

**SKB ANNUAL REPORT 1996**

**Part III**

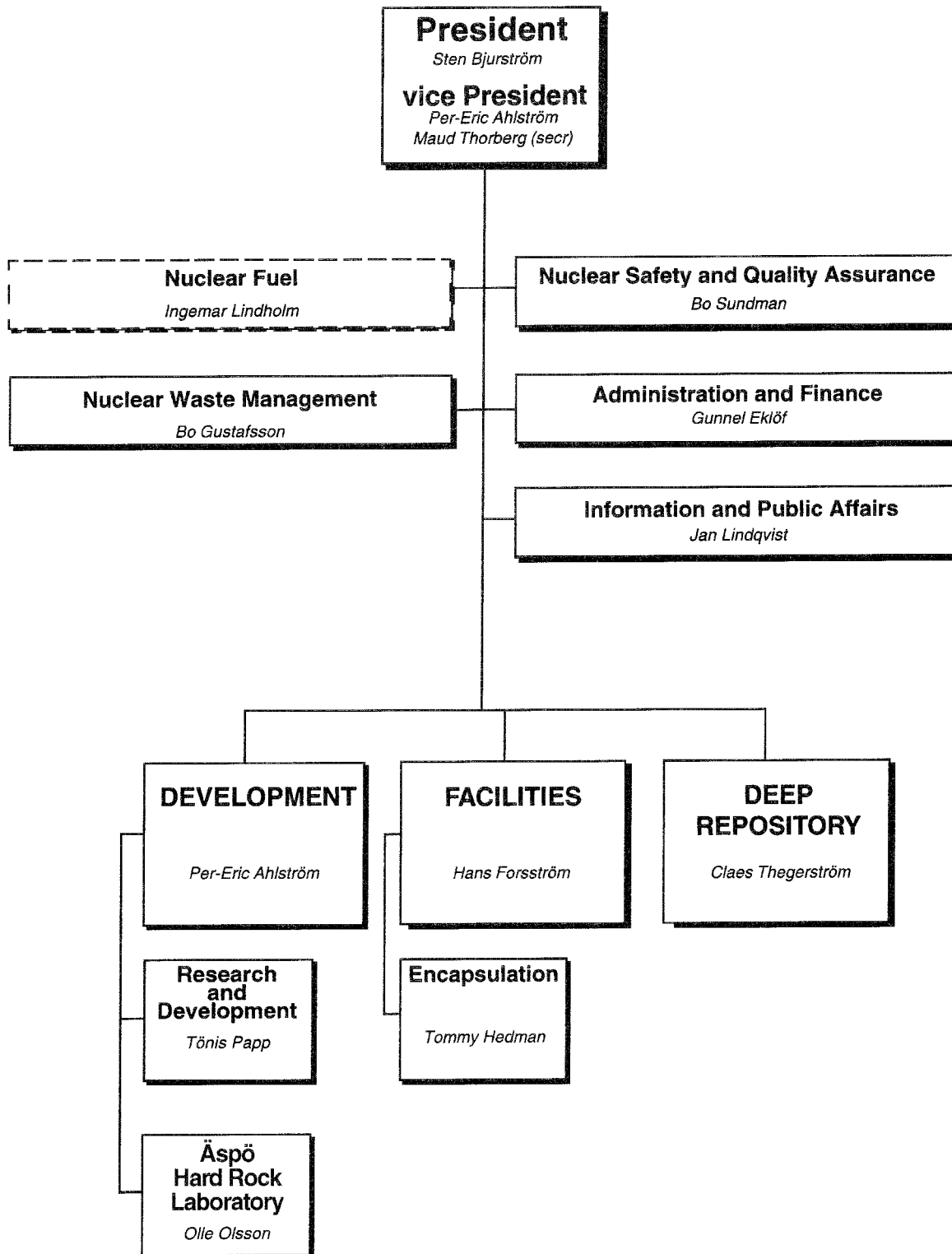
**Appendices**

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# ORGANIZATION CHART FOR SKB

## APRIL 1997



## SKB TECHNICAL STAFF

Note: Several persons of the staff work in more than one function; sometimes these functions belong to different divisions or departments.

### DEVELOPMENT

Per-Eric Ahlström	Vice President, Director Development
Monica Hammarström	International cooperation
Fred Karlsson	Chemistry, Natural analogues, Other waste types

### Research and Development:

Tönis Papp	Research Director
Lars O Ericsson	Geoscience
Allan Hedin	Uncertainties – Safety analysis
Lena Morén	Scenario – Safety analysis
Ulrik Kautsky	Biosphere – Safety analysis
Patrik Sellin	Near-field – Safety analysis
Jan-Olof Selroos	Far-field – Safety analysis
Kastriot Spahiu	Nuclear fuel
Peter Wikberg	Geochemistry, Groundwater chemistry

### Äspö Hard Rock Laboratory:

Olle Olsson	Director of Äspö Hard Rock Laboratory
Olle Zellman	Operations Manager Äspö
Lars Andersson	Service Engineer
Karl-Åke Bäckmark	Facility operation
Lars-Olof Dahlström	Project administrator, Manager Experimental services
Dan Eriksson	Computer systems
Ebbe Eriksson	Database systems
Johannes Heikillä	Service Engineer
Tomas Karlsson	Electronics Engineer
Mansueto Morosini	Project coordinator, Hydrogeology
Mats Ohlsson	Manager Data systems
Leif Stenberg	Project coordinator, Geology

### Computer Services:

Sverker Nilsson	Manager, System Administrations, Databases
Robert Perhat	PC support
Magnus Berg	PC support

## DEEP REPOSITORY

Claes Thegerström	Director Deep Repository
Kaj Ahlbom	Feasibility study Östhammar
Karl-Erik Almén	Site investigations
Anders Appelgren	Site office Nyköping
Göran Bäckblom	Overview studies and Technical coordination
Gunnar Bäckström	Public affairs
Torsten Eng	Feasibility study Nyköping, EIA studies
Camilla Fredriksson	Site office Nyköping
Torbjörn Hugo-Persson	Site office Malå
Per Johnsson	Quality control
Bengt Leijon	Feasibility study Malå
Gerd Nirvin	Site office Östhammar
Anders Ström	Performance assessment and site evaluation
Ragnar Ström	Geographic information system (GIS); Data system administration
Christer Svemar	Design studies, Buffer and Backfill material
Jerker Tengman	Project administration
Erik Thurner	Field measurements, Instruments

## FACILITIES

Hans Forsström	Technical Director Facilities
Bo Gustafsson	Deputy Director
Swen Berger	Transportation
Jan Carlsson	Quality assurance, SFR – Safety and waste, Other waste types
Peter Dybeck	SFR – Operation, Transportation
Stig Pettersson	Engineering & Costs, Design studies, Layout
Per Riggare	SFR – Safety and waste
Marie Skogsberg	SFR – Safety and waste
Bo Sundman	SVAFO
Marika Westman	Engineering & Costs
Maria Wikström	CLAB, Engineering & Costs
Jan Vogt	CLAB, Encapsulation process system

### Encapsulation:

Tommy Hedman	Project Director
Claes Göran Andersson	Canister manufacturing
Olle Broman	Project administrator
Stig Ericsson	Canister laboratory
Göran Fröman	Process systems
Kristina Gillin	Safety and environment
Kjell Mårtensson	Fuel storage
Olle Sanner	Layout
Lars Werme	Canister, Nuclear fuel

## QUALITY AND SAFETY

Bo Sundman	Director
Tomas Rosengren	Environmental issues

## **NUCLEAR FUEL**

Ingemar Lindholm  
Eva Backlöf  
Göran Schultz  
Anitha Meyerhöffer

Director Nuclear Fuel  
Transport manager  
Contracts  
Project administration

## **NUCLEAR WASTE MANAGEMENT**

Bo Gustafsson  
Claes Harfors  
Lars B. Nilsson

Director Nuclear Waste Management  
Deputy Director, Nuclear Waste Management  
Senior consultant

## LECTURES AND PUBLICATIONS 1996

**Scale dependency in rock strength***Adey, R; Pusch, R*

Workshop on Computational Methods in Engineering Geology, 7-9 October, 1996, Lund, Sweden

**Comments to ADTT impact on nuclear waste disposal, proliferation problems and nuclear energy strategies***Ahlström, P-E*

Proc. of the Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications, Kalmar, June 3-7, 1996

**Towards a Swedish repository for spent fuel***Ahlström, P-E*

Paper presented at Topseal 96', Demonstrating the practical achievements of nuclear waste management and disposal, Stockholm, Sweden, June 9-12, 1996.

Paper presented in Theological Problems in Radioactive Waste Isolation. Sec. World Wide Review, P A Wither- spoon, September 1996, DE-AC03-76SF00098

**Potential effects of hyperalkaline leachates on cementitious repository host rocks: An example from Maqarin, Northern Jordan***Alexander, W R; Smellie, J A T; Crossland, I*

Proc.: Chemical containment of wastes in the geosphere, British Geol. Surv., Sept. 3-4, 1996, Keyworth, Nottingham, UK

**Degradation of cellulose products in a cementitious environment – process studies and assessment of effects on radionuclide mobility***Allard, B*

ANDRA/Nagra/SKB Joint Meeting, Status of Sorption Databases for the Cementitious Near-field, Baden, 2-4 September 1996

**Dissolved organic matter in hyperalkaline groundwaters from Maqarin, Jordan***Allard, B*

Final Maqarin Workshop, Larnaca, 27-29 November 1996

**Nya bilder av bergets inre – djupdykning med ny borrhåls-TV***Almén, K-E; Thurner, E*

Borrsvängen 1/96

**Uraninite: A 2 GA spent nuclear fuel from the natural fission reactor at Bangombé in Gabon, West Africa***Alstrup Jensen, K; Ewing, R C; Gauthier-Lafaye, F*

MRS 1996 Fall meeting, December 2-6 1996, Boston, Massachusetts, USA, Abstracts, p. 751

**Organic carbon oxidation induced by largescale shallow water intrusion into a vertical fracture zone at the Äspö Hard Rock Laboratory (Sweden)***Banwart, S; Tullborg, E-L; Pedersen, K; Gustafsson, E;**Laaksoharju, M; Nilsson, A-C; Wallin, B; Wikberg, P*

J. of Contaminant Hydrology 21(1996):1-4, pp. 115-125

**Simultaneous determination of chloride complexes of Pt(IV) and Pd(II) by capillary zone electrophoresis with direct UV absorbance detection***Baraj, B; Sastre, A; Martínez, M; Spahiu, K*

Analytica Chimica Acta 319(1996): pp. 191-197

**Damage zone characterization in the near field in the Swedish ZEDEX tunnel using in situ and laboratory measurements***Bauer, C; Homand-Etienne, F; Slimane, K B; Hinzen, K G; Reamer, S K*

Eurock '96, ISRM International Symposium, Torino, Italy, September 2-5, 1996

**Disturbed zone assessment with permeability measurements in the ZEDEX tunnel***Bauer, C; Homand, F; Slimane, K B*

Proceedings of the Excavation Disturbed Zone Workshop, September 20, 1996 in Winnipeg, Canada (ISSN 0-919784-44-5)

**Pyrolysis GC-MS and GC-AED analysis of aquatic humic substances and hydrophilic acids***Bergh, S; Flodin, C; Allard, B; Borén, H; Grimvall, A*

8th Meeting Humic Substances Soc., Wroclaw, 9-14 September 1996 (Proc. in press)

**GPS measurements to constrain geodynamic processes in Fennoscandia***BIFROST project members (Bennet; Carlsson; Carlsson; Chen; Davis; Ekman; Elgered; Elósegui; Hedling; Jaldehag; Jarlemark; Johansson; Jonsson; Kakkuri; Koivula; Milne; Mitrovica; Nilsson; Ollikainen; Pounonen; Poutanen; Pysklywec; Rönnäng; Scherneck)*

EOS Trans. Am. Geophys. Union 77(1996): pp. 337-441

**Radioactive waste management in Sweden – Today's experience and work toward final disposal of spent fuel**

*Bjurström, S*

In: Proc. of the 11th KAIF/KNS Annual Conference, "The challenge of nuclear energy towards the 21st century", April 11-12, 1996, Seoul, Korea, pp. 77-89

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**Sammanställning av gjutningar i SFR och provningar i Bångbro under 1994 och 1995**

*Björkenstam, E*

UC 96:1Ö, Vattenfall Utveckling AB

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**Utveckling av SFR bruket**

*Björkenstam, E*

UC 96:3, Vattenfall Utveckling AB

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**Groundwater flow beneath ice sheets: Part I – Large scale patterns**

*Boulton, G S; Caban, P E; Van Gijssel, K*

Quaternary Science Reviews 14(1995): pp. 545-562

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**Modelling the ice sheet hydrological system and its application to the disposal of radioactive waste**

*Boulton, G S*

Presented at the Workshop on the Impact of Climate Change & Glaciations on Rock Stresses, Groundwater Flow and Hydrochemistry – Past, Present and Future, Stockholm, Sweden, 17-19th April 1996

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**The significance of hydrological and catchment processes for the transport and biological uptake of radionuclides in Northern aquatic ecosystems**

*Brittain, J E; Håkansson, L; Bergström, U; Björnstad, H*

In: Proc. of Tenth Int. Northern Research Basins Symposium and Workshop, Spitsbergen, Norway, Aug. 28 - Sept. 3, 1994, eds. K Sand and Å Killingtveit, 1996

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**Oklo-Natural Analogue Phase II, Behaviour of nuclear reaction products in a natural environment: New drilling campaign and geological investigations on the Bangombé natural fossil reactor (Gabon)**

*Bros, R; Gauthier-Lafaye, F*

CGS, CNRS Report, December 1996, Strasbourg, France

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**A kinetic model for the stability of spent fuel matrix under oxidic conditions**

*Bruno, J; Cera, E; Duro, L; Eriksen, T E; Werme, L O*

Journal of Nuclear Materials 238(1996): pp. 110-120

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**A kinetic model for the stability of the spent fuel matrix under oxidic conditions: Model developments against experimental evidence**

*Bruno, J; Cera, E; Duro, L; Eriksen, T E; Sellin, P; Spahiu, K; Werme, L O*

Presented at MRS Fall Meeting held in Boston, December 1996, Mat. Res. Soc. Symp. Proc. In press

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**Incorporation mechanisms of actinide elements into the structures of U<sup>6+</sup> phases formed during the oxidation of spent nuclear fuel**

*Burns, P C; Ewing, R C; Miller, M L*

Journal of Nuclear Materials (in press)

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**U<sup>6+</sup> minerals and inorganic phases: A comparison and hierarchy of crystal structures**

*Burns, P C; Miller, M L; Ewing, R C*

Canadian Mineralogist 34(1996): pp. 845-880

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**High-precision positioning using permanent GPS reference networks**

*Carlsson, T R; Elgered, G; Jarlemark, P; Johansson, J; Rönnäng, B; Scherneck, H-G*

In: Radiovetenskaplig Konferens RVK-96, ed. Zetterberg, L H, Luleå University of Technology, 1996, pp. 326-330

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**The permanent geodetic station at Onsala Space Observatory**

*Carlsson, T R; Elgered, G; Jarlemark, P O J; Johansson, J M; Nilsson, B I; Rönnäng, B O; Scherneck, H-G*

XXI General Assembly European Geophysical Soc., 6-10 May, 1996, The Hague, The Netherlands, Ann. Geophys., 14, C29 (abstract), 1996

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**Assessment of the long term performance of the Swedish final repository for radioactive waste, SFR**

*Carlsson, J; Karlsson, F; Riggare, P*

IAEA Int. Symp. on Experience in the Planning and Operation of Low Level Waste Disposal Facilities, 17-21 June, 1996, Vienna, Austria

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**The Swedish concept for disposal of waste arising from the operation of nuclear power plants**

*Carlsson, J*

Bewirtschaftung radioaktiver Betriebsabfälle aus Kernkraftwerken, Brugg-Windisch, Switzerland, March 1996

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- a) Safety principles
- b) Waste characterization
- c) Waste acceptance criteria
- d) Siting approaches

*Carlsson, J*

IAEA Interregional training course on near-surface disposal of low and intermediate level waste, Cumbria, England, October 1996

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**Characterization and dissolution behavior of a natural sample of becquerelite from Shinkolobwe (Zaire)**

*Casas, I; Bruno, J; Cera, E; Finch, R J; Ewing, R C*

Geochim. et Cosmochim. Acta. Accepted for publication

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**Uranium in natural systems. The role of pe, pH and carbonate on the solubility of UO<sub>2</sub> and uraninite (UO<sub>2+x</sub>) under nominally reducing conditions**

*Casas, I; de Pablo, J; Giménez, J; Torrero, M E; Bruno, J; Cera, E; Finch, R J; Ewing, R C*

Submitted to *Geochim. et Cosmochim. Acta*

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**Fission-track thermochronology applied to late proterozoic and phanerozoic thermal and tectonic events in Southern Sweden**

*Cederblom, C E; Larsson, S Å; Tullborg, E-L; Stiberg, J-P*  
Int. Workshop on Fission-Track Dating, Gent, Belgium, August 26-30, 1996

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**An evaluation of water layer thickness effective in the oxidation of UO<sub>2</sub> fuel due to radiolysis of water**

*Christensen, H; Sunder, S*

*Journal of Nuclear Materials* 238(1996): pp. 70-77

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**Calculation of radiation induced corrosion of UO<sub>2</sub> in solutions containing carbonate**

*Christensen, H; Sunder, S*

*Studsvik/M-96/4*

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**Current state of knowledge in radiolysis effect on spent fuel corrosion**

*Christensen, H*

Lecture presented at an EU-project meeting, Madrid, Spain, 24-25 September 1996

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**Thermoelastic stress due to a rectangular heat source in a semi-infinite medium. Presentation of an analytical solution**

*Claesson, J; Probert, T*

Contribution to Computational Methods in Rock Mechanics, Lund, October 1996

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**Reduction of pertechnetate by ferrous iron in solution, influence of sorbed and precipitated Fe(II)**

*Cui, D; Eriksen, T E*

*Environmental Science and Technology* 30(1996):7, pp. 2259-2262

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**Reduction of pertechnetate in solution by heterogeneous electron transfer from Fe(II) containing geological material**

*Cui, D; Eriksen, T E*

*Environmental Science and Technology* 30(1996):7, pp. 2263-2269

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**Trace elements distribution patterns in magnetically separated fractions of a fracture filling material**

*Cui, D; Eriksen, T E*

Mat. Res. Soc. Symp. Proc., Material Research Society, Scientific Basis of Nuclear Waste Management, Vol. 412(1996): pp. 847-853

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**Characterization of humic substances by capillary zone electrophoresis**

*Dahlén, J; Allard, B; Borén, H*

8th Meeting Humic Substances Soc., Wroclaw, 9-14 September 1996 (Proc. in press)

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**Review of excavation disturbance measurements undertaken within the ZEDEx project: Implications for the Nirex Rock Characterisation Facility**

*Davies, N; Mellor, D*

Eurock '96, ISRM International Symposium, Torino, Italy, September 2-5, 1996

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**Reasons for accepting and rejecting prospecting of a nuclear waste repository – the Swedish Community of Storuman**

*Drottz-Sjöberg, B-M*

Comparative siting of noxious facilities, Guildford, June 2, 1996

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**Experience from eight years of operation of the final storage for low level waste, SFR, in Sweden**

*Dybeck, P*

IAEA Symp. on Experience in the Planning and Operation of Low Level Waste Disposal Facilities, Vienna, Austria, June 1996

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**Clays at the natural nuclear reactor at Bangombé, Gabon; Migration of actinides**

*Eberly, P O; Ewing, R C; Janeczek, J; Furlano, A*

*Radiochimica Acta* 74(1996): pp. 271-275

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**Extraction studies with N,N'-substituted malonamides**

*Ekengren, L*

Diploma Thesis, Department of Nuclear Chemistry, Chalmers University of Technology, March 8, 1996

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**RNA extraction from deep granitic groundwater at Äspö and hybridization with group-specific 16S rRNA-directed oligonucleotide probes**

*Ekendahl, S; Vazirisani, F; Pedersen, K*

Poster presentation at the 1996 International symposium on subsurface microbiology (ISSM-96), 15-21 September 1996 in Davos, Switzerland

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**Mechanisms for redox control and their effects upon modelled properties of Äspö groundwaters**

*Emrén, A T*

In: Proceedings of the 1996 International conference on deep geological disposal of radioactive waste, September 16-19, 1996, Winnipeg, Manitoba, Canada, pp. 3-49 – 3-62

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**Siting of the Swedish deep geological repository – experiences and plans**

*Eng, T; Bäckblom, G; Thegerström, C; Ahlbom, K; Leijon, B*

In: Proceedings of the 1996 International conference on deep geological disposal of radioactive waste, September 16-19, 1996, Winnipeg, Manitoba, Canada, pp. 3-253 – 3-263

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**The siting process in Sweden and how the environmental impact assessment process now are implemented**

*Eng, T; Thegerström, C*

Poster presentation at Topseal 96', Demonstrating the practical achievements of nuclear waste management and disposal, Stockholm, Sweden, June 9-12, 1996

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**Correlation between acidity and molecular size distributions of an aquatic fulvic acid**

*Ephraim, J H; Pettersson, C; Allard, B*

*Environ. Int.* 22(1996): pp. 475-483

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**Effects of fulvic acid on the uptake of metal ions by naturally occurring solids**

*Ephraim, J H; Allard, B*

8th Meeting Humic Substances Soc., Wroclaw, 9-14 September 1996 (Proc. in press)

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**Natural glasses and the verification of the long-term durability of nuclear waste glasses**

*Ewing, R C*

National Academy of Sciences workshop "Glass as a Waste Form and Vitrification Technology", Washington, D.C., May 14, 1996

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**Regulatory time of compliance for radioactive waste disposal: Insights gained from natural analogue studies**

*Ewing, R C*

Advisory Committee on Nuclear Waste, Nuclear Regulatory Commission, Washington, D.C., March 27, 1996

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**Role of materials science in radioactive waste disposal and performance assessment**

*Ewing, R C*

DOE Council on Materials Sciences Workshop on "Radiation Effects in Glasses for the Immobilization and Disposal of High-Level Radioactive Wastes and Excess Weapons Plutonium", Santa Fe, New Mexico, February 26, 1996

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**The role of mineralogy in designing nuclear waste forms**

*Ewing, R C*

Institute of Geology, Aarhus University, Denmark, March, 1996

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**The role of waste forms in the performance assessment of nuclear waste repositories**

*Ewing, R C*

Advisory Committee on Nuclear Waste of the Nuclear Regulatory Commission, Washington, D.C., January 26, 1996

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**Where is the materials science in radioactive waste disposal?**

*Ewing, R C*

CEA Saclay, Service de Chimie Moléculaire, France, November 19, 1996

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**Where is the materials science in radioactive waste disposal?**

*Ewing, R C*

Paul Scherrer Institut, Willigen, Switzerland, November 22, 1996

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**Where is the materials science in radioactive waste disposal?**

*Ewing, R C*

Office of Basic Energy Sciences, Department of Energy, Germantown, Maryland, USA, December 6, 1996

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**Examination of the excavation-disturbed zone in the Swedish ZEDEX tunnel using acoustic emission and ultrasonic velocity measurements**

*Falls, S D; Young, R P*

Eurock '96, ISRM International Symposium, Torino, Italy, September 2-5, 1996.

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**Comparison of excavation disturbance around deep tunnels in hard rock using acoustic emission and ultrasonic velocity methods**

*Falls, S D; Young, R P*

Proceedings of the Excavation Disturbed Zone Workshop, September 20, 1996 in Winnipeg, Canada (ISSN 0-919784-44-5)

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**Clarkeite: new chemical and structural data**

*Finch, R J; Ewing, R C*

*American Mineralogist* (in press)

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**The crystal structure of schoepite, [(UO<sub>2</sub>)<sub>8</sub> O<sub>2</sub> (OH)<sub>12</sub>](H<sub>2</sub>O)<sub>12</sub>**

*Finch, R J; Cooper, M A; Hawthorne, F C; Ewing, R C*

*Canadian Mineralogist* 34(1996): pp. 1071-1088

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**On the simulation of saline intrusion for repository performance assessment**

*Follin, S*

14th Salt Water Intrusion Meeting, SWIM 96, 16-21 June 1996, Malmö, Sweden, SGU Rapport och Meddelande nr 87, pp. 300-313

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**Management of spent nuclear fuel and radioactive waste in Sweden**

*Forsström, H*

Paper presented at Int. Seminar on New Generation Nuclear Power Plants, Warsaw, Poland, 25-27 September, 1996

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**Radioactive waste management in Sweden. Experiences and plans**

*Forsström, H*

1996 Summer School "Radioactive Waste Management and Decommissioning", Cambridge, England, June 1996

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**Ten year plus experience of the operation of the Swedish waste management system**

*Forsström, H; Dybeck, P; Vogt, J*

TOPSEAL', Stockholm, Sweden, June 9-12, 1996

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**"Archives for millenia" – A strategy to inform future societies about nuclear waste repositories**

*Fryksén, A*

In: Int. Council on Archives Vol. XLXX, Memory of the world at risk, archives destroyed, archives reconstituted, K G Saur, 1996, pp. 323-334

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**Experimental investigation and mathematical simulation of coupled T-H-M processes of the engineered buffer materials, the TC3 problem**

*Fujita, T; Kobayashi, A; Börgesson, L*

In.: Coupled thermo-hydro-mechanical processes of fractured media, eds. O Stephansson, L. Jing, C-F Tsang, Developments in Geotechnical Engineering, vol. 79, 1996, Elsevier Science

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**Prediction of groutability from grout properties and hydrogeological data**

*Gustafson, G; Stille, H*

Tunnelling and Underground Space Vol. 11, No 3, 325-332, 1996

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**Designing a large scale combined pumping and tracer test in a fracture zone at Palmottu, Finland**

*Gustafsson, E; Nordqvist, R; Korkealaakso, J; Galarza, G*

Presented at OECD/NEA GEOTRAP Workshop, 28-30 August 1996, Köln, Germany

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**Coupling of the near field release to the far field transport – Using NUCTRAN and CHAN3D**

*Gylling, B; Romero, L; Moreno, L; Neretnieks, I*

In: Transactions of TOPSEAL '96, Int. Topical Meeting, European Nuclear Society, Stockholm, June 9-12, Vol. II Poster Papers, pp. 160-163, 1996

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**Transport from the canister to the biosphere – Using an integrated near and far field model**

*Gylling, B; Romero, L; Moreno, L; Neretnieks, I*

In Proc. of Scientific Basis for Nuclear Waste Management XX, 1996

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**Aperture measurements and flow experiments on a single natural fracture**

*Hakami, E; Larsson, E*

Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 33(1996):4, pp. 395-404

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**Microbial diversity in hyperalkaline groundwaters from the Maqarin area, Jordan, determined by 16S rRNA gene sequencing**

*Hallbeck, L; Pedersen, K*

Poster presentation at the 1996 International symposium on subsurface microbiology (ISSM-96), 15-21 September 1996 in Davos, Switzerland

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**On the biology of the iron-oxidising and stalkforming bacterium *Gallionella ferruginea***

*Hallbeck, L; Pedersen, K*

Poster presentation at the 1996 International symposium on subsurface microbiology (ISSM-96), 15-21 September 1996 in Davos, Switzerland

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**What has been learnt from field tracer transport experiments – A critical review**

*Hautojärvi, A; Andersson, P; Volckaert, G*

Presented at OECD/NEA GEOTRAP Workshop, 28-30 August 1996, Köln, Germany

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**The Swedish spent fuel encapsulation facility – Design features**

*Hedman, T; Acton, R*

Storage in Nuclear Fuel Cycle, Manchester, England, September 1996

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**Towards the encapsulation of spent nuclear fuel**

*Hedman, T; Werme, L*

TOPSEAL '96, Stockholm, Sweden, June 9-12, 1996

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**Creep testing of copper for radwaste canisters**

*Henderson, P; Werme, L*

Presented at EUROMAT 96 "Materials and Nuclear Power", Bournemouth, UK, October 1996

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**Modelling of radiocesium in lakes – the VAMP model**

*Håkansson, L; Brittain, J; Monte, L; Heling, R; Bergström, U; Suolanen, V*

J. Environ. Radioactivity 33(1996):3, pp. 255-308

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**A technique for modeling transport/conversion processes, applied to smectite-to-illite conversion in HLW buffers**

*Högmark, H*

Engineering Geology (in print)

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**Acceptance of emplacement hole positions – stage 1 thermo-mechanical study**

*Högmark, H*

Workshop on Computational Methods in Engineering Geology, 7-9 October, 1996, Lund, Sweden

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**Numerical study of the performance of tunnel plugs**

*Högmark, H*

Workshop on Computational Methods in Engineering Geology, 7-9 October, 1996, Lund, Sweden

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**Short description of FLAC Version 3.2**

*Israelsson, J I*

In.: Coupled thermo-hydro-mechanical processes of fractured media, eds. O Stephansson, L. Jing, C-F Tsang, Developments in Geotechnical Engineering, vol. 79, 1996, Elsevier Science

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**Short descriptions of UDEC and 3DEC**

*Israelsson, J I*

In.: Coupled thermo-hydro-mechanical processes of fractured media, eds. O Stephansson, L. Jing, C-F Tsang, Developments in Geotechnical Engineering, vol. 79, 1996, Elsevier Science

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**Uraninite and UO<sub>2</sub> in spent nuclear fuel: A comparison**

*Janeczek, J; Ewing, R C; Oversby, V M; Werme, L O*

Journal of Nuclear Materials 238(1996): pp. 121-130

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**First results from a continuously operating GPS network in Fennoscandia**

*Johansson, J M; Carlsson, T R; Davis, J L; Elgered, G; Jarlemark, P O J; Mitrovica, J X; Pysklywec, R N; Rönnäng, B O; Scherneck, H-G; Shapiro, I I*

XXI General Assembly European Geophysical Soc., 6-10 May, 1996, The Hague, The Netherlands, Ann. Geophys., 14, C271 (abstract), 1996

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**Hydraulic conductivity variation with depth – an analysis of data from Swedish crystalline bedrock**

*Jönsson, P; Wallroth, T; Wladis, D*

In: Proc. of the Nordic Hydrological Conf. 1996, Akureyri, Iceland, 13-15 Aug., 1996, Vol. 2, pp. 668-677

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**The status of world biosphere modelling of waste disposal assessments following BIOMOVs II**

*Klos, R A; Reid, J A K; Santucci, P; Bergström, U*

In: Proc.. Int. Conf. on Deep Geological Disposal of Radioactive Waste, Winnipeg, Manitoba, Canada, September 16-19, 1996. Canada Nuclear Society, pp. 4-37 – 4-52

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**New findings on the hydrogeology of hard rocks in Sweden**

*Knutsson, G*

Presented at the 2nd Workshop on Hardrock Hydrogeology of the Bohemian Massif 1996 (In print in Acta Universitatis Wratislaviensis)

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**Ecology of methanogenic *Archea* in granitic groundwater from Äspö Hard Rock Laboratory, Sweden**

*Kotelnikova, S; Pedersen, K*

The 1996 International symposium on subsurface microbiology (ISSM-96), 15-21 September 1996 in Davos, Switzerland

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**Isolation and characterization of methanogenic *Archeae* from subsurface groundwater at Äspö Hard Rock Laboratory**

*Kotelnikova, S; Pedersen, K*

Poster presentation at the 1996 International symposium on subsurface microbiology (ISSM-96), 15-21 September 1996 in Davos, Switzerland

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**Identification of the governing parameters in rock indentation by using similarity analysis**

*Kou, S; Huang, Y; Tan, X; Lindqvist, P-A*

In: Proc. of Workshop on Computational Methods in Engineering Geology, Lund, Oct. 7-9, 1996, pp. 100-110

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Department of General and Marine Microbiology, The Lundberg Institute, Göteborg University, Göteborg, Sweden

February 1996

TR 96-02

**Microbial analysis of the buffer/container experiment at AECL's Underground Research Laboratory***Stroes-Gascoyne, S 1); Pedersen, K 2); Daumas, S 3); Hamon, C J 1); Haveman, S A 1); Delaney, T L 1); Ekendahl, S 2); Jahromi, N 2); Arlinger, J 2); Hallbeck, L 2); Dekeyser, K 3)*

AECL, Whiteshell Laboratories, Pinawa, Manitoba, Canada 1); University of Göteborg, Department of General and Marine Microbiology, Göteborg, Sweden 2); Guigues Recherche Appliquée en Microbiologie (GRAM), Aix-en-Provence, France 3)

May 1996

TR 96-03

**Reduction of Tc(VII) and Np(V) in solution by ferrous iron. A laboratory study of homogeneous and heterogeneous redox processes***Cui, Daqing; Eriksen, Trygve E*

Department of Chemistry, Nuclear Chemistry, Royal Institute of Technology, Stockholm, Sweden

March 1996

TR 96-04

**Revisiting Poços de Caldas. Application of the co-precipitation approach to establish realistic solubility limits for performance assessment***Bruno, Jordi; Duro, Lara; Jordana, Salvador;**Cera, Esther*

QuantiSci, Barcelona, Spain

February 1996

TR 96-05

**SR 95****Template for safety reports with descriptive example**

SKB

December 1995

TR 96-06

**Äspö Hard Rock Laboratory****Annual Report 1995**

SKB

April 1996

TR 96-07

**Criticality in a high level waste repository. A review of some important factors and an assessment of the lessons that can be learned from the Oklo reactors***Oversby, Virginia M*

VMO Konsult

June 1996

TR 96-08

**A reappraisal of some Cigar Lake issues of importance to performance assessment***Smellie, John 1); Karlsson, Fred 2)*

Conterra AB 1); SKB 2)

July 1996

TR 96-09

**The long-term stability of cement. Leaching tests***Engkvist, Ingemar; Albinsson, Yngve;**Johansson Engkvist, Wanda*

Chalmers University of Technology, Göteborg, Sweden

June 1996

TR 96-10

**Lake-tilting investigations in southern Sweden***Påsse, Tore*

Sveriges geologiska undersökning, Göteborg, Sweden

April 1996

TR 96-11

**Thermoelastic stress due to an instantaneous finite line heat source in an infinite medium***Claesson, Johan; Hellström, Göran*

Depts. of Building Physics and Mathematical Physics, Lund University, Lund, Sweden

September 1995

TR 96-12

**Temperature field due to time-dependent heat sources in a large rectangular grid. Derivation of analytical solution**

*Claesson, Johan; Probert, Thomas*

Depts. of Building Physics and Mathematical Physics,  
Lund University, Lund, Sweden

January 1996

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TR 96-13

**Thermoelastic stress due to a rectangular heat source in a semi-infinite medium. Derivation of an analytical solution**

*Claesson, Johan; Probert, Thomas*

Depts. of Building Physics and Mathematical Physics,  
Lund University, Lund, Sweden

May 1996

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TR 96-14

**Oklo: Des reacteurs nucleaires fossiles (Oklo: The fossil nuclear reactors). Physics study (R Naudet, CEA) – Translation of chapters 6, 13, and conclusions**

*Oversby, V O*

VMO Konsult

September 1996

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TR 96-15

**PLAN 96**

**Costs for management of the radioactive waste from nuclear power production**

Swedish Nuclear Fuel and Waste Management Co

June 1996

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TR 96-16

**Diffusion of I<sup>-</sup>, Cs<sup>+</sup> and Sr<sup>2+</sup> in compacted bentonite. Anion exclusion and surface diffusion**

*Eriksen, Trygve E; Jansson, Mats*

Royal Institute of Technology, Department of Chemistry,  
Nuclear Chemistry, Stockholm

November 1996

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TR 96-17

**Hydrophilic actinide complexation studied by solvent extraction radiotracer technique**

*Rydberg, Jan*

Department of Nuclear Chemistry, Chalmers University  
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Consultant Group AB, V. Frölunda, Sweden

October 1996

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TR 96-18

**Information, conservation and retrieval**

*Eng, Torsten 1); Norberg, Erik 2); Torbacke, Jarl 3);  
Jensen, Mikael 4)*

Swedish Nuclear Fuel and Waste Management Co (SKB)  
1); National Swedish Archives 2); Department of History,  
Stockholm University 3); Swedish Radiation Protection  
Institute (SSI) 4)

December 1996

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TR 96-19

**Application of space geodetic techniques for the determination of intraplate deformations and movements in relation with the postglacial rebound of Fennoscandia**

*Scherneck, Hans-Georg; Johansson, Jan M;*

*Elgered, Gunnar*

Chalmers University of Technology,

Onsala Space Observatory, Onsala, Sweden

April 1996

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TR 96-20

**On the characterization of retention mechanisms in rock fractures**

*Selroos, Jan Olof; Cvetkovic, Vladimir*

Div. of Water Resources Engineering, Dep. of Civil and  
Environmental Engineering, Royal Institute of  
Technology, Stockholm, Sweden

December 1996

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TR 96-21

**Boring of full scale deposition holes using a novel dry blind boring method**

*Autio, Jorma; Kirkkomäki, Timo*

Saanio & Riekkola Oy, Helsinki, Finland

October 1996

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TR 96-22

**Feasibility study for siting of a deep repository within the Malå municipality**

Swedish Nuclear Fuel and Waste Management Co., Stock-  
holm

March 1996

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TR 96-23

**Analysis of the Äspö LPT2 pumping test via simulation and inverse modelling with HYDRASTAR**

*Walker, Douglas (ed.) 1); Eriksson, Lars 2); Lovius, Lars*

*2)* INTERA KB 1); Starprog AB 2)

December 1996

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TR 96-24

**A mathematical model of the shore level displacement in Fennoscandia**

*Påsse, Tore*

Sveriges geologiska undersökning, Göteborg, Sweden

December 1996

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## POST-GRADUATE THESES SUPPORTED BY SKB 1996

**Estudis termodinàmics i cinètics de dissolució de fases naturals d'urani representatives d'un procés d'alteració oxidativa de l'òxid d'urani (IV) (Thermodynamic and kinetic studies of the dissolution of natural uranium phases, relevant in the oxidative alteration of the uranium (IV) oxide)**

*Cera, E*

Doctoral thesis, Universidad Autonoma de Barcelona, Spain, 1996

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**Sorption processes and solubilities of radionuclides in deep granitic fracture systems**

*Daqing Cui*

Doctoral thesis, Dept. of Chemistry, Nuclear Chemistry, Royal Institute of Technology, Stockholm, Sweden, 1996

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**Deep subsurface ecosystems – Numbers, activity and diversity of groundwater bacteria in Swedish granitic rock**

*Ekendahl, S*

Doctoral thesis, Dept. of General and Marine Microbiology, Göteborg University, Göteborg, Sweden, 1996

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**Some basic problems in rock breakage by blasting and by indentation**

*Kou, S*

Doctoral thesis, Div. of Mining Engineering, Luleå University of Technology, Luleå, Sweden, 1996, 1995:180 D

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**Experimental study of the mechanics of rock joints**

*Lindfors, U*

Licentiate thesis, Div. of Rock Mechanics, Luleå University of Technology, Luleå, Sweden, 1996

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**Application of image processing to borehole logging**

*Quanhong Feng*

Master thesis, Div. of Engineering Geology, Dept. of Civil and Environmental Engineering, Royal Institute of Technology, Stockholm, Sweden, 1996

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**Contaminant transport by groundwater: Stochastic travel time analysis and probabilistic safety assessment**

*Selroos, J-O*

Doctoral thesis, Div. of Water Resources Engineering, Dept. of Civil and Environmental Engineering, Royal Institute of Technology, Stockholm, Sweden, 1996 (partly sponsored by SKB)

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**Modelling of drill string buckling and tool indentation in rock drilling and fragmentation**

*Tan, Xiangchun*

Doctoral thesis, Dept. of Mining Engineering, Luleå University of Technology, Luleå, Sweden, 1996

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**SKB ANNUAL REPORT 1996**

**Part IV**

**Summaries of Technical Reports Issued during 1996**

## SKB Technical Report 96-01

### Bacteria, colloids and organic carbon in ground-water at the Bangombé site in the Oklo area

Pedersen, Karsten (ed.)

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February 1996

#### ABSTRACT

Natural analogues are investigated to understand long-term geological processes as part of the task to develop safe and reliable concepts for disposal of radioactive waste. Among many different repository aspects that must be assessed are stability of the waste and the engineered barriers, behaviour of the geological system that hosts the repository, the potential migration of radionuclides in the geosphere as well as the influence of microorganisms, colloids, and organic matter on repository performance. The Oklo region contains the only known examples of natural fission reactors and is therefore, perhaps, one of the best known natural analogues for the geological disposal of radioactive waste. This report describes how microorganisms, colloids and organic matter were sampled from groundwater in 1993 and 1994 from six boreholes at the Bangombé site in the Oklo region and subsequently analysed.

For analysis of microorganisms, DNA was extracted from groundwater, amplified and cloned and information available in the ribosomal 16S rRNA gene was used for mapping diversity and distribution of bacteria. The results showed that this site was inhabited by a diversified population of bacteria. Each borehole was dominated by species that did not dominate in any of the other boreholes; a result that probably reflects documented differences in the geochemical environment. Two of the sequences obtained were identified on genus level to represent *Acinetobacter* and *Zoogloea*, but most of the 44 sequences found were only distantly related to species in the DNA database. The deepest borehole, BAX01 (105 m), had the highest number of bacteria and also of total organic carbon (TOC). This borehole harboured only Proteobacteria beta group sequences while sequences related to Proteobacteria beta, gamma and delta groups and Grampositive bacteria were found in the other four boreholes. Two of the boreholes, BAX02 (34 m) and BAX04 (10 m) had many 16S rRNA gene sequences in common and they also had similar

counts of bacteria, content of TOC, pH and equal conductivity, suggesting a hydraulic connection between them.

The colloid sampling at Bangombé was conducted from four boreholes in July 1994 and the analyses comprised: colloids on membrane for scanning electron microscopy (SEM) analysis, colloids on membrane for ICP-MS analysis, and groundwater samples in bottles for single particle analysis. The results from the investigations carried out by the 3 analytical procedures were consistent. The colloid concentration in these Na-Mg-Ca-HCO<sub>3</sub> type waters of pH 6–7 and slightly negative Eh was rather low, about 20–100 ppb. This low colloid concentration was a consequence of relative concentrations of calcium, magnesium and sodium in the water which reduce colloid concentration because these cations act as a colloid cement (aggregation, sticking) in the aquifer. However, the presence of Fe(II) induces a large potential of artefact material. Trace element results show that transition metals and some heavy metals are associated with the colloid phase. Iodine, sulphur and selenium may be trace components of the organic colloids. Sulphur and selenium may be associated with transition (Cu, Zn, Fe, Ni, Pt, etc.) and heavy metals (Pb) in the colloid phase. Distribution coefficients of trace elements between the water and colloid phases ( $K_p$ ) were estimated. For example, for uranium, an average of 200 pg ml<sup>-1</sup> was detected in the water, and 40 pg ml<sup>-1</sup> was detected in the colloid phase. For uranium, a  $K_p$  value of  $2 \cdot 10^6$  ml g<sup>-1</sup> was calculated considering [colloid] = 100 ng ml<sup>-1</sup>. With this large  $K_p$  value, it is likely that uranium is not only sorbed but also associated with groundwater colloids.

Groundwater samples were collected for analysis of the concentration of organic carbon (TOC), humic substances and metals associated with the humic substances. Humic substances and associated metals were isolated on a weak anion exchange resin. TOC varied in the range 4–14 mg l<sup>-1</sup> in BAX01, BAX02 and BAX03 whereas BAX04 had a TOC of <1.5 mg l<sup>-1</sup>. The result of the isolation procedure indicated that humic substances comprised only a minor fraction (<3%) of the TOC which is in agreement with results obtained in studies performed with groundwater from granitic bedrock where, however, the TOC in general is only a few mg/l. The molecular weight distribution, determined with gel filtration, indicated that the humic matter consisted of fractions with different molecular weights. The presence of a low molecular weight fraction suggests ongoing subsurface processes in which the humic substances are decomposed. The metal speciation study indicated that a large fraction, i.e. 8–67%, of uranium (U) was bound to the humic matter compared to the fractions of Ca and Fe (<0.4% and 0.02–10%, respectively). The largest fraction of U associated with humic substances was found in BAX03, i.e. in the reactor.

## SKB Technical Report 96-02

### Microbial analysis of the buffer/container experiment at AECL's Underground Research Laboratory (also published as AECL-11436, COG-95-446, ANDRA C RP 0.AEC 96-001)

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May 1996

### ABSTRACT

The Buffer/Container Experiment (BCE) was carried out at AECL's Underground Research Laboratory (URL) for 2.5 years to examine the in situ performance of compacted buffer material in a single emplacement borehole under vault-relevant conditions. During decommissioning of this experiment, numerous samples were taken for microbial analysis to determine if the naturally present microbial population in buffer material survived the conditions (i.e., compaction, heat and desiccation) in the BCE and to determine which group(s) of microorganisms would be dominant in such a simulated vault environment. Such knowledge will be very useful in assessing the potential effects of microbial activity on the concept for deep disposal of Canada's nuclear fuel waste, proposed by AECL.

Microbial analyses were initiated at WL within 24 hours of sampling for all types of samples taken. Representative samples were shipped to a laboratory in France experienced in the microbial analysis of clays. Microbial analysis of the BCE samples included analyses for total viable aerobic and anaerobic heterotrophs at 25 and 50°C, viable specialized organisms, such as sulphate-reducing bacteria (SRB), methanogens, fermenters, fungi, sulphur-oxidizing bacteria (SOB), iron-related bacteria and slimeformers. Microbial activity was measured by determining the assimilation of <sup>3</sup>H-Leucine and the mineralization of <sup>14</sup>C-labelled glucose and a <sup>14</sup>C-labelled amino acids mixture. Bacteria in selected samples were identified from biochemical reactions in API<sup>®</sup> strips and DNA sequencing of the 16S rRNA genes. Phospholipid fatty acid (PLFA) analysis was used to determine potential viability, nutritional status and community structure without the need for culturing. Electron microscopy (both ESEM and TEM) allowed direct observation of any bacteria present. All culture results (almost 400) were evaluated with a statisti-

cal method (General Linear Model) to determine which variables affected the number of colony-forming units (CFU) in each sample analyzed.

The culture results showed an almost universal disappearance of viable microorganisms (both heterotrophic and specialized bacteria) in the samples taken from near the heater surface, where the moisture content was low (<15%) and the temperature high (as high as 60°C). The microbial activity measurements confirmed the lack of viable organisms with very weak or no activity measured in most of these samples. Generally, aerobic heterotrophic culture conditions gave the highest mean CFU values at both 25 and 50°C. Under anaerobic conditions, and especially at 50°C, lower mean CFU values were obtained. In all samples analyzed, numbers of SRB were <1000 CFU/g dry material. Methanogens were either not present or were found in very low numbers (<200 CFU/g dry material). Anaerobic SOB were found in higher numbers in most sample types with sufficient moisture.

More than 67% of the aerobically isolated strains were identified with the API method as belonging to either the species *Pseudomonas stutzeri* or the genus *Bacillus*. Two of the three dominating species found using 16S rRNA gene sequencing had a high identity with the typical groundwater bacteria *Pseudomonas flavescens* and *Acinetobacter calcoaceticus*. A third organism identified was an actinomycete related to *Streptomyces*. The PLFA analysis suggested the presence of potentially viable populations, but these showed characteristics of severe starvation, implying that the bacteria were not actively growing in situ. The electron microscopy examinations revealed an absence of easily observable microorganisms.

The statistical evaluation of all culture data demonstrated clearly that the water content was the variable limiting the viability of the bacteria present, and not the temperature. The water content below which viable bacteria could not be detected on culture media was about 15%. Calculations have shown that  $a_w$  for buffer material (used in the BCE) with a 15% moisture content is ~0.96. This is at the boundary where most Gram negative bacteria cease to grow although some groups of bacteria such as *Pseudomonas*, SRB and *Vibrio* are still able to grow. Virtually no viable bacteria were found in the samples of buffer material from the BCE that contained 15% water or less.

The present attention at AECL with regard to microbially influenced corrosion (MIC) effects on waste containers is focused on the effects of SRB, because of the expected reducing conditions in a vault and the presence of sulphate in buffer materials (as a gypsum impurity). The harsh conditions (radiation, high temperature, desiccation) in the zone adjacent to the container would likely result in the destruction of microbes. If repopulation of this zone is limited or prevented, SRB activity would be limited to regions outside this depleted zone. In this case the only microbial impact on the container would result from the diffusion of microbially reduced sulphur species to the container surface. But the results from the BCE

have also shown that in buffer samples with sufficient moisture for microbial activity, the numbers of viable SRB were not large, most likely because conditions during the BCE were not sufficiently reducing, but maybe also because of a lack of suitable organics. The latter would limit SRB activity outside the affected zone around the container, which would imply that the indirect MIC effects (i.e., sulphide diffusion) could also be limited, as long as low redox conditions have not developed. The present attention in Sweden is on experiments to determine at which water activity SRB can no longer survive in buffer materials.

### SKB Technical Report 96-03

#### **Reduction of Tc(VII) and Np(V) in solution by ferrous iron. A laboratory study of homogeneous and heterogeneous redox processes**

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March 1996

#### **ABSTRACT**

The redox chemistry of technetium and neptunium in deep groundwater systems has been studied under well controlled conditions in laboratory experiments. The measured redox potentials in anoxic deep groundwater systems are consistent with redox reactions between Fe(II) in solution and hydrous Fe(III)-oxide phases.

The fracture filling material and groundwater in transmissive fractures in bedrock constitute two different compartments in the groundwater system and experiments were therefore carried out in homogeneous Fe(II) containing solutions and in heterogeneous mixtures of solution with Fe (II) containing solid mineral phases.

Reduction of the strongly sorbing neptunyl cation ( $\text{NpO}_2^+$ ) and the slightly sorbing pertechnetate anion ( $\text{TcO}_4^-$ ) by Fe(II) in solution was found to proceed very slowly, if at all in reaction vessels with hydrophobic inner surfaces. However, in the heterogeneous systems we observed surface mediated reduction to the slightly soluble ( $<10^{-8} \text{ mol} \cdot \text{dm}^{-3}$ ) tetravalent (hydr)oxides  $\text{TcO}_2 \cdot n\text{H}_2\text{O}$  ( $=\text{Tc}(\text{OH})_4$ ) and  $\text{NpO}_2 \cdot n\text{H}_2\text{O}$  ( $=\text{Np}(\text{OH})_4$ ). By Fe(II) sorbed on quartz, precipitated  $\text{Fe}(\text{OH})_2(\text{s})$ ,  $\text{Fe}(\text{II})\text{CO}_3(\text{s})$  and Fe(II) bearing minerals such as magnetite, hornblende and Fe(II)-chlorite.

It is concluded that surface mediated redox-reactions will be the most effective pathway for the reduction of Tc(VII) and Np(V) in deep groundwater systems. On

exposure of the surface-precipitated tetravalent (hydr)oxides to air saturated groundwater solutions the oxidative dissolution was found to be a very slow process and high concentration of hydrogen peroxide was required for oxidative dissolution. The slow rate of oxidative dissolution is most probably due to kinetic suppression of the reactions between dissolved oxygen and the precipitated (hydr)oxides. The kinetic suppression is caused by competing redox reactions at the surface of the Fe(II)-bearing minerals which consumes the dissolved oxygen.

### SKB Technical Report 96-04

#### **Revisiting Poços de Caldas. Application of the co-precipitation approach to establish realistic solubility limits for performance assessment**

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February 1996

#### **ABSTRACT**

Solubility limits constitute a critical parameter for the determination of the mobility of radionuclides in the near field and the geosphere, and consequently for the performance assessment of nuclear waste repositories. Traditionally, these solubility limits have been calculated by assuming that the radionuclides are in equilibrium with their individual solid phases. However, the mounting evidence from Natural System Studies indicates that trace elements, and consequently radionuclides, are associated to the dynamic cycling of major geochemical components.

We have recently developed a rigorous but simple thermodynamic approach to take into consideration the coprecipitation and codissolution processes that mainly control this linkage. The approach has been tested in various Natural System Studies with encouraging results. In order to build up our confidence on the predictive capabilities of this approach this has to be tested in various sites where there is a large quantity and quality of trace element geochemical data. The Poços de Caldas Natural Analogue was one of these sites where a full testing of our predictive geochemical modelling capabilities was done during the Analogue Project. Therefore, we have revisited the Poços de Caldas data and expanded the trace element solubility calculations by considering the documented trace metal/major ion interactions. This has been done by using the coprecipitation/codissolution approach. The outcome of the work is as follows:



- A satisfactory modelling of the behaviour of U, Zn and REE's is achieved by assuming co-precipitation with ferrihydrite.
- Strontium concentrations are apparently controlled by its co-dissolution from Sr-rich fluorites.

From the PA point of view, the present work indicates that calculated solubility limits using the coprecipitation approach are in close agreement with the actual trace elements concentrations. Furthermore, the calculated radionuclide concentrations are 2–4 orders of magnitude lower than *conservative* solubility limits calculated by assuming equilibrium with individual trace element phases.

### SKB Technical Report 96-05

#### SR 95. Template for safety reports with descriptive example

SKB

December 1995

#### ABSTRACT

**FOREWORD:** This report provides a template for future safety reports on long-term safety in support of important decisions and permit applications in connection with the construction of a deep repository system.

The template aims at providing a uniform structure for describing long-term safety, after the repository has been closed and sealed. The availability of such a structure will simplify both preparation and review of the safety reports, and make it possible to follow how safety assessments are influenced by the progressively more detailed body of data that emerges.

A separate section containing “descriptive examples” has been appended to the template. This section illustrates what the different chapters of the template should contain. For chapters that are independent of the siting and design of the deep repository – e.g. the chapter on safety goals – the text is a preliminary version of the text in coming reports. System- and site-specific chapters are exemplified with material from ongoing or previous work. The assumptions or conditions presented may very well change during the work of preparing future safety reports.

The chapters in a safety report that are supposed to describe applied methods and quantifying calculations are utilized in the “descriptive example” for a presentation of available methods and calculation tools/models. The applicability and quality of the methods and models are discussed and illustrative calculations are presented. The contents of these chapters are based on work currently in

progress and constitute a general review of the state of the art.

The purpose of the “descriptive example” is to clarify the contents of the template. The aggregate description does not meet the requirements on completeness and consistency between the different parts that must be met by a safety report. The first complete safety report will be compiled in support of an application for siting and erection of an encapsulation plant.

### SKB Technical Report 96-06

#### Äspö Hard Rock Laboratory Annual Report 1995

SKB

April 1996

#### ABSTRACT

The Äspö Hard Rock Laboratory has been constructed as part of the preparations for the deep geological repository for spent nuclear fuel in Sweden. The Annual Report 1995 for the Äspö Hard Rock Laboratory contains an overview of the work conducted and important results.

The construction of the laboratory was completed during 1995 and the operating phase has now begun. The Äspö Research Village with office facilities, workshops, hoist and ventilation building was completed in June 1994.

During the construction phase data has been collected from the tunnel and boreholes drilled from the tunnel. These data have been compared to models of Äspö made before construction of the facility started. Results from these investigations have been reported and a comprehensive evaluation is in progress. The results will be used to design the site characterization programme for the deep repository.

The objective of the ZEDEX project has been to compare the mechanical disturbance to the rock for tunnel boring and blasting. The preliminary results show very little disturbance to the rock due to tunnel boring. The damage to the rock from blasting was also limited due to the special blast design applied. The damage in the wall was very limited while it reached an extent of 0.8 m in the floor of the blasted drift.

Ten organizations, including SKB; from nine countries are now participating in the work at the Äspö Hard Rock Laboratory and contribute to the results. An important part of the cooperative work is performed within the framework of the Task Force on groundwater flow and transport of solutes. An evaluation has been made of the Long Term Pumping test which was performed at Äspö some years ago. It showed that the modelling tools that

exist today has the ability to give a three-dimensional description of groundwater flow at a site like Äspö. The Task Force will perform predictive modelling of the tracer experiments performed within the TRUE project. Characterization of the experimental site for TRUE and preparations for the tracer tests were completed during 1995.

Tests of the engineered barriers have been started with the test of technology for backfilling of deposition tunnels.

### SKB Technical Report 96-07

#### **Criticality in a high level waste repository. A review of some important factors and an assessment of the lessons that can be learned from the Oklo reactors**

*Oversby, Virginia M*

**VMO Konsult**

June 1996

#### **ABSTRACT**

The conditions and scenarios that might allow sufficient  $^{239}\text{Pu}$  and/or  $^{235}\text{U}$  to accumulate together with enough water to allow for moderation of neutron energies and thereby achieving a state where neutron-induced fission reactions could be sustained at a rate significantly above the natural rate of spontaneous fission is discussed. The uranium deposit in Oklo, Gabon, which was the site of naturally-occurring neutron-induced fission reactions approximately 2000 My ago is described. The chemistry, mineralogy, and conditions of the nuclear reactor operations are reviewed. Results of modelling the conditions for criticality at Oklo are used to estimate the amounts of spent fuel uranium that must be assembled in a favorable geometry in order to produce a similar reactive situation in a geologic repository. The amounts of uranium that must be transported and redeposited to reach a critical configuration are extremely large in relation to those that could be transported under any reasonably achievable conditions. In addition, transport and redeposition scenarios often require opposite chemical characteristics. It is concluded that the likelihood of achieving a critical condition due to accumulation of a critical mass of uranium outside the canisters after disposal is negligible. Criticality inside the canister is rendered impossible by the use of low-solubility materials inside the canisters that fill space and

prevent the entry of enough water to allow moderation of neutron energies. Criticality due to plutonium outside the canister can be ruled out because it requires a series of processes, each of which has a vanishingly small probability.

### SKB Technical Report 96-08

#### **A reappraisal of some Cigar Lake issues of importance to performance assessment**

*Smellie, John 1); Karlsson, Fred 2)*

**Conterra AB 1); SKB 2)**

July 1996

#### **ABSTRACT**

The AECL/SKB Cigar Lake Analogue Study was carried out from 1989 to 1993, the final report being published in 1994. As with many of these international multidisciplinary analogue studies, time schedules are tight and often there is inadequate time to evaluate fully the wealth of scientific data with regard to repository performance assessment issues, one of the major objectives of such studies. Consequently, SKB have allocated time and resources for selected experts, some of whom have been already involved in the Cigar Lake study, to reappraise available data in the light of greater exposure to analogue studies and the development of more realistic models used in performance assessment.

Although several of the areas proved to have been adequately addressed, one of the areas that particularly benefitted concerned radiolysis. In this case a model for radiolysis was developed and tested, significantly narrowing the gap between calculated and predicted oxidant production. Considerable progress was also made in understanding and modelling the initial formation of the deposit under hydrothermal conditions, and using this conceptual model to evaluate the changes that have subsequently occurred under "ambient" repository conditions over geological timescales. Moreover, the physical properties of clay as a potential buffer to groundwater flow and radionuclide migration were addressed with some success.

This Cigar Lake exercise has underlined the advantages of reviewing and reappraising existing analogue data when the dust has settled.

## SKB Technical Report 96-09

### The long-term stability of cement – Leaching tests

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June 1996

#### ABSTRACT

The concrete construction in the Swedish repository for long-lived low and intermediate level waste (SFL 3-5) will give a stable chemical nearfield environment for  $10^5$  years. The pH is expected to exceed 12 for the life time for most of the radionuclides in the repository in both saline and non-saline groundwaters.

This is shown by static leaching experiments performed in saline and non-saline granitic groundwater conditions. Five gram portions of crushed Ordinary Portland cement paste were equilibrated with 20 ml of synthetic saline or non-saline groundwater in a nitrogen atmosphere. Each week 12 ml (60%) of the water was replaced. The withdrawn water was used for chemical analyses and the results were used to monitor the degradation of the cement paste.

After eighty weeks, some samples were analysed for mineral composition and compared with the original unleached paste. The results indicated no secondary ettringite or calcite formation. The results also supported the conclusion that the salinity of the contacting water is of minor importance for the long-term performance of the cement paste.

## SKB Technical Report 96-10

### Lake-tilting investigations in southern Sweden

Påsse, Tore

Sveriges geologiska undersökning, Göteborg, Sweden

April 1996

#### ABSTRACT

A nonuniform glacio-isostatic uplift results in differential uplift for different parts of a lake. If the lake outlet is situated in the area with the greatest rate of uplift, then the lake will be continuously transgressed. Ancient lake levels

can be estimated by dating transgressed peat at different depths in such a lake. Four lakes in southern Sweden have been investigated using this method and **the course of the glacio-isostatic uplift has been determined empirically.**

The investigation shows that the difference in uplift between the outlet and the sampling site can be expressed as

$$\Delta U = 0.6366 \times \Delta A (\arctan (T/B) - \arctan ((T-t)/B))$$

where  $\Delta U$  is the difference in uplift (in m),  $\Delta A$  is half of the difference of the total uplift between the outlet and the sampling site (in m),  $T$  is the time for the maximal uplift (in calendar years),  $t$  is the variable time (in calendar years) and  $B$  is a declining factor (in calendar years). The values for  $\Delta A$ ,  $B$  and  $T$  are determined at the four lakes. These determinations are used to predict the future uplift.

## SKB Technical Report 96-11

### Thermoelastic stress due to an instantaneous finite line heat source in an infinite medium

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September 1995

#### ABSTRACT

The thermoelastic response due to a line heat source of finite length in an infinite medium is analyzed. The problem originates from studies of nuclear waste repositories in rock. The idea is to deposit canisters containing nuclear waste along boreholes very deep below the ground surface. An important concern is that dangerous waste from damaged canisters may eventually reach the biosphere by groundwater moving in cracks and fractures in the rock. The stress and strain fields are therefore of main interest, since they influence crack formation and crack widths.

The problem is by superposition reduced to the case of a single, infinite, antisymmetric, instantaneous line heat source. The dimensionless problem turns out to depend on the dimensionless radial and axial coordinates only, although the original time-dependent problem contains several parameters.

An exact analytical solution is derived. The solution is surprisingly handy, considering the complexity of the

initial problem. The radial and axial displacements  $u$  and  $w$  become:

$$u = \frac{\Phi_0}{\rho} \left[ \frac{z}{r} \operatorname{erf} \left( \frac{r}{\sqrt{4at}} \right) - e^{-\rho^2/(4at)} \operatorname{erf} \left( \frac{z}{\sqrt{4at}} \right) \right]$$

$$w = -\frac{\Phi_0}{r} \operatorname{erf} \left( \frac{r}{\sqrt{4at}} \right)$$

The stress and strain fields are readily obtained from derivatives of the displacement components. These fields are studied and presented in detail. Asymptotic behavior, field of principal stresses, regions of compression and tension, and largest values of compression and tension of the components are given from exact formulas. The solution may be used to test numerical models for coupled thermoelastic processes. It may also be used in more detailed numerical simulations of the process near the heat sources as boundary conditions to account for the three-dimensional global process.

### SKB Technical Report 96-12

#### Temperature field due to time-dependent heat sources in a large rectangular grid – Derivation of analytical solution

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January 1996

#### ABSTRACT

The temperature field in rock due to a large rectangular grid of heat-releasing canisters containing nuclear waste is studied. The solution is by superposition divided into different parts. There is a global temperature field due to the large rectangular canister area, while a local field accounts for the remaining heat source problem.

The global field is reduced to a single integral. The local field is also solved analytically using solutions for a finite line heat source and for an infinite grid of point sources. The local solution is reduced to three parts, each of which depends on two spacial coordinates only.

The temperatures at the envelope of a canisters are given by the global and local solutions. The local part is here represented by a single thermal resistance, which is given by an explicit formula.

The results are illustrated by a few numerical examples dealing with the KBS-3 concept for storage of nuclear waste.

### SKB Technical Report 96-13

#### Thermoelastic stress due to a rectangular heat source in a semi-infinite medium – Derivation of an analytical solution

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May 1996

#### ABSTRACT

The thermoelastic response due to a time-dependent rectangular heat source in a semi-infinite medium is analysed. The problem originates from studies of nuclear waste repositories in rock. Canisters containing nuclear waste are deposited over a large rectangular area deep below the ground surface. An important concern is that dangerous waste from damaged canisters may eventually reach the biosphere by groundwater moving in cracks and fractures in the rock. The stress and strain fields are therefore of main interest, since they influence crack formation and crack widths.

The solution for a time-dependent heat source is obtained from the corresponding instantaneous heat source by a Duhamel superposition. The thermoelastic problem for the instantaneous rectangular heat source in an infinite surrounding is solved exactly. An important step is the introduction of so called quadrantal heat sources. The solution for the rectangle is obtained from four quadrantal solutions. The solution for the quadrantal heat source depends on the three dimensionless coordinates only. Time occurs in the scale factors only.

The condition of zero normal and shear stresses at the ground surface is fulfilled by using a mirror heat source and a boundary solution. The boundary solution accounts for the residual normal stress at the ground surface. Using a Hertzian potential, a surprisingly simple solution is obtained.

The final analytical solution is quite tractable, considering the complexity of the initial problem. The solution may be used to test numerical models for coupled thermoelastic processes. It may also be used in more detailed numerical simulations of the process near the heat sources as boundary conditions to account for the three-dimensional global process.

## SKB Technical Report 96-14

**Oklo: Des reacteurs nucleaires fossiles (Oklo: The fossil nuclear reactors). Physics study (R. Naudet, CEA) – Translation of chapters 6, 13, and conclusions**

*Oversby, V O*

VMO Konsult

September 1996

## SKB Technical Report 96-15

**PLAN 96 – Costs for management of the radioactive waste from nuclear power production**

Swedish Nuclear Fuel and Waste Management Co

June 1996

## SKB Technical Report 96-16

**Diffusion of  $\Gamma^-$ ,  $\text{Cs}^+$  and  $\text{Sr}^{2+}$  in compacted bentonite. Anion exclusion and surface diffusion**

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November 1996

### ABSTRACT

The diffusion of  $\Gamma^-$ ,  $\text{Cs}^+$  and  $\text{Sr}^{2+}$  in bentonite compacted to a dry density of  $1.8 \text{ g cm}^{-3}$  and saturated with two ground waters of different ionic strength have been studied experimentally using the through diffusion technique.

The  $\Gamma^-$  diffusivity and diffusion porosity were found to be concentration independent in the concentration range  $10^{-8}$  to  $10^{-2} \text{ mol dm}^{-3}$ . The diffusion porosity, being only a fraction of the water porosity for normal ground waters, is strongly ionic strength dependent due to anion exclusion.

The dependence of the diffusion of  $\text{Cs}^+$  and  $\text{Sr}^{2+}$  on the sorption intensity is accommodated by a model encompassing diffusion of the sorbed cations within the electrical

double layer next to the mineral surface in addition to diffusion in the pore water.

## SKB Technical Report 96-17

**Hydrophilic actinide complexation studied by solvent extraction radiotracer technique**

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October 1996

### ABSTRACT

Actinide migration in the ground is enhanced by the formation of water soluble complexes between the actinide ions (*central atoms*) and inorganic and/or organic complex formers (*ligands*) dissolved in the ground water. It is essential to the risk analysis of a wet repository to know the concentration of the central atoms and the ligands in the ground water, and the stability of the complexes formed between them (*the complex formation constant*); from such data the concentration of all dissolved actinide species can be calculated, and – using additional data on sorption, diffusion, and ground water flow rate – the migration rate of the actinides in the ground can be predicted.

The important actinides in nuclear waste are U, Np, Pu and Am, all radioactive and with half-lives long enough to allow the determination of their macroscopic properties, usually at  $>10^{-4} \text{ M}$ . However, when dissolved in nature, their concentrations are hardly macroscopic; typical concentration values are  $<10^{-7} \text{ M}$  (*trace concentrations*). Because the chemical behavior at trace concentrations often differ from that at macro concentrations (for example polynuclear complex formation), it is important to know the chemical behavior of actinides at trace concentrations in the ground water. One method commonly used for such investigations is the *solvent extraction radiotracer (SXRT)* technique, by which the radioactive properties of the actinides are used for their detection.

This report describes the SXRT technique in some detail. A particular reason for this analysis is the claim that complex formation constants obtained by the SXRT technique differs even at same actinide concentration, or are less reliable than results obtained by alternative techniques. It is true that several difficulties are encountered in the application of the SXRT technique to actinide

solutions, as for example redox instability, hydrophilic complexation by side reactions and sorption, but it is also shown that a careful application of the SXRT technique yields results as reliable as by any other technique.

The report contains a literature survey on solvent extraction studies of actinide complexes formed in aqueous solutions, particularly by using the organic reagent tetrakis(trifluoroacetyl)acetone (TTA) dissolved in benzene or chloroform (Table 1). Hydrolysis constants obtained by solvent extraction are listed in Table 9. The last two tables contain all actinide complexes studied by SX with inorganic ligands (Table 11) and with organic ligands (Table 12).

Part of this work was done under the auspices of the OECD/NEA Nuclear Data Group through the support of the Swedish Nuclear Fuel and Waste Management Co (SKB).

## SKB Technical Report 96-18

### Information, conservation and retrieval

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December 1996

### ABSTRACT

Foreword: The radioactivity in spent nuclear fuel will decay with time. The direct radiation, and thereby also the highest risks, will diminish in about 1 000 years. The fuel will though still be dangerous to man if any of its content of long-lived radionuclides somehow would escape from the deep geological repository and enter into the environment where man could drink, digest or inhale them. The timeframe that these risks will be present is in the order of 100 000 of years.

A group of scenarios where a collapse of the isolation features of the deep repository can occur, are human intrusion scenarios. Human intrusion can be thought of as either intentional (for using the spent fuel as a resource or to repair or alter the disposal technology) or unintentional (i.e. drilling through a repository area at prospecting, mining, constructing of geothermal facilities etc.).

To ensure that future generations have a proper freedom of action for intentional intrusions for whatever purpose, the knowledge of the deep repository should be kept as long as possible. Also knowledge in society of location and content in the deep repository can mitigate the conse-

quences of unintentional intrusion scenarios. This knowledge need can be obtained with several means which is described in part III in this report.

The need for information, conservation and retrieval was discussed at a seminar at the Swedish transportation ship for radioactive waste, the M/S Sigyn, in August 1996. M/S Sigyn is each year used as a exhibition ship during the summer months and in 1996 a series of seminars were held to further increase the base of interest from the public.

The seminar on information conservation and retrieval took up items both related to general information needs in society as a whole and questions related to nuclear waste. The seminar had about 50 attenders. Speakers were Dr Erik Norberg who is the Director General of the National Swedish Archives, Professor Jarl Torbacke from the Department of History at Stockholm University and Mr Torsten Eng from the Swedish Nuclear Fuel and Waste Management Co (SKB). This report which tries to cover the essence of the seminar, contains the papers of Dr Erik Norberg and Professor Jarl Torbacke as well as a reprint (slightly edited) of a report published by the Nordic Council of Ministers and its Nuclear Safety Research Group NKS, "Conservation and Retrieval of Information – Elements of a Strategy to Inform Future Societies about Nuclear Waste Repositories". The NKS report was originally edited by Dr Mikael Jensen from the Swedish Radiation Protection Institute (SSI).

## SKB Technical Report 96-19

### Application of space geodetic techniques for the determination of intraplate deformations and movements in relation with the postglacial rebound of Fennoscandia

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April 1996

### ABSTRACT

This report introduces into space geodetic measurements of relative positions over distances ranging from tens to thousands of kilometres. Such measurements can routinely be carried out with repeatabilities on the order of a few millimeters.

The basic techniques which are presented at detail are Very Long Baseline Interferometry (VLBI), employing observations of radioastronomical objects in the distant

universe, and ranging measurements to satellites of the GPS, the Global Positioning System.

We report that these techniques have helped to trace plate tectonic motions. More recently deformation within continents, i.e. strain patterns of more regional character have been detected.

We present the SWEPOS system of permanently operating GPS stations as one of the major geoscience investments starting in 1993. This system has been designed, devised and furnished as a joint effort between the National Land Survey of Sweden and ourselves, the geoscience group at Onsala Space Observatory, Chalmers University of Technology, using funds provided by Knut and Alice Wallenberg's Foundation and the Swedish Council for Planning and Coordination of Research (FRN).

We describe the operations within SWEPOS with the main purpose to detect crustal motions in Fennoscandia. For this purpose a project named BIFROST was created; BIFROST stands for Baseline Inferences for Fennoscandian Rebound Observations, Sea-level and Tectonics. It combines the efforts of a number of investigators at different sites and contributes to a number of international research programs in geophysics and geodesy. We foresee observing operations within BIFROST of at least ten years if deformation rates of 0.1 mm/yr are to be concluded at a 95 percent confidence level.

First results are presented, indicating movements which generally support the notion of a dominating displacement pattern due to the postglacial rebound of Fennoscandia. However, deviations exist. In order to discern regional movements of a presumably tectonic origin the coverage of the region must be extended, both concerning the areas that neighbour Sweden and array densification within the country. Densification is indicated in those areas which are notable for an increased seismicity. These are an area of 200 km radius encircling lake Vänern and the coastland of upper Norrland and its extension into northern Bothnia.

## SKB Technical Report 96-20

### On the characterization of retention mechanisms in rock fractures

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December 1996

## ABSTRACT

Following a hypothetical leakage from a deep-rock nuclear waste repository, radionuclides may migrate through the geosphere to the biosphere. Since most nuclides are retarded during the migration process, the geosphere is considered part of the multibarrier system. Hence it is of interest to understand the relevant retention processes in the fractured rock of the geosphere.

Radionuclide transport in fractured media is controlled by advection and mass transfer processes. Advection primarily takes place along single fractures, whereas mass transfer such as surface sorption and matrix diffusion occurs at the fracture surfaces. Aperture heterogeneity thus affects both advection and mass transfer characteristics. This spatial heterogeneity, in combination with sparse aperture measurements, results in a prediction uncertainty with implications for both fracture characterization in the field and for safety assessment applications.

An analytical solution for the mass flux in a single fracture is derived using the stochastic Lagrangian travel time approach. Combined matrix diffusion and equilibrium sorption (matrix and surface) are incorporated in the analysis. The solution is dependent on three variables: the conservative solute travel time,  $\tau$ , a parameter accounting for solute characteristics,  $\kappa$ , and a parameter related to the fluid discharge and surface available for diffusion and sorption,  $\beta$ . Based on the analytical mass flux solution and underlying moments of  $\beta$  and  $\tau$ , the first two mass flux moments and first two moments of the time for a given accumulated mass fraction are derived.

The results are illustrated for a kinematic flow path with pre-defined aperture and width statistics. The moments of  $\beta$  and  $\tau$  are derived analytically for the simplified flow case. The effect of variability and spatial correlation structure of aperture and width on the mass flux moments and moments of the time for a given accumulated mass fraction are investigated. The implications of the results for field-scale tracer test (characterization) and for safety assessment applications are discussed. The possible correlation between travel time,  $\tau$ , and parameter  $\beta$  for increasingly complex flow conditions and/or evolving scales is identified as a key issue in both applications.

## SKB Technical Report 96-21

### Boring of full scale deposition holes using a novel dry blind boring method

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October 1996

## ABSTRACT

Three holes the size of deposition holes (depth 7.5 m and diameter 1.5 m) were bored in the Research Tunnel at Olkiluoto in Finland. A novel full-face boring technique was used based on rotary crushing of rock and removal of crushed rock by vacuum flushing through the drill string. The purpose of the work was to demonstrate the feasibility of the technique. During the boring test procedures were carried out in order to determine the effect of changes in operating parameters on the performance of the boring machine and the quality of the hole.

The boring method was found to be technically feasible and efficient. The correlation between the rate of advance and the thrust used was established and this can be used to estimate the performance of a similar, but more powerful, boring machine.

Evaluation of the quality of the hole included studies of the geometry of the holes, measurements of surface roughness using a laser profilometer and study of excavation disturbances in the zone adjacent to the surface of the holes using two novel methods, the He-gas diffusion method and the  $^{14}\text{C}$ -polymethylmethacrylate method. It was found that there is a distinct disturbed zone adjacent to the surface of the full scale deposition holes which can be divided into three different zones. The zones are as follows: a crushed zone penetrating to a depth of about 3 mm from the surface, a fractured zone extending to a depth of 6 – 10 mm from the crushed zone and a microfractured zone extending to a depth of 15 – 35 mm from the fractured zone. The porosity of the rock in the disturbed zone measured using the  $^{14}\text{C}$ -PMMA-method was clearly greater than the porosity of undisturbed rock to a depth of about 11 mm. The values of permeability and diffusion coefficient in the disturbed zone measured in a direction perpendicular to the disturbed surface were found to be approximately one order of magnitude larger than those of undisturbed rock.

### SKB Technical Report 96-22

#### Feasibility study for siting of a deep repository within the Malå municipality

Swedish Nuclear Fuel and Waste Management Co., Stockholm

March 1996

#### ABSTRACT

Feasibility studies examine the prospects for a deep repository in potentially suitable and interested municipalities.

Desk studies are performed to compile existing information on a variety of factors relevant to siting. This includes geoscientific conditions as well as technical, environmental and societal aspects. The feasibility study of the Malå municipality – the second to be conducted – was completed during 1996.

The report summarises results from the feasibility study and outlines conclusions that are drawn with respect to siting premises. An important conclusion is that there are large areas within the municipality that – as far as can be judged from existing information – would offer good siting premises with respect to bedrock conditions. The areas of interest are located within vast regions covered with predominantly granitic rocks. Malå municipality is located in the inland region of northern Sweden, and transportation of spent fuel and backfill material to a repository within the municipality would therefore involve both sea- and overland components. Both railway and road are found to be feasible alternatives for the land transport part, although improvements of present infrastructure would be required. The municipality is furthermore found to offer good siting premises with respect to current and planned land use, as well as a number of land preservation interests.

On the basis of these results, it is concluded Malå municipality may become of interest for further investigations in later stages of the siting process. Decisions in this respect can however not be made at this stage of the process.

### SKB Technical Report 96-23

#### Analysis of the Äspö LPT2 pumping test via simulation and inverse modelling with HYDRA-STAR

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December 1996

#### ABSTRACT

A stochastic groundwater modelling study is presented for the second Long-term Pumping Test (LPT2) conducted at the Äspö Hard Rock Laboratory (HRL). It is a test case for HYDRASTAR, a stochastic continuum groundwater flow and transport model developed by Starprog AB for Swedish Nuclear Fuel and Waste Management Company (SKB). Unlike previous modelling studies of the LPT2, this study uses the inverse modelling capabilities



ties of HYDRASTAR to condition the model results to the observed hydraulic heads. The purpose of this conditioning via inverse modelling is to improve the reliability of input hydraulic conductivity fields and thus minimise the uncertainty of the model predictions. Preliminary simulations evaluated the boundary conditions, grid extent and grid density, all of which were restricted by the computational demands of a larger domain and by code limitations. The preliminary simulations also indicated that the model is quite sensitive to changes in specific storativity and kriging parameters. The final calibrated model simulations were successful in representing the response of the rock mass to the LPT2. Specifically, the mean of the Monte Carlo realisations of simulated drawdowns generally reproduced the magnitude, timing, and shape of the observed drawdowns. The observed drawdowns generally were bracketed by an interval of plus or minus one standard deviation from the mean of the realisations. Some discrepancies in the magnitude and timing of the observed versus the simulated drawdowns were revealed at several locations, such as the upper sections of borehole KAS07. However, the ensemble of model realisations were centred on the observed drawdowns and bracketed the observed responses. This indicates that the ensemble of realisations has bracketed the true characteristics of the HRL, supporting both the conceptual model and its representation by HYDRASTAR.

## SKB Technical Report 96-24

### A mathematical model of the shore level displacement in Fennoscandia

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December 1996

## ABSTRACT

The shore level displacement in Fennoscandia is mainly due to two co-operative vertical movements, the glacio-isostatic uplift and the eustatic sea level rise. The course of the glacio-isostatic uplift has recently been made discernible according to an investigation of the lake-tilting phenomenon (Påsse 1996). This new information has made it possible to start an iteration process for detailed estimations of the glacio-isostatic uplift and the eustatic rise using empirical data of the shore level displacement. *Arctan*-functions have proved to be suitable tools for describing the glacio-isostatic uplift.

The model indicates that there are two mechanisms involved in the glacio-isostatic uplift, one slow and the other fast. The main uplift, still in progress, acts slowly. The time of the maximal rate of the slow uplift is isochronous in the entire Fennoscandia, which means that the slow uplift occurred as a sympathetic movement. For the slow uplift there is a relationship between the rate of declining and the crustal thickness. In areas with great crustal thickness the rate of declining of the glacio-isostatic recovery is lower than in areas with thinner crust. The fast mechanism gave rise to a crustal subsidence during the Younger Dryas restored by a fast uplift during Preboreal time. The courses of the fast subsidence and the fast uplift are related to the deglaciation pattern. The fast subsidence was caused by a renewed down-loading of the crust during the glacial advance which culminated during the Younger Dryas.

The existence of the two uplift mechanisms implies that there are two physical processes involved in the glacio-isostatic rebound. The slow mechanism can be linked to viscous flow. The explanation of the fast mechanism may be compression followed by decompression.

The future development regarding the glacio-isostatic uplift, the eustasy and the shore level displacement is predicted in Fennoscandia using the results from the modelling. The predictions are based on the assumption that the crustal and eustatic developments will follow the trends that exist today.

The development of the Baltic have been outlined in this paper.