SKB

TECHNICAL REPORT 91-14

Channel widths

Kai Palmqvist, Marianne Lindström

BERGAB-Berggeologiska Undersökningar AB

February 1991

SVENSK KÄRNBRÄNSLEHANTERING AB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

BOX 5864 S-102 48 STOCKHOLM

TEL 08-665 28 00 TELEX 13108 SKB S
TELEFAX 08-661 57 19

CHANNEL WIDTHS

Kai Palmqvist, Marianne Lindström

BERGAB-Berggeologiska Undersökningar AB

February 1991

CHANNEL WIDTHS

Kai Palmqvist

Marianne Lindström

BERGAB-Berggeologiska Undersökningar AB

February 1991

ABSTRACT

At the request of SKB, BERGAB-Berggeologiska Undersökningar AB have carried out a study of documented water leakage in two TBM tunnels.

The hydrogeological mapping of the tunnels include a classification of leakage according to flowrate and width. This report is based upon the hydrogeological mapping and gives a further analysis of the documented data. The objective is to study the distribution of flowrates and leak widths in channels. Further the object has been to examine if the flowrates are dependent of the widths.

TABLE OF CONTENTS

		Page
	ABSTRACT	ii
	SUMMARY	iv
	ACKNOWLEDGEMENT	vi
1	GENERAL INFORMATION	1
1.1	INTRODUCTION	1
1.2	TERMINOLOGY	1
2	INVESTIGATION IN THE KYMMEN - AND SALTSJÖ TUNNELS	2
2.1	BEDROCK CONDITIONS	2
2.2	GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS	2
2.3	CLASSIFICATION OF LEAKS	2
3	ANALYSIS OF LEAKAGE	4
3.1	THE KYMMEN TUNNEL	4
3.2	THE SALTSJÖ TUNNEL	7
4	CONCLUSIONS	10
5	REFERENCES	11

SUMMARY

The objective of this report is to study documented water leakage in tunnels in order to examine the distribution of flowrates and widths in ground water channels. The issue is suggested by I. Neretnieks.

The report is based upon previous investigations of water leakage in two TBM tunnels, the Kymmen tunnel (1) and the Saltsjö tunnel (2). In these tunnels a hydrogeological mapping has been carried out. The mapped leaks are visually estimated and classified into five classes designated v - ⩛. The classification system represent the flowrate of the leaks. Each of the five classes has, by experiences from measurements in several tunnels, been "translated" to quantities (3).

v : = < 0.04 l/min

⩒ : = 0.04 - 0.3 l/min

⩛ : = 0.3 - 1.5 l/min

⩛ : = 1.5 - 6.5 l/min

⩛ : = > 6.5 l/min

All information about leakage from the Kymmen - and Saltsjö tunnels are put together and analysed. According to the definition a leak is regarded as a drapery leak if the width is $\geq$ 0.1 m. Leaks < 0.1 m are classified as point leaks.

When mapping the flowrate of some of the extended drapery leaks several symbols for water leakage class (v-⩛) were noted on the drawings. In order to compare and make statistics of the different leaks it is necessary to estimate the total amount of water coming from such a leak. Hence the symbols are quantified separately according to the amounts above. The average of each class have been used to calculate the amount of water for the present class.

In the Kymmen tunnel the geological and hydrogeological investigations include 4 496 m. No grouting has been carried out in this tunnel. A total of 1 575 leaks have been noted in the Kymmen tunnel.

In the Saltsjö tunnel the geological and hydrogeological investigations include 720 m. Grouting has been carried out within this section which surely has reduced both number of leaks and the flowrates of the leakage.

Within aquiferous sections with considerable inflow the general water leakage has been noted. These sections have not been analysed since there is a lack of information about separate leaks. A total of 336 leaks have been noted in the Saltsjö tunnel.

In both tunnels the majority of leaks have a width < 0.1 m (so called point leaks). In the Kymmen tunnel these leaks make up 98.1% and in the Saltsjö tunnel 97.9%.

As the leaks < 0.1 m are so predominant it should be observed that an analysis of the remaining leaks is based upon few observations. It is therefore difficult to draw any general conclusions from these analyses.

The frequency distribution of flowrate in the Kymmen tunnel shows that most of the drapery leaks are classified as $\overset{v}{v}$.

In the Saltsjö tunnel most drapery leaks are of the order v. As mentioned above grouting surely has reduced both number of leaks and the flowrates.

Statistics of the frequency distribution of widths consequently show a strong dominance for the width 0 - 0.1 m in both tunnels. The remaining leaks are rather evenly distributed among the different widths. There is however some tendency of concentration for the widths 0.5 and 1.0 m.

The analysis of the data from the Kymmen- and Saltsjö tunnels has not shown that the flowrates are dependent of the widths.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to I. Neretnieks, KTH who suggested this analysis of documented water leakage with respect to channel widths. I. Neretnieks has set out the issue in three tangible questions on which this study is based. He has also been helpful in giving his opinions on the report during production.

1 GENERAL INFORMATION

1.1 INTRODUCTION

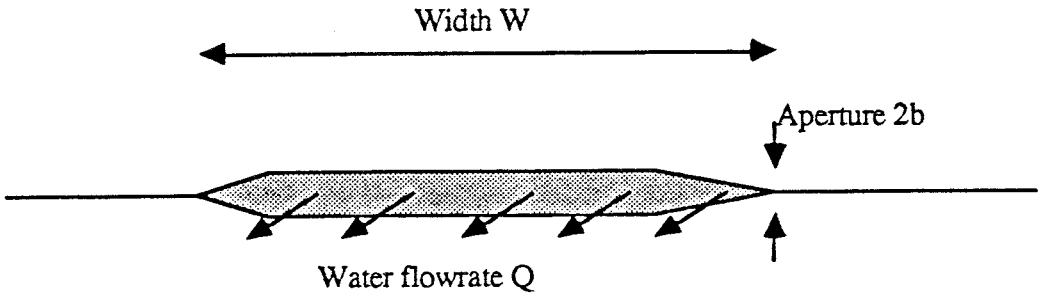
At the request of SKB, BERGAB Berggeologiska Undersökningar AB have carried out a study of documented water leakage. The documentation has been carried out simultaneously with the geological mapping in two TBM tunnels. One of the tunnels belongs to the Kymmen power station in the province of Värmland (1). This tunnel has a total length of 4 500 m. The other tunnel is the Saltsjö tunnel in Stockholm with a total length of 7 500 m. In this tunnel the detailed hydrogeological mapping has been carried out along 720 m (2).

The objective of studying documented water leakage is to try to find an answer to some questions suggested by I. Neretnieks. The questions are concentrated on following parameters:

- the flowrate distribution in channels
- the width distribution in channels
- the relationship between widths and flowrates

1.2 TERMINOLOGY

The terminology used by I. Neretnieks is shown in the figure below



The term "width" has been used in the reports from the Kymmen and Saltsjö tunnels. In these reports the term "fracture width" is used when talking about the aperture of the fractures. To avoid misunderstanding the terminology according to the figure above is used in this report, even when referring to the investigations in the Kymmen and Saltsjö tunnels.

2 INVESTIGATION IN THE KYMMEN AND SALTSJÖ TUNNELS

2.1 BEDROCK CONDITIONS

The rock cover above the Kymmen tunnel varies between 50-200 m. The bedrock consists of four different rock types. Approximately 40 % of the mapped stretch consists of leptite, 40% of granite gneiss with amphibolite plates, 13% of granite gneiss and finally amphibolite constitutes 7% of the mapped stretch. Amphibolite in this case designates continuous sections $\geq$ 25 m.

The rock cover of the Saltsjö tunnel is about 50 - 60 m. The bedrock consists mainly of grey and red granite with several inclusions of grey gneiss. Amphibolite lenses and pegmatite veins are also present.

2.2 GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

The bedrock conditions in the Kymmen and Saltsjö tunnels have been classified according to a rock quality system based on two main categories - mechanically crushed zones and bedrock conditions outside these crush zones. Each mapped fracture has been examined with regard to potential water-bering capacity, strike and dip, character of the surface, width and possible fracture filling. The degree of clay-alteration has also been noted.

Ground water leakage occurs as point leaks and drapery leaks. In the first case, the water follows a channel ending in a simple point. Drapery leakage has been defined as a single leak along a fracture. The width of the leak is 0.1 m or more. Sometimes difficulties arise to distinguish many closely distributed point leaks along a fracture from a real drapery leak.

In the tunnels a general estimation of dry and damp sections were also made.

2.3 CLASSIFICATION OF LEAKS

The mapped leaks in the Kymmen and Saltsjö tunnels are visually estimated and classified into five different classes. This classification system represent the flowrate of the leaks.

v : "minor drip" indicates damp bedrock surfaces with occasional water droplets.

 : "major drip - slowly running water" indicates dense water droplet formations, developing at times into running water.

 : "fast running water - flushing water" indicates major ground water leakage, usually caused by isolated major open fissures.

 : "fast flushing water" usually indicates major leakage from channel formations.

 : "very fast flushing water" indicates gushing ground water inflow, usually from a channel formation.

By measuring visually estimated leaks some efforts have been made to "translate" the five classes into measured quantities. The result is presented below

v : = < 0.04 l/min

 : = 0.04 - 0.3 l/min

 : = 0.3 - 1.5 l/min

 : = 1.5 - 6.5 l/min

 : = > 6.5 l/min

These values are based on experiences from hydrogeological mapping in several tunnels (3).

3 ANALYSIS OF LEAKAGE

All information about leakage from the Kymmen and Saltsjö tunnels are put together and analysed. According to the definition a leak is regarded as a drapery leak if the width is $\geq$ 0.1 m. Leaks $<$ 0.1 m are classified as point leaks.

When mapping the flowrate of some of the extended drapery leaks several symbols for water leakage class (v -) were noted on the drawings. In order to compare and make statistics of the different leaks it is necessary to estimate the total amount of water coming from such a leak. Hence the symbols are quantified separately according to the amounts above. The average of each class have been used to calculate the amount of water for the present class. This means that if a drapery leak is illustrated with two , the symbol is quantified as the average value in its class, i.e 0.9 l/min. As the leak consists of two the total amount of this drapery leak is determined to be 2 x 0.9 l/m = 1.8 l/min. According to the quantities given above this leak should be classified as . Thus the calculated values are just approximate.

3.1 THE KYMMEN TUNNEL

In the Kymmen tunnel the geological and hydrogeological investigations include 4 496 m. No grouting has been carried out in this tunnel.

A total of 1 575 leaks have been noted in the Kymmen tunnel. Table 3.1.1 shows the distribution of leaks according to flowrate. The relative frequency of the total leakage for each class is included in the table.

Table 3.1.1 Frequency distribution of flowrate in the Kymmen tunnel

Flow-rate	Point leak	Drapery leak	Total leakage	Relative frequency
v	1.182	8	1.190	75.5
vv	230	11	241	15.3
vvv	123	8	131	8.3
vvvv	6	3	9	0.6
vvvvv	4	-	4	0.3
	1.545	30	1.575	100.0

The frequency distribution of the flowrate is shown in fig 3.1.1. The horizontal axis is divided according to the water leakage classification system above. The y-axis represents the amount of channels in percentages.

Almost all of the mapped leaks have a width < 0.1 m which means that they are classified as point leaks. Only 1.9 % of all leaks are drapery leaks. The frequency distribution of the leak widths is shown in table 3.1.2.

Table 3.1.2 Frequency distribution of leak widths in the Kymmen tunnel.

Width (m)	Frequency	Relative frequency
< 0.1	1 545	98.1
0.2	3	0.2
0.5	6	0.4
1.0	6	0.4
1.5	2	0.1
2.0	3	0.2
3.0	2	0.1
4.0	5	0.3
5.0	1	0.1
6.0	2	0.1
	1 575	100.0

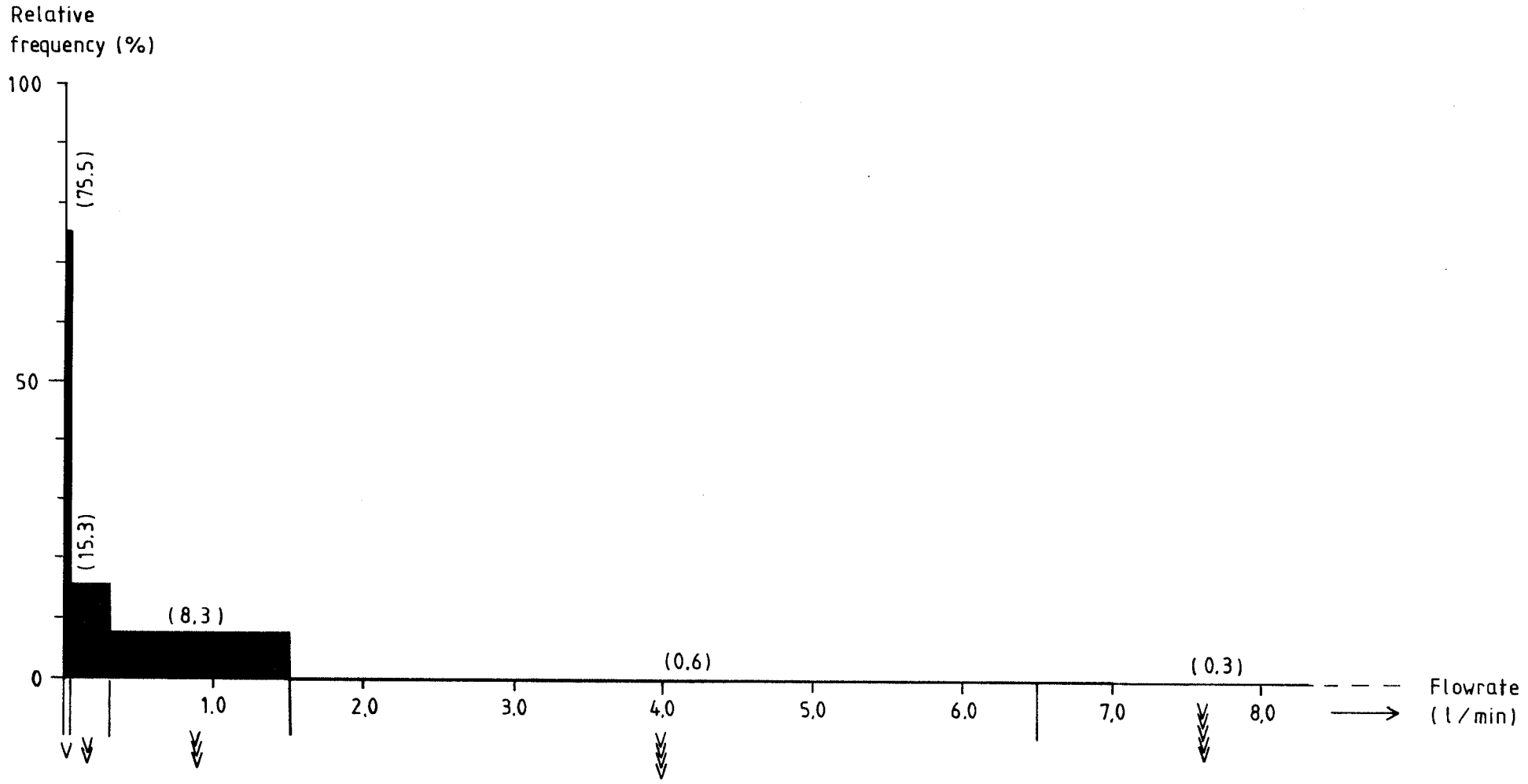


Fig 3.1.1 Frequency distribution of flowrate in the Kymmen tunnel

Table 3.1.3 shows the distribution of leakage classes among different widths. It is not possible to find any relation between the flowrates and the leak widths. The number of drapery leaks are however very few which makes it difficult to draw any general conclusions.

Table 3.1.3 Distribution of leakage classes in the Kymmen tunnel.

Width (m)	v	vv	vvv	vvvv	vvvvv	Σ
< 0.1	1.182	230	123	6	4	1.545
0.2	1	1	1			3
0.5		2	4			6
1.0	3	1	1	1		6
1.5		2				2
2.0	2		1			3
3.0	1	1				2
4.0	1	2	2			5
5.0		1				1
6.0		1		1		2

3.2 THE SALTSJÖ TUNNEL

In the Saltsjö tunnel the geological and hydrogeological investigations include 720 m. Grouting has been carried out within this section which surely has an effect on number of leaks as well as the flowrates of the leakage.

Within aquiferous sections with considerable inflow the general water leakage has been noted as at least one leak(v) every meter. These sections have not been analysed in this report as it is difficult to estimate the separate leaks.

A total of 336 leaks from the Saltsjö tunnel have been analysed. The distribution of leaks according to flowrate is shown in table 3.2.1.

Table 3.2.1 Frequency distribution of flowrate in the Saltsjö tunnel.

Flow-rate	Point-leak	Drapery leak	Total leakage	Relative frequency
v	278	5	283	84.2
vv	47	2	49	14.6
vvv	2	-	2	0.6
vvvv	2	-	2	0.6
	329	7	336	100.0

As in the Kymmen tunnel most of the leaks are classified as point leaks. Point leaks make up 97.9% and drapery leaks the remaining 2.1%.

The frequency distribution of the leak widths is shown in table 3.2.2.

Table 3.2.2 Frequency distribution of leak widths in the Saltsjö tunnel.

Width (m)	Frequency	Relative frequency
< 0.1	329	97.9
0.2	2	0.6
0.5	4	1.2
1.5	1	0.3
	336	100.0

Table 3.2.3 shows the distribution of leakage classes among different leak widths.

Table 3.2.3 Distribution of leakage classes in the Saltsjö tunnel.

Width (m)	v	vv	vvv	vvvv	Σ
< 0.1	278	47	2	2	329
0.2	1	1			2
0.5	3	1			4
1.5	1				1

4 CONCLUSIONS

The most obvious result of the analysis of the water leakage from the two TBM tunnels is that the majority of leaks have a width < 0.1 m. Hence they are so called point leaks. In the Kymmen tunnel a total of 1 575 leaks have been analysed. Point leaks make up 98.1% of these. In the Saltsjö tunnel there are 336 leaks of which 97,9% are point leaks. Most of them are classified as v in both tunnels.

As the leaks < 0.1 m are so predominant it should be observed that an analysis of the remaining leaks is based upon few observations. It is therefore difficult to draw any general conclusions from these analyses.

The frequency distribution of flowrate in the Kymmen tunnel, where no grouting has been carried out, shows that most of the drapery leaks are classified as V. In the Saltsjö tunnel most drapery leaks are of the order v. In this tunnel grouting surely has reduced both the number of leaks as well as the flowrates.

Statistics of the frequency distribution of leak widths consequently show a strong dominance for the width 0 - 0.1 m in both tunnels. The remaining leaks are rather evenly distributed among the different widths. There is however some tendency of concentration for the widths 0.5 and 1.0 m.

The analysis of the data from the Kymmen- and Saltsjö tunnels has not shown that flowrates are dependent of the leak widths.

5 REFERENCES

(1) Palmqvist K, Stanfors R 1987. The Kymmen Power Station TBM Tunnel. Hydrogeological Mapping and Analysis. SKB Technical Report 87-26

(2) Palmqvist K, Lindström M 1988. The Saltsjö TBM tunnel. Hydrogeological Mapping and Analysis. SKB arbetsrapport 88-36.

(3) Palmqvist K 1990. Ground Water in Crystalline Bedrock. SKB (in course of publication).

List of SKB reports

Annual Reports

1977-78
TR 121
KBS Technical Reports 1 – 120
Summaries
Stockholm, May 1979

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

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

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

1982
TR 82-28
The KBS Annual Report 1982
KBS Technical Reports 82-01 – 82-27
Summaries
Stockholm, July 1983

1983
TR 83-77
The KBS Annual Report 1983
KBS Technical Reports 83-01 – 83-76
Summaries
Stockholm, June 1984

1984
TR 85-01
Annual Research and Development Report 1984
Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01 – 84-19)
Stockholm, June 1985

1985
TR 85-20
Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01 – 85-19)
Stockholm, May 1986

1986
TR 86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

1987
TR 87-33
SKB Annual Report 1987
Including Summaries of Technical Reports Issued during 1987
Stockholm, May 1988

1988
TR 88-32
SKB Annual Report 1988
Including Summaries of Technical Reports Issued during 1988
Stockholm, May 1989

1989
TR 89-40
SKB Annual Report 1989
Including Summaries of Technical Reports Issued during 1989
Stockholm, May 1990

Technical Reports
List of SKB Technical Reports 1991

TR 91-01
Description of geological data in SKB's database GEOTAB
Version 2
Stefan Sehlstedt, Tomas Stark
SGAB, Luleå
January 1991

TR 91-02
Description of geophysical data in SKB database GEOTAB
Version 2
Stefan Sehlstedt
SGAB, Luleå
January 1991

TR 91-03
1. The application of PIE techniques to the study of the corrosion of spent oxide fuel in deep-rock ground waters
2. Spent fuel degradation
R S Forsyth
Studsvik Nuclear
January 1991

TR 91-04
Plutonium solubilities
I Puigdomènech[1], J Bruno[2]
[1]Enviromental Services, Studsvik Nuclear, Nyköping, Sweden
[2]MBT Tecnologia Ambiental, CENT, Cerdanyola, Spain
February 1991

TR 91-05
Description of tracer data in the SKB database GEOTAB
SGAB, Luleå
April, 1991

TR 91-06
Description of background data in the SKB database GEOTAB
Version 2
Ebbe Eriksson, Stefan Sehlstedt
SGAB, Luleå
March 1991

TR 91-07
Description of hydrogeological data in the SKB's database GEOTAB
Version 2
Margareta Gerlach[1], Bengt Gentzschein[2]
[1]SGAB, Luleå
[2]SGAB, Uppsala
April 1991

TR 91-08
Overview of geologic and geohydrologic conditions at the Finnsjön site and its surroundings
Kaj Ahlbom[1], Sven Tirén[2]
[1]Conterra AB
[2]Sveriges Geologiska AB
January 1991

TR 91-09
Long term sampling and measuring program. Joint report for 1987, 1988 and 1989. Within the project: Fallout studies in the Gideå and Finnsjö areas after the Chernobyl accident in 1986
Thomas Ittner
SGAB, Uppsala
December 1990

TR 91-10
Sealing of rock joints by induced calcite precipitation. A case study from Bergeforsen hydro power plant
Eva Hakami[1], Anders Ekstav[2], Ulf Qvarfort[2]
[1]Vattenfall HydroPower AB
[2]Golder Geosystem AB
January 1991

TR 91-11
Impact from the disturbed zone on nuclide migration – a radioactive waste repository study
Akke Bengtsson[1], Bertil Grundfelt[1],
Anders Markström[1], Anders Rasmuson[2]
[1]KEMAKTA Konsult AB
[2]Chalmers Institute of Technology
January 1991

TR 91-12
Numerical groundwater flow calculations at the Finnsjön site
Björn Lindbom, Anders Boghammar,
Hans Lindberg, Jan Bjelkås
KEMAKTA Consultants Co, Stockholm
February 1991

TR 91-13
Discrete fracture modelling of the Finnsjön rock mass
Phase 1 feasibility study
J E Geier, C-L Axelsson
Golder Geosystem AB, Uppsala
March 1991