 1993). The observed bentonite alteration in laboratory tests, due to percolation with high alkaline solutions, has in general only concerned a minor part of the montmorillonite mass and has not affected the buffer functions in a significant way. The illitization rate seems to be retarding with time according to percolation tests. Swelling pressure and hydraulic conductivity may change due to ion exchange from the original charge balancing cation to alkali or calcium ions (Karnland 1997).

3.2.3 Microbiology

Survival

The survival of bacteria in bentonite has been suggested to depend on the water activity (a_w) and laboratory test showed that two different species of sulfate reducing bacteria was killed when the a_w was decreased to 0.96, corresponding to the conditions in an unpressurized and fully saturated clay at a clay density of 2000 kg/m^3 (Motamedi et al, 1995). It can be argued that the closed system (batch) laboratory conditions used may have added constraints not present in full scale and that other bacteria may survive better.

Activity

Concerns have been raised that sulfate reducing bacteria will produce hydrogen sulfide and that methanogens may produce a gasphase in the clay. This will only occur in the clay if such bacteria can survive the low a_w as discussed above. However, data from Äspö shows that sulfate reduction is an ongoing process in the groundwater (Lakksoharjou et al 1995), so sulfide can be produced outside the buffer and also in the backfill material, possibly with hydrogen (geogas) as the ultimate energy source. Modeling suggest diffusion of H_2S in buffer to be a very slow process due to the low solubility of the sulfide.

Migration

It has been argued that bacteria should be able to colonize the buffer from the groundwater. The presence of viable bacteria in deep clay sediment is usually interpreted as if the bacteria were mixed in with the clay during burial. Theoretically, the pore size of compacted bentonite is far to small for bacteria but convincing evidence is missing.

3.2.4 Cation migration

The diffusion of radionuclides in compacted bentonite has been studied rather extensively in laboratory experiments with synthetic groundwater. The pore water diffusion model, generally used to interpret the experimental data, is based on the assumption that diffusion takes place in pore water and is retarded by sorption of the diffusing species on the solid phase. This model is adequate for cations sorbed on the solid phase by surface compexation mechanisms e.g. Co^{2+}. For cationic species sorbed by ion exchange, e.g. Cs^+ and Sr^{2+}, experimental data indicate an additional diffusion mechanism in which migration takes place within the electrical double layers next to the mineral surface. The diffusivities of Cs^+ and Co^{2+} in compacted bentonite saturated with groundwater with different ionic strength (salinity) are rather well documented at room temperature and, in principle, it should be possible to model the diffusive transport of these cations in the actual bentonite system.

3.2.5 Copper corrosion

The rate of the canister corrosion is in principle determined by the chemical reactivity at the canister surface and the mass transfer from and to this surface. For a specific canister, the rate depends on the geochemical conditions of the nearfield, i.e. the type, content and mobility of dissolved constituents in the surrounding bentonite buffer. Thermodynamic calculations show that alteration products of copper are stable and that the corrosion process is expected to be affected by the redox conditions of the clay medium (Wersin, 1993). By use of simple transport related calculations a range of possible fluxes of degrading agents, such as O_2 and HS^-, can be derived and conservative estimates of upper corrosion rates can thereby be made (Neretnieks, 1983).

In general there are several different types of uncertainties associated with estimation of the copper corrosion rate in bentonite:

- model validity,
- time scale of oxic/anoxic transition,
- pitting factor,
- transport properties in the clay.

Modeling which takes in account diffusional transport in addition to flow, equilibrium reactions and kinetic processes at the bentonite canister interface has been made (Wersin 1994). The results indicate conservative corrosion depths of $2*10^{-8}$ and $7*10^{-6}$ m/y, respectively for anoxic and oxic conditions. A sensitivity analysis indicate that the main uncertainties arise from the diffusion properties in the clay.

Preliminary gravimetric results from the pilot test parcels give a calculated mean corrosion depth of approximately $3*10^{-6}$ m/y, which is well in agreement with calculated model results for oxidizing conditions.

3.2.6 Gas transport

A certain amount of air will be entrapped in the bentonite after emplacement. The water saturation give rise to a swelling pressure which will compress the air to of around 2% of the original volume as calculated by Hook's law. The gas will dissolve and diffuse from the deposition hole parallel to chemical reaction which will consume mainly the oxygen (redox reactions). Laboratory experiments confirm this scenario and no entrapped undissolved air, which may stop the water saturation, is expected in the deposition holes (Börgesson 1995, Karnland 1995:2).

In case of a fuel canister damage in a KBS3 repository, water may enter the interior of the canister and steel corrosion may produce hydrogen gas. The production may lead to high pressure (MPa range) in the relatively big canister cavities (~1 m^3). The mechanisms for gas transport out through the buffer and its effect on the bentonite is consequently of great interest. A few laboratory test series have been carried through in order to investigate gas transport through compacted bentonite with respect to the transport nature. The first series (Pusch 1983) indicated only a small amount of gas penetration at low gas pressure. At high pressure a substantial increase in the gas flow was recorded. It was concluded that the gas flow had taken place in relatively fine channels and no desaturation of the clay had taken place. Partial drying was noticed in one sample in a hydrogen gas experiment. Later tests series (Pusch 1985, Horseman) have shown a substantial increase in gas flow through the bentonite at a critical gas pressure, which was found to be close to the sum of the clay swelling pressure and the prevailing water pressure. The flow was concluded to have taken place in relatively small channels and no desaturation of the clay was noticed. No tests have been made concerning effects of elevated temperature, temperature gradients or possible chemical effects. Test technicalities such as gas transport at the interface between bentonite and tubing or confining vessel has not been sufficiently investigated. Additional bench scale laboratory tests are therefore planned before gas tests are started in the present field tests series.

3.3 JUSTIFICATION

The buffer longevity in a KBS3-type repository is considered satisfactory based on laboratory results and studies of natural analogs. However, the conditions in a repository are complex and difficult to simulate in laboratory tests, and well defined and entirely adequate natural analogues can hardly be found. Previous field tests have in different ways deviated from possible repository conditions, i.e. low-salinity ground water in the Buffer mass test in Stripa, low water pressure in the Buffer test at URL, and buffer clay composition and high temperature in the French clay test at Stripa. It seems therefore urgent to verify the existing models, as far as possible, in long-term tests in a repository-like environment. However, several expected reactions are shown to be extremely slow at repository conditions, but may in a long term perspective still be a threat to the buffer function. In order to study also these reactions, within a reasonable time scale, the processes have to be accelerated by use of adverse conditions, e.g. high temperature, high ion content etc. The planned relatively long exposure time periods are intended to show possible changes in physical properties of the buffer system after full water saturation. A long term test series, including tests exposed to KBS3 conditions and to adverse conditions, are consequently proposed.

4 EXPERIMENTAL CONCEPT

4.1 GENERAL

The basic arguments for the proposed type and layout of the test series are:

- A large number of laboratory tests have been performed, but since the repository system is complex, the overall function is not possible to fully simulate in laboratory environment.
- Field tests are cheaper and easier to perform compared to complex large scale and long term laboratory experiments.

The test series may be described as a multi-task experiment in which the test parcels are exposed to conditions similar to those in a KBS3-repository. The parcel material will thereafter be examined by a general, well defined set of tests and analyses in order to provide data for the different aims. The measurements and analyses will be approximately the same in all buffer stability tests since combination of test results are needed for several of the evaluations. Specific analyses will be made with respect to bacteria activity, radionuclide transport, copper corrosion and gas transport. The following models and hypotheses will be tested:

Preservation of physical properties

Hypotheses:	The buffer properties are preserved under repository conditions. No significant changes in physical properties or in clay lattice structure are expected during the water uptake phase. Small changes concerning ion exchange and redistribution of easily dissolved minerals are expected to take place.
Main aspects:	Physical properties, clay mineral alteration, distribution of accessory minerals.

Smectite-to-illite reaction

Model:	The reaction rate can be calculated by use of the kinetic smectite-to-illite conversion model proposed by Huang et al..
Main aspects:	Check of the relevance in reaction mechanism, applicability of laboratory determined activation energy and frequency factor constants.

Table 4-1 shows expected conversion according to the Huang et a. model for proposed constants and for maximum conservative evaluated constants according to Karnland 1995. K-feldspar will be mixed with bentonite and compacted to small cylinders (plugs), which will be placed in defined bentonite blocks designed for the adverse condition parcels.

Table 4-1. Calculated smectite-to-illite conversion at high K^+ concentration (7 M), according to the Huang et al. model, by use of proposed constants and evaluated maximum conservative constants. Result figures are expressed in % illite.

constants	time	Temperature			
	years	60°C	90°C	120°C	150°C
proposed	1	0	0	0	10
	5	0	0	6	40
	10	0	0	10	60
conservative	1	10	35	70	85
	5	30	70	90	95
	10	50	75	95	100

XRD technique is a precise and powerful tool with respect to the detection of illite neoformation. However, the mineral conversion quantification by use of XRD is complicated and may be facilitated by computer code analyses (commercially available codes), and has to be supported by element analyses and CEC determinations. The detection limit is difficult to specify since it depends on the form of illite that is produced. Only a few percent is possible to detect if the illite is a pure face, on the other hand significantly more illite is required if the illite is in the form of mixed layer structures.

Salt enrichment

Model:	Accessory mineral enrichment may take place due to at least two separate processes.
Main aspects:	Confirmation of results from laboratory experiments indicating that the enrichment will be negligible at repository conditions. Study the effects of an increased temperature gradient.

The enrichment of new minerals in a bentonite buffer due to the prevailing temperature gradient is found to be affected by the clay density, content of accessory minerals in the buffer, electrolyte concentration in surrounding ground water, and water pressure. In the proposed test series the conditions will vary partly by controlled actions and partly by the nature of the experiment and the natural variation in boundary conditions. Temperature, content of accessory minerals and salinity will be controlled and higher compared to KBS3 conditions in the adverse condition parcels. Calcite and gypsum will be mixed into small bentonite cylinders, which in turn will be placed in defined blocks in the adverse condition parcels. The proposed analyses (ICP/AES, XRD, SEM) at test termination are sensitive enough to show the original variation in the bentonite material with respect to accessory minerals according to laboratory studies. Systematic redistribution or neoformation within the test parcels are therefor believed to be detected and possible to quantify. Effects on buffer performance are also possible to detect since the tests program includes geotechnical examination (triaxial-, beam- and oedometer tests).

Cement/bentonite interaction

Hypotheses:	Bentonite under repository conditions resists short term attack from cement pore-water without major alteration.
Main aspects:	Confirm laboratory experiments concerning mineral neoformation and clay lattice alteration.

Possible effects on the bentonite of an exposure to cement pore water are believed to be replacement of the original charge balancing cation, cementation of the bentonite due to precipitation of cement matter in clay pore space, and attack of the clay mineral lattice due to the induced high pH. The cation exchange is analyzed by replacement of the present cations by NH_4^+ (part of CEC analyses). The accuracy is a few percent according to laboratory studies. Montmorillonite lattice alteration or breakdown is not well substantiated experimentally but possible significant changes will be detected by XRD and CEC analyses. High pH cement in the form of 2 cm plugs will be placed in defined bentonite blocks intended for the adverse condition test parcels.

Buffer cementation

Hypotheses:	No major cementation processes will take place at normal repository conditions.
Main aspects:	Qualitative and quantitative data concerning possible buffer cementation will be determined by use of microscopy and rheological tests.

Cementation of the bentonite is analyzed qualitatively by electron microscopy and quantitatively by standard shear tests (triaxial cell) and tensile strength tests (beam test).

Additional

The existence of relatively fast buffer degradation processes will be possible to exclude.

The work will serve as pilot tests to the planned full scale test series with respect to emplacement, clay preparation, and characterization, instrumentation, data handling, excavation and evaluation.

Survival and activity of bacteria

Hypotheses: Bacteria survival is governed by water activity/induced swelling pressure. The expected low water activity/high swelling pressure in compacted bentonite around waste canisters is expected to act as a strong limiting factor for bacterial survival and activity, thereby reducing or eliminating the risk for bacterial production of gas and corrosive metabolic products.

Main aspects: Detection of possible survival and activity of bacteria.

Laboratory experiments have demonstrated that a low water activity was lethal to the sulfate reducing bacteria (SRB) studied (Motamedi et al. 1995). It may, however, be argued that other, more halotolerant SRB could survive and be active.

Migration of bacteria

Hypothesis: The pore size of compacted bentonite is too small for bacteria to move in.

Main aspect: Detection of migration of bacteria from groundwater into the buffer.

The pore size of highly compacted bentonite is in the nanometer range which makes contamination of a compacted buffer with microorganisms, migrating into the buffer from groundwater, improbable.

Cation migration

Hypothesis: Cation transport may take place by two different transport mechanisms i.e. solely by diffusion in the pore-water and by an additional migration within the electrical double layers next to the mineral surface.

Main aspect: A difference in diffusive transport is expected between cations sorbed by surface complexation mechanisms e.g. Co^{2+} and cationic species sorbed by ion exchange e.g. Cs^{+} and Sr^{2+}. A faster transport is expected to take place for the latter cations.

Copper corrosion

Hypothesis: The mean corrosion rate will be less than $7 \cdot 10^{-6}$ m/y.

Main aspects:	Determine the mean corrosion rate, identify possible pit corrosion and corrosion products.

Gas conductivity

Hypothesis:	The gas transport capacity through a fully saturated bentonite buffer is low at low gas pressures. Flow is initiated at a certain ”critical” gas pressure and the transport capacity increases dramatically. The ”critical” gas pressure is close to the total macroscopic pressure of the system which is the sum of the bentonite swelling pressure and the water pressure in the system.
Main aspects:	Determine ”critical” pressure, examine the self sealing mechanism after gas pressure decrease.

4.2 EXPERIMENTAL CONFIGURATION

4.2.1 Test parcels

The testing philosophy for all planned tests in the series (Table 4-2) is to emplace prefabricated units of clay blocks surrounding heated copper tubes in vertical boreholes. The test series will be performed under realistic repository conditions except for the scale and the controlled adverse conditions in three tests.

The test series have been extended, compared to the original test plan, by the A0 parcel in order to replace the part which was lost during the uptake of the A1 parcel.

Table 4-2. Lay out of the planned Long Term Test series.

Type	No.	T °C	Controlled parameter	Time years
A	0	120<150	T, $[K^+]$, pH, am	1
A	2	120<150	T, $[K^+]$, pH, am	5
A	3	120<150	T	5
S	2	90	T	5
S	3	90	T	>>5

A = adverse conditions
T = temperature
pH = high pH from cement

S = standard conditions
$[K^+]$ = potassium concentration
am = accessory minerals added

Adverse conditions in this context refer to high temperatures, high temperature gradients over the buffer, and additional accessory minerals leading to i.a. high pH and high potassium concentration in clay pore water. The central copper tubes will be equipped with heaters in order to simulate the decay power from spent nuclear fuel. The heater effect will be regulated or kept constant at values calculated to give a maximum clay temperature of 90°C in the standard tests and in the range of 120 to 150°C in the adverse condition tests. Test "parcels" containing heater, central tube, clay buffer, instruments, and parameter controlling equipment will be placed in boreholes with a diameter of 300 mm and a depth of around 4 m (Figure 4-1 and 4-2).

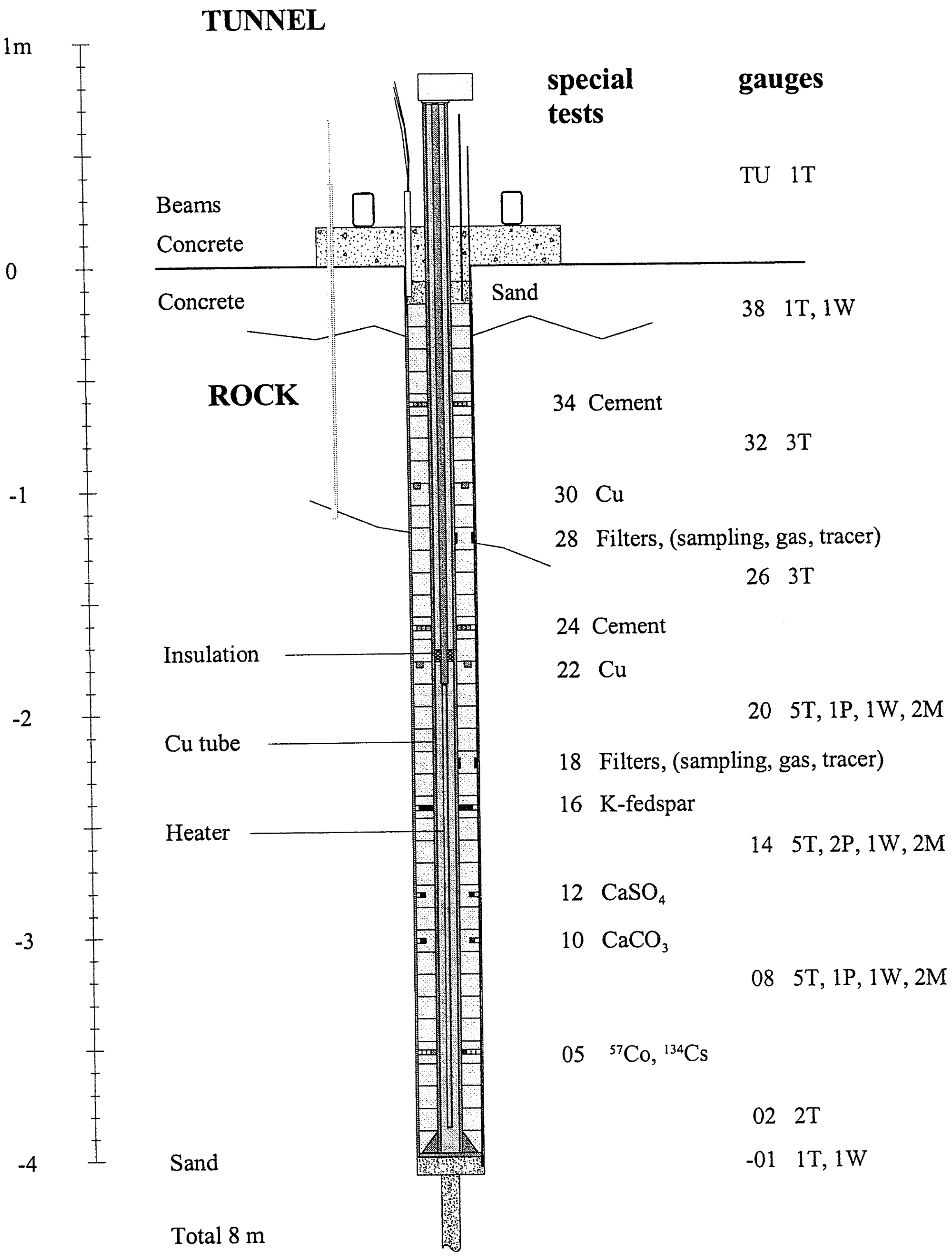

Figure 4-1. *Principle layout of an A-type test parcel. T denotes temperature gauges, W water pressure gauges, P total pressure gauges, M moisture gauges. Figures show block number (first) and number of gauges at each level.*

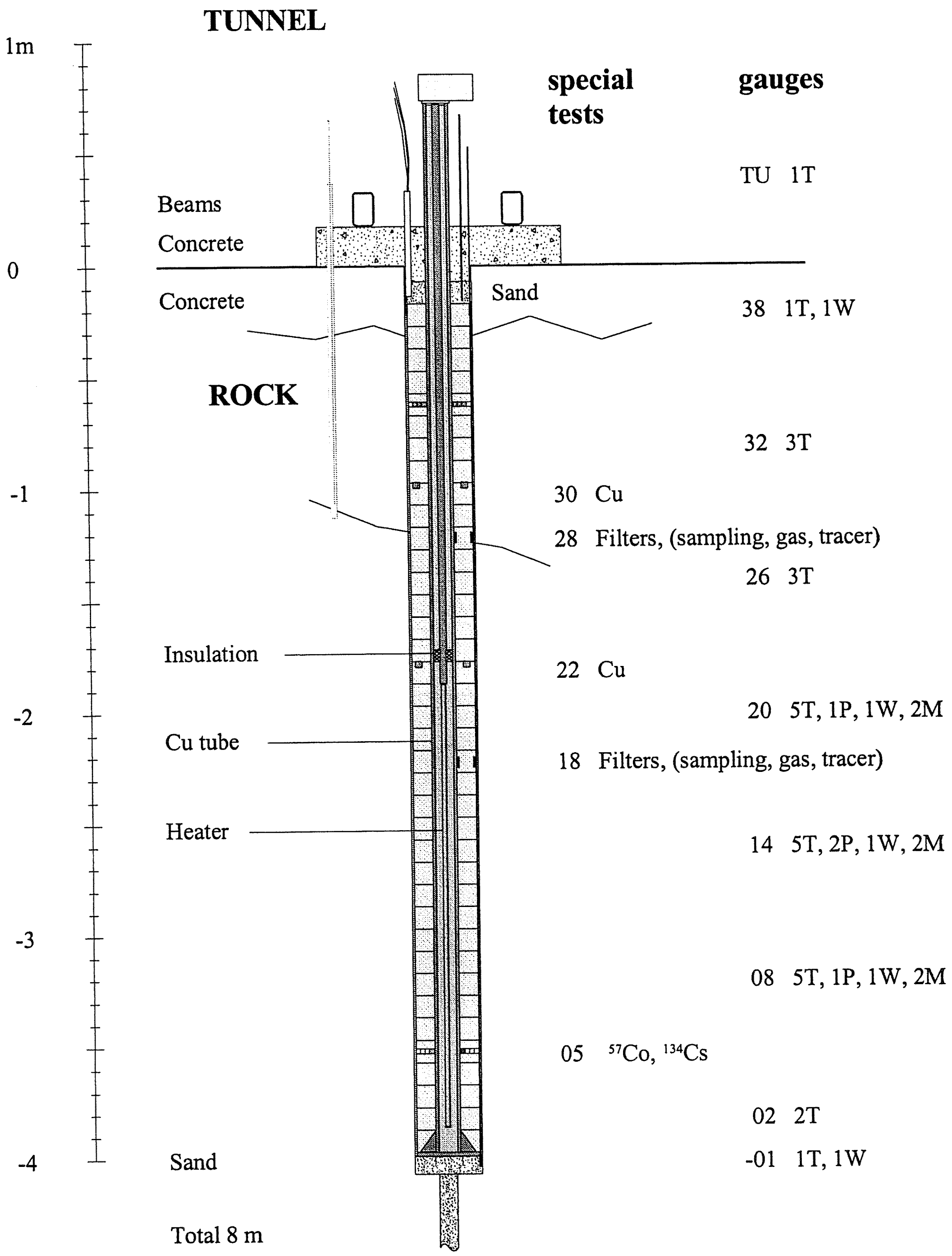

Figure 4-2. *Principle layout of a S-type test parcel. T denotes thermocouples, W water pressure gauges, P total pressure gauges, Moistures gauges. Figures show block number (first) and number of gauges at each level.*

4.2.2 Instrumentation

Principle drawings of the proposed A and S parcels are shown in Figure 4-1 and Figure 4-2, respectively.

The heaters used in the pilot tests, delivered by Backer AB, Sösdala, turned out to function well and the same type will therefore be used also in the proposed test series. The heaters have a built in reserve capacity in the form of three elements of steel-encased MgO-shielded heat wires deigned so that suitable power may be generated. The heaters will be inserted into the central tubes from the top, which is exposed in the tunnel, and the heaters may thereby easily be replaced in case of failure. The maximum power of the heaters is 2 kW. According to the previous FLAC calculations and pilot test data, the power supply is expected to be around 600 W and 1000 W for an S- and A-type parcel, respectively.

Thermocouples will be used for temperature recordings in order to give a detailed picture of the temperature distribution in the buffer material (minimum 5 levels and 3 sensors at each level in every test parcel). Alternatively, an optic system will be tested and if so partly replace thermocouples. Heavy corrosion was noticed on a few inconel jacketed units in the pilot tests. Cupro-nickel jacketed thermocouples is therefore considered. In the bentonite the thermocouples will be covered by a tecalan tubing equipped with a titanium tip in order to reduce the corrosion problem.

Total pressure cells designed for total pressures of up to 15 MPa and water pressure cells (5 MPa) are planned to be placed in every test parcels. Several major principle types of pressure gauges are considered:

- previously used mechanical type manufactured by Glötzl (Germany),
- piezo-electronic type supplied by several companies,
- vibrating wire type supplied by a few manufacturers, and
- different principles for optical sensors supplied by a few manufacturers.

The critical properties are physical dimensions and long term stability with respect both to chemical attack and to signal stability. The dimensions will govern the number of gauges. Two entirely different types of gauges are planned to be used (likely vibrating wire and optical sensors) in the 20 year test (parcel S3). All electric cables are planned to be protected by titanium tubes in order to get mechanical and moisture protection.

Filters are planned to be placed at 2 levels in accordance with Figure 4.1 and 4.2. One of the two levels will be selected to be in the vicinity of a water-bearing fracture in order to make water sampling possible and to measure ground water pressure. In at least one test there will be drilled a small bore-hole parallel to the test hole in order to sample water both from the bentonite and from the fracture. The filters are further planned to be used for the gas and tracer tests.

Pore-water pressure gauges and a limited amount of water content indicators (mainly capacitive type) will be used in order to follow the water saturation in the test parcels.

The four planned long term test parcels are intended to be placed in the inner part of the G-tunnel at Äspö. The additional A0 parcel will be placed in the outermost part of the test area in order to reduce interference with the remaining parcels after uptake.

The rock structure has to supply the parcels with pressurized water either by a number of well distributed fractures or by a "disturbed zone" in the surface of the test hole. The number of water-bearing fractures in the G-tunnel is expected to be relatively low, and the pilot characterization holes will therefore be drilled below the test section down to 8 m in order to simulate the water supply and pressure in a KBS3 deposition hole. The subsequent test holes will be drilled by a technique similar to the planned full scale holes, which is expected to give a disturbed zone and an increase of rock permeability. The separating rock cover distance between the deposition holes in a KBS3 repository is 4.25 m which is planned to be used also in the present tests in order to give realistic interference conditions. The center distance will consequently be 4.55 m (Figure 4.3)

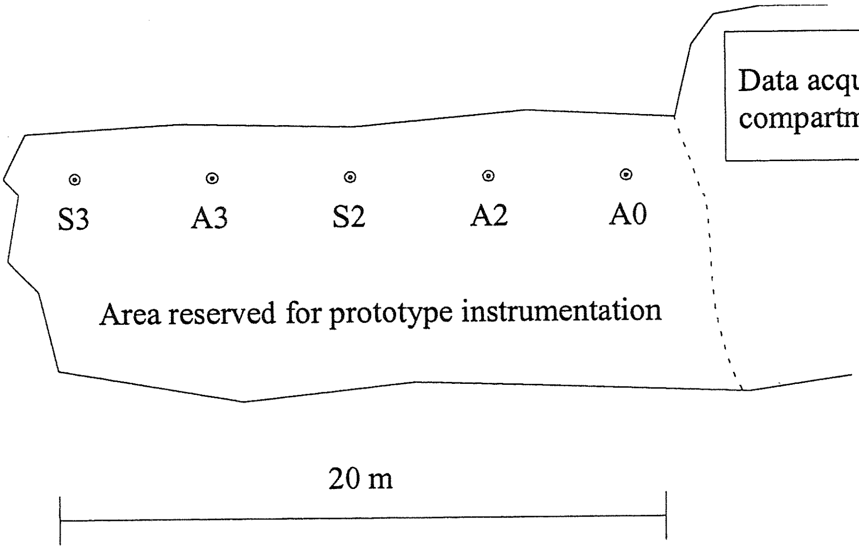

Figure 4.3 Principle placing of the five test parcels in the G-tunnel.

4.2.3 Bentonite tests

Temperature, total pressure, pore-water pressure and water content will be measured in a number of strategic positions in the buffer during the heating period approximately to the same extent as in the pilot tests. In addition, the water content will be better monitored, and the temperature on the central tube will be measured. At test termination the clay will be fast extracted in order to reduce water redistribution before sampling. Subsequent chemical, mineralogical and physical testing will be performed by which the following conditions and properties will be determined at strategic positions in the buffer:

- water distribution,
- element distribution (ICP/AES, SEM, (STEM)),
- pore-water composition (ICP/AES, titration) ,
- mineralogical composition, smectite/illite ratio, (XRD),
- cation exchange capacity, CEC (wet chemistry),
- swelling capacity (test tube),
- swelling pressure (oedometer & triaxial test),
- hydraulic conductivity (oedometer test),
- clay structure (SEM, TEM)
- shear strength (triaxial test)
- tensile strength (beam test)

4.2.4 Bacteria tests

Start values of the numbers and types of bacteria and other microorganisms that are introduced during prefabrication of the bentonite blocks will be studied. The survival of natural populations has been demonstrated possible under realistic, full scale conditions (Stroes-Gascoyne et al. 1995). Activity of possibly surviving bacteria will be measured with isotopic techniques as was done during decommission of the BMC test at URL (Pedersen et al 1991) and in the recent pilot S1 tests.

Parts of the buffer are expected to have contact with water conducting fractures, and naturally occurring groundwater bacteria will enter into the buffer at such positions during the saturation phase. The microbial population in the groundwater will be analyzed before emplacement and at the end of the experiments. After test termination the bentonite samples will be analyzed by culturing and molecular methods at different distances from groundwater inlet positions and in positions representing different physical conditions, i.e. mainly different temperatures.

4.2.5 Tracer tests

Two different techniques for supply of radionuclides are planned to be used in the test series. One is based on doped dry bentonite and the other on solutions circulated in a porous cell in the bentonite. Only the dry preparation method is suitable to apply in the one year test (parcel A0) since unsaturated conditions will prevail close to the copper tube a substantial part of the of the test time. The bentonite around the activity source will be analyzed with respect to content and distribution of the tracers used. Sr-85, Cs-134 and Co-57 are generally used in laboratory experiments. The short half life of Sr-85 (64.8 days) makes the use of this tracer impractical since high initial specific activity has to be used. Analyses of the alternative tracer Sr-90 is cumbersome and the proposed tracers will consequently be Cs-134 and Co-57. The activity of 1 MBq per experiment was used in the pilot tests and will likely be used in the planned tests as well.

Dry supply method:
A small plug of dry compacted "radionuclide doped" bentonite will be inserted, in a drilled hole in one of the prefabricated bentonite blocks, to a position close to the copper tube. The remaining hole outside the active bentonite will be sealed off by inactive dry bentonite with the same density as the original block. No significant diffusion is expected to take place before water reaches the active plug since the diffusion of cations is several orders of magnitude lower in dry bentonite compared to water saturated according to laboratory tests. This method was used in the pilot tests and will be used in the planned A0 parcel.

Wet supply method:
A small cell with porous walls will be inserted into a drilled hole in one of the prefabricated bentonite blocks and connected to a HPLC pump by fine tubings. PEEK is the main option material but it has not been used in this kind of system before and an alternative may be titanium. After complete saturation of the bentonite, the cell will be percolated with groundwater in which the radionuclides have been dissolved. The radionuclides will diffuse through the porous walls into the clay, simulating a small leakage of radionuclides into the clay system. This method is considerably more complicated technically, compared to the plug method, but is planned to be used in at least one of the long term tests.

4.2.6 Copper corrosion tests

Possible interesting parts of the central copper tubes will be examined by SEM-EDX after the tests have been terminated. Sawn Cu-plates will be placed at defined positions in the bentonite in a similar way as was made in the pilot tests. In addition, polished Cu-plates will be placed at two levels in each parcel in order to facilitate the study of corrosion depth. In situ monitoring of corrosion potential will be tried. The mean corrosion rate will be determined by change in weight after repeated cleaning in water and sulfuric acid. The plates will be analyzed by use of SEM-EDX with respect to surface structure and element content, and by XRD with respect to possible corrosion products.

4.2.7 Gas tests

At full water saturation the filters close to the central tube will be used as gas inlet. The peripheral filters will initially be used as pressure gauges. In subsequent tests the outer filters may be used as well defined outlet points. The exact procedure will be determined after the planned preparatory laboratory tests have been made.

4.2.8 Water sampling tests

During the heating time water sampling will be made through the filters. pH, Eh and corrosion potential for the copper will be measured on line if suitable equipment can be found. Small ampoules, equipped with filters, are planned to be placed in the bentonite at strategic positions in order to get representative water solutions at test termination.

4.3 EXPECTED OUTCOME

The tests and analyses are expected to produce a large number of various kinds of data concerning the following fields:

Buffer

- Quantitative information of the long term performance of the buffer material, i.e. mainly possible changes, in hydraulic conductivity, swelling pressure and cation exchange capacity as an effect of the water saturation process.
- Information of the applicability of existing smectite-to-illite conversion models and, if necessary, data for adjustment of model constants for repository conditions.
- Detection and identification of possible cementation reactions (e.g. anhydrate at the warm side, SiO_2 at the cold side)
- Quantitative information of possible mineral redistribution and its effects on the physical properties of the buffer.
- Qualitative and quantitative information about the effects of cement on the clay mineral lattice, extent of cation exchange and clay cementing processes.
- Qualitative and quantitative information of other possible additional mineralogical alteration in the buffer.

Bacteria

- Quantitative and qualitative information about present microorganisms in prefabricated bentonite blocks.
- Quantitative and qualitative information about the survival of present bacteria in buffer at different temperatures.
- Information about activity of possibly surviving bacteria.
- Quantitative and qualitative information about possible migration of bacteria in the buffer.

Cation migration

- Quantitative data concerning distribution, and thereby of migration, of released radionuclides.
- Information about expected different diffusion mechanisms between Co^{2+} and Cs^{+}.

Copper corrosion

- Quantitative information about the mean corrosion rate.
- Qualitative information about pit corrosion and corrosion products.

Gas transport

- Determination of ”critical” gas pressure, and if possible quantitative information on gas transport capacity.
- Qualitative information concerning possible effects on the buffer of gas penetration.

General

- Information concerning buffer preparation, instrumentation, installation, data handling and evaluation.

4.4 PROBLEM AREAS AND ALTERNATIVE SOLUTIONS

An important function is the stability in heater effect since buffer related fluctuations in temperature are informative. Long term heater failure will complicate the interpretation of measured data and the data acquisition system will therefore be equipped with an alarm function. Backup systems have to be available at Äspö, e.g. spare power generator and easily exchangeable spare heaters.

The support and concentration-regulation of ions in the pore-water has not been tested in repository environment. Different possible systems have been used in laboratory scale and should be validated before a final choice is made.

Equipment testing has partly been made with respect to test range, choice of materials, result sampling system etc. Choice of material in the gauges may be problematic due to the aggressive physico-chemical conditions i.e. the salt content in combination with the elevated temperature. The pilot tests showed problems also with relatively corrosion resistant materials such as inconel. Equipment made of titanium did not show any sign of corrosion and will consequently be first choice. All types of equipment are, however, not available in titanium as standard, and new or other solutions have to be found, either in the form of improvement of existing gauges or development of new types.

Some of the proposed principles and type of equipment have not been used in earlier test. The long term stability of electronic in situ device (pressure gauges and psycrometers) is not well known in this environment and investigation and discussions with contractors and producers proceed. A final decision of instrumentation will be taken in January 1999.

The conditions in the pilot test area were problematic especially with respect to water inflow and fractured rock, and the emplacement and uptake activity during the pilot tests were related to minor and considerable problems, respectively. Substantially easier conditions are expected in the intended long term test area (G-tunnel). On the other hand, the opposite conditions, i.e. few fractures and minor water inflow may lead to slow water saturation of the bentonite .

The number of water-bearing fractures in the G-tunnel is expected to be relatively low, and the pilot characterization holes will therefore be drilled below the test section down to 8 m in order to simulate the water supply and pressure in a KBS3 deposition hole. The subsequent test holes are planned to be drilled by use of rotation or percussion drilling technique. The purpose of this technique is to imitate the expected rock wall disturbance in the full scale deposition holes, which is expected to give a disturbed zone and an increase of rock permeability.

The open holes after the successive removal of the parcels will give new boundary conditions for the remaining parcels. A possible technique to minimize this interference is to seal the holes by a mixture of compacted bentonite and crushed rock.

A new drilling technique with the intention of avoiding contact between the drilling fluid and the parcel is presently being searched for in order to minimize the risks at the uptake operation. The ultimate move is to use a dry technique. Mixing additives into entire bentonite blocks will not be used in order to further minimize risks for excavation damages of the parcels. Small plugs (diameter 20 mm), similar to the previously used bacteria and tracer doped samples, will instead be used.

The calculated minimum temperature with respect to evaluation of illitization is 120°C at saturated potassium chloride conditions ($[K^+] = 7M$). This very high potassium concentration will not be possible to use in the long term test. Final temperature will be the same in all three adverse condition tests, and will be settled after the ground water pressure in the test holes have been measured.

5 SCOPE

5.1 MAIN PROJECT TASKS

The planned work may be divided in the following major parts:

- development, choice and production of test equipment,
- supporting laboratory tests,
- drilling and characterization of test holes,
- preparation of bacteria, tracer and copper samples,
- manufacturing of bentonite block,
- preparation of test parcels and measuring system,
- installation of parcels,
- measurement during heating period (temperature, water pressure, total pressure and humidity, possibly also pH and eh),
- special tests during the heating period (water sampling, gas and tracer tests),
- termination and sampling,
- laboratory tests and analyses,
- evaluation of results,
- models check off,
- reporting.

5.1.1 Site choice, characterization and preparation

The G-tunnel was blasted in order to give a sheltered test area suited for long term tests. The inner part of the tunnel has been reserved for the tests holes and the sampling system will be placed in a permanent building in the outer part of the tunnel, probably in co-existence with the prototype sampling system.

Pilot holes will likely be made by 76 mm triple-core-drilling in order to facilitate detection and characterization of existing fractures, and to determine the ground water flow, pressure and chemistry. Important test hole properties are access to water, water pressure, relatively undisturbed conditions with respect to water flow, pressure and chemistry. The characterization of the site are planned to be made by use of the bore-map system (core mapping, BIPS and UCR), and major interconnected fracture will be localized by packer-tests and radar examination. Hydraulic conductivity will be determined for a few cores representing the major existing rock types (likely diorite, fine grained granite, and pegmatite) by use of triaxial test equipment (Figure 5.2).

The subsequent test holes are planned to be drilled by use of rotation or percussion drilling technique. The purpose of this technique is to imitate the expected rock wall disturbance in the full scale deposition holes.

5.1.2 Numerical model calculations

Calculations concerning suitable heater power for the pilot holes were made by use of the thermal logic in FLAC finite difference code. The calculated values turned out to well give the desired temperature conditions. The same calculated power will be used in the long term tests since the rock boundary and the parcel conditions in principle are the same.

The water saturation process will be modeled by use of the ABACUS model developed for unsaturated clay conditions. Calculations will be made for conservative and probable scenarios based on the rock characterization data.

5.1.3 Preparation of test parcel

Bentonite block manufacturing, central tube preparation and calibration of test gauges are planned to be made in Lund by CT personal. Equipment for each parcel is transported to Äspö by road. Mounting and instrumentation are made by CT and Äspö personal at the test site immediately before emplacement in the test holes.

5.1.4 Predictions

The following predictions will be made in a parcel preparation report based on the calculated final bentonite density and ground water conditions:

- swelling pressure,
- hydraulic conductivity,
- temperature distribution and
- course of saturation.

Prediction data for the former two items will be based on laboratory data and analytical models, and the latter two predictions will be made by use of numerical modeling.

5.1.5 Heating period

The heater power will be individually turned on as soon as possible after each parcel emplacement. Initially, the power will be regulated, by use of temperature readings, in order not to exceed the individual parcel maximum temperatures. The power will be fixed to a constant value subsequent to fairly constant power and temperature conditions have been reached.

All sensors will be scanned with short time intervals and conceivable fast events will be recorded by use of "change-guard" technique. The expected relatively slow processes will be caught by regular but sparse recordings (hour intervals). Water sampling, gas permeability tests and tracer test are planned to be made by use of the preinstalled filters

5.1.6 Excavation and sampling

The general idea at test termination is to release the parcel and a rock-cover of approximately 20 cm by drilling a slot in the rock outside the parcel. The remaining contact in the bottom will be sawn off, and the entire released rock column, including the central test parcel, will be lifted. This technique enables a fast and precise sampling of the bentonite and the various additives may fairly easy be localized and analyzed.

The drilling technique used in the pilot tests was successful in the pilot S1 parcel but caused loss of material in the A1 parcel. The cause of the loss was likely due to a combination of drilling/pumping problems, existing fractures and the high salt content in the bentonite blocks. It is of course most important to assure that the future recapture technique minimizes the risk of loosing or affecting the bentonite material. At present, different techniques are being discussed but no final proposal is at hand.

The temperature will drop relatively fast in the test parcel when the heater power is switch off, which leads to minor redistribution of water and dissolved substances. On the other hand, drying may lead to the same result if the excavation is made at high temperature and the clay is exposed to air during the sampling.

5.1.7 Buffer tests and analyses

The following tests and analyses will be made after excavation and heat termination. The sampling and determination of water content distribution will be made in direct conjunction with the excavation and the following tests and analyses will be made at CT in Lund in conjunction with university institutions mainly in Lund (Geological and Chemical departments, Swedish Geological Survey (SGU), and the electron microscopy unit at University Hospital).

The following technique will be used in order to separate the clay fraction (mean particle diameter < 2µm) in all subsequent tests which involve the clay fraction. Approximately 10 g of representative material will be crushed by percussion and gently ground in an porcelain mortar to a grain size less than 1 mm. The material will be dispersed in 1 liter of distilled water, and disintegrated by use of an ultrasonic bath and a mechanical stirrer for 15 minutes. The fraction coarser than 2 µm, as evaluated by Stoke´s law, will be separated by centrifugation. The clay fraction in the supernatant is decanted off and dried at 60°C.

<u>Element analyses:</u>

The element analyses will be made on unsorted material and on the clay fraction. The bulk material and the clay fraction, respectively, will be melted in a mixture of lithium carbonate and dibortrioxide, dissolved in nitric acid and analyzed by use of ICP-AES techniques.

Cation exchange capacity:

A modified version of Chapman's ammonium acetate method will be used in order to determine the content of present cations and the CEC value. The ion exchange property of a mineral is related to the abundance and nature of the lattice charge and can be expressed by the cation exchange capacity (CEC). The CEC analyses will be made on non-fractionated material in order to include e.g. possible zeolites. Approximately 2g of material from each sample will be saturated with NH_4^+, by repeated washings with 1 M ammonium acetate solution. The suspensions will be centrifuged and the supernatants will be analyzed with respect to extracted cations. pH will be kept at 7 during the procedure by adding NH_4OH (ammonia water) or CH_3COOH (acetic acid). The ammonium saturated clay samples will be washed 3 times with propanol in order to eliminate excess ammonium acetate. The samples will be ion-exchanged to sodium state by repeated (3 times) washings in acidified 2 M NaCl solution. The supernatants from the washings will be finally analyzed with respect to the ammonium concentration, from which the CEC value will be calculated.

X-ray diffraction analyses:

The analyses aims at identifying the main minerals and estimating the relative amounts of clay minerals and accessory minerals. Two different preparation techniques will therefore be used, one in order to produce specimens with unsorted and unoriented material, and the other to produce specimens with oriented material from the clay fraction. The former technique gives complete "three-dimensional fingerprints" from all types of minerals which will be necessary for general identification and quantification, and the latter technique enhances basal reflections from minerals with a "two-dimensional" structure, thereby facilitating the identification of clay minerals. The oriented samples will be treated with ethylene glycol (EG) in order to identify characteristic swelling. The clay fraction will be extracted in the same way as for the element analyses. The suspension will be placed in a vacuum filtration device, in which the clay will be settled on to a ceramic tile. The thereby oriented specimen will be transferred to a glass XRD sample holder and dried at ambient relative humidity and temperature. A Siemens D500 diffractometer with Cu Kα radiation will be used for the analysis. The 2θ interval 3-40° will be scanned, and after saturation with ethylene glycol (EG) the 2θ interval 3-15° will be scanned again in order to analyze possible swelling. The packed, unoriented and unsorted specimens will be scanned in the 2θ interval 3-65°.

Scanning electron microscopy (SEM):

The preparation technique intends to give freshly broken surfaces for morphological studies and EDX element analyses. Samples with a size of a few cubic millimeter will be frozen in liquid nitrogen and freeze-dried at a temperature of -20°C and a pressure of 1 Pa. The specimens will be broken and mounted on aluminum sample holders by use of carbon glue, and gold-sputtered to a film thickness of 15 nm. The samples will be analyzed with respect to morphology and element content and distribution at magnifications between 50 to 5000 times by use of a Philips SEM 515 microscope equipped with a LINK 2000 energy dispersive X-ray analyzer (EDX).

Transmission electron microscopy (TEM):

Bulk material will be cut to yield specimens with a size of a few cubic millimeters which will be frozen in liquid nitrogen, and freeze-dried at a temperature of -20°C and a pressure of 1 Pa. The specimens will be placed in a 85/15% mixture of butyl/methyl-methacrylate for about one week and polymerization will be achieved by heating to 60°C for 24 h. An LKB ultramicrotome will be used to cut 50 to 100 nm thick sections, which will be transferred to copper grids. The general morphology will be studied at instrument magnifications between 10'000 and 50'000 times, and specific particles may be studied at magnifications up to 150'000 times. The study will be made by use of a Jeol 100 TEM and the documentation will be made by b/w photos.

Grain size distribution:

A standard settling method (USA, ASTM:D 422-63) will be used to determine the clay fraction of the samples, and to determine the grain size distribution of particles coarser than 2 μm. Samples will be crushed by percussion and gently ground in an porcelain mortar to a grain size less than 0.2 mm and thereafter dried at 105°C. From each sample an amount of 20 g dry material will be dispersed in 0.1 liter of an 0.05 M $Na_4P_2O_7$ solution. The volume of the suspension will thereafter be increased to 1 liter by adding distilled water. An ultrasonic bath with a water temperature of 60°C and a mechanical stirrer will be used for 15 minutes in order to enhance the dispersion. The suspension will be left overnight and additional mechanical agitation will be performed before the settling will be started. A standard glass cylinder will be filled with the soil suspension and a hydrometer will be placed in the suspension. The position of the hydrometer will be recorded after standard time intervals (from 1 minute to 24 h after test start) and the grain size distribution will be evaluated from these data by use of Stoke's law.

Oedometer tests:

Swelling pressure and hydraulic conductivity will be measured by use of a rigid oedometer (Figure 5-1). The clay sample will be placed in the stainless steel cylinder, and confined between filters at the top and bottom. Artificial rock ground water will be used for percolation of the sample, which will be made by applying a water pressure at the bottom of the oedometer. The water flow will be recorded by regular readings of the meniscus position in the outlet tubes. The swelling pressure will be recorded by a pressure transducer placed between the piston and the upper lid. When swelling pressure has stabilized, a water pressure gradient will be applied over the sample in order to determine the hydraulic conductivity.

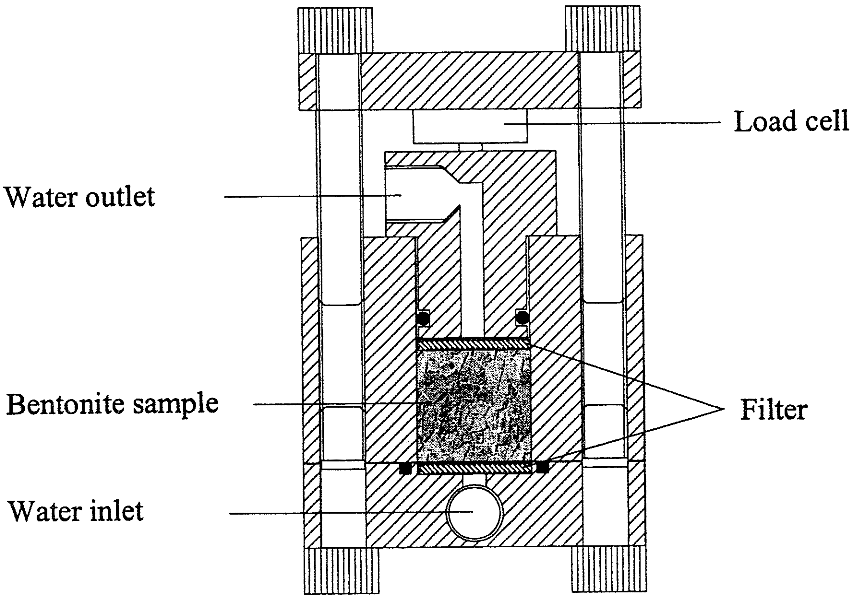

Figure 5-1. *Schematic drawing of the swelling pressure oedometer used for determination of swelling pressure and hydraulic conductivity.*

Triaxial tests:

Shear strength data are required for predicting the rheological behavior of the buffer. The shear strength (τ_f) of a soil can be expressed as a linear function of the effective normal stress (σ'_f) on critical planes:

$$\tau_f = c' + \sigma'_f \cdot \tan \phi'$$

where the cohesion intercept (c′) and the angle of shearing resistance (ϕ') are the shear parameters. In order to determine these parameters triaxial apparatus will be used (figure 5-2). The samples will be equilibrated for about one week before the shear tests will be started. The shearing will be made under undrained conditions with the cell pressure (σ_3) adapted to the swelling pressure arrived at in the oedometer tests and applied back pressure (u).

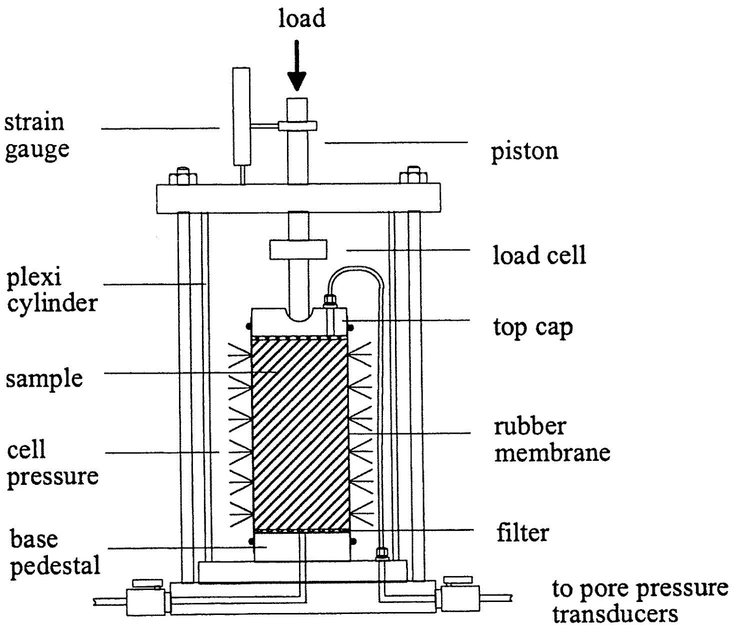

Figure 5.2. *Triaxial test equipment used for determining the clay shear parameters, clay swelling pressure and rock hydraulic conductivity.*

5.1.8 Bacteria tests and analyses

Cultivation of bacteria:

Methods used for culturing of bacteria will follow earlier published protocols from Lundberg laboratory, Göteborg University. See following publications for more information: Pedersen and Ekendahl 1990.

Molecular analysis:

Methods used for molecular analysis of bacteria will follow earlier published protocols from Lundberg laboratory, Göteborg University, adapted to buffer as was done at URL. See following publications for more information: Ekendahl et al 1993, Stroes-Gascoyne et al. 1995.

Activity measurements:

Methods used for measuring the activity of bacteria will follow earlier published protocols from Lundberg laboratory, Göteborg University. See following publication for more information: Pedersen et al 1991.

5.2 SUPPORTING PROJECT TASKS

5.2.1 Rock tests

Cores from the pilot drilling will be examined with respect to hydraulic conductivity in laboratory tests in order to get boundary conditions for modeling of the water uptake progress. A triaxial tests program will be made for the species of stone of current interest.

5.2.3 Gas tests

Oedometer tests will be used in order to find an appropriate gas injection technique. The purpose is i.a. to exclude wall transport of gas. A more complete laboratory clay test setup will be constructed with the same radial dimensions as the field tests. The setup will include measurement of total pressure, water pressure, temperature and equipment for gas injection.

5.3 TIME SCHEDULE

The mapping of the G tunnel has been made. The drilling of the pilot holes are planned to start in January 1999 and will be followed the characterization of the holes. The selection of gauges will be made in January parallel to the selection for the Prototype project. The block manufacturing are planned to start in March and the first parcel will be mounted and emplaced in May 1999. The subsequent parcels are planned to be placed with an interval of 2 weeks. Detailed plans are shown in the HRL Plan Right document.

6 PROJECT ORGANIZATION AND RESOURCE REQUIREMENTS

6.1 ORGANIZATION

The project will be organized in accordance with the guidelines given in the quality Handbook for the Äspö HRL. The project manager will be Ola Karnland, Clay Technology Lund, the microbiological part of the project will be run by Karsten Pedersen, Göteborg University, and the radionuclide tests by Trygve Eriksen, Royal Institute of Technology Stockholm, who also is responsible for handling of radioactive material. Lennart Börgesson is responsible for the water saturation modeling, which will be made at FEMTECH (Västerås). Responsible for the copper tests will preliminary be Bo Rosborg at Studsvik Material AB. Torbjörn Sandén will be responsible for the mechanical parts (construction of block compaction device, block production and parcels construction, parcel mounting etc) and Mats Collin will be responsible for the instrumentation and data acquisition system.

6.2 DATA MANAGEMENT

The data collected during the parcel preparation and data from laboratory analyses and tests will be stored at CT in Lund and delivered to Äspö HRL. All data will be accompanied with a description of how it is collected and formatted. The field test data will be stored in the Äspö data base and at CT in Lund. The project manager is responsible for the accuracy and collecting frequency and the Äspö HRL for handling and storing.

6.3 REPORTING

The documentation will be made in the following four classes:

- Activity logs
- Technical notes
- Progress reports
- Final report

Technical notes will be made to support important decisions. Foreseen are notes in before summer 1999 concerning pilot hole characterization. A progress report describing the parcel construction and emplacement will be made in the fall 1999. Technical notes will be produced every six month concerning results and functioning of the running tests. A progress report concerning predictions of the water saturation and tests and analyses will be delivered before the end of 1999.

6.4 COST

The total costs for the Long Term Test is estimated to be 12 MSEK. The major parts is concentrated to the start during 1999 and to the termination during 2004.

REFERENCES

Börgesson L., Johannesson L.-E., Sandén T., Hernelind J., 1995. Modelling of the physical behaviour of water saturated clay barriers. SKB TR 95-20, SKB, Stockholm, Sweden.

Börgesson L., Johannesson L.-E. 1995. Thermo-hydro-mechanical modelling of water unsaturated buffer material. SKB TR 95-32, SKB, Stockholm, Sweden

Eberl D.D., Velde B. and McCormic T., 1993. Synthesis of illite-smectite from smectite at earth surface temperatures and high pH. Clay Minerals 28, 49-60.

Ekehdahl S., Arlinger J., Ståhl F., Pedersen K. (1993) Carbon transformations in deep granitic groundwater by attached bacterial populations characterized with 16S rRNA gene sequencing technique and scanning electron microscopy. SKB Technical Report 93-22.

Wersin P., Spahiu K., Bruno J. (1994) Kinetic modelling of bentonite-canister interaction. Long-term predictions of coper canister corrosion under oxic and anoxic conditions. SKB Technical Report 94-25. SKB Stockholm, Sweden.

Huang W.-L., Longo J.M. and Pevear D.R., 1993. An experimentally derived kinetic model for smectite-to-illite conversion and its use as a geothermometer. Clays and Clay Minerals 41, 162-177.

Johannesson L.-E., Bögesson L., Sandén T., 1995. Compaction of bentonite blocks. SKB TR 95-19. SKB Stockholm, Sweden.

Karnland O., Warfvinge P., Pusch R., 1995. Smectite-to-illite conversion models. SKB AR 95-27. SKB Stockholm, Sweden.

Karnland O. 1995:2. Salt redistribution and enrichment in compacted bentonite exposed to a thermal gradient. SKB AR 95-31, SKB, Stockholm, Sweden.

Karnland O. 1997. Cement/bentonite interaction - Results from 16 months laboratory tests. SKB TR 97-32, SKB Stockholm, Sweden.

Laaksoharju M., Pedersen K., Rhen I., Skårman C., Tullborg E.-L., Wallin B. and Wikberg W. 1995. Sulphate reduction in the Äspö HRL tunnel. SKB Technical Report 95-25. SKB Stockholm, Sweden.

Milodowski A.E., Kemp S.J., Pearce J.M., Hughes C.R., 1991. Characterisation of bentonite alteration in reacted cement-bentonite blocks from swelling-test experiments. Interner Bericht 91-33. NAGRA, Baden, Schweiz.

Motamedi M., Karnland O. and Pedersen K. 1995. Survival of bacteria in nuclear waste buffer materials - The influence of nutrients, temperature and water activity. SKB Technical Report 95-27. SKB Stockholm, Sweden.

Neretnieks I. 1983. Approximate calculations of what happends with oxygen that is entrappedin the repository at the time of its enclosure. In corrosion resistance of a copper canister for spent nuclear fuel. The Swedish corrosion Research Institute and its referens group.

Pedersen K., Ekendahl S. 1990. Distribution and activity of bacteria in deep granitic groundwaters of southeastern Sweden. Microbial Ecology (20) 37-52.

Pedersen K., Ekendahl S., Arlinger J. 1991. Microbes in crystalline bedrock: Assimilation of CO_2 and introduced organic compounds by bacterial population in groundwater from deep crystaline bedrock at Laxemar and Stripa. SKB Technical report 91-56. SKB Stockholm, Sweden.

Pedersen K., Karlsson F. 1995. Investigations of subterranean bacteria - Their importance for performance assessment of radioactive waste disposal. SKB Technical Report 95-10. SKB Stockholm, Sweden.

Pusch R. 1983. Use of clays as buffers in radioactive repositories. SKB Technical Report 83-46. SKB Stockholm, Sweden.

Pusch R., Forsberg T. 1983. Gas migration through bentonite clay. SKB AR 94-61. SKB Stockholm, Sweden.

Pusch R., L. Ranhagen, K. Nilsson. 1985. Gas migration through MX-80 bentonite. NAGRA TR 85-36.

Stroes-Gascoyne S., Pedersen K., Daumas S., Hamon CJ., Haveman TL., Ekendahl S., Jahromi N., Arlinger J., Hallbeck L., Dekeyser K. 1995. Microbial analysis of the buffer/container experiment at AECL´s Unerground research laboratory. Atomic Energy Canada Limited (AECL) report, 11436, COG-95-446. AECL, Whiteshell laboratories, Pinawa.

Wersin P., Spahiu K., Bruno J. (1994) Time evolution of dissolved oxygen and redox conditions in a HLW repository. SKB Technical Report 94-02. SKB Stockholm, Sweden.

Wersin P., Spahiu K., Bruno J. (1994) Kinetic modelling of bentonite-canister interaction. Long-term predictions of coper canister corrosion under oxic and anoxic conditions. SKB Technical Report 94-25. SKB Stockholm, Sweden.

Wersin P., Bruno J., Spahiu K. (1993) Kinetic modelling of bentonite-canister interaction. Implications for Cu, Fe and Pb corrosion in a repository for spent nuclear fuel. SKB Technical Report 94-25. SKB Stockholm, Sweden.