

**SKB**

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**TECHNICAL  
REPORT**

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**88-28**

**Radionuclide transport in a single  
fissure**

**A laboratory flow system for tran-  
sport under reducing conditions**

Trygve E Eriksen

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December 1988

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## RADIONUCLIDE TRANSPORT IN A SINGLE FISSURE

A laboratory flow system for transport under reducing conditions

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Department of Nuclear Chemistry

December 1988

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RADIONUCLIDE TRANSPORT IN A SINGLE FISSURE.

A laboratory flow system for transport under reducing conditions.

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TABLE OF CONTENTS.

ABSTRACT	i
TABLE OF CONTENTS	ii
	Page
1. INTRODUCTION	1
2. EXPERIMENTAL	2
2.1 Flow system	2
2.2 Rock material	3
2.3 Solutions	3
2.4 Tracer measurements	6
3. RESULTS	7
3.1 Lignosulfonate ion	7
3.2 Technetium	9
4. DISCUSSION	11
5. CONCLUSION	13
6. REFERENCES	14
FIGURE LEGENDS	16
FIGURES	

ABSTRACT.

A flow system for laboratory studies of radionuclide transport in natural fissures in granitic rock under reducing conditions is described. The system based on the use of synthetic ground water equilibrated with granitic rock in a well sealed system, allow experiments to be carried out at -240mV. In flow experiments with technetium the retardation was found to be dependent on the method used for reducing  $\text{TcO}_4^-$ .

## 1. INTRODUCTION.

The study of radionuclide migration through rock is currently of great interest due to its relevance to the possible escape paths into the biosphere of radionuclides released from high level radioactive wastes buried in deep geological repositories.

While water will provide the vehicle for transportation, interaction with geological material may greatly influence the radionuclide movement relative that of water. The identity and thereby the geochemical reactivity of the compounds formed by the radionuclides will depend on the oxidation state of the radionuclides, the redox properties of the ground water and surrounding rock, the pH and concentration of complexing agents in the water. In our earlier studies of radionuclide migration in granitic drill-cores containing natural fissures (Neretnieks, Eriksen and Tähtinen 1982), (Eriksen 1985), (Moreno, Neretnieks and Eriksen, 1985) all but one of the experiments were carried out under oxic conditions. The conditions in a repository will, however, as indicated by the measured redox potentials of deep ground waters be reducing (Wikberg, 1987). The present work describes a laboratory flow system which allows experiments to be carried out under reducing conditions and some experiments carried out with  $^{99}\text{Tc}$  and  $^{99\text{m}}\text{Tc}$ .

The long lived fission product  $^{99}\text{Tc}$  ( $t_{1/2} = 2.1 \cdot 10^5$  years) is present in large quantities in nuclear waste. Under oxidizing

condition technetium is existing in solution as  $\text{TcO}_4^-$  but is expected to exist as Tc(IV) in a reducing environment. Whereas no or very little sorption of  $\text{TcO}_4^-$  occurs on geologic material Tc(IV)-species may possibly be sorbed. Experiments were therefore carried out with reduced  $^{99\text{m}}\text{Tc(VII)}$  to obtain information on the sorption of Tc(IV) on granite rock.

## 2. EXPERIMENTAL.

### 2.1 Flow system.

Reducing water can be obtained in laboratory, as demonstrated by Wikberg (1987) by contacting deoxygenated water with granitic rock in a well sealed vessel. Our experimental set up (Fig. 1) is therefore based on the use of granitic rock to secure low Eh of the synthetic water used in our flow experiments. The synthetic ground water, equilibrated with crushed granitic rock in a water reservoir, is fed through granitic drill-cores containing natural fissures by means an encapsulated HPLC-pump. All connecting tubes are of stainless steel quality and the drill-cores are encapsulated in a plexiglas cylinder continuously flushed with argon to avoid any oxygen leakage into the system.

Prior to any tracer experiment water from the reservoir was circulated through the entire flow system for several days to equilibrate the fissure surfaces. The redox potential was continuously monitored with Pt or Ag/AgCl electrodes during the equilibration. The tracer experiments were initiated by connecting an injection loop initially containing

3.40 cm<sup>3</sup> tracer solution to the flow system. During the tracer experiments the effluent from the drill-core was fed continuously to a fractional collector for analysis. The waterflow was characterized by a nonsorbing tracer.

## 2.2 Rock-material.

The rock sample used in our experiments is granitic rock from the Stripa mine taken at a depth of 360 m below ground level. The drill-core (37 mm diameter, 126 mm long) used in the present experiments had a natural fissure running parallel to the axis. The cylindrical surfaces of the drill-core were sealed with a coat of polyurethane lacquer, and fitted with plexiglas endplates containing shallow inlet and outlet channels slightly wider than the fissures.

## 2.3 Technetium solutions.

Determination of the Tc(IV) concentration in the effluent by the use of <sup>99</sup>Tc as tracer would be very difficult due to the low solubility of Tc(IV),  $2.6 \cdot 10^{-9}$  mol·dm<sup>-3</sup> according to Meyer et al (1987, 1988), and the long half life of <sup>99</sup>Tc (see Table 2). The experiments were therefore carried out using the short lived  $\gamma$ -emitter <sup>99m</sup>Tc as tracer and <sup>99</sup>Tc as "carrier" to regulate the overall initial Tc-concentration.



Table 1

Characteristics of tracers used.

Tracer	Half-life	Mode of decay	Measured
Lignosulfonate ion (LS <sup>-</sup> ) mol wt 24 000			Optical abs. at 280 nm. $\epsilon$ 3.10 M <sup>-1</sup> cm <sup>-1</sup>
<sup>99</sup> Tc	2.1·10 <sup>5</sup> y	$\beta^-$	
<sup>99m</sup> Tc	6 h	IT	$\gamma$ (0.14 MeV)

The radionuclides used were <sup>99</sup>Tc delivered as TcO<sub>4</sub><sup>-</sup> in 0.1 mol·dm<sup>-3</sup> aqueous NH<sub>4</sub>OH solution from Amersham and <sup>99m</sup>Tc recovered as TcO<sub>4</sub><sup>-</sup> in 0.4 mol·dm<sup>-3</sup> aqueous NaCl solution from a <sup>99</sup>Mo generator (Kjeller). Most radionuclide solutions were prepared by diluting stock solutions with artificial ground water, synthesized according to the composition given in Table 2.

Table 2

Composition of synthetic ground water <sup>a)</sup> used in the flow experiments.

Species	Concentration mg·dm <sup>-3</sup>	Species	Concentration mg·dm <sup>-3</sup>
HCO <sub>3</sub> <sup>-</sup>	123	Ca <sup>2+</sup>	18
SO <sub>4</sub> <sup>2-</sup>	9.5	Mg <sup>2+</sup>	4.3
Cl <sup>-</sup>	70	K <sup>+</sup>	3.9
SiO <sub>2</sub> (total)	12	Na <sup>+</sup>	65

a) ph = 8.2, Eh -240 mV

Two different procedures were used to reduce the TcO<sub>4</sub><sup>-</sup>

1) The reduction was carried out by means of H<sub>2</sub>(Pd). The hydrogen gas was freed from oxygen by bubbling the gas through an aqueous solution containing Hg/Zn, HCl and CrCl<sub>3</sub>. Solutions containing two different total Tc concentrations were used in the experiments.

a)  $3 \cdot 10^{-12}$  mol·dm<sup>-3</sup> <sup>99m</sup>Tc,

b)  $3 \cdot 10^{-12} \text{ mol} \cdot \text{dm}^{-3} \text{ } ^{99\text{m}}\text{Tc}$ ,  $1 \cdot 10^{-7} \text{ mol} \cdot \text{dm}^{-3} \text{ } ^{99}\text{Tc}$

2) The reduction was carried out using a redox-buffer with measured reduction potential  $-520 \text{ mV}$  versus a saturated calomel electrode. The composition is given in Table 3. The initial Tc concentrations, i.e before reduction, were  $1 \cdot 10^{-11} \text{ mol} \cdot \text{dm}^{-3} \text{ } ^{99\text{m}}\text{Tc}$  and  $1 \cdot 10^{-8} \text{ mol} \cdot \text{dm}^{-3} \text{ } ^{99}\text{Tc}$ .

Table 3

Composition of redox-buffer solution a).

Species	Concentration $\text{mg} \cdot \text{dm}^{-3}$	Species	Concentration $\text{mg} \cdot \text{dm}^{-3}$
$\text{NaHCO}_3$	1 680	$\text{CaCO}_3$	10 mg (tot)
$\text{Na}_2\text{CO}_3$	76	$\text{FeSO}_4$	88
KCl	10		

a) pH = 8.2, Eh  $-520 \text{ mV}$  versus saturated calomel electrode

#### 2.4 Tracer measurements.

Sodium lignosulfonate (NaLS) with a mean molecular weight of 24000 was used as nonsorbing tracer. The  $\text{LS}^-$  ion displays a

strong optical absorption band with maximum at 280 nm ( $\epsilon \approx 3 \cdot 10^5 \text{ M}^{-1} \text{ cm}^{-1}$ ) and the  $\text{LS}^-$  concentration was monitored photometrically at this wavelength. The concentration of  $^{99\text{m}}\text{Tc}$  in the effluent was determined from measurements of its  $\gamma$ -radiation using a (2-x2 in.-) NaI well type detector. The  $^{99\text{m}}\text{Tc}$ -activity on the fissure surfaces was measured with a planar (2-x2 in.) NaI detector fitted with a 7x37 mm lead collimator.

### 3. RESULTS.

#### 3.1 Lignosulfonate.

The lignosulfonate ( $\text{LS}^-$ ) concentration-time curve is plotted in Figure 3a . The tracer solution loop volume was  $3.40 \text{ cm}^3$  and the volume of the tube between the tracer loop and the sampling point of the fractional collector was  $0.36 \text{ cm}^3$  (see Fig. 2).

The fissure volume can be calculated from the  $\text{LS}^-$  data using the equation

$$V_f = q_w \cdot t_w \quad (1)$$

where  $V_f$  = fissure volume ( $\text{cm}^3$ )

$q_w$  = water flux ( $\text{cm}^3 \cdot \text{min}^{-1}$ )

$t_w$  = residence time of  $\text{LS}^-$  in fissure (min)

The volumes of the flow system are given in Figure 2, the water flux was  $0.42 \text{ cm}^3 \cdot \text{min}^{-1}$  and the measured residence time

(Fig 3a) is 16.5 min. Thus, taking into account the time delay caused by the tube volume we obtain

$$V_f = 0.42(16.5 - 3.4/2 \cdot 0.42 - 0.360/0.42) = 4.87 \text{ cm}^3$$

Based on the simple assumption of parallel, plane fissure surfaces the fissure width and the surface area/volume ratio is given by the equation

$$\delta = V_f/d \cdot l \quad (2)$$

$$a = 2 \cdot d \cdot l / V_f = 2/\delta \quad (3)$$

where  $a$  = surface area/volume ratio (cm)

$d$  = drill core diameter (cm)

$l$  = drill core length (cm)

$\delta$  = fissure width (cm).

The flow parameters calculated from the LS<sup>-</sup> break through curve are given in Table 4.

Table 4

Drill-core parameters calculated from  $LS^-$  flow data.

Fissure volume ( $V_f$ ) $cm^3$	Fissure surface ( $A_f$ ) $cm^2$	Fissure width ( $\delta$ ) cm	$A_f/V_f$ $cm^{-1}$
4.87	93.2	0.105	19.1

### 3.2 Technetium.

The measured potential of the ground water was in the range  $-(485-495)$  mV versus the saturated calomel electrode during all experiments. For solution (a) with very low overall Tc-concentration no change in  $^{99m}Tc$  activity on reduction with  $H_2/(Pd)$  was observed and as can be seen from the break-through curves in Figure 3b no delay in the  $^{99m}Tc$  migration relative to  $LS^-$  was observed. On adding  $10^{-7}$  mol·dm $^{-3}$   $^{99}Tc$  as carrier a brownish deposit was formed on the electrode and the  $^{99m}Tc$  activity in the solution was lowered by about 50 per cent on reduction. No delay in the  $^{99m}Tc$  transport through the fissure was, however, observed (Fig. 3c).

In earlier experiments with a redox-buffer (method 2) a significant retardation ( $R=40$ ) in the  $^{99m}Tc$  migration through a natural granitic fissure was observed (Eriksen, 1985).

In the present experiment, the tracer solution was prepared using the same redox-system but artificial ground water was used to eluate the  $^{99m}\text{Tc}/^{99}\text{Tc}$ . During the reduction more than 95 per cent of the  $^{99m}\text{Tc}/^{99}\text{Tc}$  was precipitated. No  $^{99m}\text{Tc}$  was detected in the effluent during 50 minutes eluation.

The fissure was thereafter opened and the  $^{99m}\text{Tc}$  activity on the fissure surfaces measured. From the activity data plotted in Figure 4 and the  $\text{LS}^-$  data we can calculate the  $^{99m}\text{Tc}$  retardation using the equation

$$R = (V_w/V_f) \cdot (l/X_{rm})$$

where  $V_w$  = volume of water and tracer solution pumped through fissure ( $\text{cm}^3$ )

$V_f$  = volume of fissure ( $\text{cm}^3$ )

$l$  = length of fissure (cm)

$X_{rm}$  = mean distance travelled by the radio-nuclide (cm)

The experimental Tc-data are summarized in Table 5, together with results obtained in earlier experiments (Eriksen 1985).

Table 5

Experimental transport parameters calculated from effluent  $^{99m}\text{Tc}$ -activity-time curves and activity distribution on fissure surfaces.

Radionuclide sol.	$^{99m}\text{Tc}$ a)	$^{99}\text{Tc}$ a)	$A_f/V_f$	Retardation
Method of red.	$\text{mol}\cdot\text{dm}^{-3}$	$\text{mol}\cdot\text{dm}^{-3}$	$\text{cm}^{-1}$	R
-----				
$\text{H}_2(\text{Pd})$	$3\cdot 10^{-12}$			1
	$3\cdot 10^{-12}$	$10^{-7}$		1
Redox-buffer (see Table 2)	$3\cdot 10^{-11}$	$10^{-8}$	19.1	14
$\text{TcO}_4^{-\text{b}}$		$3\cdot 10^{-6}$	52.4	1
Redox-buffer b) ( -280 mV)			41.6	40
-----				

a) initial conc., before reduction

b) Eriksen 1985

#### 4. DISCUSSION.

All Tc-experiments were carried out using reducing synthetic ground water with  $E_h \approx -240$  mV. The great differences in retardation obtained in the experiments are therefore somewhat



astonishing, but must be due to differences in the reduction procedures used. According to Meyer et al (1987, 1988) the reduction potential  $E^{\circ}$  for the Tc(VII)-Tc(IV) redox couple is 0.747 V and the solubility of Tc(IV) species  $2.56 \cdot 10^{-9} \text{ mol} \cdot \text{dm}^{-3}$ . Very little, if any  $\text{TcO}_4^-$  should therefore be present in the reducing ground water used in our experiments.

The reduction potential of the  $\text{H}_2(\text{Pd})$  system is given by  $Eh(\text{V}) = -0.059 \cdot \text{pH} - 0.0295 \cdot \log \text{H}_2$ . At equilibrium the potential of the reducing solution should therefore be -484 mV, assuming  $p(\text{H}_2) = 1$ , ie much lower than the potential of the synthetic ground water. A possible explanation may therefore be that  $\text{TcO}_4^-$  was reduced to lower oxidation states eg Tc(III).

The retardation R calculated from the flow data obtained in experiments with  $\text{TcO}_4^-$  reduced in the redox-buffer system with  $Eh = -280 \text{ mV}$  agree, within a factor two with the retardation obtained in earlier experiments when the  $A_f/V_f$  ratio is taken into account.

It is evident from the experimental results that the reduction procedure is of great importance. The time required to reduce Tc(VII) also indicates very sluggish redox reactions.

Electrodeposition of Tc(IV) oxides at a well defined potential and equilibration of the electrodeposited Tc(IV)-oxides with ground water may possibly be the preferred technique to obtain well defined tracer solutions. The dynamic of the  $\text{TcO}_4^-$  reduction is to be studied in further experiments.

#### 5. CONCLUSION.

Flow experiments can be carried at Eh -240 mV in synthetic ground water.

The preparation of the tracer solutions is crucial, as some of the redox-reactions may be very slow. The dynamics of the Tc(VII) reduction and also speciation need to be carried out in separate experiments.

#### ACKNOWLEDGEMENTS.

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6. REFERENCES.

Eriksen T E

A Laboratory Study of Radionuclide Migration in  
Single Natural Granitic Fissures.

Nuclear Technology 70, 261 (1985).

Meyer R E, Arnold W D and Case F I

The Solubility of Electrodeposited Tc(IV) Oxides.

NUREG/CR-4685, ORLN-6374.

Oak Ridge National Laboratory (1987).

Meyer R E, Arnold W D, Case F I and O'Kelley G D

Thermodynamic Properties of TC(IV) Oxides: Solu-  
bility and the Electrode Potential of the  
Tc(VII)/Tc(IV)-Oxide Couple.

NUREG/CR-5108, ORNL-6480.

Oak Ridge National Laboratory (1988).

Moreno L, Neretnieks I, Eriksen T E

Analysis of some laboratory tracer runs  
in natural fissures.

Water Resources Res 21:4, 951 (1985).

Neretnieks I, Eriksen T E, Tähtinen P

Tracer Movement in a Single Fissure in Granitic  
Rock: Some Experimental Results and Their Inter-  
pretation.

Water Resources Res 18:4, 849 (1982).

Wikberg P

The chemistry of deep ground water in crystalline  
rock.

Dissertation, The Royal Institute of Technology,  
Stockholm (1987).

FIGURE LEGENDS.

Figure 1 Schematics of experimental set up for flow experiments through granitic drill-cores containing natural fissures.

Figure 2 Details of flow system. Volumes of sample injection system.

Figure 3 Break through curves obtained with 10 min tracer pulse, flow  $0.43 \text{ cm}^3 \cdot \text{min}^{-1}$ , sampling time 1 min

a)  $\text{LS}^-$ , b)  $^{99\text{m}}\text{Tc}_{\text{Tot}} * \text{Tc} - 3 \cdot 10^{-12} \text{ mol} \cdot \text{dm}^{-3}$

c)  $^{99\text{m}}\text{Tc}_{\text{Tot}} * \text{Tc} - 1 \cdot 10^{-7} \text{ mol} \cdot \text{dm}^{-3}$

\* concentration before reduction of  $\text{TcO}_4^-$

Figure 4  $^{99\text{m}}\text{Tc}$  distribution on fissure walls after 50 minutes eluation.

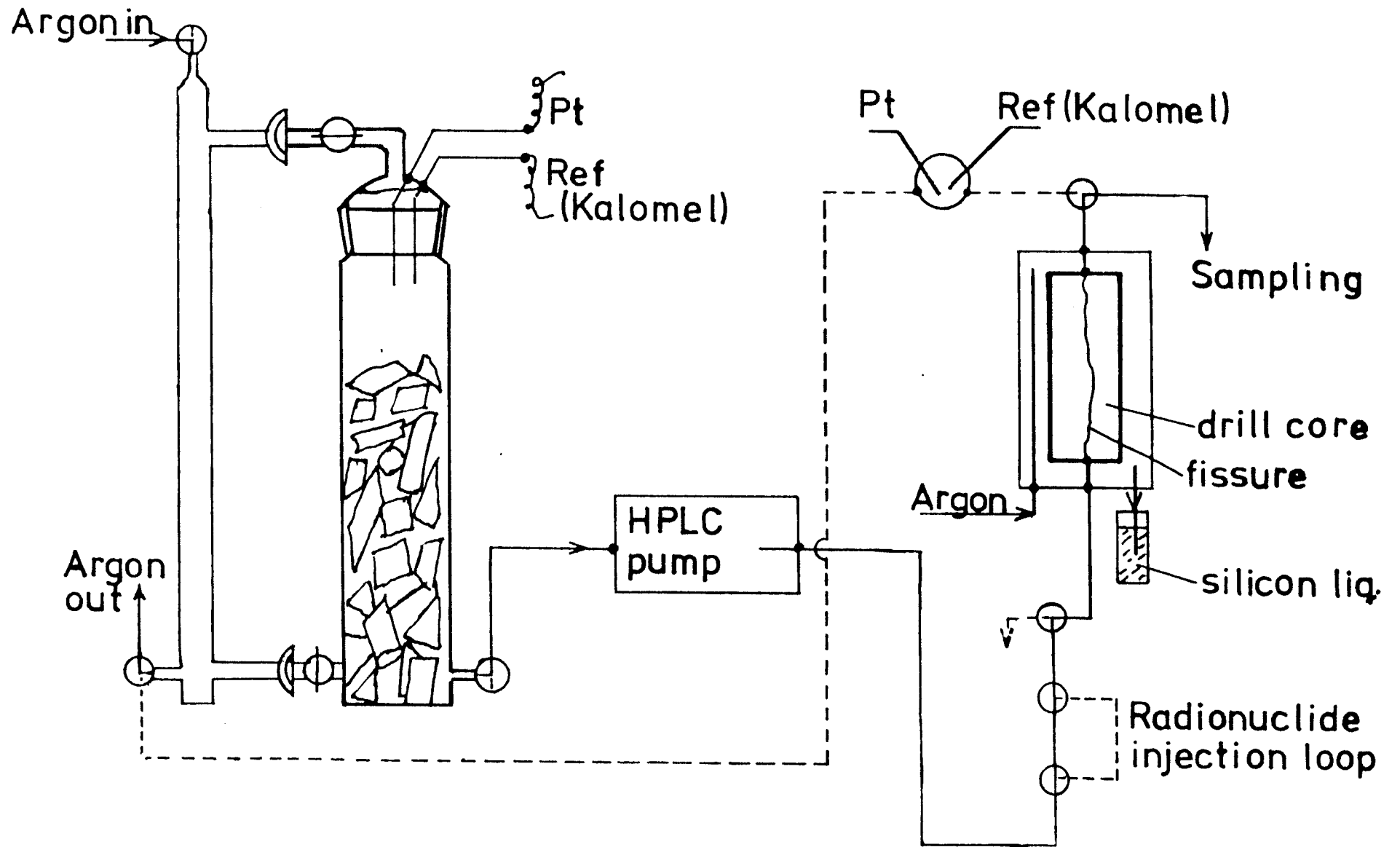
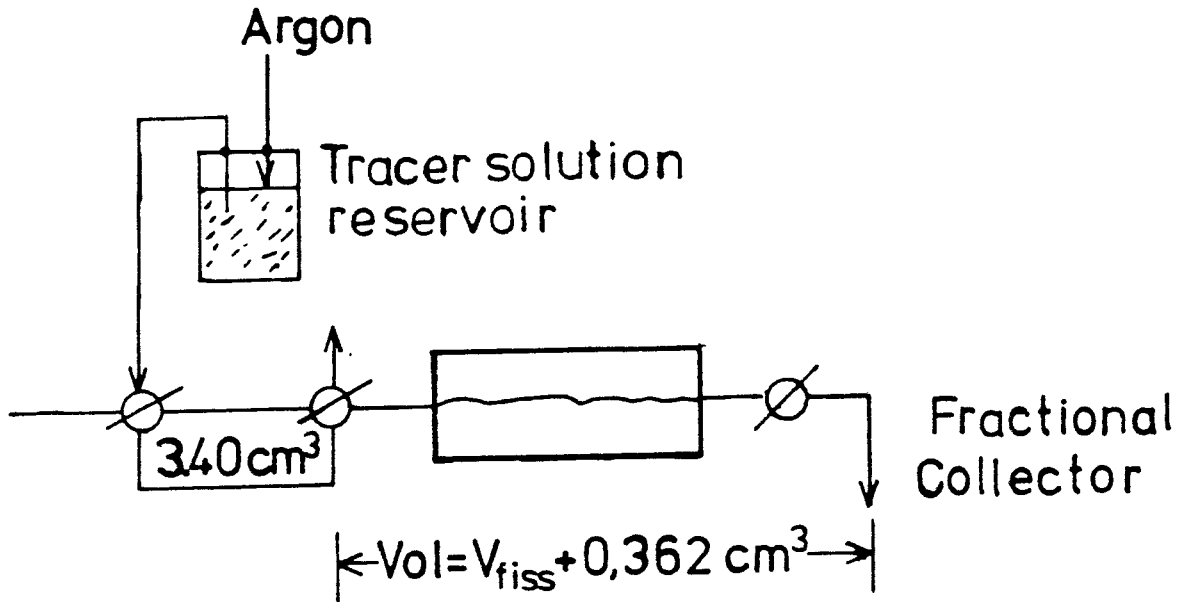



Fig. 1

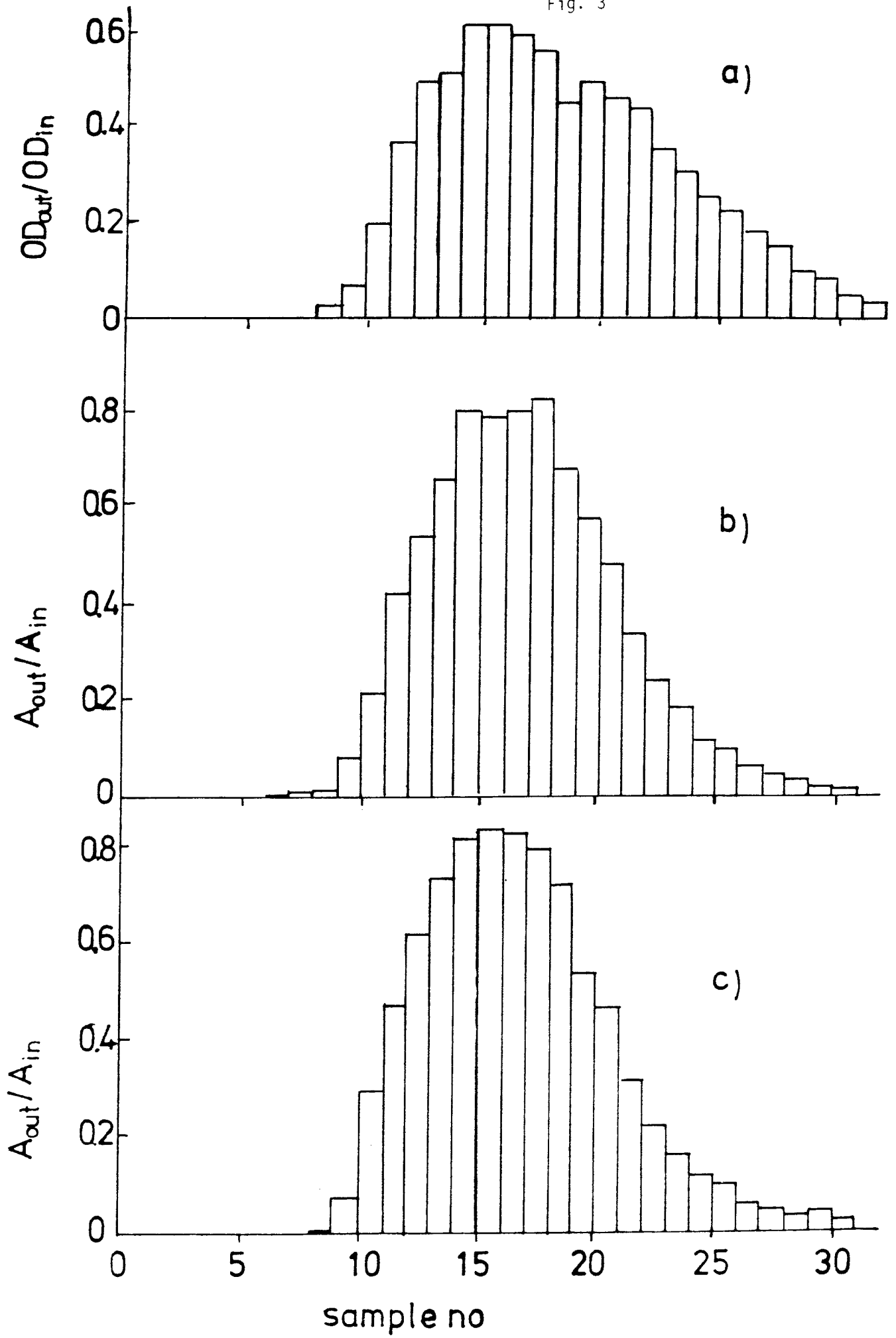


  
 Puls length:  $3.4/q \text{ min}$   
 $q = \text{water flux}$   
 $\text{cm}^3 \text{min}^{-1}$

Delay:  $0.362q/\text{min}$   
 $0.362 = \text{tube vol.}$

Fig. 2

Fig. 3





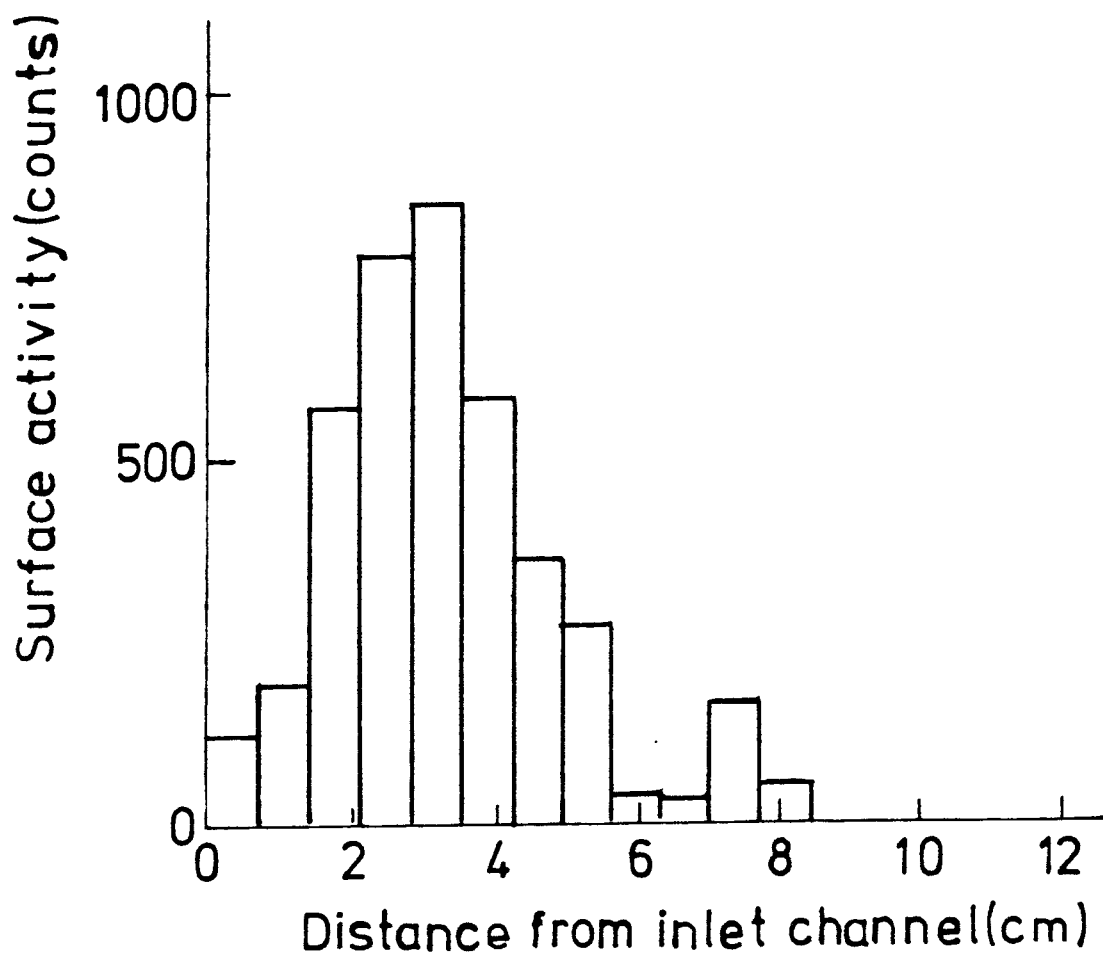


Fig. 4

# List of SKB reports

## Annual 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.

1982

TR 82-28

### **The KBS Annual Report 1982.**

KBS Technical Reports 82-01 – 82-27.

Summaries. Stockholm, July 1983.

1983

TR 83-77

### **The KBS Annual Report 1983.**

KBS Technical Reports 83-01 – 83-76

Summaries. Stockholm, June 1984.

1984

TR 85-01

### **Annual Research and Development Report 1984**

Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01-84-19)  
Stockholm June 1985.

1985

TR 85-20

### **Annual Research and Development Report 1985**

Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01-85-19)  
Stockholm May 1986.

1986

TR 86-31

### **SKB Annual Report 1986**

Including Summaries of Technical Reports Issued during 1986  
Stockholm, May 1987

1987

TR 87-33

### **SKB Annual Report 1987**

Including Summaries of Technical Reports Issued during 1987

Stockholm, May 1988

## Technical Reports

1988

TR 88-01

### **Preliminary investigations of deep ground water microbiology in Swedish granitic rocks**

Karsten Pedersen

University of Göteborg

December 1987

TR 88-02

### **Migration of the fission products strontium, technetium, iodine, cesium and the actinides neptunium, plutonium, americium in granitic rock**

Thomas Ittner<sup>1</sup>, Börje Torstenfelt<sup>1</sup>, Bert Allard<sup>2</sup>

<sup>1</sup>Chalmers University of Technology

<sup>2</sup>University of Linköping

January 1988

TR 88-03

### **Flow and solute transport in a single fracture. A two-dimensional statistical model**

Luis Moreno<sup>1</sup>, Yvonne Tsang<sup>2</sup>, Chin Fu Tsang<sup>2</sup>,

Ivars Neretnieks<sup>1</sup>

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<sup>2</sup>Lawrence Berkeley Laboratory, Berkeley, CA, USA

January 1988

TR 88-04

### **Ion binding by humic and fulvic acids: A computational procedure based on functional site heterogeneity and the physical chemistry of polyelectrolyte solutions**

J A Marinsky, M M Reddy, J Ephraim, A Mathuthu

US Geological Survey, Lakewood, CA, USA

Linköping University, Linköping

State University of New York at Buffalo, Buffalo, NY, USA

April 1987

TR 88-05

### **Description of geophysical data on the SKB database GEOTAB**

Stefan Sehlstedt

Swedish Geological Co, Luleå

February 1988

TR 88-06

**Description of geological data in SKBs data-base GEOTAB**

Tomas Stark  
Swedish Geological Co, Luleå  
April 1988

TR 88-07

**Tectonic studies in the Lansjärv region**

Herbert Henkel  
Swedish Geological Survey, Uppsala  
October 1987

TR 88-08

**Diffusion in the matrix of granitic rock. Field test in the Stripa mine. Final report.**

Lars Birgersson, Ivars Neretnieks  
Royal Institute of Technology, Stockholm  
April 1988

TR 88-09

**The kinetics of pitting corrosion of carbon steel. Progress report to June 1987**

G P Marsh, K J Taylor, Z Sooi  
Materials Development Division  
Harwell Laboratory  
February 1988

TR 88-10

**GWHRT – A flow model for coupled ground-water and heat flow  
Version 1.0**

Roger Thunvik<sup>1</sup>, Carol Braester<sup>2</sup>  
<sup>1</sup> Royal Institute of Technology, Stockholm  
<sup>2</sup> Israel Institute of Technology, Haifa  
April 1988

TR 88-11

**Groundwater numerical modelling of the Fjällveden study site – Evaluation of parameter variations  
A hydrocoin study – Level 3, case 5A**

Nils-Åke Larsson<sup>1</sup>, Anders Markström<sup>2</sup>  
<sup>1</sup> Swedish Geological Company, Uppsala  
<sup>2</sup> Kemakta Consultants Co, Stockholm  
October 1987

TR 88-12

**Near-distance seismological monitoring of the Lansjärv neotectonic fault region**

Rutger Wahlström, Sven-Olof Linder,  
Conny Holmqvist  
Seismological Department, Uppsala University,  
Uppsala  
May 1988

TR 88-13

**Validation of the rock mechanics HNFEMP code against Colorado school of mines block test data**

Ove Stephansson, Tomas Savilahti  
University of Luleå, Luleå  
May 1988

TR 88-14

**Validation of MUDEC against Colorado school of mines block test data**

Nick Barton, Panayiotis Chryssanthakis,  
Karstein Monsen  
Norges Geotekniske Institutt, Oslo, Norge  
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TR 88-15

**Hydrothermal effects on montmorillonite. A preliminary study**

Roland Pusch  
Ola Karnland  
June 1988

TR 88-16

**Swedish Hard Rock Laboratory First evaluation of preinvestigations 1986-87 and target area characterization**

Gunnar Gustafson  
Roy Stanfors  
Peter Wikberg  
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TR 88-17

**On the corrosion of copper in pure water**

T E Eriksen<sup>1</sup>, P Ndalamba<sup>1</sup>, I Grenthe<sup>2</sup>  
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March 1988

TR 88-18

**Geochemical modelling of the evolution of a granite-concrete-water system around a repository for spent nuclear fuel**

Bertrand Fritz, Benoit Madé, Yves Tardy  
Université Louis Pasteur de Strasbourg  
April 1988

TR 88-19

**A Bayesian nonparametric estimation of distributions and quantiles**

Kurt Pörn  
Studsvik AB  
November 1988

TR 88-20

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Bo Ivarsson, Jan-Olof Österberg  
Swedish Institute for Metals Research  
August 1988

TR 88-26

**Geological evidence of smectite longevity  
The Sardinian and Gotland cases**

Roland Pusch, Ola Karnland  
Clay Technology AB  
December 1988

TR 88-21

**Modelling uranium solubilities in aqueous solutions: Validation of a thermodynamic data base for the EQ3/6 geochemical codes**

I Puigdomenech<sup>1</sup>, J Bruno<sup>2</sup>  
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October 1988

TR 88-27

**On the formation of a moving redox-front by a-radiolysis of compacted water saturated bentonite**

Trygve E Eriksen, Pierre Ndalamba  
The Royal Institute of Technology, Stockholm  
Department of Nuclear Chemistry

TR 88-22

**Radiolysis of ground water: influence of carbonate and chloride on the hydrogen peroxide production**

T E Eriksen<sup>1</sup>, P Ndalamba<sup>2</sup>, H Christensen<sup>2</sup>,  
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December 1988

TR 88-23

**Source parameters of major earthquakes near Kiruna, northern Sweden, deduced from synthetic seismogram computation**

W T Kim, E Skordas, Y P Zohu, O Kulhanek  
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**Fission product concentration profiles (Sr, Xe, Cs and Nd) at the individual grain level in power-ramped LWR fuel**

R S Forsyth, O Mattsson, D Schrire  
Studsvik Nuclear, Nyköping  
December 1988

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**Postglacial faulting and paleoseismicity in the Lansjärv area, northern Sweden**

Robert Lagerbäck  
October 1988