

**SKBF**  
**KBS**

**TEKNISK**  
**RAPPORT**

**82-28**

**KBS ANNUAL REPORT 1982**

**Summaries of Technical Reports  
Issued during 1982**

KBS Stockholm, July 1983

**SVENSK KÄRNBRÄNSLEFÖRSÖRJNING AB / AVDELNING KBS**

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# **KBS ANNUAL REPORT 1982**

## **Summaries of Technical Reports Issued during 1982**

KBS Stockholm, July 1983

## TABLE OF CONTENTS

GENERAL	1
REFERENCES	3
APPENDICES	
1 Lectures and Presentations 1982	4
2 List of KBS Technical Reports 1982	7
3 Authors of KBS Technical Reports 1982 in alphabetical order	12
4 Key word register for Technical Reports	15
5 Summaries of Technical Reports	16

## GENERAL

The purpose of the KBS Annual Report is to inform interested organizations and individuals of the research and development work performed by the division KBS within the Swedish Nuclear Fuel Supply Co (SKBF) on the handling, treatment and final storage of nuclear wastes in Sweden.

The Annual Report normally contains a presentation of the legal and organizational situation followed by an account of the progress within different areas of the R&D-work. This account also includes indications of the activities planned for the future. At the end of the report the summaries of the technical reports and other publications issued during the year are listed in special appendices.

Due to special circumstances the Annual Report for 1982 will only contain the appendices mentioned above.

One reason for this is that most of the results of the R&D-work performed up to 1982 are evaluated and published in the KBS-3-report./1/This report describes one method for safe final storage of spent fuel from the Swedish nuclear reactors.

A second reason is that, according to a law of 1981, an annual plan for the research, development and implementation needed to provide for a safe waste management has to be presented to the authorities.

Such a plan was published in 1982 /2/ and it has been revised in 1983 /3/.

Furthermore a revision of the Swedish legislation is expected around the turn of this year. This might change the requirements for how the reporting to the authorities shall be organized. The future annual reports will be coordinated to this system.

## REFERENCES

- /1/ Swedish Nuclear Fuel Supply Co  
Final Storage of Spent Nuclear Fuel - KBS-3  
Summary  
I General  
II Geology  
III Barriers  
IV Safety  
Stockholm May 1983
- /2/ Swedish Nuclear Fuel Supply Co  
Radioactive Waste Management Plan, PLAN 82  
Part I General  
KBS TR 82-09:1, Stockholm June 1982  
Part 2 Facilities and costs  
KBS TR 82-09:02, Stockholm June 1982
- /3/ Svensk Kärnbränsleförsörjning AB  
Plan för kärnkraftens radioaktiva restprodukter  
Stockholm Juni 1983  
(This report is an updated version of PLAN 82 /1/  
and it will not be translated into English.

A central repository for final disposal of the Swedish low and intermediate level reactor wastes

L B Nilsson (SKBF)

International Symposium on Waste Isolation in the US and elsewhere, Technical Programs and Public Communications, Tucson, Arizona, 8-11 March 1982

Research priorities for the Swedish nuclear waste isolation

T Papp (SKBF)

Panel presentation at the Fifth International Symposium on the Scientific Basis for Radioactive Waste Management Berlin, 7-10 June 1982

Burial effects on nuclear waste glass

L Werme (SKBF), A Lodding (Chalmers University of Technology)

L L Hench (University of Florida, Gainesville, Florida)

Fifth International Symposium on the Scientific Basis for Radioactive Waste Management Berlin, 7-10 June 1982

Effect of overpack materials on glass leaching in geological burial

L Werme (SKBF), L L Hench (University of Florida, Gainesville, Florida), A Lodding (Chalmers University of Technology, Gothenburg)

Fifth International Symposium on the Scientific Basis for Radioactive Waste Management Berlin, June 7-10 1982

Migration in a single fissure

H Abelin, J Gidlund, I Neretnieks (KTH, Stockholm)

Fifth International Symposium on the Scientific Basis for Radioactive Waste Management Berlin, June 7-10 1982

Model for near-field migration

G Andersson, A Rasmuson, I Neretnieks (KTH, Stockholm)

Fifth International Symposium on the Scientific Basis for Radioactive Waste Management Berlin, June 7-10 1982

A comparison of in-situ radionuclide migration studies in the Studsvik area and laboratory measurements  
O Landström (Studsvik Energiteknik AB), C E Klockars, O Persson, S A Larsson, E-L Tullborg (Swedish Geological Survey), K Andersson, B Torstenfelt, B Allard (Chalmers University of Technology, Gothenburg)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10, 1982

Diffusion in the matrix of granitic rock; Field test in the Stripa Mine  
I Neretnieks, L Birgersson (KTH)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10, 1982

Leach rates of high-level waste and spent fuel - Limiting rates as determined by backfill and bedrock conditions  
I Neretnieks (KTH)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10 1982

Modelling of the migration of lanthanoids and actinoids in groundwater, The medium dependence of equilibrium constants  
G Biedermann, J Bruno, D Ferri, I Grenthe, F Salvatore and K Spahn (KTH)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10 1982

Properties and mobilities of actinide colloids in geologic systems  
U Olofsson, B Allard, B Torstenfelt, K Andersson (Chalmers University of Technology, Gothenburg)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10, 1982

Ion/water migration phenomena in dense bentonites  
R Pusch, A Jacobsson (University of Luleå)  
T Eriksen (KTH, Stockholm)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10, 1982

Model for far-field migration  
A Rasmuson, I Neretnieks (KTH)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10 1982

Diffusion in crystalline rocks  
K Skagius, I Neretnieks (KTH)  
Fifth International Symposium on the Scientific Basis for Radioactive Waste Management  
Berlin, June 7-10 1982



Transport of actinides through a bentonite backfill  
B Torstenfelt, H Kipatsi, K Andersson, B Allard,  
U Olofsson (Chalmers University of Technology)  
Fifth International Symposium on the Scientific  
Basis for Radioactive Waste Management  
Berlin, June 7-10, 1982

Hydrothermal conditions around a radioactive waste repository  
R Thunvik (KTH, Stockholm), C Braester (Israel Institute  
of Technology, Haifa)  
Fifth International Symposium on the Scientific Basis  
for Radioactive Waste Management  
Berlin, June 7-10, 1982

PILO - A Swedish concept for the central treatment of  
spent ion exchange resins  
C Thegerström (SKBF), B Bergström (Studsvik)  
International Symposium on the Conditioning of  
Radioactive Wastes for Storage and Disposal  
Utrecht, June 21-15, 1982

Standard program for site selection studies in Sweden  
for a high-level nuclear waste repository  
H Carlsson (SKBF)  
23rd Rock Mechanics Symposium, Berkeley, USA  
August 24-28, 1982

Swedish radioactive waste management  
T Papp (SKBF)  
Lecture at the Canadian Nuclear Society  
Winnipeg, Manitoba, Canada, September 13-16, 1982

Management of decommissioning waste from the Swedish  
nuclear program  
H Forsström (SKBF)  
1982 International Decommissioning Symposium  
Seattle, Washington, USA, October 10-14, 1982

Effects of solution chemistry and atmosphere on  
leaching of alkali borosilicate glass  
H P Hermansson, H Christensen (Studsvik Energiteknik AB,  
Nyköping)  
D E Clark (University of Florida, Gainesville)  
L Werme (SKBF)  
Sixth International Symposium on the Scientific Basis  
for Radioactive Waste Management  
Boston, November 1982

Radionuclide migration into natural fracture surfaces  
of granitic rock  
B Torstenfelt, T Eliasson, B Allard, K Andersson,  
S Höglund, T Ittner, U Olofsson (Chalmers University of  
Technology, Göteborg)  
Sixth International Symposium on the Scientific Basis  
for Radioactive Waste Management  
Boston, November 1982

## List of KBS Technical Reports 1982

## APPENDIX 2

In order to have the full reports available to all interested persons, they have been filed as microfiche at

INIS CLEARINGHOUSE  
International Atomic Energy Agency  
P O Box 100  
A-1400 VIENNA, AUSTRIA

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 82-01 Hydrothermal conditions around a radioactive waste repository  
Part 3 - Numerical solutions for anisotropy  
Roger Thunvik  
Royal Institute of Technology, Stockholm, Sweden  
Carol Braester  
Institute of Technology, Haifa, Israel  
December 1981

TR 82-02 Radiolysis of groundwater from HLW stored in copper canisters  
Hilbert Christensen  
Erling Bjergbakke  
Studsvik Energiteknik AB, 1982-06-29

- TR 82-03 Migration of radionuclides in fissured rock:  
Some calculated results obtained from a model based  
on the concept of stratified flow and matrix  
diffusion  
Ivars Neretnieks  
Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden, October 1981
- TR 82-04 Radionuclide chain migration in fissured rock -  
The influence of matrix diffusion  
Anders Rasmuson \*  
Akke Bengtsson \*\*  
Bertil Grundfelt \*\*  
Ivars Neretnieks \*  
April, 1982
- \* Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden
- \*\* KEMAKTA Consultant Company  
Stockholm, Sweden
- TR 82-05 Migration of radionuclides in fissured rock -  
Results obtained from a model based on the concepts  
of hydrodynamic dispersion and matrix diffusion  
Anders Rasmuson  
Ivars Neretnieks  
Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden, May 1982
- TR 82-06 Numerical simulation of double packer tests  
Calculation of rock permeability  
Carol Braester  
Israel Institute of Technology, Haifa, Israel  
Roger Thunvik  
Royal Institute of Technology  
Stockholm, Sweden, June 1982
- TR 82-07 Copper/bentonite interaction  
Roland Pusch  
Division Soil Mechanics, University of Luleå  
Luleå, Sweden, 1982-06-30
- TR 82-08 Diffusion in the matrix of granitic rock  
Field test in the Stripa mine  
Part 1  
Lars Birgersson  
Ivars Neretnieks  
Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden, July 1982

- TR 82-09:1      Radioactive waste management plan  
PLAN 82  
Part 1 General  
Stockholm, June 1982
- TR 82-09:2      Radioactive waste management plan  
PLAN 82  
Part 2 Facilities and costs  
Stockholm, June 1982
- TR 82-10      The hydraulic properties of fracture zones and  
tracer tests with non-reactive elements in Studsvik  
Carl-Erik Klockars  
Ove Persson  
Geological Survey of Sweden, Uppsala  
Ove Landström  
Studsvik Energiteknik, Nyköping  
Sweden, April 1982
- TR 82-11      Radiation levels and absorbed doses around  
copper canisters containing spent LWR fuel  
Klas Lundgren  
ASEA-ATOM, Västerås, Sweden 1982-08-11
- TR 82-12      Diffusion in crystalline rocks of some sorbing  
and nonsorbing species  
Kristina Skagius  
Ivars Neretnieks  
Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden, 1982-03-01
- TR 82-13      Variation in radioactivity, uranium and radium-226  
contents in three radioactive springs and along  
their out-flows, northern Sweden  
John Ek  
Sverker Evans  
Lennart Ljungqvist  
Studsvik Energiteknik AB  
Nyköping, Sweden, 1982-06-03
- TR 82-14      Oral intake of radionuclides in the population  
A review of biological factors of relevance for  
assessment of absorbed dose at long term waste  
storage  
Lennart Johansson  
National Defense Research Institute, Dept 4  
Umeå, Sweden, October 1982
- TR 82-15      Radioactive disequilibria in mineralised drill core  
samples from the Björklund uranium occurrence,  
northern Sweden  
J A T Smellie  
Geological Survey of Sweden  
Luleå, December 1982
- TR 82-16      The movement of a redox front downstream from a  
repository for nuclear waste  
Ivars Neretnieks  
Royal Institute of Technology  
Stockholm, Sweden, 1982-04-19

- TR 82-17 Diffusion of hydrogen, hydrogen sulfide and large molecular weight anions in bentonite  
Trygve E Eriksen  
Department of Nuclear Chemistry  
Royal Institute of Technology, Stockholm  
Arvid Jacobsson  
Division of Soil Mechanics  
University of Luleå  
Sweden, 1982-07-02
- TR 82-18 Radiolysis of ground water from spent fuel  
Hilbert Christensen  
Erling Bjergbakke  
Studsvik Energiteknik AB  
Nyköping, Sweden, 1982-11-27
- TR 82-19 Corrosion of steel in concrete  
Carolyn M Preece  
Korrosionscentralen  
Glostrup, Denmark, 1982-10-14
- TR 82-20 Fissure fillings from Finnsjön and Studsvik, Sweden  
Identification, chemistry and dating  
Eva-Lena Tullborg  
Sven Åke Larson  
Swedish Geological, Gothenburg  
December 1982
- TR 82-21 Sorption of actinides in granitic rock  
B Allard  
Department of Nuclear Chemistry  
Chalmers University of Technology  
Göteborg, Sweden 1982-11-20
- TR 82-22 Natural levels of uranium and radium in four potential areas for the final storage of spent nuclear fuel  
Sverker Evans  
Svante Lampe  
Björn Sundblad  
Studsvik Energiteknik AB  
Nyköping, Sweden, 1982-12-21
- TR 82-23 Analysis of groundwater from deep boreholes in Kråkemåla, Sternö and Finnsjö  
Sif Laurent  
IVL  
Stockholm, Sweden 1982-12-22
- TR 82-24 Migration model for the near field  
Final report  
Göran Andersson  
Anders Rasmuson  
Ivars Neretnieks  
Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden 1982-11-01

- TR 82-25 On the pH-buffering effects of the  
CO<sub>2</sub>-CO<sub>3</sub><sup>2-</sup>-system in deep groundwaters  
B Allard  
Department of Nuclear Chemistry  
Chalmers University of Technology  
Göteborg, Sweden 1982-12-10
- TR 82-26 Mobilities of radionuclides in fresh and fractured  
crystalline rock  
B Torstenfelt  
T Ittner  
B Allard  
K Andersson  
U Olofsson  
Department of Nuclear Chemistry  
Chalmers University of Technology  
Göteborg, Sweden 1982-12-20
- TR 82-27 Diffusivities of some dissolved constituents in  
compacted wet bentonite clay -MX80 and the impact on  
radionuclide migration in the buffer  
I Neretnieks  
Royal Institute of Technology  
Stockholm, Sweden 1982-10-29

Authors of KBS Technical Reports 1982  
in alphabetical order

APPENDIX 3

AUTHORS	TECHNICAL REPORT NO 82-
Allard, Bert Chalmers University of Technology	21, 25, 26, x)
Andersson, Göran Royal Institute of Technology	24, x)
Andersson, Karin Chalmers University of Technology	26, x)
Bengtsson, Akke KEMAKTA Consultant AB	04, x)
Birgersson, Lars Royal Institute of Technology	08, x)
Bjergbakke, Erling Studsvik Energiteknik AB	02, x) 18, x)
Braester, Carol Institute of Technology, Haifa	01, x) 06, x)
Christensen, Hilbert Studsvik Energiteknik AB	02, x) 18, x)
Ek, John Studsvik Energiteknik AB	13, x)
Eriksen, Trygve E Royal Institute of Technology	17, x)
Evans, Sverker Studsvik Energiteknik AB	13, x) 22, x)
Grundfelt, Bertil KEMAKTA Consultant Company	04, x)

x) The report is written by more than one person

AUTHORS	TECHNICAL REPORT NO 82-
Ittner, T Chalmers University of Technology	26,x)
Jacobsson, Arvid University of Luleå	17,x)
Johansson, Lennart Nat. Defense Research Institute	14,
Klockars, Carl-Erik Geological Survey of Sweden	10,x)
Lampe, Svante Studsvik Energiteknik AB	22,x)
Landström, Ove Studsvik Energiteknik AB	10,x)
Larson, Sven-Åke Swedish Geological, Göteborg	20,x)
Laurent, Sif IVL	23,
Ljungqvist, Lennart Studsvik Energiteknik AB	13,x)
Lundgren, Klas ASEA-ATOM	11,
Neretnieks, Ivars Royal Institute of Technology	03, 04,x) 05,x) 08,x) 12,x), 16, 24x), 27
Olofsson, Ulla Chalmers University of Technology	26,x)
Persson, Ove Geol. Survey of Sweden, Uppsala	10,x)
Preece, Carolyn M Korrosionscentralen, Glostrup	19,
Pusch, Roland University of Luleå	07,
Rasmuson, Anders Royal Institute of Technology	04,x), 05,x), 24x)
Skagius, Kristina Royal Institute of Technology	12,x)
Smellie, J A T Geological Survey of Sweden, Luleå	15,

x) The report is written by more than one person



## AUTHORS

## TECHNICAL REPORT NO 82-

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Sundblad, Björn Studsvik Energiteknik AB	22,x)
Thunvik, Roger Royal Institute of Technology	01,x) 06,x)
Torstenfelt, B Chalmers University of Technology	26,x)
Tullborg, Eva-Lena Swedish Geological, Gothenburg	20,x)

## Key word register for Technical Reports

## APPENDIX 4

KEY WORDS	TECHNICAL REPORT NO 82-
Activity, natural	13, 15, 22
Actinides	21
Bentonite	07, 17, 27
Biosphere	13, 14
Buffer material	07
Canisters	07, 11
Corrosion	19
Costs	09:2
Diffusion	04, 05, 08, 12, 17, 26, 27
Dispersion	05
Dose	14
Facilities	09:1, 09:2
Fissure fillings	20
Geology	20
Groundwater chemistry	23, 24
Hydrogeological modelling	01
In-situ migration	10
Legislation	09:01
Matrix diffusion	04, 05, 08, 12, 26
Migration geosphere	03, 04, 05, 06
Modelling	01, 03, 04, 05, 16, 24
Packer tests	06
Permeability	06
Radiolysis	02, 18
Redox front	16, 24
Sorption	21, 26
Thermal effects	01
Tracer tests	10
Waste management plan	09:1, 09:2

KBS Technical Report No 82-01
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HYDROTHERMAL CONDITIONS AROUND A RADIOACTIVE WASTE  
REPOSITORY

Part 3 - Numerical Solutions for Anisotropy

Roger Thunvik  
Royal Institute of Technology, Stockholm, Sweden

Carol Braester  
Israel Institute of Technology, Haifa, Israel

December 1981

ABSTRACT

Numerical solutions for the hydrothermal conditions around a hard rock repository for nuclear fuel waste are presented. The objective of the present investigation is to illustrate in principle the effect of heat released from a hypothetical radioactive waste repository with regard to anisotropy in the rock permeability. Permeability and porosity are assumed to be constant or to decrease exponentially with depth. The hypothetical repository is situated below a horizontal ground surface or below the crest of a hill, and it is assumed that the water table follows the topography. Major interest in the analysis is directed towards the influence of anisotropy in the permeability on the flow patterns and travel times for water particles, being traced from the repository to the ground surface. The presented results show that anisotropy in the permeability may have a significant influence on the flow conditions around the repository and subsequently also on the travel times from the repository.

RADIOLYSIS OF GROUNDWATER FROM HLW STORED IN  
COPPER CANISTERS

Hilbert Christensen  
Erling Bjergbakke  
Studsvik Energiteknik AB  
1982-06-29

## ABSTRACT

A large number of computer calculations of the radiolysis of ground water outside copper canisters have been carried out.

At dose rates higher than  $5 \times 10^{-2}$  rad/s the hydrogen concentration is constant, approximately  $10^{-3}$  mol/dm<sup>3</sup> and independent of time and dose rate. Therefore the rate of diffusion out of the system is constant, approximately  $7 \times 10^{-4}$  mol/year. At dose rates lower than  $5 \times 10^{-4}$  rad/s the logarithm of the hydrogen production is proportional to the logarithm of the dose rate. The hydrogen production depends on fuel type, burn-up and canister thickness only to the extent that the dose rate varies with these parameters.

The hydrogen production is independent of the volume of water in which the energy is assumed to be absorbed (5 or 15 cm layers outside the surface of the canister).

The hydrogen production depends on the concentration of Fe<sup>2+</sup> ions in the water. In the basic calculations the concentration was assumed to be 5 ppm. An increase to 50 ppm increases the total hydrogen production after one million years outside a 1 cm thick canister from 360 to 1000 mol. A decrease to 0.5 ppm decreases the same yield to 80 mol.

KBS Technical Report No 82-03

MIGRATION OF RADIONUCLIDES IN FISSURED ROCK:  
SOME CALCULATED RESULTS OBTAINED FROM A MODEL BASED ON  
THE CONCEPT OF STRATIFIED FLOW AND MATRIX DIFFUSION

Ivars Neretnieks  
Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden October 1981

ABSTRACT

Some computed results of radionuclide migration in fissured rock are presented. The computations are based on a model which describes flow as occurring in a multitude of independent fissures (stratified flow). This gives rise to strong "dispersion" or channeling. The radionuclide migration in the individual fissures is modelled by the advection equation in a parallel walled channel with porous walls. The nuclides may diffuse into the pores and sorb reversibly on the pore surfaces.

The effluent rates of 23 important nuclides are presented as functions of distance and time for various values of important parameters such as rock permeability, diffusion coefficients, release rates, time of first release, fissure spacing and fissure width distribution.

RADIONUCLIDE CHAIN MIGRATION IN FISSURED ROCK -  
THE INFLUENCE OF MATRIX DIFFUSION

Anders Rasmuson        1)  
Akke Bengtsson        2)  
Bertil Grundfelt       2)  
Ivars Neretnieks      1)

1)    Royal Institute of Technology  
      Department of Chemical Engineering

2)    KEMAKTA Consultant Company

Stockholm, Sweden April 1982

ABSTRACT

Diffusion into the rock matrix has a large impact on the migration of radionuclides in the geosphere. The aim of the present study is to investigate the effect of this mechanism on radionuclide chain migration. For this purpose a previously used numerical code TRUMP is extended to incorporate chain decay. The algorithm is also changed to directly include the decay terms. The extended version was given the acronym TRUCHN. Numerical solutions from TRUCHN are compared with the analytical solutions developed by Lester et al. A good agreement is obtained.

To illustrate the impact of matrix diffusion on the arrival times to the biosphere of the members of a radionuclide chain a number of numerical calculations were done for the two chains  $U-238 \rightarrow Th-230 \rightarrow Ra-226$  and  $Pu-239 \rightarrow U235 \rightarrow Pa-231$ . The resulting curves are compared with the results for surface sorption (penetration depth  $10^{-4}$  m) and volume sorption (complete penetration) obtained with the computer program GETOUT. The differences in first arrival times are very large. The arrival times in the surface and volume

sorption cases, differ with as much as four orders of magnitude. The corresponding times for instationary diffusion are located between these extreme values.

A daughter nuclide which is strongly sorbed may be heavily retarded if it is produced far inside the rock matrix and has a long way to diffuse before it reaches the flowing water. This effect is investigated, by considering diffusion only of a radionuclide chain, with analytical and numerical (TRUCHN) methods.

Finally, in connection with the reconcentration effect, some means of describing the outflow of a daughter nuclide in terms of the outflow of its parent nuclide are proposed.

MIGRATION OF RADIONUCLIDES IN FISSURED ROCK -  
RESULTS OBTAINED FROM A MODEL BASED ON THE CONCEPTS  
OF HYDRODYNAMIC DISPERSION AND MATRIX DIFFUSION

Anders Rasmuson  
Ivars Neretnieks

Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm Sweden May 1982

ABSTRACT

The migration of individual radionuclides in a porous medium where hydrodynamic dispersion takes place and where the radionuclides migrate in the matrix of solid medium by diffusion has been calculated for a variety of cases. The cases center around the main case in the second KBS study on spent fuel. The main differences from the KBS study is the inclusion of matrix diffusion and the use of large dispersivities.

The effluent rates of 23 important nuclides are presented as functions of distance and time for various values of important parameters such as rock permeability, diffusion coefficients, release rates, time of first release, fissure spacing and longitudinal dispersion coefficients.



NUMERICAL SIMULATION OF DOUBLE PACKER TESTS  
Calculation of Rock Permeability

Carol Braester  
Israel Institute of Technology, Haifa, Israel

Roger Thunvik  
Royal Institute of Technology, Stockholm, Sweden  
June 1982

ABSTRACT

The permeability of a fractured hard rock formation is usually calculated using the recorded overpressure and the rate of flow during a double packer test. Existing formulae assume that the formation is both homogeneous, and isotropic, and that the borehole is sealed in the region outside the packers, but in practice these assumptions are not fulfilled. The objective of the present investigation is to check the influence on the calculated rock permeability of inhomogeneities, anisotropy and return of flow from the formation into the unsealed part of the borehole by numerical simulation of double packer tests. For this purpose different formations with known permeabilities were considered.

## COPPER/BENTONITE INTERACTION

Roland Pusch  
Division Soil Mechanics  
University of Luleå  
Luleå, Sweden 1982-06-30

## ABSTRACT

The prediction of the processes and rate of corrosion of the KBS 2 copper canisters must be based on a proper scenario, which involves the physical state of the bentonite surrounding the canisters, and the chemical interaction between copper and bentonite. Literature data suggest slow Cu migration and Cu exchanging originally adsorbed cations. Two tests involving copper/bentonite contacts for 3-6 months in boreholes have yielded certain valuable information. Thus, Cu ion migration is indeed very slow and where it yields a sufficiently high concentration, it is associated with replacement of originally adsorbed Na ions, which should result in an increased permeability.

In one of the tests the copper was separated from the bentonite by a partly air-filled slot. These conditions caused the formation of copper oxides and hydroxides which intermingled with the bentonite that expanded to fill the slot. Due to the low solubility of these copper compounds, the Cu ion concentration was too low to produce ion exchange during the time of observation.

DIFFUSION IN THE MATRIX OF GRANITIC ROCK  
FIELD TEST IN THE STRIPA MINE  
PART 1

Lars Birgersson  
Ivars Neretnieks

Royal Institute of Technology  
Department of Chemical Engineering  
Stockholm, Sweden July 1982

ABSTRACT

A migration experiment in the rock matrix is presented. The experiment has been carried out in "undisturbed" rock, that is in rock under its natural stress environment. Since the experiment was performed at the 360m-level (in the Stripa mine), the rock had nearly the same conditions as the rock surrounding a nuclear waste storage.

The results show that all three tracers (Uranine, Cr-EDTA and I<sup>131</sup>) have passed the disturbed zone from the injection hole and migrated into "undisturbed" rock. At the distance of 11 cm from the injection hole 5-10% of the injection concentration was found.

The results also indicate that the tracers have passed through fissure filling material.

These results indicate that it is possible for tracers (and therefore radionuclides) to migrate from a fissure, through fissure filling material, and into the undisturbed rock matrix.

RADIOACTIVE WASTE MANAGEMENT PLAN  
PLAN 82  
Part 1 General  
Part 2 Facilities and Costs  
SKBF/KBS, Stockholm, Sweden, June 1982

#### ABSTRACT

In Sweden, the primary responsibility for the safe handling and final disposal of radioactive waste from nuclear power production lies with the nuclear power producers. The waste management program is supervised by a special governmental authority.

The nuclear power utilities have delegated their obligations with respect to radioactive waste management to the Swedish Nuclear Fuel Supply Company (SKBF), owned jointly by them. The supervisory authority designated by the Government is the National Board for Spent Nuclear Fuel, NAK.

Swedish legislation requires the reactor owners (i.e. SKBF) to establish a program to ensure that:

- 1 The radioactive waste is handled and disposed of in a safe manner,
- 2 The reactors are decommissioned in a safe manner,
- 3 The necessary research and development is conducted to ensure compliance with 1 and 2.

The program shall contain an outline of all measures that may be necessary and shall specify in greater detail actions needed during a period of at least five years. An annually updated program shall be submitted to NAK for review.

Another requirement in the Swedish legislation is that

the future cost of radioactive waste management shall be borne by the nuclear utilities that have produced the waste. A system of funds will be built up from special fees charged on every kWh produced by the nuclear power plants. The fee is set annually by the government on recommendation by NAK, and is based on, among other things, the program plan from SKBF mentioned above.

The criteria that determine the size of the fee are the estimated costs and the times at which various facilities and systems will be needed.

The present legislation entered into force in July, 1981, and the first of the annual plans was presented to NAK in June, 1982. The present report is an English translation of this plan (PLAN 82). The report is divided into two parts. Part 1 describes the present situation and existing plans for the research and development work and part 2 presents the costs and timetables for the necessary facilities and activities. Chapter 8 and 9 in part 1 present the timetables and cost estimates, respectively.

THE HYDRAULIC PROPERTIES OF FRACTURE ZONES AND  
TRACER TESTS WITH NON-REACTIVE ELEMENTS IN STUDSVIK

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April 1982

ABSTRACT

Tracer technique was applied in a rock formation within the Studsvik Energiteknik area in order to study hydrodynamic properties of discrete fracture zones between boreholes. The two-hole method was applied in these studies; a non-reactive tracer is injected in one hole into a fracture zone which is in hydraulic contact with a central pump hole (observation hole). Hydraulic tests and TV inspection were carried out in the fracture zones. Chemical composition of the groundwater was determined.

In summary, the following hydraulic properties were found for the fracture zones between the boreholes B1N-B6N and B5N-B6N respectively, under the prevailing conditions:

- The fracture zones studied consist of a number of transport pathways with different mean transit times, varying from 100 to 1200 hours.
- The fracture zone between boreholes B1N and B6N has a mean hydraulic conductivity of  $6-7 \cdot 10^{-5}$  m/s and the fracture zone between boreholes B5N and B6N,  $2 \cdot 10^{-4}$  m/s.
- The kinematic porosity of the fracture zones studied, calculated as the ratio between the hydraulic conductivity of the rock mass and that of the fracture zone, is  $2 \cdot 10^{-3}$

and  $5 \cdot 10^{-3}$ , respectively.

- The roughness factor  $\beta$ , which expresses the ratio between measured and theoretically calculated (plane-parallel) fracture conductivity for the fracture zones studied, is approximately 0.04 and 0.06, respectively.
- Dispersivity for the flow channels within the fracture zones is of the order of 0.3-0.8 m.
- The groundwater encountered is a nearly neutral, probably reducing Na-Ca-HCO<sub>3</sub> water.

The results of the tracer tests reveal the following:

- I-131 is a suitable nonreactive tracer for the test area. A test with simultaneous injection of I-131 and T (tritium) gave comparable breakthrough curves.
- Of the three flow paths investigated by tracer technique, two are suited for further tests with sorbing radionuclides, B1N-B6N and B5N-B6N. The third flow path, B8N-B6N, is not well-defined in relation to overlying fracture zones.

RADIATION LEVELS AND ABSORBED DOSES AROUND  
COPPER CANISTERS CONTAINING SPENT LWR FUEL

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ABSTRACT

Spent fuel from Swedish LWRs is planned to be enclosed in canisters of copper and be buried in the final repository. The radiation levels during handling of canisters and the radiation energy absorbed in water (causing radiolysis) have previously been reported in KBS TR-106. However, there exists a desire to enclose BWR/PWR fuel with higher burnup and use canisters with thinner walls. New radiation source term calculations have been made available and a new concept for making canisters has also been discussed. All this has given rise to a need for new radiation shielding calculations, which are presented in this report.



DIFFUSION IN CRYSTALLINE ROCKS OF SOME SORBING AND  
NONSORBING SPECIES

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ABSTRACT

Laboratory experiments to determine the sorption and the rate of diffusion of cesium and strontium in pieces of granite have been performed. The effective diffusivity,  $D_p \cdot \epsilon_p$  was found to be  $1 - 2 \cdot 10^{-12}$  m<sup>2</sup>/s for both cesium and strontium.

The diffusion of non-sorbing species in granites and other rock materials has been studied in laboratory scale. The non-sorbing species were iodide, tritiated water, Cr-EDTA and Uranine. In granites the effective diffusivities were determined to be  $0.7 - 1.3 \cdot 10^{-13}$  m<sup>2</sup>/s for iodide and  $1.3 - 1.8 \cdot 10^{-13}$  m<sup>2</sup>/s for tritiated water.

Electrical resistivity measurements in salt water saturated rock cores have been performed. The resistivity is measured in the saturated core and in the salt solution with which the core has been saturated. The ratio between these two resistivities has a direct relation to the ratio of the effective diffusivity for a component in the rock material and the diffusivity in free water for the same component.

The results from the electrical resistivity measurements and the experiments with diffusion of non-sorbing species are in fair agreement. The effective diffusivity for cesium

and strontium (sorbing species) are, however, more than ten times higher than expected from the results of diffusion of non-sorbing species and the electrical resistivity measurements. This is interpreted as an effect of surface diffusion.

VARIATION IN RADIOACTIVITY, URANIUM AND RADIUM-226  
CONTENTS IN THREE RADIOACTIVE SPRINGS AND ALONG  
THEIR OUT-FLOWS, NORTHERN SWEDEN

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1982-06-03

ABSTRACT

An investigation was performed in three uranium-rich springs in northern Sweden with the aim to observe the temporal and spatial variations of uranium and radium within a natural ecosystem in contact with groundwater. The contents of uranium and radium in spring water, peat and sediment together with measurements of stable elements and environmental data were determined along the furrows during different seasons. There was mostly a disequilibrium between the content of uranium in peat and water. The very high adsorption capacity of peat and its low leaching rate was assumed to be responsible for this discrepancy. The field data were supported by some laboratory experiments. The accumulation by peat was always much higher than the corresponding losses. The effect of freezing seemed not to be of any importance for the leaching rate. However, lowering the pH will highly affect the release of uranium bound to the peat.

## ORAL INTAKE OF RADIONUCLIDES IN THE POPULATION

A review of biological factors of relevance for assessment of absorbed dose at long term waste storage

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Umeå, Sweden October 1982

## ABSTRACT

Dose factors of some radionuclides have been reviewed with respect to a chronic oral intake by members of the public. The radionuclides taken into account are Pu-239, Np-237, Ra-226, Th-230, Pa-231, Tc-99 and I-129, all of which might be of potential hazard at a long term storage disposal.

The parameter that has the major influence on the dose factor, for most of the radionuclides studied, is the uptake from the gut. In order to assess the dose factor it is therefore essential to make a good estimate of the gastrointestinal uptake of the radionuclides under the actual conditions. The "annual limit of intake" (ALI) given in ICRP 30, is intended to be applicable on a population of workers, and for a single intake. Since the gut uptake figures in the ICRP-publication are based mainly on uptake values received in experimental animals, given single relatively large oral doses of the isotope studied.

From a review of current literature gut absorption factors and dose factors, to be used for members of the public at a chronic oral intake, are suggested. Compared with those for workers in ICRP 30, the dose factors increases for plutonium and protactinium, and decreases for neptunium. An attempt to predict possible future changes of the ALI for members of the general public is also made.

RADIOACTIVE DISEQUILIBRIA IN MINERALISED DRILL CORE  
SAMPLES FROM THE BJÖRKLUND URANIUM OCCURRENCE,  
NORTHERN SWEDEN

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Luleå December 1982

ABSTRACT

Forming the bases of a pilot study to investigate the natural mobility of uranium and its daughter products within the geological environment, a series of six samples, chosen from two mineralised fracture zones at depths of 100-130 m within a homogeneous leucocratic granite, were examined mineralogically and isotopically to establish the presence or absence of radioactive equilibrium that may indicate recent rock/water interaction processes (i.e. during the last 0.5 m.y.).

The results show clear evidence of radioactive disequilibrium, and hence recent rock/water interaction, in four of the six samples. Some is attributable mostly to solution-solid  $^{234}\text{U}$  recoil gain (weakly mineralised zones adjacent to the main mineralisation) and others to solid-solution  $^{234}\text{U}$  recoil loss (moderate to highly mineralised zones). The richer type of impregnation mineralisation indicates apparent radioactive equilibrium.

The absence of significant  $^{238}\text{U}$  loss in the samples helps to underline the reducing conditions prevalent within open fracture systems at these depths. This has meant that uraninite, now found in fractured rock at about 100 m depth, has been chemically stable in its environment for most, if not all, of its 1750 m.y. existence, including the last 0.5 m.y. when it has been closest to the atmosphere. This could indicate that spent nuclear fuel,

which essentially is crystalline  $\text{UO}_2$ , and comparable to uraninite once the main fission products have decayed, would also have been stable in this environment for similar periods of time.

THE MOVEMENT OF A REDOX FRONT DOWNSTREAM FROM A  
REPOSITORY FOR NUCLEAR WASTE

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ABSTRACT

In a final repository for nuclear waste it is envisaged that the waste will eventually come in contact with water. When this happens the  $\alpha$ -radiation will radiolyse water. The main products will be hydrogen and hydrogen peroxide. The hydrogen is fairly nonreactive and will be transported away by diffusion and convection. The hydrogen peroxide is a strong oxidizing agent and will oxidize any ferrous iron it encounters to ferric iron. This will change the electrochemical potential of the water in the region, from reducing to oxidizing conditions. In oxidizing waters many of the potentially hazardous radionuclides - actinides and technetium - will have a high solubility and low sorption compared to reducing conditions.

The movement of the redox front along the fissures downstream of a repository has been investigated theoretically. The rock is modelled as having parallel fissures where the water flows. The rock matrix has a connected porosity into which the hydrogen peroxide diffuses and quickly reacts with the minerals containing ferrous iron. The movement of the sharp boundary between oxidizing and reducing conditions in the fissures as well as in the matrix of the rock is described mathematically. A calculated example based on expected flowrate of water, rate of  $\alpha$ -radiolysis, fissure spacing and measured values of matrix diffusivity and ferrous iron content of the

bedrock is made. The results indicate that under some conditions the redox front may move tens of meters downstream during  $10^6$  years in fairly good rock, poor in ferrous iron.

It is conceivable that the extension of the redox front is larger as well as shorter because many of the important factors governing the front movement may vary considerably.



DIFFUSION OF HYDROGEN, HYDROGEN SULFIDE AND LARGE  
MOLECULAR WEIGHT ANIONS IN BENTONITE

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1982-07-02

ABSTRACT

The diffusivities of  $\text{HS}^-$  and  $\text{H}_2$  have been determined from profile analysis and steady state transport experiments.

The diffusivity of  $\text{HS}^-$  was found to be  $9 \cdot 10^{-12}$  and  $4 \cdot 10^{-12} \text{ m}^2 \cdot \text{sec}^{-1}$  in MX-80 and Erbslöh bentonite respectively. The results are in fair agreement with the results earlier obtained for  $\text{Cl}^-$  and  $\text{I}^-$ . The  $\text{H}_2$  diffusivity calculated from steady state transport was found to be surprisingly low ( $3.6 \cdot 10^{-12} \text{ m}^2 \cdot \text{sec}^{-1}$ ). Various heavy anions with molecular weights  $290-30 \cdot 10^3$  were found to migrate through MX-80 bentonite with diffusivities in the range  $(2,1-0,75) \cdot 10^{-15} \text{ m}^2 \cdot \text{sec}^{-1}$ .

## RADIOLYSIS OF GROUND WATER FROM SPENT FUEL

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## ABSTRACT

The effects of the radiolysis of water exposed to mixed alpha- and beta-radiation originating from spent fuel have been calculated. The water is assumed to have penetrated the copper canister and fuel cladding, and then to exist as a 30  $\mu\text{m}$  thin surface film on the fuel pellets.

The combined effects of alpha and beta-radiation, and the presence of iron in the water have been found to be important parameters. The beta-radiation will lower the yield of hydrogen, and so will the presence of low concentrations of iron ions. The most likely conditions for water exposed fuel give rise to a total production of 1 mol  $\text{H}_2$  per  $\text{m}^2$  fuel surface after 1 million years. A stoichiometric amount of oxygen is also formed.

The presence of an iron buffer, with a continuous supply of  $\text{Fe}^{2+}$  ions to the irradiated water phase increases the yield of hydrogen. After 1 million years the total hydrogen production is 70 mol per  $\text{m}^2$  exposed fuel surface. A stoichiometric amount of  $\text{Fe}^{3+}$  is also formed.

If pure water is irradiated (i.e. iron is excluded) the yields of hydrogen and oxygen produced are high. The integrated production of hydrogen after 1 million years is 200 mol per  $\text{m}^2$  exposed fuel surface. A stoichiometric amount of oxygen is also formed.

## CORROSION OF STEEL IN CONCRETE

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## ABSTRACT

A comparative study has been made of those properties of Massiv and Standard cements which are considered to determine their ability to protect steel reinforcement from corroding. Saturated Massiv cement has a higher evaporable water content, but a significantly finer pore structure than has saturated Standard cement. This fine structure resulted in an electrical resistivity ten times higher and chloride diffusivity ten times lower than those of Standard cement.

Electrochemical measurements have shown that the passive current density of steel in Massiv mortar is higher than that of steel in Standard mortar, but the higher current should lead to a more rapid decrease in potential to a level at which neither chloride attack or hydrogen evolution will occur. Whereas steel in Standard mortar was found to be highly susceptible to crevice corrosion, no such attack has been observed in Massiv mortar. Moreover, the initiation of chloride induced corrosion and the subsequent rates of corrosion were both lower in Massive mortar than in Standard mortar.

Thus, it may be predicted that Massiv cement would provide greater protection for steel reinforcement in underground structures exposed to chloride containing ground water than would Standard cement.

FISSURE FILLINGS FROM FINNSJÖN AND STUDSVIK, SWEDEN  
IDENTIFICATION, CHEMISTRY AND DATING

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Sven Åke Larson  
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Gothenburg, Sweden December 1982

ABSTRACT

To be able to find out frequency, equilibrium conditions and age of filling minerals, an identification and a chemical characterization of fissure fillings have been carried out. The sampling includes minerals from Finnsjön and Studsvik test sites respectively. The Studsvik investigations were also carried out in order to interpret results from the in situ migration experiments which have been made earlier. Samples were taken from cores and were collected at different levels.

The bedrock at Finnsjön is a Svecokarelian granite-granodiorite. The most frequent mineral in fissures is calcite. Other common fissure fillings are laumontite, prehnite, quartz and chlorite. Other clay minerals, pyrite, wairakite-analcime, epidote and dolomite have also been recorded.

Three generations of calcite can be detected within one and the same fissure filling. Two texturally different types of calcite could have formed due to different stress regimes. A chemical difference is established for texturally different types.

Waters pumped from boreholes in Finnsjön have got a mean  $\delta^{18}\text{O}$  value of  $-12\text{ ‰}$ . Most waters showed saturation in respect of calcite. To see if the calcites were crystallized or not from present waters a  $\delta^{18}\text{O}$  value of calcites precipitated during present temperature conditions was

calculated. The result shows that approximately 50 % of calcites from open fissures could have been precipitated from present waters. In contrast, only a few calcites from sealed fissures were in isotopic equilibrium with the waters. Isotopically three different groups of calcite have been distinguished. One group contains calcites precipitated from a water richer than the present  $\delta^{18}\text{O}$ .

Another group, which contains most of the calcite fillings includes those calcites which are in isotopic equilibrium with sampled groundwaters. This group also contains calcites precipitated by hydrothermal solutions. This is evident from fluid inclusion studies.

The third group represents calcites from sealed fissure fillings precipitated at temperature conditions similar to those required from prehnite and laumontite formation (hydrothermal conditions). Results from fluid inclusion studies show that temperatures from 175 °C to < 50°C prevailed during formation of the crystals. That is, several events of fluid activation are responsible for the calcite fissure fillings.

Dating of calcites were tried by the U-series method. Ages of  $29 \pm 13 \times 10^3$  years to  $79 \pm 25 \times 10^3$  years were estimated. It is reasonable to consider the ages as composite in the light of textural, fluid inclusion and isotopic data. Next to calcite is prehnite and laumontite the most common fissure fillings. Both minerals require hydrothermal temperature conditions and are mostly coprecipitated with the calcite group exhibiting lowest  $\delta^{18}\text{O}$ . Laumontite seems to be most frequent within the eastern part of the Finnsjön test area. At least two generations of quartz are recognized in the Finnsjön samples. Both granular as well as prismatic crystals appear.

Water analyses from Finnsjön show that laumontite is in chemical equilibrium with present waters. All waters analysed (from Finnsjön, Kråkemåla and Sternö) are saturated in respect of quartz. Feldspars are chemically unstable.

In Kråkemåla most waters are saturated in respect of fluorite. This is also the only place investigated where fluorite has been found as a fissure filling mineral.

Most fissure filling minerals identified have got cation exchange capacities (CEC) which are different from what has been established for the host granite. Thus e.g. quartz and calcite have got a very low CEC in contrast to zeolites and clay minerals.

The bedrock at Studsvik is a Svecokarelian gneiss of sedimentary type which is migmatized. Core mapping present calcite and chlorite as the most common fissure filling minerals. Clay minerals of smectite type are also frequent. This mineral type exhibits a high CEC. Feldspar, pyrite and palygorskite have also been identified. Most fissure fillings are thin and simple.

## SORPTION OF ACTINIDES IN GRANITIC ROCK

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## ABSTRACT

The sorption of americium (III), neptunium (V) and plutonium on geologic media under oxic conditions has been measured by a batch technique. The aqueous phase was a synthetic groundwater or 4 M NaCl solution. The solid phase was a pure mineral, representative of igneous rocks, or granite. Altogether 40 different minerals and rocks were used. The effects of pH and the ionic strength of the aqueous phase as well as of the cation exchange capacity and the surface/mass ratio of the solid sorbent are discussed. Empirical equations giving the distribution coefficient as a function of pH in the environmental pH-range 7-9 are suggested. Some observations and conclusions concerning sorption mechanisms are given.

NATURAL LEVELS OF URANIUM AND RADIUM IN FOUR POTENTIAL  
AREAS FOR THE FINAL STORAGE OF SPENT NUCLEAR FUEL

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ABSTRACT

An environmental sampling programme was performed in four potential areas suitable for the final storage of spent nuclear fuel. The background concentrations of uranium and radium in water, sediments, soils, peat and vegetation were determined. The values obtained for the different parts of the biosphere showed a close agreement with values recorded earlier in Sweden except for some vegetation samples. Thus the calculated plant-soil concentration factors for both uranium and radium showed somewhat higher values compared to earlier investigations of crops and soils in Sweden.



ANALYSIS OF GROUNDWATER FROM DEEP BOREHOLES IN  
KRÅKEMÅLA, STERNÖ AND FINNSJÖN

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ABSTRACT

Groundwater from deep boreholes in granitic rock at three different sites in Sweden - Finnsjön, Kråkemåla and Sternö - has been sampled and analysed. A total of ten different boreholes have been sampled, one at Kråkemåla, two at Sternö and seven at Finnsjön.

In general four levels per hole containing water-bearing fractures have been selected. Prior to sampling, a water-bearing level is isolated between packer sleeves. The deepest levels are down to about 500 m. The sampling was carried out by the Geological Survey of Sweden and a number of laboratories have participated in the water analyses.

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 will present the basic results from the groundwater analyses to be further evaluated by experts in different fields.

MIGRATION MODEL FOR THE NEAR FIELD  
Final Report

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ABSTRACT

The near field model describes the transport of substances dissolved in the groundwater to and from a canister in which radioactive materials are stored.

The migration of substances that can cause corrosion (oxidants) of the canister is described by means of a mathematical model. The model takes into account diffusion through the buffer material and water flow in the rock fractures. The oxidants are carried by the groundwater in the fractures up to the clay barrier and then diffused through the buffer material to react finally with the canister material. Two distinct transport resistances can be distinguished in this transport process. The first consists of the diffusion resistance in the buffer material and the second arises due to diffusion resistance in the flowing water in the thin fractures in the rock. The two transport resistances have been calculated under steady-state conditions for three-dimensional geometry.

The waterbearing fractures in the rock are modelled as equidistant and situated in parallel planes perpendicular to the longitudinal direction of the canister. The flow is described by potential flow. In the calculations, the resistances have been calculated separately and then added to obtain a total resistance using the formula:

$$R_{TOT} = R_L + R_V$$

$R_L, R_V$  denote the resistances in the buffer material and between the buffer material and the groundwater ( $s/m^3$ )  
( $R = 1/kA$ )

$k =$  mass transfer coefficient (m/s)

$A =$  diffusion area ( $m^2$ )

Calculations have also been performed where the diffusion in the flowing water in the fractures and the diffusion in the clay barrier have been calculated simultaneously. These calculations produce results in agreement with those where the resistances have been calculated separately. The former method is much more computer-time-consuming, however.

This model for the inward transport of oxygen has also been compared with the simplified model used in KBS TR 79. The agreement between these models is very good. Both models show that the resistance in the buffer material is of less importance for the total resistance.

The model can also be used to calculate the non-steady-state phase of the inward or outward transport of dissolved species.

The model has also been used to calculate how a redox front caused by radiolytically produced oxidants moves out through the clay and into the rock. It has been shown that the migration rate of the redox front can be calculated with good accuracy by means of simple mass balance computations, except where very short times are involved.

The transport of radiolytically formed hydrogen away from the fuel has been calculated. When dissolved in the water,

hydrogen can be transported through the clay barrier by means of diffusion without the partial pressure of the hydrogen exceeding the hydrostatic pressure.

Calculations have been performed to ascertain whether the inward transport of water through a hole in the canister can be a limiting factor for radiolysis. The possibility that even small holes can transport significant quantities of water cannot be ruled out.

ON THE pH-BUFFERING EFFECTS OF THE  $\text{CO}_2\text{-CO}_3^{2-}$ -SYSTEM IN  
DEEP GROUNDWATERS

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ABSTRACT

Equilibria in the system  $\text{H}_2\text{O-CO}_2\text{-CaCO}_3(\text{s})$  are discussed and data from some deep granitic groundwaters are summarized. For most waters pH would be in the range 7-9 and the total carbonate concentration in the range 30-400 mg/l (more often 90-275 mg/l). The observed field data represent reasonably well closed water systems with fixed total carbonate concentrations.

The carbonate concentration ( $\text{CO}_3^{2-}$ ) can be estimated from  $\log [\text{CO}_3^{2-}] = 0.76 \text{ pH} - 10.83 \pm 0.08$  which would represent about 50% of all the observed concentration/pH-data (for the waters with the highest carbonate concentrations).

MOBILITIES OF RADIONUCLIDES IN FRESH AND FRACTURED  
CRYSTALLINE ROCK

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## ABSTRACT

Sorption and migration of technetium, cesium and americium on fracture surfaces and fresh surfaces of granites taken from drilling cores from the Finnsjön and Studsvik areas and the Stripa mine are reported. The three elements were used as reference elements with different chemistry and behaviour in water; under the conditions used in the experiments technetium exists as the heptavalent  $\text{TcO}_4^-$ -ion, cesium as the non-complexed monovalent cation  $\text{Cs}^+$  and americium as the strongly hydrolysed  $\text{Am}(\text{OH})_x^{3-x}$  ( $x=1-4$ ). The waters used were synthetic groundwaters representative of waters from the drilling holes. After the exposure of the fracture samples to spiked groundwater solutions for a period of three up to six months the penetration depths and concentration profiles were analysed and autoradiographs of cesium and americium distribution vs depth were taken. The sorption of technetium was found to be negligible. The transport of  $\text{TcO}_4^-$  depends on accessibility to fractures and micro-fissures in the rock. Cesium is sorbed through an ion-exchange process. Migration of cesium depends not only on the transport in water into fractures and micro-fissures, but also on migration through mineral veins with a high CEC. Americium is strongly sorbed on most solid surfaces and did not migrate significantly during the contact time of three months. The diffusivity in granite was found to be around  $10^{-13}$   $\text{m}^2/\text{s}$  for cesium; preliminary values for technetium and americium were  $10^{-12}$   $\text{m}^2/\text{s}$  and less than  $10^{-16}$   $\text{m}^2/\text{s}$ , respectively.

DIFFUSIVITIES OF SOME DISSOLVED CONSTITUENTS IN COMPACTED  
WET BENTONITE CLAY -MX80 AND THE IMPACT ON RADIONUCLIDE  
MIGRATION IN THE BUFFER

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ABSTRACT

The diffusivities measured by various investigations of several species in compacted bentonite clay have been compiled and analysed. Small anions diffuse slower than an uncharged molecule such as methane. Large anions move orders of magnitude slower still. The actinides Th, U, Pu, Np and Am are considerably retarded by sorption effects. Their movement can be explained by pore diffusion with retardation. Cs, Sr and Pa move considerably faster than can be explained by these effects. The faster mobility is probably due to surface migration.

A simplified model is presented by which the importance of the backfill barrier in retarding the radionuclides can be assessed. It is based on the computation of the evolution of the concentration profile of the diffusing nuclide in the backfill. The flowrate out from the backfill to the flowing water can be compared to the inflow into the backfill due to leaching.

Using the previously obtained diffusivities it is found that a 0.375 m thick backfill will eventually let through all  $I^{129}$ ,  $Tc^{99}$ ,  $RA^{226}$ ,  $Pa^{231}$ ,  $U^{234}$ ,  $U^{235}$ ,  $U^{238}$  and  $Np^{237}$ . The maximum release rate for  $Cs^{137}$ ,  $Sr^{90}$ ,  $Pu^{239}$ ,  $Pu^{240}$  and  $Am^{243}$  will decrease by one to three orders of magnitude compared to the leach rate.  $Am^{241}$  will decay to insignificance in the backfill.