Analysis of groundwater from deep boreholes in Svartboberget

Sif Laurent

Swedish Environmental Research Institute
Stockholm, Sweden 1983-06-10

ANALYSIS OF GROUNDWATER FROM DEEP BOREHOLES IN SVARTBOBERGET

Sif Laurent

IVL, Swedish Environmental Research Institute
Stockholm, Sweden 1983-06-10

A list of other reports published in this series during 1983 is attached at the end of this report. Information on KBS technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17) and 1982 (TR 82-28) is available through SKBF/KBS.

ANALYSIS OF GROUNDWATER FROM DEEP BOREHOLES IN SVARTBOBERGET

Sif Laurent, IVL, Swedish Environmental Research Institute,
Stockholm, 1983-06-10

SUMMARY

Groundwater from two boreholes in granitic rock at an investigation site in Svartboberget has been sampled and analysed. This is part of a larger program of geological, geophysical and hydrogeological investigations aimed at finding a suitable site for a high level radioactive waste repository.

Four water-bearing levels in each borehole down to the deepest at about 600 m were selected. Prior to sampling, the water-bearing level is isolated between packer sleeves. The water is then pumped to the surface where sensitive parameters such as redox potential, pH, sulphide and oxygen content are measured electrochemically on the flowing water in a system isolated from the air. Water, filter and gas samples are sent to several laboratories for further analysis.

The present report is a presentation of the results of the groundwater analyses. The reliability of the results is discussed but there is no evaluation in relation to geology and hydrogeology. This report presents the basic results from the groundwater analyses to be further evaluated by experts in different fields.

CONTENTS

ANALYSIS OF GROUNDWATER FROM DEEP BOREHOLES IN SVARTBOBERGET

1 INTRODUCTION

Groundwater from two boreholes in Svartboberget has been sampled and analyzed. The sampling levels were chosen on the basis of hydological measurements in the boreholes. Sampling was carried out by Sveriges Geologiska AB. Personnel from IPK and VIAK performed the field measurements and sampling. Several laboratories participated in the water analysis (see below).

The boreholes were pumped out with a gas lift prior to the hydrological investigation and immediately before the equipment for water sampling was lowered to the first sampling level. On the latter occasion, three gas lift pumpings - called mammoth pumpings - were performed in a row. Iodide (NaI, 0.01 mmol/l) was added to the drilling water during drilling to enable any residual drilling water to be traced in the groundwater. The selected fracture zones were sealed off by packers spaced at a distance of 2.7 m.

The work was carried out in periods of 14 days - lowering and start of the sampling pump, 4 days off and 9 days field measurements. When the supply of water is adequate, approximately 4.5 m^3 can be pumped up during one period.

Sampling was carried out in SV4 during April-May and in SV5 during October-December 1982. Four levels were sampled in each of the boreholes. Depth is given both as vertical depth (depth) and/or as borehole length (length). It is always vertical depth that is given, unless otherwise specified in the table heading.

The present report consists primarily of a presentation of the results of the groundwater analyses from SV4. The isotope conditions and the chemical composition of the sampled waters from SV5 indicate massive contamination by near-surface waters, which intruded during the sampling procedure due to some mishap - presumably via the borehole. The analyses from SV5 are therefore not presented in this report. A further investigation of the conditions at Svartboberget should, however, include renewed sampling in SV5 or supplementary sampling in some nearby borehole.

The reliability of the results is subjected to some scrutiny. There is, however, no evaluation in relation to geology or hydrology. The material in this report will be further analyzed by experts in different fields.

The geology and hydrology of the study area are described in KBS TR 83-55.

A general description of the chemistry of the groundwater from great depths in granite and gneiss has previously been published by G. Jacks (KBS TR 88). The same author has also described the chemistry of groundwater in Blekinge (KBS TR 79-07), where Sternö is situated. The results of analyses of the groundwater from Finnsjön, Gideå and Fjällveden are presented in KBS TR 82-23, 83-17 and 83-19, respectively. A geochemical evaluation of fracture minerals and the relation between fracture minerals and groundwater composition in Finnsjön has been published by E-L Tullborg and co-workers (KBS TR 82-20). The relationship between pH and carbonate content in deep groundwaters is discussed by Bert Allard in KBS TR 82-25. The expected groundwater composition and its importance for the final storage of radioactive waste are discussed in KBS TR 90 and the final report KBS-2 Volume 2 (Handling and Final Storage of Unreprocessed Spent Nuclear Fuel, Technical Volume). Hydrology and groundwater age are also taken up in the latter report. The sampling equipment is described in KBS TR 83-44.

2 SAMPLING

2.1 Drilling water

Some of the drilling water that is used in the core drilling of the sampling holes can penetrate into rock fractures and contaminate the groundwater there. In order to get rid of the drilling water to as great an extent as possible prior to sampling, three mammoth pumpings (using nitrogen gas) are performed immediately prior to installation of the sampling equipment.

The sampling equipment (2.2) is lowered to the chosen level and allowed to work for 3-4 days before sampling begins. Periodic sampling during a period of 8-9 days makes it possible to follow changes in the composition of the water that might derive from drilling water or some other source of contamination. The changes may also be due to the incursion of water from different aquifers.

Water from percussion-drilled boreholes has been used as drilling water. The drilling water was filtered through mechanical filters of cellulose (18 CMC 3-2), which are supposed to retain particles with diameters larger than 5 μm. The filtered drilling water was then analyzed. The results for the boreholes in question are presented at the bottom of the respective tables (tables 5, 6 and 8).

Before the drilling water was used, it was "marked" by the addition of sodium iodide (0.01 mmol/l in the drilling water) in order to make sure that it would be possible to trace any drilling water that may have contaminated the sampled water. Unfortunately, it has been found that both the drilling water and sampled groundwater can have considerable contents of natural iodide (KBS TR 83-17). Iodide was not determined in the drilling waters in question, but due to the low chloride content of the water, the natural content of iodide can be expected on good grounds to be very low. In Stripa, for example, 3×10^{-4} mg of iodide per mg of chloride has been observed.

2.2 Sampling equipment

The boreholes are core-drilled with a diameter of 56 mm. The 2.7 m long sampling zone is sealed off by rubber packers that are expanded to a pressure of 0.8-1 MPa above the groundwater pressure. The sampling pump is positioned immediately above the sealed-off zone.

The intake is from the upper part of the zone. The pump, which is made of steel and furnished with teflon seals, has a maximum capacity of 0.12 l/stroke, equivalent to 330 l/d. The water flow available for sampling decreases if the flow of water in the measured rock is lower than the capacity of the pump. A schematic illustration of the sampling pump and packers is shown in Fig. 1.

The water is pumped up through teflon-lined iron pipes to a test chamber of stainless steel on the ground surface. The test chamber is equipped with electrodes and measuring cells for recording pH, Eh (glassy carbon), Eh (platinum), pS, oxygen content and conductivity. The test chamber is also equipped with valves for the extraction of water samples.

2.3 Procedure

Work at the boreholes is conducted in periods of 14 days. On the last day of a period, the sampling equipment is set up at the level that is to be sampled during the following period, and the sampling pump is started. The personnel then go home for four days off while the sampling pump works. Sampling then proceeds for 8-9 consecutive days.

2.4 Water flow during sampling

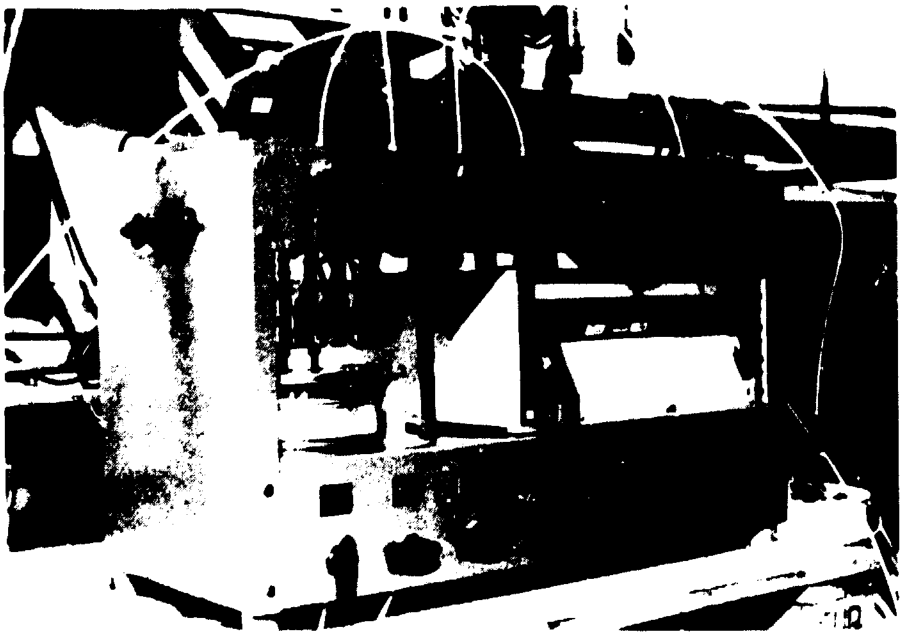
The water flow at different levels is shown in the table below. The approximate pumped-up water volume has also been calculated. "Prior" refers to the quantity of water pumped up from the level before sampling started, and "Sampl." to the quantity of water during the sampling period.

BH	Depth m	Mean flow l/day	Prior m^3	Sampl. m^3	Total m^3
SV4	82	295	1	2.6	3.6
	324	295	1.5	2.6	4.1
	373	295	1.5	2.6	4.1
	551	260	1.3	2.6	3.9

3 FIELD MEASUREMENTS

The field measurements are recorded in table 1, the E^0 values obtained from the field calibrations in table 2 and the field values obtained during water sampling in table 3.

The photograph below shows the field equipment with test chamber, measuring equipment and valves for water sampling.



3.1 Calibrations

Each calibration has been assigned a calibration number. Measurements made after the calibration have the same number.

All calibration solutions are freshly prepared from concentrate and deaerated distilled water. During calibration, the solutions are circulated through the test chamber.

Three buffer solutions with pH 4, 7 and 10 are used for calibration of the pH electrode. Quinhydrone is added to the buffer solutions with pH 4 and 7 for simultaneous calibration of the Eh electrodes.

Concentrate diluted to solutions that are 0.01 and 0.05 molar with respect to sulphide ion is used for calibration of the sulphide electrode. The E^o values obtained are presented in table 2.

The oxygen probe is calibrated against air-saturated distilled water and the conductivity cell against 0.01 and 0.1 mol/l KCl.

3.2 Measurement results

Each measuring occasion is identified with a calibration number, borehole designation, length of borehole (core length) as well as day and time. The vertical depths corresponding to the borehole lengths are shown in the table below.

Borehole	Length m	Depth m
SV4	96	82
	376	324
	430	373
	630	551

Owing to the fact that it takes some time after each calibration before the water in the test chamber is representative of the borehole water and before the Eh and pS values have stabilized, no measurement results have been included until at least 24 hours after the calibration - in general, from and including the second day after calibration. Nor are values included that have been obtained from obviously unsuccessful measurements owing to problems encountered in the field.

Conductivity values are lacking due to delayed delivery of the measuring instrument.

3.3 Temperature measurement

The temperature is measured in the test chamber to permit calibration and calculation of the electrode potentials.

Owing to the relatively slow rate of water turnover in the test chamber, the temperature measured is not representative of the groundwater. It is theretore not reported.

3.4 Measurement of pH, Eh and pS

The system often seems to need to remain undisturbed for about a week before the Eh and pS values are more or less stable. The pH value normally stabilizes much faster. In the beginning of SV4, which was the first borehole to be sampled with this equipment, much too frequent calibrations were made. No field measurements are therefore included from the uppermost level.

The calibrations show that the electrodes must be cleaned relatively frequently. Normally, they are cleaned when they are lowered to a new level. Electrodes were also cleaned prior to calibrations 17, 20 and 21. The optimum time between two calibrations is probably between 7 and 10 days.

3.5 Oxygen measurement with probe

In connection with the calibrations starting with SV4, 551 m, the reading of the oxygen probe in the air-saturated water before adjustment was noted. In two cases, the error was found to be more than 20%. Oxygen values before such a calibration have been omitted. It appears as if the oxygen probe has to be recalibrated more frequently than is possible according to 3.4 in order for reliable results to be obtained.

Despite the difficulties encountered in oxygen measurement, the field values often show good correlation with pS, high oxygen content - high pS (low sulphide content).

4 MAIN COMPONENTS OF THE WATER

Each sampling occasion has been assigned a unique sampling number, which is the same for all samples taken on the same occasion ("No." in the tables).

The main components were analyzed by SGAB's water laboratory in Uppsala and by Hydroconsult in Stockholm. The analysis results are presented in tables 3-6. The table below shows which laboratory carried out the analyses and which method was used. Where there are two analyses of the same parameter, the mean value is reported.

	SGAB	H-con.		SGAB	H-con.
pH	*	*	HCO_3	g	b
Cond.	*	*	Cl	i	h
Turb.		*	F	i	k
Ca	a	b	SO_4	i	j
Mg	a		PO_4		f
Na	a	c	NO_3		f
K	a	c	NO_2		f
Mn	a	d	NH_4		f
Fe(II)	e	e	SiO_2	m	m
Fe-tot	a		S	n	r
Al		f	I	o	
Cu	a		TOC	p	q
Sr	a				

*	Conventional according to Swedish standard (SS)
a	Optical emission with ICP (own design)
b	Titrimetric with EDTA according to SS
c	Emission with flame
d	Atomic absorption
e	Colorimetric with o-phenanthroline according to Standard Methods
f	Colorimetric according to SS
g	Specially designed titrator
h	Titration according to Mohr (SS), high concentrations only
i	Ion chromatograph, for chloride, low concentrations only

j	Turbidity measurement according to the Swedish Environment Protection Board
k	Potentiometrically according to SS
m	Colorimetrically with methylene blue according to Standard Methods
n	Potentiometrically
o	Colorimetrically, higher concentrations also potentiometrically
p	Carbon analyzer from Carlo-Erba
q	Carbon analyzer from Oceanographic
r	Colorimetrically on Zn-preserved sample according to SS (starting with No. 306)

The field values obtained simultaneously with the water sampling and the laboratory analyses of the same parameters are presented in table 3. Note that the field values, which are measured during water sampling, are often not representative of the borehole. Sampling may, for example, have been done immediately after a calibration.

The date is given for both the sampling day and the day the samples were received at the laboratories. In both cases, the date is given with the number of the week followed by the number of the day of the week. Day 1 is Monday.

All determinations of metal ions are presented in table 4, while table 6 shows TOC, turbidity and the negative ions that do not contain nitrogen.

The parameters that contain nitrogen are compiled in table 5. The analysis results are given as the concentration of the ion and the concentration of nitrogen.

"Drilling water residue, I%" (table 6) is the percentage fraction of the added iodide concentration in the drilling water (2.1) that has turned up in the groundwater. No correction is made for the water's natural iodide content (2.1).

If the redox-sensitive parameters are excepted, the concentrations within the levels are relatively uniform, even though there are certain trends.

4.1 Sampling

The water samples were taken through a valve immediately after the test chamber. On each sampling occasion, a new tube, kept well protected from dust, was attached to the valve. The free and untouched end of the tube was inserted down to the bottom of the sample bottle. At least two bottle volumes of sample water were allowed to run over before the bottle was sealed, without any air having been trapped inside. The samples were kept in a refrigerator awaiting transport (4.2).

4.1.1 Unpreserved samples for analyses of negative ions etc. were taken in bottles of borosilicate glass (1 litre) with a ground, filled stopper held in place with a steel clip. In order to keep the ground surface moist so that no air can leak through, the bottles were stored and transported upside-down.

4.1.2 Preserved samples for analysis of metal ions were taken in acid-washed polyethylene bottles (250 ml).

The samples were preserved with 2.5 ml of concentrated hydrochloric acid (super-pure). The acid was added through a dispenser below the sample surface immediately before the sample bottle was sealed. Hydrochloric acid was chosen as a preservative because iron(II) was to be determined.

Only occasionally are the anlysis results specified to more than two decimal places. No adjustment has therefore been made for dilution of the samples with acid.

4.2 Transport of samples

The samples were packed in specially-made insulated boxes with frozen blocks. The boxes were mailed "express" on the afternoon of the sampling day and delivered to the laboratory the following morning. No water sampling took place on Fridays and Saturdays, since the samples could then not be taken care of by the laboratory until Monday or Tuesday. The Sunday samples were sent together with the Monday samples.

4.3 pH

pH was determined directly in the field and by both laboratories (table 3). Field values are systematically around 5% higher than the laboratory values. A similar difference has been noted in many groundwaters. There is also a small systematic difference between the laboratories, which may be attributable to the fact that Hydroconsult, which notes the lower value, thermostated its samples at 25°C for measurement.

The differences within the levels are small, as a rule. The highest difference, 0.3 pH points was measured in SV4, 324 m.

4.4 Conductivity

Conductivity was only measured in the laboratories in this round of sampling. There is a systematic difference of 4% between the laboratories.

4.5 Organic carbon (TOC)

No parameter exhibits such large differences between the laboratories as TOC - SGAB's results are often more than twice Hydroconsult's results. Control analysis at two Swedish laboratories comes closer to verifying SGAB's high results, while analysis at a laboratory in the United States, which specializes in the determination of humic and fulvic acids, confirmed Hydroconsult's low values. The mean value is reported to only one decimal place (table 6).

The concentrations are low throughout (normally 1-3 mg/l) except in SV4, 324 m where the concentration drops from 30 to 10 mg/l. High concentrations may be due to the fact that the borehole has been contaminated during drilling.

4.6 Negative ions

The negative ions are compiled in tables 5 and 6. The results generally show good consistency within the sampling zones, although trends do occur.

Sample 109 (SV4, 324 m) has an unexpectedly high concentration of nitrate and phosphate, which is only matched by a slightly elevated ammonia concentration. The iron concentration is low in comparison.

4.7 Positive ions

The positive ions are compiled in table 4. Agreement within the levels is good here as well, despite the fact that trends are common.

4.7.1 Lanthanum, neodymium and ytterbium were determined in the same samples as strontium. In all cases, the concentrations were below the detection limit (<0.005 mg/l).

5 PARTICULATE MATTER

The particulate matter was subjected to several different types of analyses (5.1-5.5).

5.1 Chemical composition

The water was filtered through a membrane filter (Millipore, pore diameter 0.45 µm) installed directly after the test chamber. The filtered volume is shown in the table below. The total concentration on the membrane was determined by X-ray fluorescence at SGU's (the Geological Survey of Sweden) laboratory in Luleå. The concentrations are presented below as mg/l of filtered sample. The quantity of copper, strontium, lanthanum, neodymium and ytterbium was below the detection limit (1, 1, 3, 2 and 2 µg, respectively).

Borehole	Depth m	No	Sample ml	S, prt mg/l	Fe, prt mg/l	Al, prt mg/l
SV4	82	103	2250	.0004	.007	.0036
SV4	82	105	2250	.0004	.002	.0022
SV4	324	109	700	.0014	.080	.27
SV4	324	111	1900	.0011	.095	.19
SV4	373	114	2250	.0009	.62	.12
SV4	373	116	2000	.0010	.80	.11
SV4	551	120	2000	.0030	.039	.0340
SV4	551	122	1350	.0067	.15	.027

5.2 Tubidity

Turbidity (table 6) was determined by Hydroconsult in the samples from SV4, 551 m.

5.3 Humic and fulvic acids

A sample from the deepest level in SV4 was analyzed. The determination was performed at Batelle, USA, through combined dialysis and gel film chromatography (GFC). The method, which fractionates the sample into humic acids and four molecular weight fractions of fulvic acid, is described by Means et al 1977 (Limnol. Oceanogr., 22, 957-965). Sodium tetraborate (pH 9.1) was used on recommendation by Swift and Posner 1971 (J. Soil Science, 22, 237-249).

Owing to the sample's low content of organic matter, it was concentrated 10 times before analysis. No loss of volatile organic matter was found in connection with the concentration process.

No humic acids were present in the sample. The percentage distribution of the fulvic-acid-like substances in different molecular weight fractions is shown in the table below.

Level	No.	>1000	700-1000	300-700	<300
SV4,551m	122	41	40	9	10

According to Means, the results strongly indicate that the most important organic constituents are hydrophilic polymeric substances with low to medium molecular weights - probably fulvic acids or similar substances, which are the predominant substances in natural waters.

6 ISOTOPE ANALYSIS

Isotope analysis of light substances in the water is done mainly to permit calculations of the age and origin of the water. The heavy radioactive substances are determined primarily because the natural background concentrations are of great interest for the KBS project.

The analyses were carried out at the following laboratories:

Laboratory for Isotope Geology, Stockholm (6.1, 6.3)
Institute for Radiohydrometry, Neuherberg, West Germany (6.2, 6.4)
Studsvik Energiteknik, Nyköping (6.5)

6.1 Carbon isotopes

The determination was used for dating by means of the carbon 14 method. The water's contents of carbon dioxide and carbonate have to be concentrated before the determination. It is thereby of the utmost importance that the concentrate not be contaminated by chemicals or contact with air. Sample No. 311 may have been contaminated by air during transport.

6.1.1 Sample preparation is done in the field. A polyethylene barrel holding 130 l and filled from the beginning with nitrogen is filled with water. Hydrochloric acid is added to disintegrate carbonates present in the water. A nitrogen gas stream is then used to drive the carbon dioxide over to a wash bottle containing carbonate-free sodium hydroxide.

6.1.2 Groundwater age is presented in the table below as "Age BP" and age after correction for the carbon-13 content as "Age BP, corr".

Borehole	Depth m	No.	Age BP	Age BP corr	C-13 o/oo
SV4	324	110	14700	14820	-17.3
	373	116	12820	12935	-17.8
	551	122	13080	13210	-16.8

6.2 Deuterium and oxygen

The analyses can furnish information on the climatic conditions prevailing at the time of infiltration.

The concentrations in the table refer to deviations in per mill from SMOW (Standard Mean Oceanic Water). The analyses were performed in West Germany.

Borehole	Depth m	No.	H-2	0-18
SV4	82	105	-90	-12.51
SV4	324	110	-95.3	-13.22
SV4	373	116	-95	-13.09
SV4	551	122	-95.4	-13.10

6.3 Tritium

Owing to its short half-life (about 12 years), tritium is an important isotope in hydrologic studies. The amount of tritium in the atmosphere has increased drastically due to experiments with nuclear fission. The tritium content of rainwater has increased by more than 10 times, which makes it possible to determine whether "young" water is present in a groundwater sample.

Borehole	Depth m	No.	Tr TU
SV4	82	105	5
SV4	324	110	<3
SV4	373	116	<3
SV4	551	122	<3

The tritium content is given in the tables in the unit TU, which is the number of tritium atoms per 10^{18} hydrogen atoms.

No tritium determination was carried out on the drilling water used here.

6.4 Uranium, thorium, radium and radon

The natural concentration of these elements in the groundwater is of great interest for the project. The following results were obtained:

Bore-hole	Depth m	No.	Th ug/l	U Bq/l	Ra-226 Bq/l	Rn-222 Bq/l
SV4	82	105	<1.9 E-1	(8.8±0.5)E-2	(3.7±1.2)E-3	316±5
SV4	324	110	<1.6 E-1	<2.5 E-3	(1.2±0.3)E-3	87±9
SV4	373	116	<5.8 E-2	<4.8 E-3	(1.5±0.6)E-3	105±5
SV4	551	122	<6.6 E-2	<2.4 E-3	<1.4 E-3	76±3

The concentrations for U, Ra and Rn are given in Bq/l. The following relationships apply:

39.4 μg U per Bq
2.74×10^{-5} μg Ra-226 per Bq
1.76×10^{-10} μg Rn-222 per Bq

7 GAS ANALYSIS

Helium was determined in the gas that spontaneously leaves the water on its passage through a Horst bottle. The analysis was carried out by AGA SpecialGas, Lidingö, Sweden. No gas sample was taken from the uppermost levels.

In the table below, besides the percentage content of helium in the gas phase, the amount of water that has passed through the Horst bottle is also given. This enables the reader to form his own rough idea of the quantity of dissolved gases in the water. The helium content of the water has not been calculated, since degassing is dependent on a number of uncontrolled parameters. We know, for example, that temperature variations of >20°C occur in the tent where the borehole opens out and the sampling equipment is located. Data on gas volume are lacking, but according to AGA, no less than 50 ml is analyzed.

Borehole	Depth m	No.	Helium %	Water volume l
SV4	373	116	0.091	47
	551	122	0.11	50

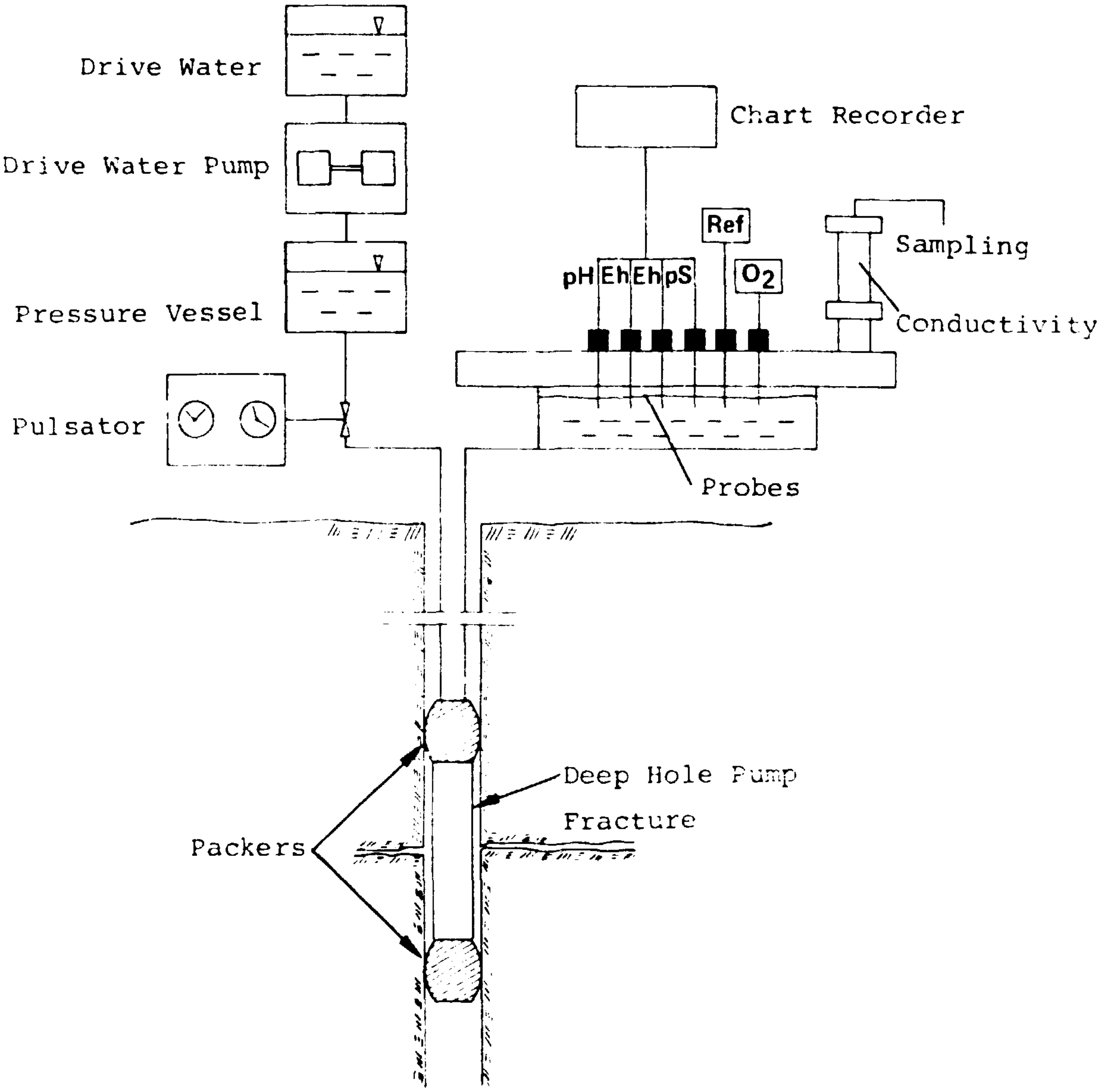


Figure 1. Schematic illustration of sampling equipment

Table 1

SVARTBOBERGET - Field measurements

Calibration nr	Borehole	Hole-length m	Date ww-d	Time	Oxygen mg/1	pH	Eh,C mV	Eh,Pt mV	pS
12	SV4	376							
			16-4	845	.02	9.6	-144	-110	13.9
			16-4	1050	.00	9.5	-182	-128	13.4
			16-4	1410	.00	9.5	-185	-134	13.2
13	SV4	376							
			17-1	740	.00	7.2	-113	-104	17.2
			17-1	930	.01	7.2	-128	-116	16.3
			17-1	1100	.01	7.2	-129	-118	16.0
			17-1	1200	.01	7.2	-129	-121	15.8
			17-1	1400	.01	7.2	-133	-124	15.6
			17-1	1601	.02	7.2	-142	-132	15.1
			17-2	656	.00	7.2	-138	-132	13.5
			17-2	800	.12	7.2	-141	-124	13.5
			17-2	925	.00	7.2	-145	-136	13.1
			17-2	1110	.00	7.2	-145	-137	13.0
			17-2	1220	.03	7.2	-144	-136	12.9
			17-3	735	.01	7.2	- 83	- 63	15.3
16	SV4	430							
			18-3	900	.29	9.1	- 48	- 39	18.5
			18-3	1040	.30	9.1	- 51	- 44	18.3
			18-3	1246	.23	9.1	- 54	- 47	18.1
			18-3	1340	.21	9.1	- 55	- 49	18.1
			18-4	800	.14	9.1	- 63	- 60	17.2
			18-4	945	.09	9.1	- 72	- 69	16.8
			18-4	1100	.11	9.1	- 75	- 72	16.6
			18-4	1240	.09	9.1	- 77	- 74	16.5
			18-4	1429	.09	9.1	- 74	- 74	16.5
			18-4	1530	.08	9.1	- 79	- 77	16.4
			18-5	713	.03	9.1	- 91	- 87	15.7
			18-5	900	.05	9.5	- 96	- 94	15.4
			18-5	1215	.06	9.1	- 95	- 93	15.3
17	SV4	430							
			18-7	814	.18	9.1	- 57	- 49	19.4
			18-7	920	.18	9.1	- 58	- 52	19.3
18	SV4	430							
			19-1	1633	.35	9.0	- 64	- 58	18.7
			19-1	1843	.17	9.1	- 74	- 73	18.1
			19-1	2000	.11	9.0	- 75	- 74	18.1
			19-2	816	.16	9.1	- 69	- 64	18.4
			19-2	940	.09	9.1	- 69	- 64	18.3
			19-2	1103	.12	9.1	- 69	- 64	18.3
20	SV4	630							
			20-2	1200	.05	9.1	-125	-109	20.4
			20-2	1355	.04	9.1	-134	-128	18.2
			20-2	1545	.14	9.1	-134	-129	17.1
			20-3	835	.04	9.0	-135	-134	15.2
			20-3	1037	.03	9.0	-138	-136	15.1
			20-3	1345	.03	9.1	-137	-136	14.9
			20-3	1540	.03	9.1	-138	-137	14.9
			20-3	1745	.06	9.1	-137	-139	14.8
			20-4	815	.01	9.1	-141	-141	14.4
			20-4	925	.01	9.1	-142	-141	14.4
21	SV4	630							
			20-5	725	.01	9.0	-160	-148	16.0
			20-5	800	.11	9.1	-160	-149	15.8
			20-5	958	.16	9.0	-159	-149	15.3
			20-5	1105	.20	9.0	-159	-150	15.1
			20-5	1300	.10	9.1	-159	-149	14.7
			20-5	1458	.10	9.1	-158	-149	14.5
			20-6	725	.01	9.1	-158	-149	13.4
			20-6	942	.02	9.1	-158	-149	13.3
			20-6	1256	.02	9.2	-160	-150	13.2
			20-6	1353	.40	9.1	-159	-151	13.1
			20-6	1555	.02	9.1	-157	-152	13.1
			20-7	755	.04	9.1	-159	-148	12.7
			20-7	900	.01	9.1	-160	-149	12.7
22	SV4	630							
			21-2	714	.01	9.0	-140	-122	14.5
			21-2	915	.01	9.0	-143	-124	14.3
			21-2	1105	.04	9.0	-144	-125	14.2
			21-2	1250	.03	9.0	-145	-124	14.0
			21-2	1435	.10	9.0	-148	-127	13.9
			21-2	1550	.01	9.0	-148	-127	13.8
			21-2	1750	.00	9.0	-149	-126	13.8
			21-2	1900	.15	9.0	-149	-126	13.7
			21-3	716	.00	9.0	-152	-125	13.2
			21-3	840	.65	8.9	-153	-125	13.1
			21-3	1040	.02	9.1	-155	-127	13.0
			21-3	1143	.04	9.1	-154	-126	12.9

Table 2

SVARTBOBERGET - E^{o}-values

Bore-hole	Hole-length m	Cali-bration nr	Date ww-d	Glass pH4 mV	Glass pH7 mV	Glass pH10 mV	C pH4 mV	C pH7 mV	Pt pH4 mV	Pt pH7 mV	Ag,S 0.01M mV	Ag,S 0.05M mV
SV4	96											
		1	14-1	391.5	400.0	401.5	268.5	252.6	266.5	257.1	-866.8	-855.9
		2	14-2	390.2	397.3	400.9	257.1	248.2	273.1	248.2		
		3	14-3	411.8	422.1	424.7	261.9	248.0	259.9	248.0	-841.3	-845.3
		4	14-4	397.1	401.5	403.8	253.3	248.5	251.3	247.5	-845.1	-844.9
		5	14-5	392.4	394.9	397.6	259.6	251.[illegible]	254.6	250.9	-817.7	-827.0
		6	14-6	400.1	401.6	402.8	254.5	247.2	248.5	246.2	-843.3	-844.6
		7	14-7	396.1	400.6	404.4	250.5	246.2	247.5	244.2	-834.7	-831.0
		8	15-1	393.9	398.7	400.4	250.6	248.1	249.6	247.1	-827.0	-830.4
		9	15-2	391.7	403.2	404.8	259.2	246.3	251.2	244.3		
SV4	376											
		10	16-1	389.1	404.6	401.5	253.5	245.1	252.5	245.1		
		11	16-2	396.3	398.8	401.4	253.2	245.3	250.2	246.3	-871.2	-865.8
		12	16-3	403.6	404.8	402.5	241.0	240.7	244.0	241.7		-867.7
		13	16-5	391.1	396.9	394.5	250.5	245.2	251.5	247.2	-848.7	-856.4
SV4	430											
		14	17-3				242.0	243.2	242.0	241.2		-857.0
		15	18-1	391.7	398.5	396.8	244.5	240.7	248.5	241.7	-850.9	-851.1
		16	18-2		391.2			242.7		243.7	-769.1	-762.1
		17	18-5	395.6	392.7	393.4	244.8	247.5	245.8	248.5	-816.7	-830.4
		18	18-7	386.3	393.6	391.1	255.0	247.2	257.0	248.2	-819.5	-825.6
SV4	630											
		19	19-3	373.4	383.5	387.7	267.5	253.5	271.5	259.5	-802.3	-820.5
		20	20-1	383.9	387.9	391.1	249.6	246.2	249.6	244.2	-815.1	-817.7
		21	20-4	378.5	388.7	387.1	251.5	248.1	254.5	250.1	-818.5	-817.4
		22	20-7	358.2	380.5	387.7	257.1	253.0	264.1	259.0	-818.1	-807.7

Table 3

SVARTBOBERGET - Field measurements and corresponding laboratory values

Bore-hole	Depth m	Hole-length m	No	Date sampling yy-ww-d	Date lab ww-d	pH field	pH lab	Eh,C field mV	EH,Pt field mV	pS field	S2- lab mg/l	Cond lab mS/m	Oxygen field mg/l
SV4	82	96											
			101	82-14-2	14-3	8.4	8.1	40	71	23.1	<.01	23	.38
			102	82-14-3	14-4	8.3	8.1	55	100	24.0	<.01	23	30
			103	82-14-6	15-3	8.6	8.2	45	42	23.2	<.01	23	58
			104	82-14-7	15-3	8.5	8.2	61	53	22.5	<.01	23	18
			105	82-15-1	15-3	8.4	8.2	51	50	22.2	<.01	23	.42
			106	82-15-2	15-3	8.6	8.3	37	45	23.0	<.01	23	.48
SV4	324	376											
			107	82-16-2	18-3	9.6	9.2	-104	- 37	18.5	.07	25	.01
			108	82-16-3	16-5	9.6	9.1	-170	- 79	16.3	<.01	24	.01
			109	82-16-7	17-2		9.1	- 37	- 4	20.5	.03	25	.06
			110	82-17-1	17-2		9.0	-132	-122	15.6	.03	23	.01
			111	82-17-2	17-3		8.9	-144	-136	13.0	<.01	23	.02
SV4	373	430											
			112	82-18-2	18-3	9.1	8.8	34	28	20.1	<.01	22	00
			113	82-18-3	18-4	9.1	8.7	- 53	- 46	18.3	<.01	23	27
			114	82-18-4	18-5	9.1	8.7	- 77	- 74	16.5	<.01	23	09
			115	82-18-7	19-2	9.1	8.7	- 23	- 9	20.2	<.01	23	00
			116	82-19-1	19-2	9.1	8.7	- 54	- 47	18.9	<.01	23	23
SV4	551	630											
			117	82-20-1	20-2	9.0	8.7	- 41	- 37	17.5	<.01	23	05
			118	82-20-2	20-3	9.1	8.7	-134	-128		<.01	23	04
			119	82-20-2	20-5	9.1	8.8	-138	-138	14.9	<.01	23	03
			120	82-20-4	20-5	9.0	8.8	- 38	- 18	20.0	<.01	23	00
			121	82-20-7	21-2	9.0	8.7	- 85	- 64	17.2	<.01	24	00
			122	82-21-1	21-2	9.1	8.7	-112	-103	15.7	<.01	23	.50
			123	82-21-2	21-3	9.0	8.7	-148	-127	13.9	05	23	10
			124	82-21-3	21-4	9.1	8.7	-155	-127	13.0	.02	23	02

Table 4

SVARTBOBERGET - Metal ions

Bore-hole	Depth m	Length m	No	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Mn mg/l	Fe2+ mg/l	Fe-tot mg/l	Al mg/l	Cu mg/l	Sr mg/l
SV4	82	96											
			101	25	3.3	23	1.7	.04	.07	.23	.02		
			102	25	2.9	23	1.7	.04	.08	.21	.02		
			103	25	2.9	23	1.7	.05	.03	.22	.04	< .005	.078
			104	25	3.0	23	1.7	.05	.04	.22	.04		
			105	25	3.2	24	1.7	.05	.04	.22	.03	< .005	.078
			106	25	3.3	23	1.7	.04	.07	.21	.04		
SV4	324	376											
			107	9	.8	50	.9	.02	.11	.46	<.02		
			108	11	1.1	47	.9	.02	.16	.49	<.02		
			109	10	1.1	48	.7	.02	.06	.32	<.02	< .005	.035
			110	13	1.7	40	.8	.03	.21	.49	<.02		
			111	15	1.9	36	.7	.03	.09	.50	<.02	< .005	.060
SV4	373	430											
			112	17	1.7	35	.9	.05	.17	.72	<.02		
			113	18	1.9	35	.9	.05	.22	.71	<.02		
			114	18	2.0	35	.9	.05	.29	.73	<.02	< .005	.069
			115	18	2.0	35	.9	.05	.40	.71	<.02		
			116	17	2.0	35	.9	.05	.25	.69	<.02	< .005	.066
SV4	551	630											
			117	17	2.0	35	.9	.05	.16	.56	<.02		
			118	17	1.8	35	.9	.04	.46	.61	<.02		
			119	17	1.8	35	.8	.05	.40	.64	<.02		
			120	17	1.5	35	.9	.05	.17	.56	<.02	< .005	.067
			121	17	1.6	35	.8	.04	.26	.53	<.02		
			122	17	1.9	35	.7	.04	.27	.44	<.02	< .005	.062
			123	16	2.1	36	.7	.04	.32	.49	<.02		
			124	16	2.0	36	.7	.03	.32	.45	<.02		

Table 5

SVARTBOBERGET - Nitrogen containing ions

Bore-hole	Depth m	Length m	No	NO2 mg/l	NO3 mg/l	NH4 mg/l	NO2-N mg/l	NO3-N mg/l	NH4-N mg/l	Sum-N mg/l
SV4	82	96								
			101	.004	.020	.022	.001	.005	.017	.023
			102	.004	.020	.022	.001	.005	.017	.023
			103	<.002	.035	.025	<.001	.008	.019	.028
			104	<.002	.025	.020	<.001	.006	.016	.022
			105	<.002	.025	.025	<.001	.006	.019	.026
			106	.002	.030	.025	.001	.007	.019	.027
SV4	324	376								
			107	<.002	.055	.020	<.001	.012	.016	.029
			108	<.002	.090	.010	<.001	.020	.008	.029
			109	.002	.300	.045	.001	.068	.035	.103
			110	.004	.020	.025	.001	.005	.019	.025
			111	.005	.035	.025	.002	.008	.019	.029
SV4	373	430								
			112	<.002	.060	.020	<.001	.014	.016	.030
			113	<.002	.070	.020	<.001	.016	.016	.032
			114	<.002	.050	.035	<.001	.011	.027	.039
			115	.005	.025	.020	.002	.006	.016	.023
			116	.005	.025	.020	.002	.006	.016	.023
SV4	551	630								
			117	.004	.025	.010	.001	.006	.008	.015
			118	<.002	.030	.010	<.001	.007	.008	.015
			119	.004	.045	.010	.001	.010	.008	.019
			120	<.002	.030	.010	<.001	.007	.008	.015
			121	<.002	.025	.010	<.001	.006	.008	.014
			122	<.002	.030	.020	<.001	.007	.016	.023
			123	<.002	.030	.010	<.001	.007	.008	.015
			124	.004	.030	.015	.001	.007	.012	.020

Table 6

SVARTBOBERGET - Remaining anions and other parameters

Bore-hole	Depth m	Length m	No	HCO3 mg/l	Cl mg/l	F mg/l	SO4 mg/l	PO4 mg/l	SiO2 mg/l	Turb. NTU	TOC mg/l	Drilling water residue, I%
SV4	82	96										
			101	140	2.3	2.3	2.0	.005	12		3	.9%
			102	140	2.2	2.3	2.0	.005	12		4	.9%
			103	139	2.3	2.2	1.9	.005	12		3	.8%
			104	138	2.4	2.2	1.9	.006	11		3	1.0%
			105	138	2.3	2.2	1.9	.005	11		3	1.0%
			106	138	2.2	2.2	1.8	.005	12		3	.6%
SV4	324	376										
			107	128	11	6.3	1.3	.86	7.1		30	4.3%
			108	124	10	5.9	1.0	.76	6.1		30	4.2%
			109	125	11	6.2	.7	1.04	8.8		16	3.0%
			110	127	9	5.1	.8	.41	8.1		12	1.9%
			111	129	7	4.7	.8	.27	8.5		10	1.3%
SV4	373	430										
			112	131	6	4.4	1.0	.080	9.1		3	9%
			113	130	6	4.2	1.0	.070	9.1		3	.7%
			114	131	7	4.5	1.0	.065	9.2		3	.6%
			115	130	7	4.6	1.0	.070	9.5		3	6%
			116	130	8	4.7	1.2	.070	9.3		3	1.0%
SV4	551	630										
			117	128	7	4.2	1.0	.080	7.8	5.1	5	.6%
			118	128	7	4.2	.9	.075	8.0	5.5	5	6%
			119	129	7	4.2	.9	.085	8.3	8.0	5	.5%
			120	129	7	4.4	.9	.085	8.4	14.0	5	5%
			121	127	7	4.7	.8	.085	8.2	3.4	5	6%
			122	126	7	4.7	.8	.080	8.2	4.1	4	6%
			123	126	8	4.8	1.6	.085	7.5	4.7	4	.6%
			124	127	8	4.8	1.3	.080	7.5	4.9	4	.6%

LIST OF KBS's TECHNICAL REPORTS

1977-78

TR 121 KBS Technical Reports 1 - 120.
Summaries. Stockholm, May 1979.

1979

TR 79-28 The KBS Annual Report 1979.
KBS Technical Reports 79-01--79-27.
Summaries. Stockholm, March 1980.

1980

TR 80-26 The KBS Annual Report 1980.
KBS Technical Reports 80-01--80-25.
Summaries. Stockholm, March 1981.

1981

TR 81-17 The KBS Annual Report 1981.
KBS Technical Reports 81-01--81-16
Summaries. Stockholm, April 1982.

1983

TR 83-01 Radionuclide transport in a single fissure
A laboratory study
Trygve E Eriksen
Department of Nuclear Chemistry
The Royal Institute of Technology
Stockholm, Sweden 1983-01-19

TR 83-02 The possible effects of alfa and beta radiolysis
on the matrix dissolution of spent nuclear fuel
I Grenthe
I Puigdomènech
J Bruno
Department of Inorganic Chemistry
Royal Institute of Technology
Stockholm, Sweden January 1983

TR 83-03 Smectite alteration
Proceedings of a colloquium at State University of New York at Buffalo, May 26-27, 1982
Compiled by Duwayne M Anderson
State University of New York at Buffalo
February 15, 1983

TR 83-04 Stability of bentonite gels in crystalline rock - Physical aspects
Roland Pusch
Division Soil Mechanics, University of Luleå
Luleå, Sweden, 1983-02-20

TR 83-05 Studies in pitting corrosion on archeological bronzes - Copper
Åke Bresle
Jozef Saers
Birgit Arrhenius
Archaeological Research Laboratory
University of Stockholm
Stockholm, Sweden 1983-01-02

TR 83-06 Investigation of the stress corrosion cracking of pure copper
L A Benjamin
D Hardie
R N Parkins
University of Newcastle upon Tyne
Department of Metallurgy and Engineering Materials
Newcastle upon Tyne, Great Britain, April 1983

TR 83-07 Sorption of radionuclides on geologic media - A literature survey. I: Fission Products
K Andersson
B Allard
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-31

TR 83-08 Formation and properties of actinide colloids
U Olofsson
B Allard
M Bengtsson
B Torstenfelt
K Andersson
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-30

TR 83-09 Complexes of actinides with naturally occurring organic substances - Literature survey
U Olofsson
B Allard
Department of Nucluear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-02-15

TR 83-10 Radiolysis in nature:
Evidence from the Oklo natural reactors
David B Curtis
Alexander J Gancarz
New Mexico, USA February 1983

TR 83-11 Description of recipient areas related to final storage of unreprocessed spent nuclear fuel
Björn Sundblad
Ulla Bergström
Studsvik Energiteknik AB
Nyköping, Sweden 1983-02-07

TR 83-12 Calculation of activity content and related properties in PWR and BWR fuel using ORIGEN 2
Ove Edlund
Studsvik Energiteknik AB
Nyköping, Sweden 1983-03-07

TR 83-13 Sorption and diffusion studies of Cs and I in concrete
K Andersson
B Torstenfelt
B Allard
Department of Nuclear Chemistry
Chalmers University of Technology
Göteborg, Sweden 1983-01-15

TR 83-14 The complexation of Eu(III) by fulvic acid
J A Marinsky
State University of New York at Buffalo, Buffalo,NY
1983-03-31

TR 83-15 Diffusion measurements in crystalline rocks
Kristina Skagius
Ivars Neretnieks
Royal Institute of Technology
Stockholm, Sweden 1983-03-11

TR 83-16 Stability of deep-sited smectite minerals in crystalline rock - chemical aspects
Roland Pusch
Division of Soil Mechanics, University of Luleå
1983-03-30

TR 83-17 Analysis of groundwater from deep boreholes in Gideå Sif Laurent
Swedish Environmental Research Institute
Stockholm, Sweden 1983-03-09

TR 83-18 Migration experiments in Studsvik
O Landström
Studsvik Energiteknik AB
C-E Klockars
O Persson
E-L Tullborg
S Å Larson
Swedish Geological
K Andersson
B Allard
B Torstenfelt
Chalmers University of Technology
1983-01-31

TR 83-19 Analysis of groundwater from deep boreholes in
Fjällveden
Sif Laurent
Swedish Environmental Research Institute
Stockholm, Sweden 1983-03-29

TR 83-20 Encapsulation and handling of spent nuclear fuel
for final disposal
1 Welded copper canisters
2 Pressed copper canisters (HIPOW)
3 BWR Channels in Concrete
B Lönnerberg, ASEA-ATOM
H Larker, ASEA
L Ageskog, VBB
May 1983

TR 83-21 An analysis of the conditions of gas migration
from a low-level radioactive waste repository
C Braester
Israel Institute of Technology, Haifa, Israel
R Thunvik
Royal Institute of Technology
November 1982

TR 83-22 Calculated temperature field in and around a
repository for spent nuclear fuel
Taivo Tarandi, VBB
Stockholm, Sweden April 1983

TR 83-23 Preparation of titanates and zeolites and their
uses in radioactive waste management, particularly
in the treatment of spent resins
Å Hultgren, editor
C Airola
Studsvik Energiteknik AB
S Forberg, Royal Institute of Technology
L Fälth, University of Lund
May 1983

TR 83-24 Corrosion resistance of a copper canister for
spent nuclear fuel
The Swedish Corrosion Research Institute and its
reference group
Stockholm, Sweden April 1983

TR 83-25 Feasibility study of EB welding of spent nuclear
fuel canisters
A Sanderson, T F Szluha, J Turner
Welding Institute
Cambridge, United Kingdom April 1983

TR 83-26 The KBS UO_2 leaching program
Summary Report 1983-02-01
Ronald Forsyth, Studsvik Energiteknik AB
Nyköping, Sweden February 1983

TR 83-27 Radiation effects on the chemical environment
in a radioactive waste repository
Trygve Eriksen
Royal Institute of Technology, Stockholm
Arvid Jacobsson
University of Luleå, Luleå
Sweden 1983-07-01

TR 83-28 An analysis of selected parameters for the
BIOPATH-program
U Bergström
A-B Wilkens
Studsvik Energiteknik AB
Nyköping, Sweden 1983-06-08

TR 83-29 On the environmental impact of a repository for
spent nuclear fuel
Otto Brotzen
Stockholm, Sweden April 1983

TR 83-30 Encapsulation of spent nuclear fuel -
Safety Analysis
ES-konsult AB
Stockholm, Sweden April 1983

TR 83-31 Final disposal of spent nuclear fuel -
Standard programme for site investigations
Compiled by
Ulf Thoregren
Swedish Geological
April 1983

TR 83-32 Feasibility study of detection of defects in thick
welded copper
Tekniska Röntgencentralen AB
Stockholm, Sweden April 1983

TR 83-33 The interaction of bentonite and glass with
aqueous media
M Mosslehi
A Lambrosa
J A Marinsky
State University of New York
Buffalo, NY, USA April 1983

TR 83-34 Radionuclide diffusion and mobilities in compacted
bentonite
B Torstenfelt
B Allard
K Andersson
H Kipatsi
L Eliasson
U Olofsson
H Persson
Chalmers University of Technology
Göteborg, Sweden April 1983

TR 83-35 Actinide solution equilibria and solubilities in
geologic systems
B Allard
Chalmers University of Technology
Göteborg, Sweden 1983-04-10

TR 83-36 Iron content and reducing capacity of granites and
bentonite
B Torstenfelt
B Allard
W Johansson
T Ittner
Chalmers University of Technology
Göteborg, Sweden April 1983

TR 83-37 Surface migration in sorption processes
A Rasmuson
I Neretnieks
Royal Institute of Technology
Stockholm, Sweden March 1983

TR 83-38 Evaluation of some tracer tests in the granitic rock at Finnsjön
L Moreno
I Neretnieks
Royal Institute of Technology, Stockholm
C-E Klockars
Swedish Geological, Uppsala
April 1983

TR 83-39 Diffusion in the matrix of granitic rock
Field test in the Stripa mine. Part 2
L Birgersson
I Neretnieks
Royal Institute of Technology
Stockholm, Sweden March 1983

TR 83-40 Redox conditions in groundwaters from Svartboberget, Gideå, Fjällveden and Kamlunge
P Wikberg
I Grenthe
K Axelsen
Royal Institute of Technology
Stockholm, Sweden 1983-05-10

TR 83-41 Analysis of groundwater from deep boreholes in Svartboberget
Sif Laurent
Swedish Environmental Research Institute
Stockholm, Sweden 1983-06-10

TR 83-42 Final disposal of high-level waste and spent nuclear fuel - foreign activities
R Gelin
Studsvik Energiteknik AB
Nyköping, Sweden May 1983

TR 83-43 Final disposal of spent nuclear fuel - geological, hydrological and geophysical methods for site characterization
K Ahlbom
L Carlsson
O Olsson
Swedish Geological
Sweden May 1983

TR 83-44 Final disposal of spent nuclear fuel - equipment for site characterization
K Almén, K Hansson, B-E Johansson, G Nilsson
Swedish Geological
O Andersson, IPA-Konsult
P Wikberg, Royal Institute of Technology
H Åhagen, SKBF/KBS
May 1983