Codell, Richard
Received letter 10/3/88

SKi
STATENS KÄRNKRAFTINSPEKTION
Swedish Nuclear Power Inspectorate
INTRAVAL Project Secretariat

Datum - Date
1988-10-03
Ert datum - Your date

Vår ref - Our ref
INTRAVAL (88)10
Er ref - Your ref

To INTRAVAL Participants

Meeting documentation

Please find the following documents on a series of INTRAVAL meetings:

- Minutes of the second INTRAVAL Coordinating Group meeting held in Barcelona, April 29, 1988, INTRAVAL M(88)2

- Minutes of the first INTRAVAL Coordinating Group meeting held in Stockholm, October 7-9, 1987.

  These minutes, earlier distributed as INTRAVAL M(87)2, were approved at the second meeting with the Coordinating Group. Attached to the minutes is the final INTRAVAL Agreement, also finally approved at the second Coordinating Group meeting.

- Meeting minutes from a special workshop on unsaturated zone INTRAVAL test cases, Washington D.C., July 19-20, 1988 (Appendix 1).

- Notes from an INTRAVAL workshop on salt-related test cases, Bilthoven, September 19-20, 1988 (Appendix 2).

Working Group on salt related test cases

Also please find the following material produced by the INTRAVAL working group on salt related test cases to be discussed at the next INTRAVAL workshop (Tucson in November 1988)

- Draft test case description based on a brine transport experiment (Appendix 3).

- A RIVM report on the brine experiment ,RIVM Internal Report 728717006 (Appendix 4) .

Meetings connected to the INTRAVAL Tucson meeting

In the INTRAVAL Letter (88)9 it was informed on two meetings to be held in connection with the INTRAVAL workshop, one meeting on licensing issues related to final disposal to be held at the U.S. NRC, Washington D.C. and one modelling workshop with the Alligator Rivers Analogue Project (ARAP).

It has now been decided that the ARAP meeting will be held on November 21-22 (Monday and Tuesday after the INTRAVAL meeting) at the Department of Hydrology, University of Arizona. Special experts in the Alligator Rivers Project will present their work at the INTRAVAL meeting. INTRAVAL participants are also envited to take part in the ARAP meeting. Preliminary information on participation has been received by SKI. Since the ARAP meeting arrangements now have been decided the participants are adviced to contact Peter Duerden at ANSTO or Tim McCartin at the U.S. NRC regarding detailed meeting arrangements.

The NRC licensing meeting is still being planned to be held on Monday the November 21st. INTRAVAL participants interested to discuss licensing issues or to present recent developments in their countries are invited by the U.S. NRC to take part. For practical purposes INTRAVAL participants should inform the INTRAVAL Secretariat on participation in the NRC meeting using the form that was attached to the letter INTRAVAL (88)9.

With best regards,

Kjell Andersson
Secretary to the Coordinating Group

SKi

Kjell Andersson

INTRAVAL M(88)2
October 2, 1988

INTRAVAL

MINUTES OF THE SECOND COORDINATING GROUP MEETING HELD IN BARCELONA, APRIL 29,1988.

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1. ATTENDANCE AND OPENING OF MEETING.

The meeting was attended by fortyfour participants, including seventeen representatives of the Parties setting up the INTRAVAL study, five members of the Project Secretariat, twenty accompying experts and two observers. Appendix 1 gives a list of the participants.

The meeting was opened by Mr. Larsson, chairman of the Coordinating Group.

2. ADOPTION OF THE AGENDA.

The proposed agenda for the meeting was adopted with a few changes. The agenda is given in Appendix 2.

3. MINUTES OF THE FIRST COORDINATING GROUP MEETING.

The minutes of the first INTRAVAL Coordinating Group meeting in Stockholm, October 7-9, 1987 were approved. The final INTRAVAL Agreement attached to the minutes from the first meeting was thereby finally approved by the Group.

4. STATUS REPORT BY THE PROJECT SECRETARIAT.

The Secretary informed on the present status of the INTRAVAL participation and gave a brief overview of the activities by the Secretariat since the first meeting with the Coordinating Group.

At the present 20 Parties set up the INTRAVAL project with 26 Project Teams (see Appendix 3). In addition the State of Nevada takes part as observer.

The main part of the Secretariat's work after the first meeting with the Group has been devoted to development of test case descriptions with various kinds of interactions with the different Pilot Groups. These activities have included a meeting in Washington D.C. with the U.S. NRC and U.S. DOE and participation in a modelling meeting in Australia with the Alligator Rivers Natural Analogue Project.

The Coordinating Group meeting had been preceeded by a workshop on April 25-29 (Appendix 4). During this workshop the test case descriptions for all cases decided at the Stockholm meeting had been presented and discussed exept for case 6 which had been withdrawn from the project. Indications of interest during the workshop had shown that substantial contributions with calculation efforts can be expected from several project teams for all remaining eight cases. For some of the cases the first modelling calculations had also been presented.

At the first Coordinating Group meeting three working groups were set up for preparing proposals for salt related cases, unsaturated media cases and a synthetic experiment. These working Groups had presented their proposals at the workshop.

A fourth working group for development of a strategy for the systematic application of experiences and knowledge gained from the various INTRAVAL test cases had been set up in Stockholm following a proposal from Mr. Eisenberg. It was foreseen that this group would suggest a format for a special committee within INTRAVAL with the task to assist in integrating and focusing the project. At the workshop, the working group proposal for a Validation Oversight and Integration Committee (VOIC) had been presented by the group leader, Mr. Nicholson. The Coordinating Group discussed the issue at point 12 of the agenda.

5. DECISIONS ON TEST CASES BASED ON LABORATORY EXPERIMENTS

<u>Case 1a</u>

This case was found to be in good shape. An updated version will produced by Mr. Lever.

<u>Case 1b</u>

This case was well defined and the case is ready for calculations in INTRAVAL.

<u>Case 2</u>

Also this case was found to be well defined and remaing data will shortly be distributed to participating Project Teams.

<u>Case 9</u>

The case will get continued support by the U.S. DOE and AECL. Mr. Gureghian is the Pilot Group leader. He will complete the test case description before the next INTRAVAL workshop with experimental data.

6. DECISIONS ON TEST CASES BASED ON FIELD EXPERIMENTS

Case 3

This case is now defined and the data from the experiments are ready for distribution.

Case 6

This case has been withdrawn from INTRAVAL due to the U.S. decision to cancel other repository programs than the NNWSI Project. This means that there will be no continued experiments in the basalt formations at the Hanford site. A case based on a synthetic experiment (see point 10) will be the new test case 6.

Case 4

The case is defined and background data has been distributed to interested Project Teams. As for other cases data can be made avaiable to new Project Teams on request.

Case 5

The experimental program consists of three parts. For the first part (a radially converging tracer experiment) predictive modelling had been presented at the workshop by two Project Teams (SKB/KTH and TVO/VTT). Although the experiment is now completed it is still open for modelling (non-predictive).

The remaning two parts of the Finnsjön experiments are a dipole tracer test and a natural gradient tracer experiment. The INTRAVAL Project Teams are encouraged to make predictive modelling for these experiments. Teams interested in this case should interact closely with Peter Andersson who is the Pilot Team leader. Also written comments on any part of experimental program are much welcomed.

7 DECISIONS ON TEST CASES BASED ON NATURAL ANALOGUES

Two international natural analogue projects are being studied as test cases in INTRAVAL, the Pocos de Caldas Project in Brazil (Case 7) and the Australian analogue Alligator Rivers Project which has recently been set up as an OECD/NEA project (Case 8).

Case 7

The Pocos de Caldas Project consists of two parts. The first part studies redox front behaviour (Case 7a) and the second part deals with studies on colloid formation and mobility (Case 7b). These subcases had been described by Mr. Neretnieks and Neil Chapman respectively in papers that had been circulated to INTRAVAL participants. The Coordinating Group found that both phenomena would be interesting to study in INTRAVAL. They should therefore be further developed. For the colloid subcase, migration experiments are needed before it can be defined as a test case.

Case 8

Between the first and second INTRAVAL Coordinating Group meeting a workshop had been held within the Alligator Rivers Project on modelling issues including preparation of an INTRAVAL test case. After this meeting a document describing the analogue and possible modelling approaches had been circulated to INTRAVAL participants. A large volume of data from the site is available and further experiments are being planned within the ongoing international project. Some modelling has been made at an earlier phase of the project by Mr. Lever.

The Coordinating Group discussed the status of Alligator Rivers as an INTRAVAL test case and the possibilities to quantify and stucture available information in such a way that a real quantitative evaluation of possible processes at the site can be obtained. Comments on existing documentation should be sent to Mr. Duerden who will take the responsibility to prepare a new document to the next meeting. This document will also include previous modelling experiences.

8. DECISIONS ON SALT CASES

At the first INTRAVAL Coordinating Group meeting a working group was appointed to develop test cases related to disposal in salt formations. The working group had presented three ideas for possible salt cases at the workshop although no case was yet developed in detail. Six Project Teams had, however, indicated an interest to work actively on salt cases. The working group will thus continue its work and present more developed proposals to the next INTRAVAL meeting.

9. DECISIONS ON CASES BASED ON UNSATURATED MEDIA

Due to the change in the U.S. program the interest in INTRAVAL cases relevant for disposal in unsaturated media has increased. The working group on unsaturated media cases presented proposals for the following three test cases:

- evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil performed within a U.S. NRC trench study at Las Cruces, New Mexico.

- evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap Tuff Site near Superior, Arizona

- experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site performed by the Nevada Nuclear Waste Investigation Project of the U.S. DOE.

The Group decided to adopt these three cases in INTRAVAL as cases 10-12. The NRC Project Teams will present modelling results on cases 10 and 11 and the U.S. DOE will present data and modelling results on case 12 at the next workshop.

10. SYNTHETIC EXPERIMENT

The issue of a possible synthetic experiment as an INTRAVAL test case has been much discussed both in the INTRAVAL ad-hoc group and at the first meeting with the Coordinating Group. A working group, appointed at the first meeting, gave a presentation at the workshop. Also Mr. Codell had presented ideas for the use of synthetic experiments in the context of validation. It was concluded that there are several possible approaches to a test case development.

The Coordinating Group decided to in princple include a synthetic experiment in INTRAVAL. The Group also decided to set up a working group consisting of Mr. Codell, Mr Cole and Mr. Vomvoris to further elaborate the idea to its next meeting.

11. NEW INTRAVAL PARTICIPANTS

The Australian organisation ANSTO has been involved in the INTRAVAL project by the link to the Alligator Rivers Analogue Project which has been adopted as a test case. Representatives of ANSTO participate actively in INTRAVAL meetings, test case development and calculations. Discussions between SKI and ANSTO concerning these matters had resulted in the conclusion that it would be a suitable arrangement to have ANSTO as a formal Party in INTRAVAL. On recommendation from SKI the Coordinating Group decided to adopt ANSTO as a new INTRAVAL Party.

The Secretary informed the Group that the two German organisations BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) and PTB (Physikalisch-Technische Bundesanstalt) had by a letter to SKI announced their interest to participate in INTRAVAL. On recommendation from the Chairman it was decided to leave a place open for BGR-PTB in INTRAVAL. The organisational arrangements for this participation will be clarified to the next Coordinating Group meeting.

The Secretary also informed that the Ruder Boskovic Institute in Zagreb, Yugoslavia, had expressed an interest to participate in INTRAVAL. It was decided to invite a representative of the Institute to the next workshop. In the meantime the Secretariat will have contacts with the Institute to further investigate the issue. A decision on participation may then be taken at the next Coordinating Group meeting.

12. DECISIONS ON VOIC (VALIDATION OVERVIEW AND INTEGRATION COMMITTEE)

The proposal for a validation overview and integration committee, VOIC, was approved according to a charter presented by Mr. Nicholson (Appendix 5). Seven members in VOIC, given in

Appendix 6, were appointed with Mr. Nicholson as chairman. The Committee can later be complemented by one additional member. The Project Secretariat will assist VOIC in its work and members of the Secretariat can therefore attend VOIC meetings.

The VOIC Committee will have an important role in reviewing and integrating test cases. It is also foreseen that the VOIC can make significant contributions towards the end of INTRAVAL in the result analysis and by suggesting ideas for further work for the validation process.

13. INFORMATION ON HYDROCOIN

The Secretary informed on the status of the HYDROCOIN Project. A time schedule for finalisation of the project was decided at the seventh (and last) HYDROCOIN Coordinating Group meeting in Paris, November 19, 1987. The decided time schedule includes a number of activities by the Secretariat as well by the Project Teams. The Secretariat will have a drafting group meeting in Washington D.C. in October 1988. The aim of this meeting is to prepare a final draft of the Level 2 report, a draft of the Level 3 report to be commented by the Project Teams, and a draft of a HYDROCOIN Summary report, also to be commented by Project Teams. Following this schedule all remaining HYDROCOIN reports will be published during 1989.

14. FORMAT FOR TEST CASE DEFINITIONS

The Coordinating Group discussed the format for test case descriptions that was decided at first meeting and that has been used for a number of cases. The Group found that the used format in general had served its purpose. However, in some cases additional information should be given for geochemistry and experimental tracers. It was also agreed that more emphasis should be given to the uncertainties in experimental data and that it is important to give information of importance for a qualitative view of the experiments.

15. DECISIONS ON THE NEXT WORKSHOP AND COORDINATING GROUP MEETING

Following a suggestion from Mr. Nicholson and Mr. Eisenberg it was decided to have the next INTRAVAL workshop and Coordinating Group meeting in the United States in November 1988.

16. OTHER MATTERS

The organisation of INTRAVAL meetings and related practical matters were discussed. It was concluded that the present size of the project and the number of meeting participants requires a thorough planning for future meetings. The format for workshops and the possibility to have parallell sessions was discussed. The general opinion in the Group was that the present format for meetings should be kept, if possible. However, it may be necessary to consider modifications for future workshops.

LIST OF APPENDICES

APPENDIX 1: Meeting participants

APPENDIX 2: Meeting agenda

APPENDIX 3: List of INTRAVAL Parties and Project Teams

APPENDIX 4: Second INTRAVAL workshop : Agenda and list of participants (Notes have been distributed with INTRAVAL Letter (88)7)

APPENDIX 5: Charter for the VOIC Committee

APPENDIX 6: VOIC Members

APPENDIX 7: INTRAVAL Test cases

INTRAVAL Coordinating Group meeting, Barcelona, 1988-04-29

Participants

Johan Andersson	SKI/KTH
Kjell Andersson	SKI, Secretary
Carmen Bajos	ENRESA
Peter Bogorinski	GRS
Jesus Carrera	Un. Politecnica de Cataluna (UPC)
Richard Codell	U.S. NRC-NMSS
Charles Cole	PNL
Emilio Custodio	UPC
John P. Davis	NRPB
Paul Davis	NRC/Sandia
Peter Duerden	ANSTO
Norman Eisenberg	U.S. DOE
German Galarza	UPC
Peter Glasbergen	RIVM
Cezary Golian	ANSTO
Bertil Grundfelt	Kemakta/Secretariat
Berge Gureghian	Battelle-OWTD
Jörg Hadermann	Paul Scherrer Institut
S. Majid Hassanizadeh, RIVM	
David Hodgkinson	INTERA-ECL
Dwight Hoxie	USGS/NNWSI
Conny Hägg	SSI (observer)
Kazuya Idemitsu	PNC
Fred Karlsson	SKB
Hideo Kimura	JAERI
Alf Larsson	SKI (Chairman)
Linda Lehman	State of Nevada (observer)
David Lever	U.K. DoE, Nirex, Secretarat
Björn Lindbom	Kemakta/Secretariat
Agustin Medina	UPC
Ivars Neretnieks	SKB/KTH
Thomas Nicholson	U.S. NRC
David Noy	British Geological Survey
Pascal Oustrière	ANDRA
Esko Peltonen	TVO
Karin Pers	Kemakta/Secretariat
Javier Samper	UPC
Nick Scheier	AECL
Kristina Skagius	Kemakta/Secretariat
Claes Thegerström	OECD/NEA/Secretariat
Chin-Fu Tsang	LBL
Auguste Zurkinden	HSK
Stratis Vomvoris	NAGRA

SECOND INTRAVAL COORDINATING GROUP MEETNG

Barcelona, April 29, 1988

Place: Palau de Congressos, Avda. Reina Ma. Cristina s/n

AGENDA

1. Opening of meeting

2. Adoption of the agenda

3. Approval of the minutes of the first INTRAVAL Coordinating Group meeting

4. Status report by the Project Secretariat

5. Decisions on test cases based on laboratory experiments

   - case 1a
   - case 1b
   - case 2
   - case 9

6. Decisions on test cases based on field experiments

   - case 3
   - case 6
   - case 4
   - case 5

7. Decisions on test cases based on natural analogues

   - case 7
   - case 8

8. Decisions on salt cases

9. Decisions on cases based on unsaturated media

10. Synthetic experiment

11. New INTRAVAL participants

12. Decisions on VOIC (Validation Overview and Integration Committee)

13. Information on HYDROCOIN

14. Format for test case definitions

15. Decisions on the next workshop and Coordinating Group meeting

16. Other matters

INTRAVAL Participants

PARTIES/Coordinating Group members	Project teams / team leaders
AECL Tin Chan	<u>AECL</u> Tin Chan
ANDRA Pascal Oustriere	<u>CEA/DEMT</u> Michel Durin
ANSTO Peter Duerden	<u>ANSTO</u> Cezary Golian
CEA/IPSN Alain Cernes	<u>Ecole des Mines</u> Patrick Goblet
ENRESA Carmen Bajos	<u>Un. Politecnica de Cataluna</u> Jesus Carrera
GRS Peter Bogorinski	<u>GRS</u> Peter Bogorinski
GSF Richard Storck	<u>GSF</u> Shaheed Hossain
HMIP Nick Harrison	<u>BGS</u> Neil Chapman <u>Atkins</u> Richard Paige

HSK	<u>HSK</u>
Auguste Zurkinden	Auguste Zurkinden
JAERI	<u>JAERI</u>
Haruto Nakamura	Hideo Kimura
	<u>CRIEPI</u>
	Motoi Kawanishi
	<u>Hazama-gumi</u>
	Akira Kobayashi
NAGRA	<u>Paul Scherrer Institute</u>
Piet Zuidema	Jörg Hadermann
NRPB	<u>Solid Waste Management Group</u>
Shelly Mobbs	Shelly Mobbs
PNC	<u>PNC</u>
Hiroyuki Umeki	Hiroyuki Umeki
RIVM	<u>RIVM</u>
Peter Glasbergen	Magid Hassanizadeh
SKB	<u>KTH</u>
Fred Karlsson	Ivars Neretnieks

SKI	KTH
Alf Larsson (chairman)	Johan Andersson
(Kjell Andersson, Secretary)	
TVO	VTT
Esko Peltonen	Seppo Vuori
U.K. Nirex Ltd.	Harwell Lab.
Dennis George	David Lever
	INTERA/ECL
	David Hodgkinson
U.S. DOE	NNWSI Project
Norman Eisenberg	Dwight Hoxie
	PASS Program
	Charles Cole
	OWTD
	Berge Gureghian
U.S. NRC	U.S. NRC
Thomas Nicholson	Timothy McCartin

Member of Secretariat: OECD/NEA
Claes Thegerström

Observer : State of Nevada
Linda Lehman

FIRST INTRAVAL WORKSHOP

Barcelona, April 25-29,1988
Place: Palau de Congressos,
Avda. Reina Ma. Cristina s/n

AGENDA

April 25

9.30	Welcoming remarks by Mr. Juan-Manuel Kindelan, President of ENRESA
	Opening of meeting by Mr. Alf Larsson, Chairman of Co-ordinating Group
10.00	Project status (Kjell Andersson, SKI)
10.15	Overview of INTRAVAL test cases (Bertil Grundfelt, Kemakta)
10.45	COFFEE BREAK
11.15	CHAIRMAN: Mr Alf Larsson, SKI
	Presentation of case 1a (D. Lever, Harwell)
	Comments on modelling the Harwell migration experiment (P. Bogorinski, GRS)
	Presentation of case 1b with prelimiary results (J. Hadermann, PSI)
	Prelimiary results on case 1b (C. Cole, PNL)
	Identifiability problems with data on case 1b (J. Carrera, Un. Politecnica de Cataluna)
13.00	LUNCH
15.00	CHAIRMAN: Ms Carmen Bajos, ENRESA
	Presentation of case 2 (K. Skagius, Kemakta)
	Previous modelling of case 2 experiment (I. Neretnieks, SKB/KTH)

Preliminary results on case 2 (C. Cole, PNL)

Preliminary results of case 2 study (H. Kimura and R. Yamashita, JAERI)

Description of granitic block experiment for Case 9 (B. Gureghian, Battelle)

16.30 COFFEEE BREAK

17.00- 19.00 CHAIRMAN: Charles Cole, PNL

Introduction to case 5 (P. Andersson, Swedish Geological Company and I. Neretnieks, SKB/KTH)

Preliminary predictions of Finnsjön tracer test (I. Neretnieks, SKB/KTH)

Generalized Taylor dispersion analysis for tracer breakthrough in the radially converging experiment at Finnsjön (A. Hautojärvi and V. Taivassalo, VTT)

April 26

9.00 CHAIRMAN: David Hodgkinson, INTERA

INTRAVAL case 3, experiments and modelling calculations (C. Cole, PNL)

Comments on INTRAVAL test case 3 (J. Andersson, B. Dverstorp, W. Nordqvist, SKI/KTH)

10.30 COFFEE BREAK

10.50 Presentation of case 4, 3D migration experiment in Stripa (I. Neretnieks, SKB/KTH)

Application of the discrete fracture network concept on field data: possibilities for model calibration and validation (B. Dverstorp and J. Andersson, SKI/KTH)

13.00 LUNCH

15.00 Barcelona bus tour, dinner

April 27

9.00 CHAIRMAN: Pascal Oustrière, ANDRA

Report from the working group on formulating test cases for unsaturated media (T. Nicholson, D. Hoxie, N. Eisenberg, C. Cole and T. McCartin)

Las Cruces trench study proposal for validating unsaturated flow and transport models for porous media (G. Gee, T. Nicholson, P.J. Wierenga and L.W. Gelhar)

10.30 COFFEE BREAK

10.50 Apache Leap tuff study proposal for validating unsaturated flow and transport models for fractured rock (T.C. Rasmussen, D.D. Evans and T. Nicholson)

Empirical validation of hydrologic model simulations of changing near-field hydrologic conditions produced by transient, spatially propagating disturbances in partially saturated tuffaceous rocks (D.T. Hoxie, U.S. GS)

13.00 LUNCH

15.00 CHAIRMAN: Shaheed Hossain, GSF

Discussion on unsaturated media cases

Proposals for test cases related to rock-salt (P. Glasbergen, RIVM)

Presentation of experimental results from brine experiment (S.M. Hassanizadeh, RIVM)

17.00 COFFEE BREAK

17.30-20.00 CHAIRMAN: Thomas Nicholson, U.S. NRC

Presentation of case 7a, redox front and uranium movement at Pocos de Caldas (I. Neretnieks, SKB/KTH)

Presentation of case 7b, colloid mobility at Pocos de Caldas (N. Chapman and D. Noy, BGS)

Presentation of Koongarra and draft test case (P. Duerden and C. Golian, ANSTO)

Previous modelling of Koongarra (D. Lever, Harwell)

April 28

10.00-20.00 Tour to Tarragona with lunch, hosted by ENRESA

April 29

8.00- CHAIRMAN: Claes Thegerström, OECD/NEA

On the synthetic experiment (S. Vomvoris, F. Herzog and P. Hufschmied, NAGRA)

Discussion on synthetic experiments for INTRAVAL

Report of the working group on formulating a validation oversight and integration committee, VOIC (T. Nicholson, C. Cole and N. Eisenberg)

Discussion

10.00 Concluding remarks (A. Larsson, SKI)

FIRST INTRAVAL WORKSHOP
Barcelona, April 25-29, 1988

Participants

Johan Andersson	SKI/KTH
Kjell Andersson	SKI
Carmen Bajos	ENRESA
Peter Bogorinski	GRS
Jesus Carrera	Un. Politecnica de Cataluna (UPC)
Alain Cernes	CEA/IPSN
Richard Codell	U.S. NRC
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Conny Hägg	SSI (observer)
Kazuya Idemitsu	PNC
Andreas Jakob	Paul Scherrer Institut
Fred Karlsson	SKB
Hideo Kimura	JAERI
Juan-Manuel Kindelan,	ENRESA
Alf Larsson	SKI
Linda Lehman	State of Nevada (observer)
David Lever	Harwell Laboratory
Björn Lindbom	Kemakta
Marie-Jose Mejon-Goula,	CEA/IPSN
Ivars Neretnieks	SKB/KTH
Schlomo Neuman	University of Arizona
Thomas Nicholson	U.S. NRC
Wille Nordqvist	SKI/KTH
David Noy	British Geolcgical Survey
Pascal Oustrière	ANDRA
Richard Paige	Atkins
Esko Peltonen	TVO
Karin Pers	Kemakta
Tim Preece	Harwell
Javier Samper	UPC
Nick Scheier	AECL

Kristina Skagius	Kemakta
Richard Storck	GSF
Claes Thegerström	OECD/NEA
Chin-Fu Tsang	LBL
Auguste Zurkinden	HSK
Stratis Vomvoris	NAGRA

CHARTER FOR THE

VALIDATION OVERSIGHT AND INTEGRATION COMMITTEE

BACKGROUND:

At the first INTRAVAL Coordinating Meeting, the Secretariat approved a motion by Dr. Norman Eisenberg, US DOE to establish a working group to formulate a Validation Oversight and Integration Committee (VOIC). The need for this committee is based upon issues reported in the INTRAVAL ad hoc report, and a critique of that report and the INTRAVAL Project Proposal presented by Dr. Shlomo P. Neuman, University of Arizona, earlier at the meeting. The Vice-Chairman was requested to chair a Working Group to develop ideas and plans to implement the motion, and to report to the Coordinating Group on their specific recommendations. This Charter serves that role.

The INTRAVAL Project has selected a set of experiments (including laboratory and field experiments, and natural analogs) which include a range of media types, flow and transport processes, spatial and time scales, and various environmental conditions associated with radioactive waste disposal in geologic media. Included within these experimental studies are various performance issues and models which are the topic of these selected validation studies. However, there is presently no effort within the INTRAVAL Project which deals specifically with an overall synthesis and integration of these validation studies. This integration effort would build upon the experiences and knowledge gained from the individual INTRAVAL test cases. This proposed effort would enable the INTRAVAL Project to advance the knowledge of validation in a more comprehensive manner than if the test cases were considered separately.

It is this need for a specially designed effort dealing with the integration of these broad validation issues that is the motivation for the formation of the Validation Oversight and Integration Committee (VOIC).

As the INTRAVAL Project's progress is reviewed by the VOIC, and these broad validation issues are identified, the VOIC could also serve an oversight function by advising the INTRAVAL Coordinating Group of needed modifications and additions.

PURPOSE:

The purpose of the Validation Oversight and Integration Committee is to provide a means for the INTRAVAL Project to investigate the broad issues related to demonstrating the validity of theories and models used in the performance assessment of repositories, and to provide for a continuing technical oversight which will allow for ongoing adjustments and improvements to the selected test cases.

OBJECTIVES:

The objectives of the Validation Oversight and Integration Committee (VOIC) are to:

(1) examine the broad validation issues associated with demonstrating the validity of theories and models used in the performance assessment of repositories through a synthesis and integration of the experiences and knowledge gained from each of the INTRAVAL test cases, and review of other appropriate research studies outside of INTRAVAL.

(2) provide a technical oversight function through recommendations (based on the VOIC's synthesis and integration efforts of validation issues, reviews of non-INTRAVAL research studies, and ongoing reviews of the INTRAVAL test cases) to the INTRAVAL Coordinating Group.

MEMBERSHIP:

Composition - A list of proposed VOIC members will be submitted to the INTRAVAL Coordinating Group that will consist of 6-8 recognized experts in the field of ground-water flow and transport studies with both experimental and modeling experience.

Support - The committee could request through the Secretariat, assistance from the individual Project teams to provide the committee with required information and additional expertise. Financial support for members of the VOIC will follow the INTRAVAL Agreement, and will therefore be the responsibility of the individual organizations who are sponsoring the VOIC members.

IMPLEMENTATION:

The Validation Oversight and Integration Committee will interface with the INTRAVAL Coordinating Group and project teams through the Secretariat in an attempt to synthesize and integrate:

- the results from the efforts by the project teams on various INTRAVAL test cases,
- the accomplishments resulting from the INTRAVAL Workshops and Coordinating Group Meetings, and
- the independent research and review efforts of the VOIC

into a unified scientific approach for model validation. The VOIC will seek information and experiences both inside and outside of the nuclear waste community (e.g., USEPA, NASA, USDOD, NATO and other governmental agencies and international organizations which have had to deal with the subject of validation) to assist in development of this unified scientific approach to model validation.

The VOIC will gather the needed knowledge for their integration and synthesis efforts, and also provide continuing independent reviews and evaluations of the INTRAVAL project by: (1) attending the INTRAVAL Workshops and Coordinating Group meetings: (2) interacting with the various project teams; (3) reviewing the various project team reports; and (4) covering separate meetings preferably at the conclusion of the INTRAVAL workshops. Other mechanisms for providing for a rigorous peer review of the INTRAVAL Project and its results will also be considered by VOIC.

The VOIC will provide feedback, when appropriate, to the project teams and Coordinating Group through presentations at the INTRAVAL workshops and Coordinating Group meetings as well as through VOIC reports.

A list of potential tasks which the VOIC might undertake are:

- review the INTRAVAL Ad Hoc report, and other available information (e.g., GEOVAL papers) to determine the outstanding questions with regard to validation of radionuclide transport models;
- review the nine test cases to identify the primary hypotheses, models and theories being tested, so as to identify any missing relevant theories and models and suggest which ones could provide credible alternatives to the ones being tested:
- integrate the various test cases into a framework covering the range of theories, media, processes, and scales being considered;
- recommend modifications to existing test cases or development of new test cases to address omissions in the validation framework;
- investigate both the specific issues related to demonstrating the applicability of the chosen models to actual experiments and the broader issues related to integrating these diverse studies into a coherent program for validation of ground-water flow and radionuclide transport models.

It would also be desirable if VOIC would examine the following issues:

- the basic steps for a validation approach including the role of comparisons to experiments,

- an approach for dealing with the different spatial and temporal scales,

- the role of an iterative approach involving calibration and validation steps,

- an approach for dealing with the differences between modeling scale and measurement scale,

- the relationship between model purpose and quality of model agreement with experimental data in a model validation effort.

It should be noted that these lists of tasks and issues are presented only to portray the general topics the VOIC may wish to explore. Since VOIC is meant to be as independent and unbiased as possible, VOIC should establish a detailed action plan and specific topics utilizing the guidance provided in this Charter.

SCHEDULE:

The proposed schedule for formulating the Validation Oversight and Integration Committee is as follows:

January 1988	- Circulate first draft of the VOIC Charter to the Working Group
March 1988	- Transmit the finalized VOIC Charter to the Secretariat
March 1988	- Circulate VOIC Charter to Coordinating Group members and to formulate committee membership and chairmanship for presentation at the 2nd INTRAVAL Coordinating Group Meeting
April 1988	- Report to the INTRAVAL Coordinating Group on the VOIC Charter
May 1988	- Following approval, organize VOIC convocational meeting and establish an action plan

THE INTRAVAL VALIDATION OVERVIEW AND INTEGRATION COMMITTEE (VOIC)

Members:

Thomas Nicholson (chairman), U.S. NRC

Jesus Carrera,	Un. Politecnica de Cataluna
Neil Chapman,	BGS
David Hodgkinson,	Intera/ECL
Ivars Neretnieks,	KTH
Shlomo Neuman,	Univ. of Arizona
Chin-Fu Tsang,	LBL

INTRAVAL TEST CASES

case 1a: Radionuclide migration in intact rock and clay samples by diffusion and advection based on laboratory experiments performed at Harwell, U.K.

case 1b: Uranium migration in crystalline bore cores based on experiments performed at EIR, Switzerland

case 2: Radionuclide migration in single natural fissures in granite, based on laboratory experiments performed at KTH, Sweden

case 3: Tracer tests in a deep basalt flow top performed at the Hanford reservation, Washington, USA

case 4: Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiment performed within the International Stripa Project

case 5: Tracer experiments in a fracture zone at the Finnsjön research area, Sweden

case 6: Synthetic experiment

case 7: Natural analogue studies at Poccs de Caldas, Minas Gerais, Brazil

case 8: Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

case 9: Radionuclide migration in a block of crystalline rock based on laboratory experiments performed at AECL, Whiteshell, Canada, in cooperation with the U.S. DOE.

case 10: Evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil performed within a U.S. NRC trench study in Las Cruces, New Mexico.

case 11: Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap Tuff Site near Superior, Arizona

case 12: Experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site performed by the Nevada Nuclear Waste Investigation Project of the U.S. DOE.

SKi

Kjell Andersson 1987-12-02 (Approved 1988-04-29) INTRAVAL M(87) 2

MINUTES

FIRST INTRAVAL COORDINATING GROUP MEETING, STOCKHOLM, OCTOBER 7-9, 1987.

1. OPENING OF MEETING

The Coordinating Group meeting was opened by Mr. Alf Larsson, appointed as chairman of the Group by the Managing Participant, the Swedish Nuclear Power Inspectorate (SKI). Mr. Larsson expressed his appreciation of the great interest in the INTRAVAL project and of the broad participation in the first meeting with the Coordinating Group. Mr. Larsson also took the opportunity to thank the participants in the ad-hoc group which had assisted SKI in preparing and defining the INTRAVAL project during a period of one year.

The meeting was a meeting with the Coordinating Group extended with a number of accompanying experts related to the proposed test cases to be discussed. There were 48 participants at the meeting (see Appendix 1), 17 of these represented 18 INTRAVAL Parties in the Coordinating Group (see Appendix 2), two represented the Australian organisation ANSTO and two represented RIVM (the Netherlands). Furthermore there were 8 participants from the Project Secretariat, 13 assisting experts and 5 members of the SKI staff.

2. INTRODUCTORY REMARKS

Mr. Lars Högberg, Deputy Director General of SKI, gave an overview of the Swedish program for final disposal of spent nuclear fuel and high-level waste and stressed the importance of progress in model validation for the acceptance of a future repository both by experts and the general public. Mr. Högberg expressed his hope that INTRAVAL will contribute substantially to this process and wished all the participants success with the project work.

3. ADOPTION OF THE AGENDA

The agenda for the meeting was adopted according to Appendix 3.

4. INFORMATION ON INTRAVAL ORGANISATION, PARTICIPATION AND PROJECT SECRETARIAT

Mr. Kjell Andersson, Secretary to the Coordinating Group, summarised the background to INTRAVAL in the context of the previous projects INTRACOIN and HYDROCOIN as well as the work of the INTRAVAL ad-hoc group. An overview of INTRAVAL objectives, project organisation and participation was also given.

The INTRAVAL Parties, which formally had announced their participation in the project, are listed in Appendix 4 with their Coordinating Group Members. A Project Secretariat has been organised by SKI in cooperation with the U.K. Department of the Environment and the OECD/NEA according to Appendix 5. Kemakta Consultants Co with Mr. Bertil Grundfelt acts as principal investigator for the project on contract from SKI.

Mr. Andersson noted that some small changes and clarifications had been made in the INTRAVAL Agreement following proposals from Parties. On suggestion from the Chairman the Coordinating Group members were asked to review the final Agreement (Appendix 6) to the next Coordinating Group meeting. Any comments from the Parties will be considered at this meeting.

5. APPOINTMENT OF VICE CHAIRMAN

Mr. Thomas W. Nicholson from the United States Nuclear Regulatory Commission was appointed Vice Chairman for the Coordinating Group.

6. INFORMATION ON INTRAVAL TECHNICAL STRUCTURE AND TIME SCHEDULE

Mr. Grundfelt informed on the INTRAVAL technical structure and time schedule according to the project proposal. In INTRAVAL, results from laboratory experiments, field experiments and natural analogues will be used in a systematic effort towards the validation of geosphere performance assessment models. To this end, seven test cases were given in the proposal. It was, however, also foreseen that additional test cases would be considered by the Coordinating Group after proposals from Group members.

The main structure of INTRAVAL is a division of test cases into Part I and Part II. Part I cases are based on data from already performed experiments which can be used within INTRAVAL. The Part II cases are based on experiments and analogue studies which are being performed or are planned. These cases should give a good opportunity for interaction between the experiments and models as well as feedback from the modellers to the actual experimental designs.

The INTRAVAL project is proposed to be a three year project with an option for an additional three year period.

7. QUESTIONS REGARDING THE CONCEPT OF VALIDATION

Mr. Shlomo Neuman gave a talk with methodological comments regarding INTRAVAL. The talk dealt with different definitions of the validation concept, shortcomings of these definitions, alternative approaches, the concept of partial validation as well as the difference between model validation and code calibration. The talk reviewed the proposed INTRAVAL procedure and gave additional perspectives on the validation subject which should be taken into account in the further development of the project. Mr. Neuman emphasised the need for recognising that validation of models is an integrated part of the scientific process. Necessary components of this process are:

- the identification of outstanding issues requiring experimental/technical resolution
- the identification of experimental procedures to address these issues
- peer evaluation and review

8. REVIEW OF PROPOSED TEST CASES

The seven test cases included in the INTRAVAL proposal as well as two additional ones were presented and discussed with respect to status of experimental programmes, availability of data, documentation, means of interaction between INTRAVAL and experimental programmes, validation aspects and performance measures.

Presentation of the cases were made by the following meeting participants:

<u>David Lever (Harwell) and Jörg Hadermann (EIR)</u>

case 1: Transport in intact rock and clay by diffusion and advection based on laboratory experiments performed at Harwell, U.K. and EIR, Switzerland

<u>Tryggve Eriksen (KTH) and Ivars Neretnieks (KTH)</u>

case 2: Radionuclide migration in single natural fissures in granite, based on laboratory experiments performed at KTH, Sweden

Charles Cole (PNL)

case 3: Two recirculating non-reactive, pulse injection groundwater tracer experiments performed in a basalt flow top at the Hanford Site, Washington, USA, U.S DOE project

Ivars Neretnieks (KTH) and Johan Andersson (KTH)

case 4: Flow and tracer experiments in crystalline rock, Stripa 3-D experiment, International Stripa Project

Peter Andersson (Swedish Geological)

case 5: Tracer experiments in an fracture zone at the Finnsjön research area, Sweden

Thomas Nicholson (U.S. NRC) and Charles Cole (PNL)

case 6: Flow and tracer experiments in saturated fractured basalt, Creston Washington USA Field Site (U.S. NRC project) and new experiments in the basalt flow top at the Hanford site (U.S. DOE project)

Fred Karlsson (SKB) and Ivars Neretnieks (KTH)

case 7: Natural analogue studies at Pocos de Caldas, Minas Gerais, Brazil

Peter Duerden (ANSTO) and Cezary Golian (ANSTO)

case 8: Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Norman Eisenberg (U.S. DOE)

case 9: Radionuclide migration in a block of crystalline rock based on laboratory experiments performed at AECL, Whiteshell, Canada, in cooperation with the U.S. DOE

Cases 1-7 were proposed as test cases in the project proposal report. The Alligator Rivers studies (case 8) are briefly described in the report SKI 87:4 and are well ducumented in a number of reports. It was foreseen in the INTRAVAL proposal that these studies would be considered for inclusion in the project.

The Alligator Rivers Project has now been established as an NEA project with participation from Australia (ANSTO), Japan (JAERI and PNC), United Kingdom (Her Majesty's Inspectorate of Pollution), USA (U.S. NRC) and Sweden (SKI). The SKI participation will provide a direct link between the two projects (INTRAVAL and Alligator Rivers).

Case 9, which was proposed by Mr. Eisenberg, is based on laboratory experiments involving a large block of granite containing a single fracture. A series of experiments are planned for calibration efforts as well as collection of a validation data set. A meeting handout provides more detailed information on the experiments.

In addition to cases 1-9, three further presentations were made under this point of the agenda. Mr Hassanizadeh informed on RIVM experiments related to brine transport. Mr. Neuman gave a talk on "The Oracle Experience with fractured rock hydrology" and Mr. Hufschmied discussed synthetic experiments as a possible INTRAVAL effort.

Mr. Hassanizadeh informed on an ongoing experimental programme at RIVM to investigate the validity of the classical equations for variable density flow and mass transport at high salt concentrations. Results from the experiments will be made available when they are completed. This may be in time for a possible inclusion in Part 2 of INTRAVAL.

Mr. Neuman's talk discussed experiences from measurements in fractured granitic rocks at a test site near Oracle, Arizona. On the basis of these experiences Mr. Neuman discussed a stochastic continuum representation for the flow characteristics of such rocks as an alternative to the porous medium and the discrete fracture network approaches. The stochastic continuum approach uses hydraulic test data at scales consistent with available measurement technology.

Mr. Hufschmied discussed the role of sythetic experiments in the validation process and proposed that a sythetic experiment should be included in INTRAVAL. The different steps involved in such an exercise have been described by Mr. Hufschmied in the INTRAVAL ad-hoc group (SKI 87:4, page 19).

The participants were given brief documentation of the proposed cases and copies of the presentations.

9. DECISIONS ON TEST CASES AND TIME SCHEDULE.

In accordance with the INTRAVAL intentions the test cases that had been proposed represented a wide spread of experiments from laboratory to field scale including natural analogue studies. For several test cases the INTRAVAL Group had been invited to interact closely with the experimental programmes.

The meeting participants were asked to give preliminary indications on interest to participate actively in the INTRAVAL work on each case. It was found that there was enough interest in all nine proposed test cases to make them meaningful for the INTRAVAL project. The Coordinating Group decided to adopt all these cases as INTRAVAL test cases. As indicated in the project proposal the cases are divided into Part 1 cases and Part 2 cases.

The Coordinating Group also decided to appoint a Pilot Group leader for each test case. The Pilot Groups are resposible for the preparation of the test cases in cooperation with the Project Secretariat and for the the maintenance of a direct contact surface between INTRAVAL and the included experiments. The nine test cases are given in Appendix 7 with their Pilot Group leaders.

Furthermore, the Group adopted a time schedule for the preparation of test case descriptions and a guide to the format of these descriptions (see Appendix 8). According to this schedule a first draft of the Part 1 descriptions will be distributed to the Project Teams at the end of January, 1988. Results of the first modelling attempts for the Part 1 test cases and the descriptions of the Part 2 test cases can then be discussed at the next INTRAVAL meeting.

In the project proposal it was foreseen that additional test cases, especially related to salt and unsaturated media, should be included in the INTRAVAL project. This issue was discussed by the Coordinating Group and it was found that work should start to develop such cases. For this purpose two working groups were set up. The first working group will develop a test case specifically related to radioactive waste repositories in salt formations. The working group leader is Mr. Glasbergen. A second working group was decided for the development of a test case related to the unsaturated zone. Mr. Nicholson was appointed leader for this group.

The proposal by Mr. Hufschmied for a synthetic experiment to be included in INTRAVAL was followed up by a decision to adopt a working group with the task to formulate a test case description to be considered at the next Coordinating Group meeting. Mr. Hufschmied was appointed to be the group leader. Appendix 9 gives a summary of working groups with their leaders that were appointed at the meeting.

10. FURTHER ISSUES

The validation of geosphere models to be used in performance assessments is an extremely important subject for the disposal of radioactive waste (especially high-level). Validation is, however, not a straight-forward task. As emphasised by Mr. Neuman one must recognise that validation is an integral part of the scientific process involving theoretical work (model development) as well as experiments. In the context of radioactive waste disposal the aim of this work is to increase the understanding of relevant processes in order to achieve models with sufficient confidence for the performance assessment. With this purpose in mind the INTRAVAL project will use information from laboratory experiments, field experiments and natural analogues. The project will also interact with various experimental programmes.

Due to the complexity of the validation process and the INTRAVAL technical structure it was felt by the Group that there is a need for specific efforts to integrate and focus the project. Mr. Eisenberg proposed that a working group for development of a strategy for the systematic application of experiences and knowledge gained from the various INTRAVAL test cases should be formed. Mr. Nicholson and Mr. Cole supported the proposal. It was decided to set up a working group with Mr. Nicholson as group leader. The function of the group will be to insure that the various experiments used in INTRAVAL with their different spatial and temporal scales link together to address important aspects of validation of geosphere models.

11. DECISIONS ON FUTURE MEETINGS

The second Coordinating Group meeting and the first INTRAVAL workshop was tentatively decided to be held in Barcelona, Spain, during the week April 25-29, 1988. Ms Bajos promised to investigate this possibility and to inform the Secretariat on the issue.

12. INFORMATION MATTERS

At suitable time intervals the Secretariat will produce Progress Reports for the project. The format and level of detail of the Progress Reports was discussed. The Group found that the HYDROCOIN Progress Reports would be a good model for the INTRAVAL Progress Reports in this respect.

The possibility of producing an OECD/NEA broschure on INTRAVAL was also discussed. The preparation of such a broschure was found to be a good idea for a somewhat later stage of the project.

It was also said that the INTRAVAL Project Secretariat as well as other participants should take the opportunity to inform on the project in different fora. The Group found that matters regarding information on the project will be an important issue also for future meetings.

13. CONCLUDING REMARKS

The first INTRAVAL Coordinating Group meeting was concluded by the Chairman who thanked all the participants for a successful meeting and a promising start of the project.

A summary of abbreviations for INTRAVAL Parties and Project Teams is given in Appendix 10

LIST OF APPENDICES

INTRAVAL AGREEMENT , 1987-10-07
Approved 1988-04-29

Considering the importance of a safe final disposal of high-level radioactive waste;

taking account of the need for having an adequate physical knowledge of a proposed repository system for nuclear waste disposal;

giving attention to the necessity of obtaining suitable tools for the evaluation of the safety of repository sites;

regarding mathematical models describing the nuclide transport as valuable instruments in making such evaluation;

assuming that the safety authorities will pay great attention to the application of these models in the licensing procedure;

concluding that validation of the mathematical models used in performance assessment of repositories is of primary concern for building up confidence among the public and the authorities in the application of this methodology for safety evaluation purposes;

the organisations listed in article 1 have agreed to form a study group for investigating various techniques for the validation of mathematical models describing the transport of radioactive nuclides in geologic media.

1. PARTIES

The agreement is concluded between the following organisations, called the Parties:

ANDRA (France), AECL (Canada), CEA/IPSN (France), ENRESA (Spain), GRS (Federal Republic of Germany), GSF (Federal Republic of Germany), HSK (Switzerland), JAERI (Japan), NAGRA (Switzerland), NIREX (United Kingdom), NRPB (United Kingdom), PNC (Japan), RIVM (The Netherlands, confirmed 1987-11-13), SKB (Sweden), SKI (Sweden), TVO (Finland), U.K. DoE (United Kingdom), U.S. DOE (United States), U.S. NRC (United States)

2. ADDITIONAL MEMBERS

The Coordinating Group may decide to co-opt further members to the Study, taking into account the fact that for the Study to be successfully accomplished the number of active participants has to be limited. Such additional members shall have the same rights and responsibilities as the original Parties.

3. OBJECTIVES

The purpose of the project is to increase the understanding how various geophysical, geohydrological and geochemical phenomena of importance for the transport of radionuclides from a repository to the biosphere can be properly described by mathematical models and how models developed for this purpose can adequately simulate the nuclide transport during short as well as very long time periods.

The Study comprises:

- testing the validity of different geosphere performance assessment models using data from laboratory experiments, field experiments and natural analogues;
- effecting interaction between model developers and experimentalists in order to enhance the validation process.

4. ORGANISATION

4.1 Coordinating Group

The Study is directed by a Coordinating Group. Each Party appoints one member to the Group. The member from the Managing Participant acts as chairman. Each Party can decide to nominate a deputy for the appointed member to represent the Party at any of the Group meetings.

The Group appoints a vice chairman among its members. Secretary is provided by the project secretariat. The principal investigator participates in the meetings of the Coordinating Group. Additional representatives of the secretariat may take part in the Group meetings. The chairman, the vice chairman and the secretary will decide if non-members can attend the meetings of the Group as observers.

The tasks of the Coordinating Group are:

- to decide on the technical content, planning and time schedule of the Study;
- to give general directives for the work of the Project Teams;
- to select the cases for the Study;
- to decide on the organisation of workshops;
- to review and coordinate the results and the reports of the Project Teams;
- to take decisions on the final project reports;
- to appoint pilot groups according to needs;
- to decide on any other matter that the Group wants to take up or is referred to the Group by any of the Parties or Project Teams.

4.2 Managing Participant, Project Secretariat and Principal Investigator

The Swedish Nuclear Power Inspectorate will function as Managing Participant. The Managing Participant will set up a project secretariat in cooperation with the U.K. Department of the Environment and the OECD/NEA. Kemakta Consultants Co. will for the Study and within the project secretariat act as Principal Investigator.

The tasks of the secretariat are:

- to give administrative and technical assistance to the Coordinating Group for the fulfilment of the tasks of the Group;
- to organise meetings of the Coordinating Group and to arrange workshops;
- to compile and analyse progress results with the assistance of the Project Teams;
- to produce and distribute progress reports;
- to give administrative and technical advice to the Project Teams;
- to coordinate the preparation of final reports.

4.3 Project Teams and Workshops

Project Teams are organised by the Parties. Each project team has a head who is responsible for the execution of the tasks assigned to the team.

The tasks of the Project Teams are:

- to perform the calculations decided by the Coordinating Group and formulated by the project secretariat on the basis of discussions in workshops;
- to appoint representatives to workshops;
- to report results to the Managing Participant for distribution to the Coordinating Group;
- to propose changes in the work assigned to them if necessary;
- to assist the project secretariat in the analysis of results.

5. BUDGET

Each Party covers the costs for its participation in the Study including representation in the Coordinating Group and workshops and any other meetings necessary for the Study. Each Party covers the costs for its own Project Team or Teams including computer costs and any travelling expenses.

The costs for the Principal Investigator and the administrative efforts in the Project Secretariat are covered by the Swedish Nuclear Power Inspectorate.

6. FINALISATION OF THE STUDY

The Study is scheduled to last for three years with an optional three year period extension. It is terminated when final reports are distributed to the Parties. The Coordinating Group shall approve final reports. An extension for a second three year period has to be confirmed in writing by the Parties.

7. USE OF RESULTS

The final reports should be made publicly available.The Managing Participant and the Parties take no responsibility for the use of the results outside the framework of the Study or outside their own organisations.

8. PREMATURE TERMINATION OF THE STUDY

If the Study has to be terminated prematurely due to unforeseen circumstances, the Coordinating Group has to reach decision on the use of the results already achieved.

Stockholm, 1987-10-07

MEETING MINUTES

SPECIAL WORKSHOP ON
UNSATURATED ZONE INTRAVAL TEST CASES
July 19 - 20, 1988, WASHINGTON, D.C.

A special workshop on the unsaturated zone INTRAVAL test cases was convened at the U.S. Nuclear Regulatory Commission's (US NRC) headquarters in Washington, D.C. The workshop was co-sponsored by the U.S. Department of Energy (US DOE). The purpose of the workshop was to closely examine the field experimental and modeling aspects of the INTRAVAL test cases dealing with unsaturated media. These detailed presentations provided data and modeling approaches to the cognizant INTRAVAL Project Teams in order to enable them to simulate the test case problems prior to the 2nd INTRAVAL Workshop (to be held in Tucson, Arizona, November 14-18, 1988.)

The agenda (see Enclosure 1) was formulated to allow one full day to discuss each test case (i.e., Las Cruces Trench, Apache Leap Tuff Site, and G-Tunnel Experiments at the Nevada Test Site). The workshop attendees (see Enclosure 2) represented the U.S. DOE and U.S. NRC INTRAVAL Project Teams, and State of Nevada representative. Also in attendance were NRC contractors (i.e., MIT, NMSU, PNL, SNL, and University of Arizona), and various interested U.S. Governmental Agencies (i.e., EPA and USGS).

Las Cruces Trench Study

1. Dr. Peter Wierenga, New Mexico State University, discussed the:

   (a) field site and activities related to the trench experiments;
   (b) initial studies including the infiltration, redistribution and drainage tests at the trench and supporting laboratory and field tracer studies using tritium and non-reactive conservative tracers;
   (c) the available laboratory, lysimeter and field data (e.g., saturated hydraulic conductivity, moisture content, matric potential and concentration profiles); and
   (d) detailed wetting front profiles and tracer breakthrough curves for the first field experiment.

2. Approaches to analyzing the first field experiment which had a continuous infiltration rate of 1.78 cm/day were discussed. Details of a second planned field experiment (which began on August 7, 1988) which will have a transient low-rate infiltration rate was also discussed.

3. Dr. Glendon Gee, Pacific Northwest Laboratory (PNL), reviewed the INTRAVAL Project Status Report for the Las Cruces Trench Study (i.e.,INTRAVAL (88)5, Appendix 3:1) and discussed available documentation. It was observed by the attendees that the report needed to be expanded to incorporate discussion of deterministic modeling aspects.

4. Dr. Gee discussed model simulations of the first trench experiment using the deterministic UNSAT2 code. Model inputs were obtained from water retention testing of cores collected during the trench excavation and from hydraulic conductivity obtained from inplace testing using the Guelph

permeameter. The PNL code simulation work suggested that UNSAT2 may not be the most efficient code to use since it required tremendous computer time (i.e., CPU time approaching real time). This was particularly true when cores simulated initially dry soil conditions.

Lessons learned from the PNL simulation studies indicated that future modeling will be enhanced only with improved numerical techniques that reduce computer times, particularly for problems where the soil is initially very dry, as is the case in most arid sites (e.g., Texas, New Mexico, Nevada and California).

5. Dr. Lynn Gelhar, MIT, outlined his stochastic theory for unsaturated flow and transport that is being tested in the field studies. Dr. Gelhar discussed the relationship between the theory, and the field and laboratory data needs. He presented modeling results using a stochastic mean flow code. Future modeling will utilize information on the moisture redistribution data for both the first (i.e., continuous uniform infiltration study) and the second (i.e., short term transient infiltration study) experiments. Modifications to the theory and stochastic models to account for tension-dependent anisotropy and vapor phase will be made. The MIT investigators will assist in reviewing the problem formulation that will also incorporate parameter uncertainities.

6. Dr. Dennis McLaughlin, MIT, discussed new approaches to site characterization for unsaturated porous media. He also presented ideas on validation strategies and the relationship between models and theories to be tested.

Apache Leap Tuff Site

1. Dr. Todd Rasmussen, University of Arizona, discussed the geology, hydrology, and geochemistry of the site and environs using colored slides of the site (including aerial photographs), and viewgraphs.

   He presented and reviewed:
   (a) the rationale and mechanics of drilling, instrument emplacement, and hydraulic testing of the nine inclined boreholes;
   (b) hydraulic testing in the laboratory of collected cores from these boreholes provide data on the hydraulic and pneumatic matrix properties at 105 locations at a sampling interval of 3 meters;
   (c) in situ moisture content data using downhole sampling;
   (d) preliminary data sets for the physical and hydraulic properties of the tuff at the Apache Leap site;
   (e) physical data included bulk and grain densities, effective matrix porosity and matrix pore surface area for the matrix along with fracture geometric data including orientation, density and interconnectivity;
   (f) hydraulic data included saturated hydraulic conductivity, both in the field and using core segments;
   (g) characteristic and unsaturated hydraulic conductivity curves;
   (h) calculated flow rates through the rock matrix using observed water contents determined from calibrated neutron counts;
   (i) laboratory estimates of the fluid potential and unsaturated hydraulic conductivity at the measured water content.

2. The test case documentation (i.e., INTRAVAL Project Status Report, INTRAVAL (88)5, Appendix 4:1) was reviewed and discussed. Dr. Rasmussen outlined a tentative simulation problem based upon a large-scale wetting experiment conducted in two sets of boreholes for three months, and the subsequent moisture monitoring in the adjoining and evacuated boreholes.

3. Timothy McCartin, NRC, presented preliminary modeling results of this problem using the SUTRA Code. He indicated that the wetting front caused by an initially saturated borehole did not reach the adjoining boreholes even after 1000 days of simulation.

4. A discussion of the wetting experiment concluded that both the water injection phase as well as the subsequent redistribution should be incorporated into the test case formulation. Paul Davis, SNL, stressed the need to incorporate the unique fracture aspects of this problem into the test case. The fracture data presently being collected by the University of Arizona investigators are planned to be included. A draft database report on the hydraulic and pneumatic properties (to be issued as a NUREG/CR report) was distributed to the attendees. The use of stochastic and fracture network models was discussed as means of modeling the fracture flow component.

G-Tunnel Experiment

1. Dwight Hoxie, USGS, provided an overview of the G-Tunnel experiments.

2. Michael Chornack, USGS described the experimental design and instrumentation. Pairs of boreholes of about 10m in length will be cored into a welded and a nonwelded tuff, one of each pair using air and the other water as drilling fluid. Temperature and moisture content monitoring devices will be installed at selected packed-off intervals to analyze the recovery to ambient conditions within the boreholes.

3. Alan Flint, USGS, described the related laboratory experiments and hydrologic-property measurements to be performed on the core samples. A demonstration of imbibition by partially saturated rock cores collected at the G-Tunnel site was performed by Alan Flint, USGS.

4. Dwight Hoxie presented ideas on how to model the experiment and suggested approaches to compare the field data to the simulation results.

   Specifically, the three modeling scenarios identified were;
   (a) small-scale modeling of laboratory imbibition and moisture-release experiments,
   (b) dynamic modeling of the effects of borehole drilling as drilling proceeds, and
   (c) prediction of long-term borehole recovery.

   He indicated that the test case problem is still in the formative stage. The field work and experient are expected to begin this summer while data should be available by the November INTRAVAL Workshop.

Status of Test Cases and Resolution of Outstanding Issues

At the conclusion of the workshop, the status of each test case and resolution of outstanding issues (see Enclosure 3) were reviewed and discussed. An informal survey of interest in modeling the three test cases made were:

(1) Las Cruces Trench Study - NRC, PNL (NRC and DOE contractors), SNL, and MIT;

(2) Apache Leap Tuff Site - U. of Arizona, PNL (DOE), NRC, SNL, and the USGS;

(3) G-Tunnel Experiments - USGS, PNL (DOE) and NRC.

It is anticipated that presentations on both modeling of unsaturated flow and discussion of transport studies will be made at the 2nd INTRAVAL Workshop for the Las Cruces Trench and Apache Leap Tuff site test cases. The G-Tunnel test case is still under development and a presentation on the field work is foreseen.

RESOLUTION OF WORK ITEMS NEEDED FOR THE
INTRAVAL UNSATURATED ZONE TEST CASES FOR THE

2ND INTRAVAL WORKSHOP

NOV. 14-18, 1988

1. LAS CRUCES TRENCH (Pilot Team - NRC and contractors)

   Revise Test Case Description
   Submit a Data Report
   Formulate a Detailed Modeling Problem
   Provide Performance Measures for Modeling Comparisons
   Initiate 2nd Experiment (Transient Transport Conditions)
   Deterministic Modeling Presentation - PNL
   Stochastic Modeling Presentation - MIT

2. APACHE LEAP TUFF SITE (Pilot Team - NRC and contractors)

   Revise Test Case Description
   Revise Draft Data Report
   Reformulate Modeling Problem (Injection/Redistribution Conditions)
   Provide Performance Measures for Modeling Comparisons
   Modeling of Redistribution Conditions - NRC staff

3. G-TUNNEL EXPERIMENTS(S) (Pilot Team - USGS)

   (Goals for 2nd INTRAVAL Workshop):

   a. Borehole drilling and instrumentation will be completed
   b. Monitoring will be in progress
   c. Laboratory data will be available
   d. A description of the borehole emplacement will be available.
   e. Define those performance measures that will be appropriate for the test case
   f. Provide discussion of modeling scales and dynamics
      (1). Laboratory matrix imibition and moisture release curves
         (a) Laboratory measured psi(Sw) and K_p(Sw)
         (b) Calibrate matrix models at core-size scales
      (2). Dynamic modeling of borehole emplacement
      (3). Dynamic modeling of borehole recovery following instrument emplacement to predict time-dependent values of capillary pressure, temperature, and air pressure.

****

INTRAVAL WORKSHOP ON UNSATURATED ZONE TEST CASES

July 19-21, 1988

ROOM 013 NICHOLSON LANE BUILDING (July 19)
5650 NICHOLSON LANE, ROCKVILLE, MD

ROOM 2F-17 WHITE FLINT BUILDING (July 20-21)
11555 ROCKVILLE PIKE, ROCKVILLE, MD

AGENDA

Tuesday, July 19, 1988, Room 013 Nicholson Lane Building

8:15 a.m. Overview of INTRAVAL Workshop Objectives and Schedule
Thomas J. Nicholson, US NRC

8:30 a.m. Review of Experimental Design and Databases for Las Cruces Trench
Peter Wierenga, New Mexico State University

10:00 a.m. BREAK

10:15 a.m. Discussion of Las Cruces Trench Documentation and Planned Experiments
Glendon Gee, Pacific Northwest Laboratory

12:00 LUNCH

1:15 p.m. Discussion of Deterministic Modeling Experiences, Assumptions and Performance Measures
G. Gee, PNL

2:45 p.m. BREAK

3:00 p.m. Discussion of Stochastic Theory and Modeling Experiences
Lynn Gelhar, MIT

4:00 p.m. Model Validation Issues and Data Requirements
Dennis McLaughlin, MIT

5:00 p.m. ADJOURN

****

INTRAVAL WORKSHOP AGENDA (CONTINUED PAGE 2)

****

Wednesday, July 20, 1988, Room 2F-17, White Flint Building

8:30 a.m. Opening Remarks by Session Moderator — Charles Cole, PNL

8:45 a.m. Review of Experimental Design and Databases for Apache Leap Tuff Site
Todd C. Rasmussen, Univeristy of Arizona

10:00 a.m. BREAK

10:15 a.m. Discussion of Apache Leap Tuff Documentation and Planned Experiments
T. Rasmussen, UA

12:00 LUNCH

1:15 p.m. Proposed Modeling Problems for Apache Leap Tuff (1 & 2-Dimesional)
T. Rasmussen, UA

3:00 p.m. BREAK

3:15 p.m. Discussion of Modeling Set-up, Assumptions, and Performance Measures
T. Rasmussen, UA

4:15 p.m. NRC Staff 2-Dimensional Simulations of Moisture Movement from a Borehole — T. McCartin, US NRC

5:00 p.m. ADJOURN

****

Thursday, July 21, 1988, Room 2F-17 White Flint Building

8:30 a.m. Opening Remarks by Session Moderator — Norman Eisenberg, DOE

8:45 a.m. Overview of G-Tunnel Experiment at Nevada Test Site
Dwight Hoxie, USGS

9:00 a.m. Design of the G-Tunnel Experiment — Michael Chornak, USGS

10:00 a.m. BREAK

10:15 a.m. Laboratory Experiments and Testing for the G-Tunnel Experiment
Alan Flint, USGS

11:30 a.m. LUNCH

12:30 p.m. Demonstration of the Laboratory Techniques and Tests
Alan Flint, USGS

1:30 p.m. Modeling of G-Tunnel Experiment — D. Hoxie, USGS

2:30 p.m. Discussions and Plans for 2nd INTRAVAL Workshop

3:00 p.m. ADJOURN

****

INTRAVAL WORKSHOP ON UNSATURATED ZONE TEST CASES

JULY 19, 1988 LAS CRUCES TRENCH

ATTENDEES

NAME	ORGANIZATION	TELEPHONE
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Mel Silberberg	USNRC/Waste Mgt. Branch/RES	(FTS) 492-3810
George Lear	NRC/NMSS	(FTS) 492-3347
John Bradbury	NRC/HLTR	(FTS) 846-1978
David Updegraff	GRAM, Inc./SNLA	(FTS) 846-1978
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Dwight T. Hoxie	U.S. Geological Survey	(FTS) 776-5019
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July 21, 1988 G-Tunnel Experiments(s)

ATTENDEES

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July 21, 1988 (Continued)

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APPENDIX 2 INTRAVAL (88)10

Notes from the INTRAVAL Workshop on

<u>Salt-Related Test Cases</u>

Bilthoven, The Netherlands

19-20 September 1988

S.Majid Hassanizadeh
National Institute of Public Health
and Environmental Protection
P.O.Box 1
3720 BA BILTHOVEN
The Netherlands

Background

At the first INTRAVAL Coordinating Group meeting in Stockholm, 7-9 October 1987, a working group was appointed to study the development of test cases specifically related to the problem of transport and flow in situations relevant for disposal in rock-salt formations.

A preliminary meeting between German and Dutch teams was held on 31 March 1988 in Hannover. General ideas for formulation of three test cases based on laboratory experiments, pumping tests, and the natural geohydrological system of the Gorleben Channel were put forward and it was decided to propose the ideas to the first INTRAVAL Workshop in Barcelona, 25-29 April 1988. In Barcelona, it was decided that the Salt Working Group may go ahead with formulation of the three test cases and propose them to the INTRAVAL meeting in November 1988. At the invitation of Peter Glasbergen, chairman of the Salt Working Group, representatives of modelling teams from BGR, PTB, GSF and GRS of the Federal Republic of Germany, ANDRA and Ecoles des Mines of France, University of Catalonia of Spain and RIVM of the Netherlands met in Bilthoven on 19-20 September 1988. A summary of the presentations and discussions is given here.

Notes from the Workshop

1. The participants were welcomed by ir.N.D. van Egmond, Director of Soil and Water Research of RIVM. He stressed the importance of validation exercises for increasing our confidence in models.
2. Peter Glasbergen opened the meeting and gave a summary of the activities of the Salt Working Group (see **Background**). The purpose of the meeting was outlined as "to go through available data and decide how they can form the basis for a test case description".
3. Björn Lindbom gave an overview of the time schedule for INTRAVAL and indicated that the possibility of extending the study for a second 3-year period allows for test cases which will not be ready until next year for inclusion in INTRAVAL. He requested the pilot group to provide a time schedule for submital of test case descriptions and preparing background data. He asked the participants to indicate their interest in and discuss the validation aspects of test cases.

4. Klaus Schelkes presented samples of the large amount of data available on the Gorleben site. The Gorleben salt dome is about 5 km wide and its top lies about 300 m below ground level. It is overlied by a cap rock, clay layers (in most places), two main aquifers separated by clay layers and many intermediate clay lenses. Typical for this location is an erosion channel filled with sands which has locally removed the caprock and is in contact with salt. There is a large number of boreholes where hydrological investigations have been carried out. The geology of the area is very well described. There are data on:
   - porosity from geophysical studies,
   - permeability to fresh water from laboratory tests on core samples,
   - permeability/transmissivity and storativity values evaluated from, pumping test data,
   - groundwater level of the upper aquifer
   - values of C^{14} and $\delta^{18}O$
   - logs of electrical conductivity of water in observation wells,
   - temperature measurements in boreholes,
   - hydrographs of wells in upper and lower aquifers,
   - velocity field obtained from direct measurement made with sodium bromide.
5. Klaus Schelkes presented the data on the pumping tests carried out in the aquifers overlying Gorleben salt dome. There are four pumping tests performed:
   - two in the middle of the Gorleben Channel (called Region I): one in the upper aquifer and one in the lower aquifer,
   - one in the area to the north of the Gorleben Channel (Region II), and
   - one in the area to the southwest of the Gorleben Channel (Region III).

   The time span between consequent pumping tests has been about 6 months. All wells were fully penetrating. There are flowmeter measurements in the pumping wells and thus the distribution of flow along the well screen is known. Drawdown is monitored in all observation wells and logs of electrical conductivity of water are taken.
6. Klaus Schelkes gave an overview of the natural hydrological system in the Gorleben Channel. The idea is to describe this system using mathematical models. The geology of the area is very well known and

boundaries of the channel are well described. However, boundary conditions are not known. Two difficult boundaries are identified: an inflow area in the west where the Gorleben Channel branches and an outflow area in the east where the Gorleben Channel crosses the border into East Germany. It is not known whether the system is in a steady state. Also, it is very difficult to define an initial condition for the system in the far past. Piezometric heads and water mass density distribution is known at observation wells. Porosity may be estimated using geophysical logs.

7. Participants visited the laboratory where the brine transport experiments of RIVM is carried out. Majid Hassanizadeh explained the experimental set-up and the way measurements are carried out.
8. Majid Hassanizadeh presented the test case based on the brine transport laboratory experiments. An overview of the available data was given and the way data are processed was explained. Both one- and two dimensional experiments are possible. Simulation of the experiments can also be performed both in one and two dimensions. A two-dimensional simulation probably allows for a better specification of boundary conditions.
9. Peter Glasbergen briefly explained about the brine migration experiment carried out by the University of California at Berkeley which is proposed to be considered as an INTRAVAL test case. General opinion was that this problem is very interesting and indeed a test case on brine migration in salt formations is lacking in INTRAVAL. However, the models presently being used by INTRAVAL participants are not suitable for modelling near-field processes within the salt formations. Therefore, it was decided to recommand to the INTRAVAL Coordinating Group to invite the Berkeley team to the second INTRAVAL Workshop in Tucson to present the test case. A decision on this case will be then made.
10. On the second day of the Workshop, the three test cases were discussed and decisions, as described below, were made.
11. The **brine transport experiment** forms a very good basis for a test case.
    - The test case description prepared by the RIVM-team is accepted.
    - There is interest from German and French organizations and probably from the University of Catalonia for tackling this case.

- There is interest in experiments on nuclide transport superimposed on brine transport. However the RIVM - team does not have a possibility for doing such experiments in the near future.
- The first set of data will be sent to SKI in November 1988.

12. The **Gorleben pumping tests** were discussed in more detail. There is support for including these as a test case. A decision about the pumping test on which to base the test case could not be made. The pilot group was asked to review all the available data in detail and come up with a proposal. Then a decision will be made in a meeting between German and Dutch participants scheduled for 13 October 1988. The first draft of the test case description will be ready in November 1988.
13. There was much discussion about the relevance of the **Gorleben Channel** case to validation exercises. The value of this case would be in obtaining experience in using models to understand a complicated situation, choose appropriate initial and boundary conditions and identify various processes involved. To start with, the extent of the modelling area has to be determined. It was decided that the pilot group should prepare a "working program" and present that in Tucson. Then a test case description has to be prepared and presented before the INTRAVAL meeting in June 1989. Data sets will be made available in 1989.
14. A **summary** of the test cases and tentative time schedules is given in the following table:

Brine transport (Lab.Experiment)	Pumping Tests (Gorleben Site)	Gorleben Channel
Pilot Group: S.Majid Hassanizadeh T.Leijnse	Pilot Group Leader: Klaus Schelkes	Pilot Group Leader: Klaus Schelkes
First Data Set in November 1988	Draft Test Case in November 1988	Working Program in November 1988
Calculations 1989	Test Case Description and Data sets in May 1989	Test Case Description in May 1989
	Calculations in 1989-1990	Data sets in November 1989 Calculations in 1990

APPENDIX 3

INTRAVAL (88)10

INTRAVAL STUDY

DRAFT TEST CASE DESCRIPTION

Eperimental Study of Brine Transport in Porous Media

S. Majid Hassanizadeh

September 1988

Soil and Groundwater Research Laboratory
National Institute of Public Health and
Environmental Protection (RIVM)
P.O.Box 1
3720 BA BILTHOVEN
The Netherlands

1. INTRODUCTION

A. Pilot Group Identification

The experiments have been carried out in the Geothechnique Laboratory of the Delft University of Technology by S. Majid Hassanizadeh and Toon Leijnse. Ab Mensinga has designed and constructed the electric system for measuring salt concentration and Joop van Leeuwen has provided technical assistance.

B. Experiment Location

The experiment has been moved in April 1988 from Delft and is now set up in the Soil and Groundwater Research Laboratory of RIVM in Bilthoven.

C. Objectives

The main objective of the study is to investigate the validity of transport models based on existing equations of flow and mass transport (i.e. classical Darcy's law and Fickian dispersion law) in high-concentration situations. This is of importance for studies related to the radioactive waste disposal in deep geological formations where high concentrations of dissolved salts are encountered in the host rock itself or in overlying aquifers.

D/E. Theories Tested and Validation Aspects

Basic equations presently employed for modelling salt transport in groundwater are the same as those which are used in other mass transport processes. For a non-deformable porous medium, these equations are:

$$n \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{q}) = 0 \tag{1}$$

$$\mathbf{q} = - \frac{k}{\mu} (\nabla p - \rho \mathbf{g}) \tag{2}$$

$$n\rho \frac{\partial \omega}{\partial t} + \rho \mathbf{q} \cdot \nabla \omega + \nabla \cdot \mathbf{J} = 0 \tag{3}$$

$$\mathbf{J} = - \rho \mathbf{D} \cdot \nabla \omega \tag{4}$$

where n is medium porosity,

ρ is mass density of brine,

q is mean (Darcy) velocity of brine,

k is permeability,

μ is dynamic viscosity of brine,

p is thermodynamic pressure,

g is the gravity vector,

ω is mass fraction of salt,

J is dispersive-diffusive mass flux of salt,

D is dispersion tensor for salt,

∇ is gradient vector, and

t is time.

The main questions are: (a) do equations (2) and (4) properly describe the motion of brine and salt even at high salt concentrations, and if not, (b) what are possible modifications that have to be introduced. An alternative formulation is an extended version of Darcy's and Fick's laws suggested by Hassanizadeh [1986]:

$$q = -\frac{k}{\mu} (\nabla p - \rho g) - D^f \nabla \omega \quad (5)$$

$$J = -\rho D \cdot \nabla \omega - \omega K^s (\nabla p - \rho g) \quad (6)$$

where D^f and K^s are new coefficients associated with the effect of coupling between the motions of brine and salt. Similar equations are employed to describe the chemico-osmotic phenomenon in fine-grained soils. The planned experiments should help to evaluate the significance of these coupling effects.

2. EXPERIMENTAL DESIGN

A. Parameters Measured

Two sets of experiments are carried out. One set is used to measure porosity, permeability and dispersivity of the porous medium. Another set provides data, in the form of salt mass fraction and pressure along the column as a function of time, to be used for validation purposes.

B. Spatial and Temporal Scales

Dimensions of the porous medium are 60 cm (b) by 108 cm (h). The duration of a displacement experiment is from 2 to 5 hours.

C. Experimental Set-up

A schematic of the experimental setup is given in Figure 1. The model is designed in the form of a two-dimensional column with internal dimensions of 60 x 1 x 125 cm. The model is filled with glass beads with diameters between 0.40 and 0.52 mm. Glass beads are rained into the model which is partially filled with water. At the same time the model is vibrated by means of a high-frequency vibrator in order to achieve optimum packing. Before filling the model with water, CO_2 gas is flown through it to remove the air. Fresh water or salt water may be circulated through the model via two different circuits. All inflow and outflow reservoirs can be kept at a constant level. The pressure head along the model is monitored by means of nine sets of manometers as well as three electric pressure transducers. Salt concentration of the fluid in the model is measured at 16 points by means of 16 pairs of electrodes. A computerized data acquisition system makes it possible to record the salt concentration at intervals as short as 5 seconds at all 16 points simultaneously. The fluid temperature is recorded at the same time. Experiments are carried out in a constant-temperature room.

D. Sampling Strategy

Not applicable

E. Independence Between Data Sets

As mentioned above two sets of experiments are performed: one for calibration of the model and another for validation exercises. The two sets are completely independent. They are carried out, of course, on the same porous medium. However, different values of flowrate, resident and displacing salt mass fractions, and pressure differences are employed for different experiments.

F. Biases Inherent in the Design

The material and method used for packing the column is such that a fairly homogeneous porous medium with a very low dispersivity is obtained. The aim has been to enhance the possible effects of high salt concentration on flow and transport. However, this is partly offset by the rather high permeability of the medium and the high rate of flow, compared to field situations.

3. CURRENT STATUS AND EXPERIMENTAL SCHEDULE

A preliminary series of experiments have been completed. The data have been used to perform preliminary simulation attempts. Based on those results, the experiment has been modified in order to exclude unwanted proceses. A new series of experiments has been started. We are in the process of calibrating the model. Displacement experiments to provide a workable set of data for modelling efforts will be performed in October 1988. The first set of data for simulation exercises will be available in November 1988.

4. EXPERIMENTAL RESULTS

A. Raw Data

Raw data would be available from low-concentration experiments for evaluation of porosity and dispersivity and from high-concentration experiments to be used for predictive simulations.

B. Processed Data

The data on measurement of permeability will be processed and values of intrinsic permeability vs. salt mass fraction will be given.

C. Data Storage

The data on permeability will be avaible in tabular form and also on flopy. The data on displacement experiments will be avaible on flopy.

5. PREVIOUS MODELLING

The first series of experiments have been simulated using the METROPOL code developed in RIVM. The code predicts results of the low-concentration experiments very satisfactorily. Results of simulation of high-concentration experiments are also quite acceptable. However, it appears that the boundary conditions employed in these simulations strongly dictate the outcome of calculations. Results of simulation of the new series of experiments currently in progress are expected to yield more definitive conclusions on the ability of METROPOL to model high-concentration brine transport in porous media.

6. EXPECTATIONS FROM INTRAVAL PARTICIPANTS

A. Experimentalists' View

Because the experiments are still going on, input from experimentalists on more appropriate ways of carrying out the experiments, and design of new ones (preferably using the existing set-up without significant modifications) would be very valuable. Pointing out biases in the experiment which will have an effect on the results will be valuable.

B. Modellers' View

In modelling this experiment a number of assumptions have been employed. Also, a choice of initial and boundary conditions has been made. Comments from modellers about validity of these assumptions and ways of improving them will be valuable.

7. INFORMATION EXCHANGE

Experimentalists and modellers to be contacted for further information are:

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RIVM
P.O.Box 1
3720 BA Bilthoven
The Netherlands
Tel. xx31-(30)743368
and xx31-(30)742370
or xx31-(30)749111

8. POSSIBILITIES FOR FUTURE EXPERIMENTS

The experimental set-up is expected to remain operational up to the end of the INTRAVAL study. Therefore, the possibility of future experiments on the existing set-up (perhaps with minor modifications and/or additional instrumentation) exists.

Figure 1. A schematic of the experimental set-up

9. OUTPUT FORMAT

The format in Appendix 8 of the minutes of the first meeting of the INTRAVAL coordinating group will be used.

10. REFERENCES

1. Hassanizadeh, S.M., Derivation of basic equations of mass transport in porous media, 1, Macroscopic balance laws, *Adv. Water Resour.*, **9**, pp.196-206, 1986a.

2. Hassanizadeh, S.M., Derivation of basic equations of mass transport in porous media, 2, Generalized Darcy's and Fick's laws, *Adv. Water Resour.*, **9**, pp.207-222, 1986b.

3. Hassanizadeh, S.M., Modeling species transport by concentrated brine in aggregated porous media, *Transport in Porous Media*, **3**, pp.299-318, 1988.

4. Hassanizadeh, S.M. and Leijnse A., Modeling of brine transport in porous media, *Water Resour. Res.*, **24**, pp.321-330, 1988.

5. Hassanizadeh, S.M., A. Leijnse, W.J. de Vries and W.G. Gray, Experimental study of brine transport in porous media, RIVM Internal Report no. 728717006, RIVM, Bilthoven, The Netherlands, June 1988.

National Institute of Public Health and Environmental Protection
Bilthoven - The Netherlands

Internal report 728717006

Experimental Study of Brine Transport in Porous Media

S.Majid Hassanizadeh, Toon Leijnse,
Wilco J.de Vries and William G.Gray*

June 1988

FIRST DRAFT

*Chairman and professor, Department of Civil Engineering, University of Notre Dame, Notre Dame, Indiana 46556, USA

CONTENTS

EXECUTIVE SUMMARY

Disposal of radioactive waste in geological formations is seriously being considered in a number of countries. An integral part of the safety assessment of nuclear waste disposal is the study of nuclide transport in the geosphere. This requires a profound understanding of the various processes which take place within soil formations; among them groundwater flow. Such studies are commonly made possible by means of mathematical models. Mathematical models serve as a powerful tool for prediction of release of waste into the geosphere, movement of water and contaminants through the geosphere, and calculation of doses of radioactive material reaching the biosphere. Often such predictions need to be made for thousands of years extended into the future. The question then arises how good such predictions are and how much one can trust the results. Answers to such questions are normally sought by the validation of mathematical models. One of the important aspects of validation exercises is the identification of appropriate processes related to the problem under study.

A candidate type of formation for placement of a waste repository is a rock-salt. Groundwater in the aquifers surrounding and overlying salt formations often contains a high concentration of salt. This feature has to be properly accounted for in the studies of nuclide transport in the geosphere. However, in the vast literature on flow and transport in porous media, there is a lack of information on the effect of high salt concentration on groundwater movement and pollutant transport. Very recently, a number of works on theoretical and numerical aspects of modeling brine transport have been reported. Some of these works have concentrated on identification of appropriate processes related to brine transport in soil formation. Obviously, laboratory and field studies are also needed to assist with achieving our goals in model validation.

Based on these considerations, recently a series of laboratory experiments have been designed and carried out in collaboration with the Geotechnique Laboratory of Delft University of Technology.

The purpose of these experiments is twofold: *i)* to investigate some of the relevant processes in brine transport in porous media, and *ii)* to provide sets of data to be used for (partial) validation of transport models.
In particular, the results of the experiments will be used for the validation of the METROPOL model developed in RIVM.

This experimental set-up consists of a column filled with a porous medium and connected to two separate circuits of 'fresh' water and salt water. The column consists of two plexiglass plates spaced 1 cm apart. The column is tightly packed with glass beads of diameter 0.4 to 0.52 mm. This gives a very homogenous medium with permeability about 1.6 x $10^{-6} cm^2$ and porosity 0.38. The dispersivity is estimated to be less than 0.2 mm. There is very little dispersion because the medium is so homogenous. Salt water is injected through nine holes at the bottom and withdrawn through nine holes at the top. Initially a low salt concentration is used which is then displaced with high concentration brine. The salt mass fraction is detected using an array of 16 electrodes installed in five rows. Thus, breakthrough curves are obtained at five different levels in the column.

The experiments have been simulated using the finite element code METROPOL. Calculated and measured breakthrough curves agree very well for low-concentration experiments. For high concentrations, however, some differences are observed. The experiments are still going on and more definite results are expected at the end of 1988.

This report describes the set-up of the experiments, methods and materials used, and data acquisition and analysis. Also, it contains results of preliminary tests and of modeling attempts.

1. INTRODUCTION

Disposal of radioactive waste in geological formations is seriously being considered in a number of countries. An integral part of the safety assessment of nuclear waste disposal is the study of nuclide transport in the geosphere. This requires a profound understanding of the various processes which take place within soil formations; among them groundwater flow. Such studies are commonly made possible by means of mathematical models. Mathematical models serve as a powerful tool for prediction of release of waste into the geosphere, movement of water and contaminants through the geosphere, and calculation of doses of radioactive material reaching the biosphere. Often such predictions need to be made for thousands of years extended into the future. The question then arises how good such predictions are and how much one can trust the results. Answers to such questions are normally sought by the validation of mathematical models. One of the important aspects of validation exercises is the identification of appropriate processes related to the problem under study. (Tsang, 1987)

A candidate type of formation for placement of a waste repository is a rock-salt. Groundwater in the aquifers surrounding and overlying salt formations often contains a high concentration of salt. This feature has to be properly accounted for in the studies of nuclide transport in the geosphere. However, in the vast literature on flow and transport in porous media, there is a lack of information on the effect of high salt concentration on groundwater movement and pollutant transport. Very recently, a number of works on theoretical and numerical aspects of modeling brine transport have been reported. Among these are the works by Leijnse [1985], Lever and Jackson [1985], Hassanizadeh [1986, 1988], Davies [1987], and Hassanizadeh and Leijnse [1988].Some of these works have concentrated on identification of appropriate processes related to brine transport in soil formation. Obviously, laboratory and field studies are also needed to assist with achieving our goals in model validation.

Based on these considerations, recently a series of laboratory experiments have been designed and carried out in collaboration with the Geotechnique Laboratory of Delft University of Technology.

The purpose of these experiments is twofold: *i)* to investigate some of the relevant processes in brine transport in porous media, and *ii)* to provide sets of data to be used for (partial) validation of transport models.
In particular, the results of the experiments will be used for the validation of the METROPOL model developed in RIVM (see Sauter, 1987).

This report describes the set-up of the experiments, methods and materials used, and data acquisition and analysis. Also, it contains results of preliminary tests and of modeling attempts.

2. EXPERIMENTAL APPARATUS AND PROCEDURES (METHODS AND MATERIALS)

2.1 General Description of the Experimental Set-up

The general layout of the experimental set-up is depicted in Figure 1. A sample of soil is placed between two parallel plates which form a two-dimensional vertical column. The plates are made of plexiglass and have a thickness of 12 mm. They are spaced 10 mm apart. Inner dimensions of the column are 60 cm (b) by 125 cm (h). Upper part of the column is open (see Figure 2). There is one row of inlet/outlet holes at the very bottom of the column and one at the top (Figure 3). In principle, vertical flow both in upward and downward directions is possible. There are two separate flow circuits: fresh-water and salt-water. Each circuit consists of a main reservoir, a pump, a constant-level inflow reservoir and a constant-level outflow reservoir. By regulating the 3-way valves, one can let the fresh water or the salt water flow through the column.

2.2 Porous Medium and Methods of Packing

The material used for filling the column is glass beads, with diameters ranging from 0.40 to 0.52 mm. To clean the glass beads, they were bathed in a H_2O_2 solution and heated for about 1 hour. Then they were thoroughly washed with tap water and distilled water.

In preparing the porous medium filling the column, three main criteria were followed.

1) The packing must be stable. That is, as the time passes and under normal conditions, no settlement or other structural changes should happen.
2) The packing must be as uniform as possible. That is, properties such as porosity, permeability, and dispersivity must be almost the same at all points.
3) The dispersivity of the medium must be as low as possible. This allows second order effects to manifest themselves.

These factors are controlled by the material used and by the method of packing. Using a narrow range of glass beads diameter (high uniformity coefficient) minimizes heterogeneities and thereby also helps to attain a low dispersivity.

For packing the column a number of methods were tried out. A brief description of each method is given below.

- A hopper was made with a width equal to that of the column (60 cm). It has a narrow lip which just fits into the column. The hopper was filled with glass beads which then were rained into the column. In one case, there was no water in the column and in another case it was filled with water. In both cases the packing proved to be rather loose. Settling of glass beads was noticed as the walls of the column were being hammered. Obviously, this was not desirable. One could also see signs of layering in the packing.
- In another series of experiments, a vibrator was used to achieve optimum packing. Starting at the bottom of the column, glass beads were introduced into the column by means of a long PVC pipe attached to the end of a funnel. The PVC pipe was moved across the column to get a horizontal filling and it was raised as the column was being filled. At the same time, the whole model was being vibrated at a high frequency by means of a vibrator attached to the underside of the column. Both dry and wet filling procedures were tried, and only the wet method proved to be satisfactory. When dry-packed column was filled with water (from below and upward), at some levels a crack appeared in the glass beads packing. This indicated that the dry packing procedure did not provide an optimum packing. Such a problem did not arise for the wet packing.

Therefore, at last, it was decided that placing the glass beads in the column by means of a PVC pipe, while the column is filled with water, and vibrating at the same time provided the best result. Results obtained later on (variations in porosity and permeability and movement of a saltwater-freshwater front in the model as discussed later) supported this conclusion.

Another problem which needed careful attention was the exclusion of air from the (fluid-filled) column. To achieve this, after having placed the glass beads in a satisfactory manner, the column was drained and carbon dioxide gas was injected into the column from below. This gas being heavier than air would normally displace air up to 100%. This was continued until no air was detected to be coming out of the column at the top. Subsequently, the column was filled with water. The water easily dissolves the carbon dioxide and fills the whole column. Thereafter, during the whole process of electrodes calibration and experiments, the column was kept saturated.

2.3 Flow Regulation and Measurement

The flow rate in the column during an experiment is in principle controlled by two factors:

i) the pressure difference across the column and
ii) the density distribution in the column.

The pressure difference across the column is dictated by both the difference in level between the inflow reservoir and the outflow reservoir and the salt mass fraction (liquid density) at the inflow and outflow. This means that even for fixed levels of the inflow and outflow reservoirs, the pressure difference across (and the flow rate through) the column is not necessarily the same for different experiments, because the salt mass fractions may be different.

The density distribution in the column is dictated by the displacement of the initial fluid in the column by the injected fluid. The salt mass fraction distribution, and hence the density distribution, will change in the course of an experiment. Consequently, the flow rate in the column will also change.

For the low-concentration experiments, we can assume that the liquid density is more or less constant. In that case, the density distribution in the column will not change during the experiment and, with a constant

pressure difference, we may expect a nearly constant flow rate. This was actually observed in all low-concentration experiments. In the high-concentration experiments, however, the density distribution in the column changes significantly and therefore the rate of flow varies in time and at various places inside the column.
Fixed levels of the fluid in the inflow and outflow reservoirs are maintained by an overflow system. With this system, the capacity of the pump feeding the inflow reservoirs does not play a role, as long as it is big enough to supply more water than flows through the column. Also, possible variations in pumping rate will not influence the flow rate in the column. However, it should be remembered that when performing a high-concentration experiment, fixed levels in the inflow and outflow reservoirs do not imply a constant flow rate in the column.

At the bottom of the column, water is injected at nine points, spread evenly over the width of the model and spaced 72 mm center to center. This will introduce a two-dimensional flow, at least close to the bottom of the column. However, the flow regime is expected to become one-dimensional within a reasonable short distance, compared to the length of the column.
The breakthrough curves measured during the experiments performed so far indicate that this is in fact the case. There is very little difference in both the time of arrival and the steepness of the "displacement front" at three electrodes installed at the same z-level. As can be expected, the differences are biggest close to the inflow boundary. Two-dimensional experiments can now be performed by just opening one (or more) of the points instead of all nine.

Water from both the main salt water and the fresh water reservoirs is filtered before entering the pump in order to prevent solid particles from entering the system and clogging the porous medium.

During an experiment, the volumetric flow rate is measured at two points. In the inflow tube, a flow meter is installed. The water flows through a glass tube containing a ball which is raised by the force of the flow to a certain level. Gradings on the glass tube give, after calibration, the volumetric flowrate. Calibration of the flowmeter has been done by the manufacturer for fresh water. For two reasons, the calibration has to be repeated:

i) experiments are performed at high salt concentrations, i.e. high fluid density and increased fluid viscosity, which will influence the flow meter reading.

ii) rather than the volumetric flow rate, the mass flow rate is required for defining a boundary condition at the inflow boundary.

Calibration curves of flow meter readings vs. mass flow rates at different values of the salt mass fraction will be prepared.

Flow rates are also measured at the outflow end of the column. Water flowing from the column is collected in a measuring-glass and the time intervals for every 50 cm^3 is measured. Values obtained this way are time-averaged values instead of instantaneous values obtained with the flowmeter.

2.4 Pressure Measurements

Measurement of pressure of the fluid in the column was performed simply by means of manometers. There are nine sets of manometers at nine different levels along the column (Figure 2). Each set consists of two manometer connections, one at the far left and one at the far right side of the column. If the porous medium is homogeneous, then for a one-dimensional experiment, the two manometers which are at the same level must give the same pressure readings. This proved to be case in almost all situations.

Pressure was determined from the level and the density of water in the manometer tubes. In the beginning, it was thought that when the water in the column has a variable salt concentration, those variations may be directly felt (because of diffusion) in the manometer tubes. In such a case, the level of water in manometers could not be easily related to pressure. However, from diffusion experiments and calculations, it was determined that such a transport is extremely slow and the mass density distribtuion of water in the manometers will not be affected in short term.

2.5 Salt Mass Fraction Measurements

The measurement of salt mass fraction of the solution flowing through the model is achieved by means of electrical techniques. These techniques are based on the fact that the electrical conductivity of a salt solution is a function of the salt mass fraction. Another important factor affecting the conductivity is the temperature. But that effect was, to a large degree, excluded because these experiments were carried out in a constant-temperature environment.

The mass fraction of the solution needed to be determined outside the column (before the inflow and/or after the outflow) and also at points inside the column. Different procedures were employed for these two measurements.

2.5.1 Measurement of salt mass fraction outside the column

An electrical conductivity meter was used for determining the salt mass fraction of the solution flowing into or out of the column. It is known that the electrical conductivity of a solution, keeping other factors constant, increases with salt mass fraction. A set of calibration curves was prepared for the conductivity meter used for these experiments. The calibration procedure is briefly described as follows.

1) A large number of salt solution samples with salt concentration ranging from about 0.5 g/l to 100 g/l were prepared. To prepare a sample, a carefully-weighed batch of dry NaCl was dissolved in 200 ml of distilled water.
2) The samples were covered and left in the room to reach an equilibrium temperature with the environment.
3) The conductivity of each sample was read and recorded.

4) Plots of salt mass fraction vs. electrical conductivity were prepared.
5) The statistical program package GENSTAT was used to fit a curve through the plotted points. It appeared that two quadratic curves fit the data satisfactorily (see Figures 4 and 5).

The calibration curves were employed to determine the salt mass fraction of the solution (entering/or leaving) the column by measuring its conductivity.

2.5.2 Measurement of salt mass fraction inside the column

Measurement of salt mass fraction of the solution inside the column has been realized with the aid of electrodes. There are a total of 16 pairs of electrodes installed at 5 rows in the column (see Figure 3). Each pair of electrodes consists of two electrodes facing each other and built into the plexiglass plates such that they do not protrude into the porous medium. Therefore, measurement of salt mass fraction does not disturb the flow field. A constant-intensity alternating current is supplied to a pair of electrodes and the voltage difference across them is measured. Keeping the current intensity constant, the voltage difference will be a function of a number of factors: the electrode material, distance between the pair of electrodes, the material of the porous medium, the fluid in the porous medium, temperature, and salt concentration of the fluid. In the course of the experiments, all of these factors have been kept constant except the last one. Therefore, the voltage difference directly relates to the salt concentration (or salt mass fraction) of the solution. To obtain such a relationship, each and every pair of electrodes has been calibrated in-situ. The calibration procedure has been as follows:

1) A given salt solution is flowed through the column for about 24 hours until a uniform mass fraction has been established at all points inside the column. This was checked by monitoring the readings from electrodes. When the readings remained constant for a number of hours, it was

assumed that a uniform mass fraction had been reached. This was double-checked by comparing the conductivity of the solution entering and leaving the column.

2) The conductivity of the solution entering the column was recorded and using the calibration curve for the conductivity meter, the salt mass fraction of the solution was determined.
3) The voltage difference across all electrodes, corresponding to the salt mass fraction determined in step 2, was recorded.
4) The salt concentration of the solution flowing through the column was varied and steps (1) to (3) were repeated.
5) The procedure was repeated for a large number of salt mass fractions, and for each pair of electrodes a plot of salt mass fraction vs. voltage difference was prepared.
6) Using the program package GENSTAT, a hyperbolic curve was fitted through the plotted points.

Note that because the electrodes were calibrated in-situ, any possible effects of electrodes on each other's signal would be incorporated in the calibration curves. In total 48 calibration curves were prepared for the electrodes. As an example, the curves for pair of electrodes number 1 are given in Figures 6, 7, and 8.

2.6. Data collection

Data collection during the experiment is taken care of by a computer program written in HP-basic, and running on a HP9826 personal computer. Both the PC and all 16 pairs of electrodes are connected to a HP3497A data acquisition and control unit.

A continuous scan is performed over all channels specified by the user with a cycle time of approximately 1-3 sec., dependent on the number of channels to be scanned. At the start of the program, a reading (in mV) is stored for each of the channels, i.e. each of the electrode pairs. Each new reading is then compared with the latest recorded value. If the difference between the new reading and the latest recorded value is bigger than a prescribed value, the new reading will be stored and becomes the latest recorded value. If not, the new reading will be rejected, unless the elapsed time since the last recorded value is bigger than a prescribed time span. In that case, the new reading will be stored. This data collection system ensures a large number of measurements during the passage of the "displacement" front.

Before the measuring program is started, the following information has to be provided:

i) which channels (i.e. which electrode pairs) must be scanned;
ii) what is the smallest difference between a new reading and the latest recorded value required for the new reading to be stored; this prescribed value (in mV) can be different for each of the channels;
iii) what is the maximum time span between two consecutive readings.

The collected data is stored on a floppy disk. After the experiment, the data is loaded into a VAX 11/750. Computer programs have been developed to read the data, convert the mV to salt mass fractions with the aid of the calibration curves and produce plots of salt mass fraction vs. time or write selective data on files for further processing. The latter will especially be used for the (numerical) evaluation of the experiments.

Apart from the readings from the electrode pairs, the temperature of the injected water is also recorded to check whether any significant temperature change during the experiment occurred.

3. DISPLACEMENT EXPERIMENTS

Up till now, four displacement experiments have been carried out: two at low-concentration and two at high-concentration. In all experiments, the original fluid in the column had a low (approximately 1 g/l with mass fraction ω_0 = 0.001) salt concentration. The measuring range of the electrode pairs (inclusive of the electronics) made it impossible to start with fresh water. In the low-concentration experiments, the resident water in the column was displaced by water containing a slightly higher salt concentration (2 g/l ω_0 = 0.002). This concentration is high enough to measure the breakthrough curves with a high degree of accuracy. Concentration differences, however, are so low that the effect of differences in fluid density can be neglected. The purpose of carrying out the low-concentration experiments was twofold:

i) to provide experimental data to determine the porosity and dispersivity of the porous medium;

ii) to provide experimental data to check the numerical code (METROPOL) used to evaluate the experiments. The data from one low-concentration experiment was used to determine values of porosity and dispersivity, assuming that for these low concentrations both Darcy's law and Fick's law are valid. With the values of porosity and dispersivity, the second experiment is then simulated, partly validating the numerical model.

In the high-concentration experiments, the salt concentration of the displacing fluid was as high as 100 g/l (ω_0 = 0.093). At these high salt concentrations, density differences do have an effect on the displacement process.

Both low-concentration and high-concentration experiments require a number of systematic steps to be taken. First of all, the column is flushed with "fresh" water (salt concentration about 1-2 g/l) for a period of time (usually in the order of one or more days), to ensure a homogeneous salt concentration in the column, i.e. a well-defined known initial condition for the salt concentration. In the meantime, "salt" water is continuously

pumped into the salt water inflow reservoir and flowing back into the big salt water reservoir, partly taking care of a continuous mixing in that reservoir. This circuit up to and including the connecting pipe to the 3-way valve must be completely filled with salt water.
The experiment is now started by initiation the data acquisition program and turning the 3-way valve from fresh water inflow to salt-water inflow. Beside the measurement of the in-situ conductivity and the temperature of the inflowing water (which are recorded automatically), the pressure distribution, the flow rate of the inflowing water and the flow rate at the outflow end are measured as they varied during the experiment.

At the start of the experiment, the pipe connecting the 3-way valve with the column is still filled with fresh water. When salt water starts flowing in, dispersion and mixing will take place in this pipe. As the volume in this pipe is not negligible, the fluid entering the model will show a slowly increasing salt concentration instead of a nearly instantaneous increase.
Consequently, already at the first row of electrodes, the breakthrough curves show a very dispersed form, which is not caused by the porous medium. In the future a steeper front will be introduced in the column by moving the point where the switch is made from fresh water to salt water, very close to the column.

All experiments carried out so far lasted for about 2-3 hours. The flow rates in the column were much larger than normally encountered in the field.

4. EXPERIMENTS FOR DETERMINATION OF MEDIUM PROPERTIES

Properties which need to be measured by means of independent experiments are permeability, porosity and dispersivity of the medium. In the design of the experiment, manometers and electrodes were positioned such that possible variations of these properties in lateral as well as longitudinal directions could be detected. Results of these studies are given below.

4.1. Permeability Measurements

Permeability of the medium is measured by the standard method. That is, constant-density water is pumped through the column at a constant rate, and then the head drop between two points along the column is measured. Using Darcy's law, the permeability can be calculated:

$$k = \frac{\mu Q \Delta L}{\rho g A \Delta h}$$

where
- k is the permeability
- μ is the viscosity
- Q is the (constant) flow rate
- ΔL is the distance between two manometers
- ρ is the density of fluid in the column (and in the manometer pipes)
- g is the gravity
- A is the cross-sectional area of the column, and
- Δh is the head difference between the two manometers.

Because there are nine sets of manometers at nine different levels across the column installed, permeability of the porous medium could be measured at eight consequent reaches along the column, both at the left hand side and at the right hand side. The maximum difference between the permeability of the medium at the left- and right-hand side of the model or at different locations along the model is about 10%. The permeability of the medium to salt water seems to be (almost linearly) dependent on salt mass fraction.

The average permeability of the medium for salt water with a mass fraction of 0.001 (≈ 1 g/l) is about 1.77×10^{-6} cm^2 whereas for salt water with a mass fraction of 0.09 (≈ 96 g/l) the average permeability is about 1.56×10^{-6} cm^2 (see Figure 9). More experiments in this regard are needed.

4.2. Evaluation of Porosity

Porosity of the medium has been evaluated based on the results of low-concentration experiments ($\omega_0 = 0.002$). Breakthrough curves observed by different electrodes provide the possibility to calculate the travel time, t_r, from one electrode to the next one along the column (see e.g. Figure 10). Knowing the distance between the two electrodes, L, the actual (pore) fluid velocity, v, can be calculated from

$$v = L/t_r$$

On the other hand, from the flow rate Q, and the cross sectional area A, the bulk (Darcian) velocity of the fluid, may be calculated from

$$q = Q/A$$

Finally, the porosity is given by

$$n = q/v$$

Using this method, 11 different values for porosity for the 11 reaches between electrodes were estimated. These values showed a maximum difference of about 2%. The average porosity was evaluated to be 0.381.

4.3. Evaluation of Dispersivity

Dispersivity of the medium has been evaluated based on the results of low-concentration experiments. This has been achieved by assigning various values to the dispersivity coefficient, solving the equations numerically, and comparing the calculated breakthrough curves with the observed breakthrough curves. When the two curves (more or less) fitted together, we assumed that the right value of dispersivity has been chosen. In Figures 11, 12, and 13, results of simulation of low-concentration experiments (solid line) are compared with the measured breakthrough curves (small circles) for electrode 10 (channel number 29) for three different values of dispersivity. It is evident that as a lower value of dispersivity is used, a better agreement between measured and calculated curves is obtained. The average value of dispersivity was estimated to be less than 0.2 mm. The very small value of dispersivity observed here is the result of high degree of uniformity of the packing.

5. PRELIMINARY MODELLING ATTEMPTS

A preliminary attempt has been made to simulate the experiments done so far. These simulations have been carried out with METROPOL code. As explained earlier (see. Chapter 4), both the porosity and the dispersivity of the porous medium are estimated from results of low-concentration experiments. Then these values and the previously determined values of the permeability were used to simulate the remaining low-concentration experiment and the two high-concentration experiments.

The numerical simulations were carried out for a one dimensional column, 108 cm long and with a cross sectional area of 1 cm^2. The lenght of the column corresponds with the distance between the first and last row of electrodes. Due to the mixing of salt and fresh water in the pipes connecting the 3-way valve with injection points, it was impossible to use the salt mass fraction of the injected solution as the lower boundary for the model. Basically, no realistic boundary condition in terms of mass entering the model could be defined at this point. Consequently, we had to use the actual values of pressure and salt mass fraction, both measured at the level of the first row of electrodes, as the bottom boundary condition. This is obviously a strong boundary condition because it more or less prescribes the temporal changes in the salt mass fractions in the rest of the model.

To evaluate the difference between measured and calculated breakthrough curves at different points in the model an orthogonal error estimate is employed. Both the measured and calculated mass fraction are plotted in dimensionless, normalized form as a function of dimensionless time. The dimensionless time for each experiment is defined as:

$$\hat{t} = \frac{t}{t_0} \qquad \text{with } t_0 = \frac{\mu_0 L}{K \rho_0 g}$$

where μ_0 is viscosity of the resident solution,
L is the system length = 108 cm,
K is permeability of the porous medium,
ρ_0 is mass density of the resident solution, and
g is acceleration of gravity = 981 cm/s^2

To determine the (orthogonal) error estimate, the normal distance from each and every calculated value of the salt mass fraction to the measured curve is computed. The square root of sum of distances divided by the number of points is calculated as the standard error.
In Table 1, the values of standard errors for three different values of dispersivity are given. From this table and Figures 11-13, it is apparent that a better fit is obtained as the value of dispersivity is reduced. To ensure that the discretization error is minimal, calculations were repeated, this time keeping dispersivity constant (0.2 mm) and reducing the size of grid blocks from 1 mm to 0.5 mm. No appreciable differences in results were observed.

Results of simulation of a high-concentration experiment are shown in Figure 14, 15 and 16, where calculated (solid line) and measured (small circles) breakthrough curves for electrodes 4, 7 and 10, respectively, are given.

6. DISCUSSION AND CONCLUSION

The experimental and measuring techniques reported here appear to be functioning very well and the experiments may be considered as well-controlled. The fact that the packing of glass beads is fairly uniform and homogenous removes uncertainties in the determination of medium properties. Also, the high degree of accuracy with which the salt mass fraction is monitored lends confidence to the measurements. Thus, the experiments provide a useful and reliable tool for partial validation of transport models.

Simulation of the low-concentration experiments with the METROPOL code based on classical formulations of Darcy's and Fick's laws has been done satisfactorily. However, there are some differences, although not large, between monitored and simulated breakthrough curves for high-concentration experiments. Given the fact that METROPOL allows for nonlinear dependence of mass density and viscosity on salt mass fraction, these differences are bound to stem from shortcomings of Darcy's and Fick's laws at high salt concentrations. Results of numerical experiments by Hassanizadeh and Leijnse (1988) indicate that the difference between monitored and calculated breakthrough curves may be eliminated by introducing additional terms in Darcy's and Fick's laws. However, at this point no definitive conclusions may be made. Additional experiments are needed to study situations which are more probable to be encountered in the field. Such experiments should include the following variations:

1) A much smaller rate of flow should be used in the displacement experiment.
2) The highest value of salt mass fraction injected so far has been about 0.09 kg/kg whereas mass fractions up to 0.26 kg/kg have been observed in the field. Thus, a higher salt mass fraction (around 0.20 kg/kg) should be used.
3) The boundary conditions employed in the simulations (pressure and salt mass fraction monitored at the first row of electrodes as a function of time) strongly determine the shape of calculated breakthrough curves. More realistic boundary conditions (preferably specified fluxes of brine and salt) need to be employed.

All of these variations are expected to enhance the deviation of calculated from measured results. That is, the effect of secondary processes in the transport of high salt concentration will become more pronounced.

Presently, the experimental configuration and measuring instruments are being modified to accomodate these variations in the experiments.

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Table 1

" STANDARD ERRORS "

(Orthogonal Error Estimate) For Low-Concentration Experiment

Dispersivity (mm)	Electrode 10
1.0	0.03390
0.5	0.02998
0.2	0.02879

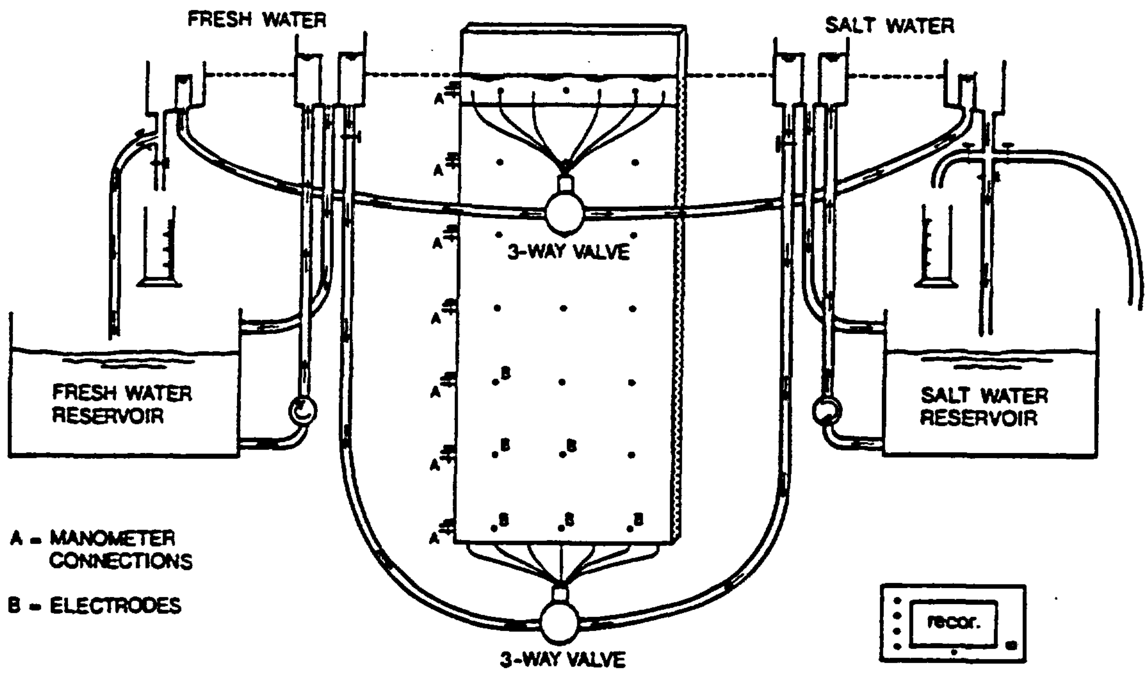


Figure 1. General configuration of the experimental set-up

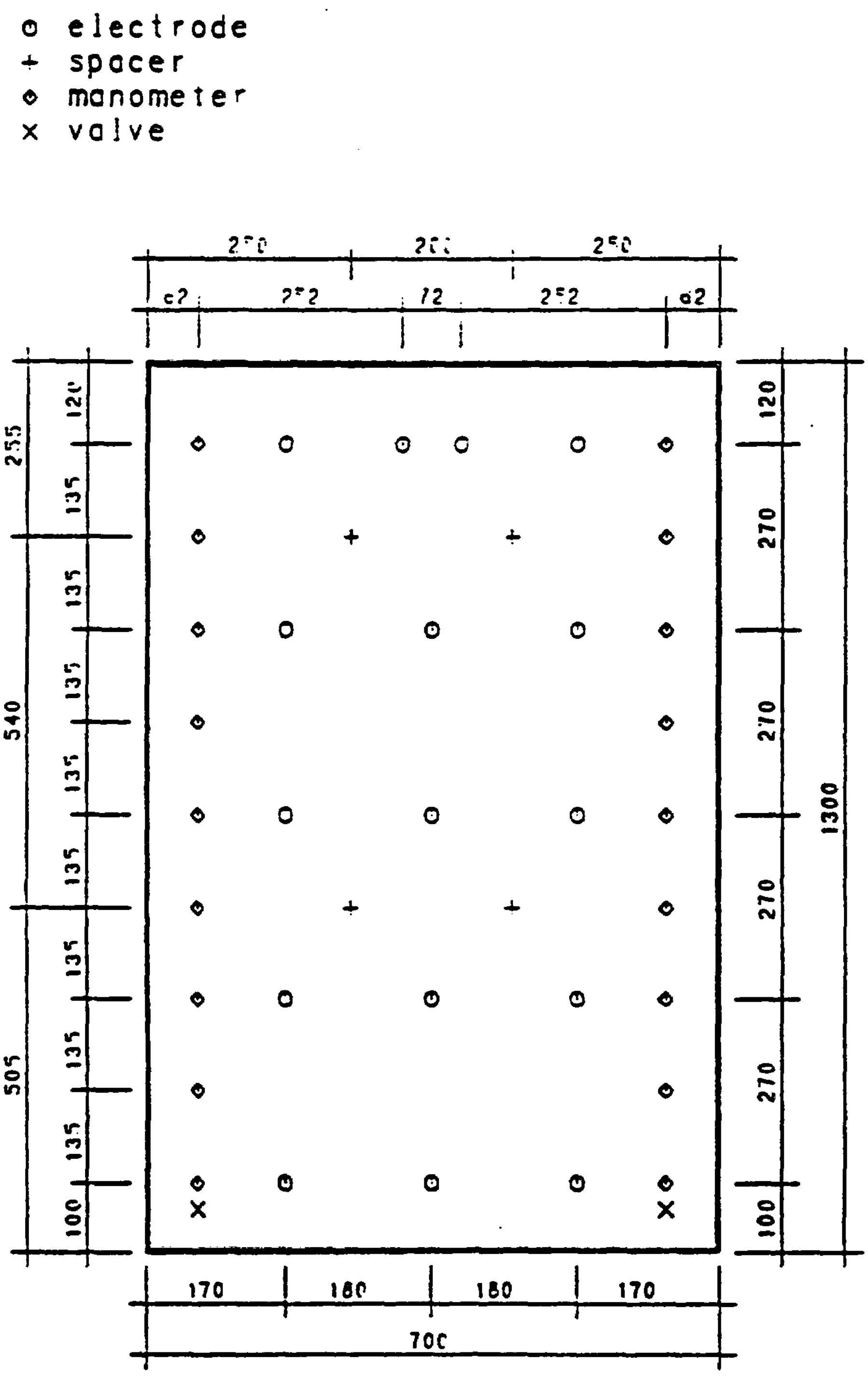


Figure 2. Location of manometers and electrodes on the front side of the column.

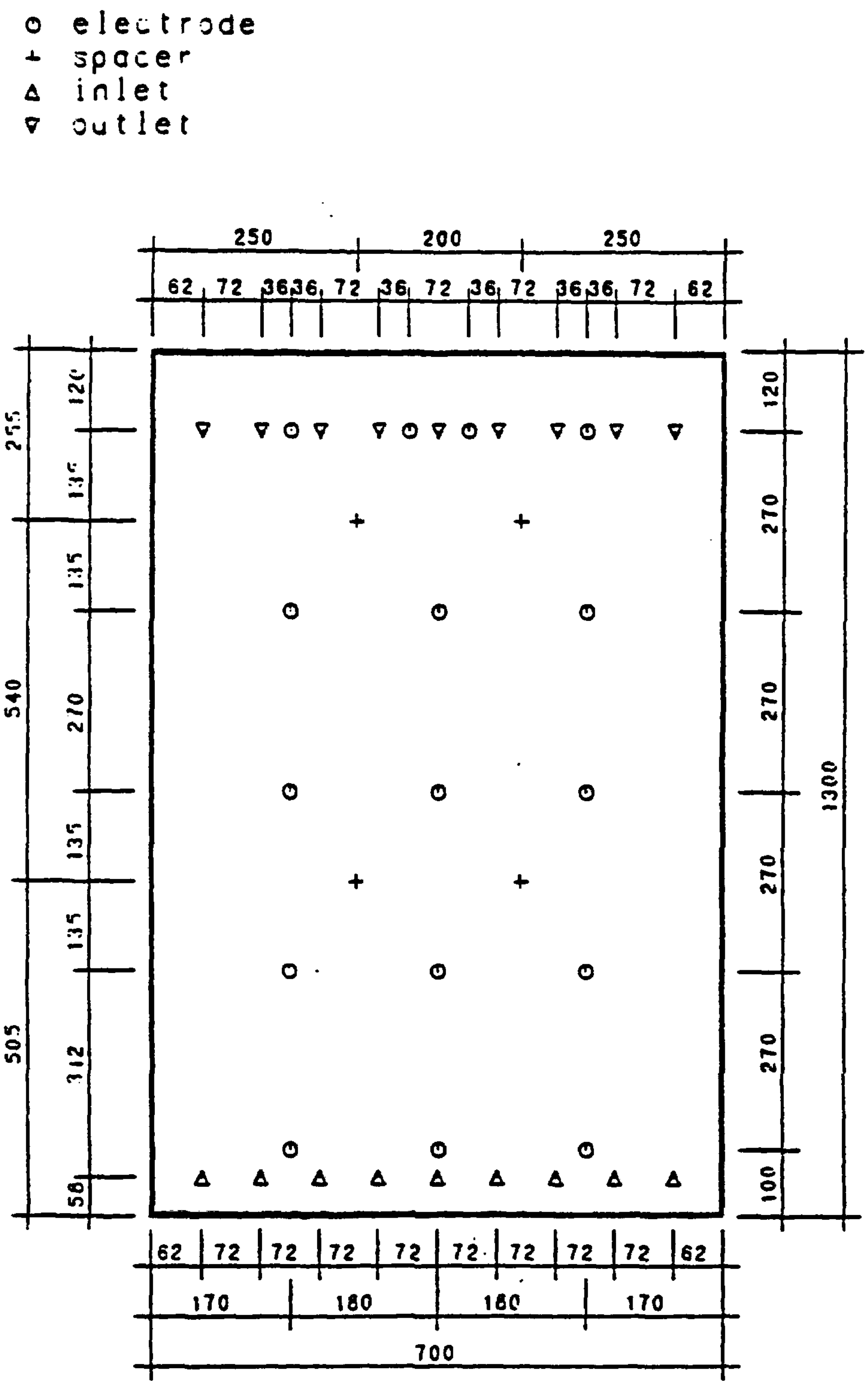


Figure 3. Location of inlet and outlet holes and electrodes on the back side of the column.

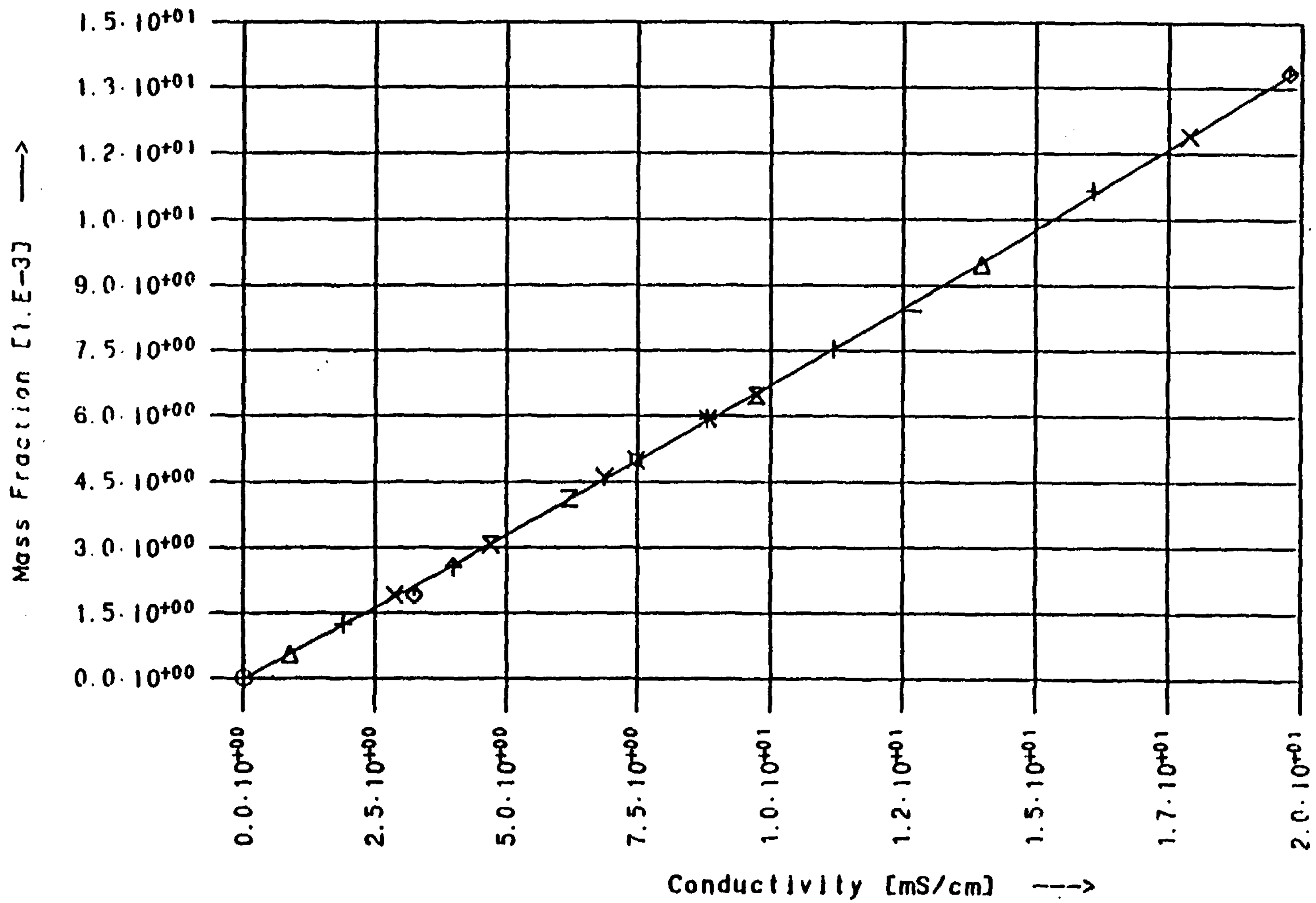


Figure 4. Calibration curve for Conductivity_meter (low ranges)

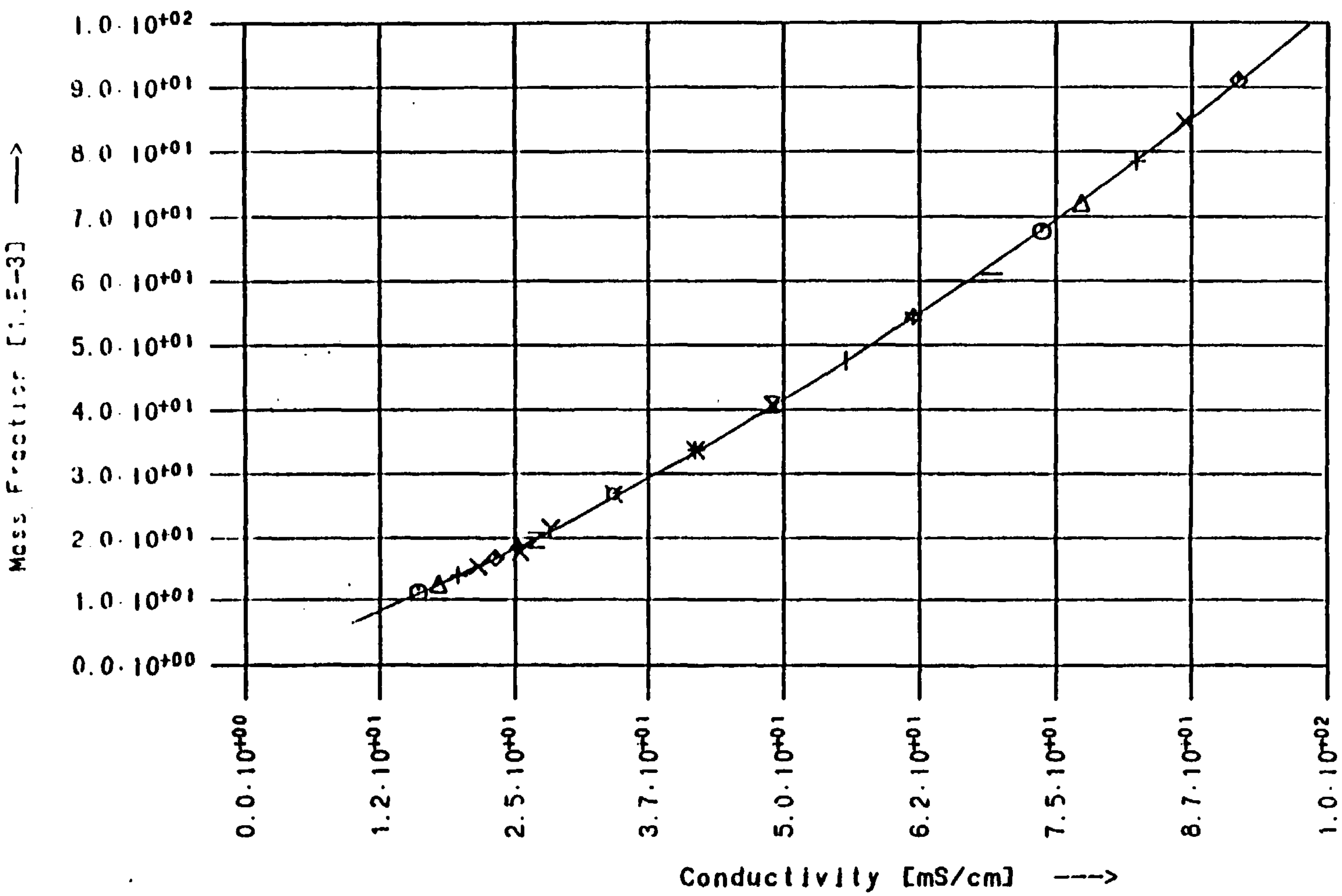


Figure 5. Calibration curve for Conductivity_meter (high ranges)

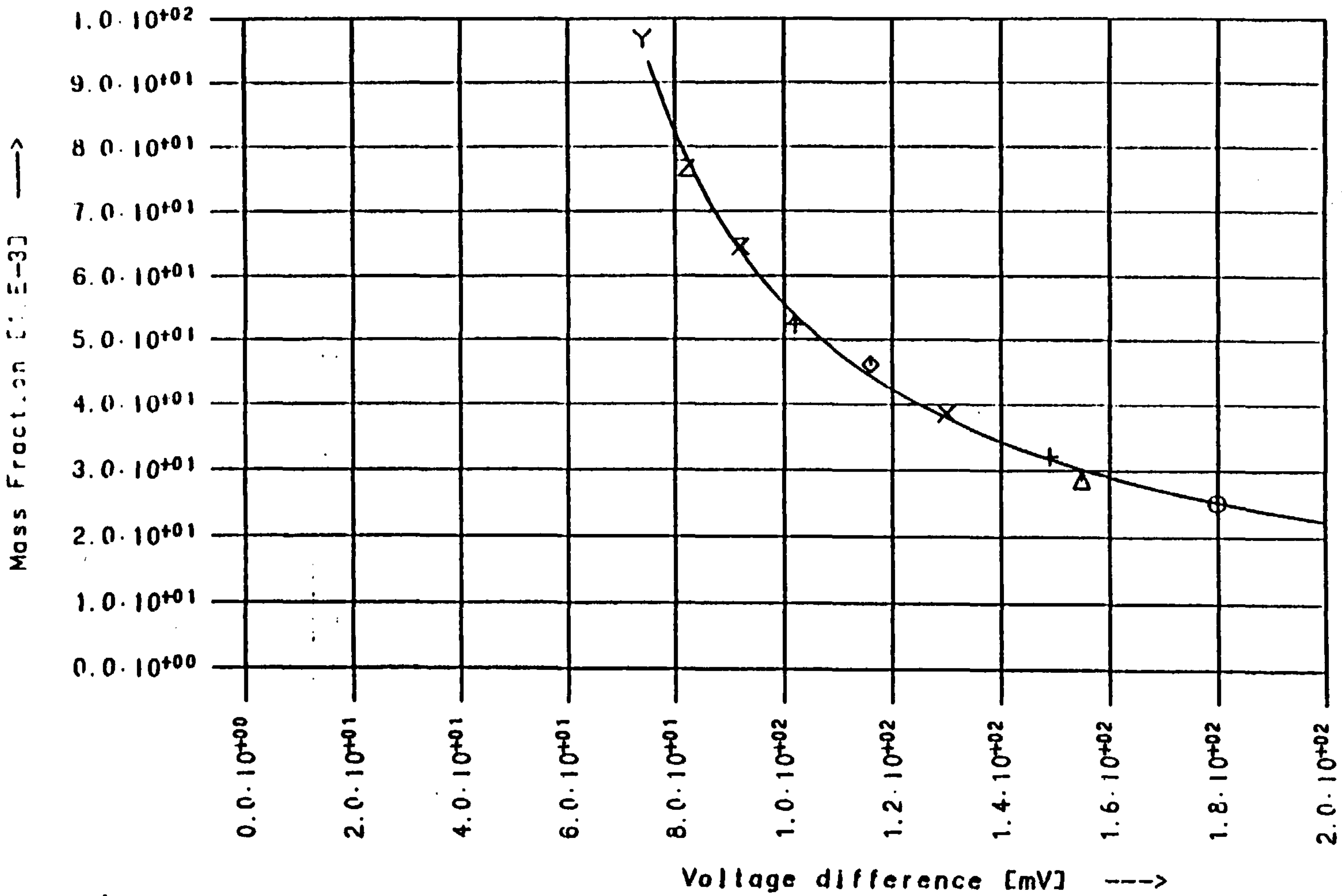


Figure 6. Calibration curve for pair of electrodes number 1 (range < 200 mV)

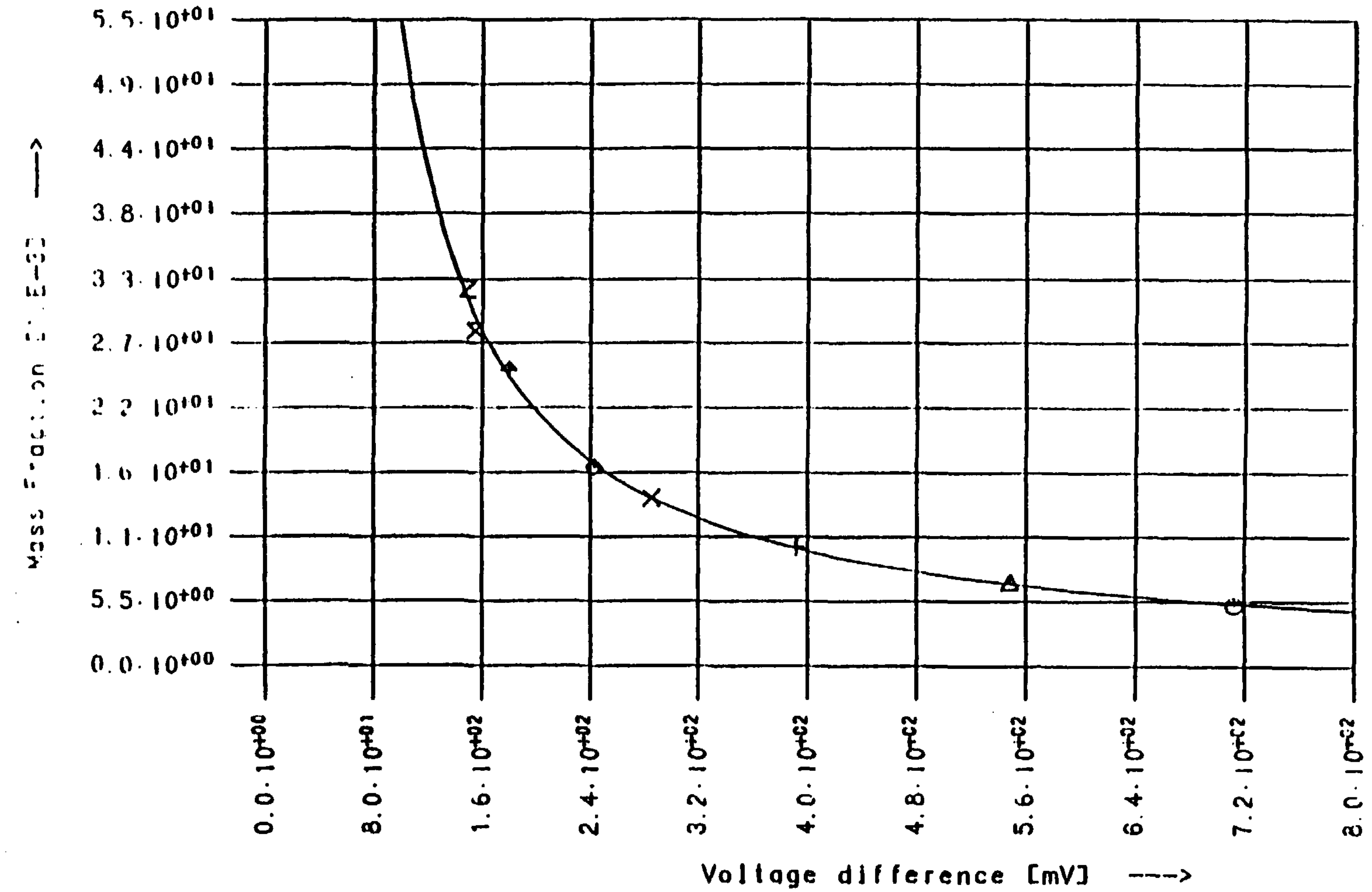


Figure 7. Calibration curve for pair of electrodes number 1 (range 200 - 800 mV)

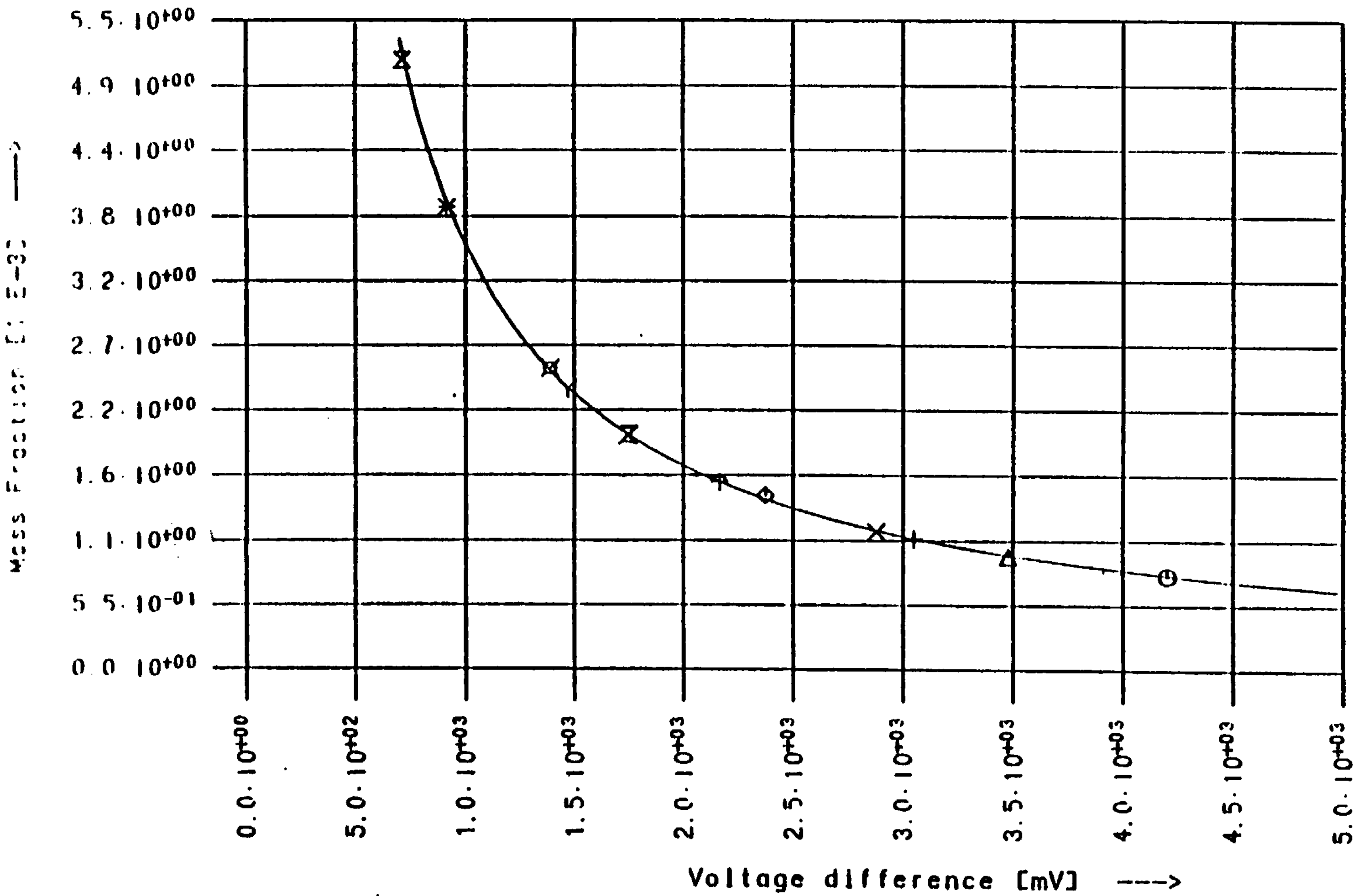


Figure 8. Calibration curve for pair of electrodes number 1 (range > 800 mV)

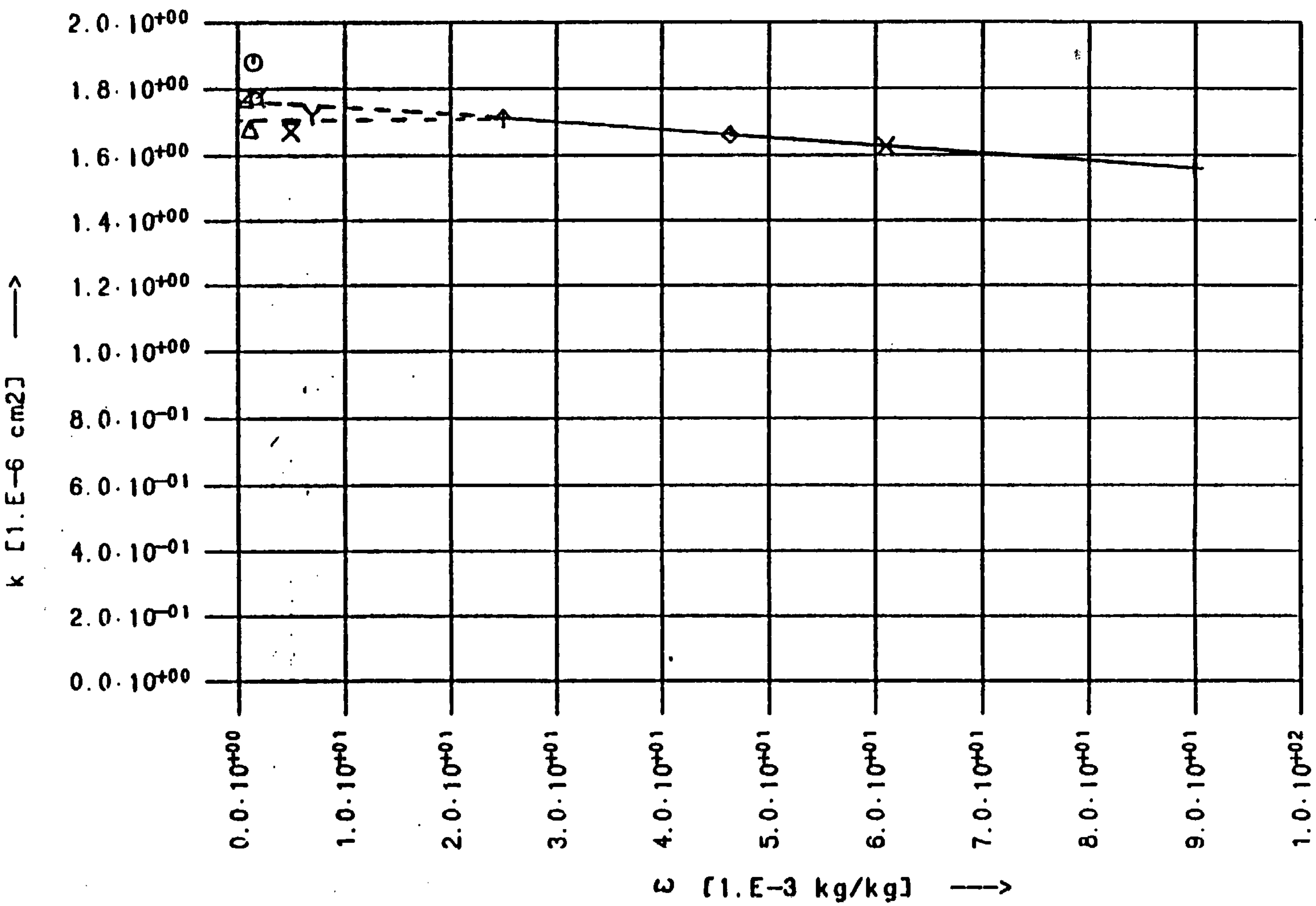


Figure 9. Variation of permeability with salt mass fraction.

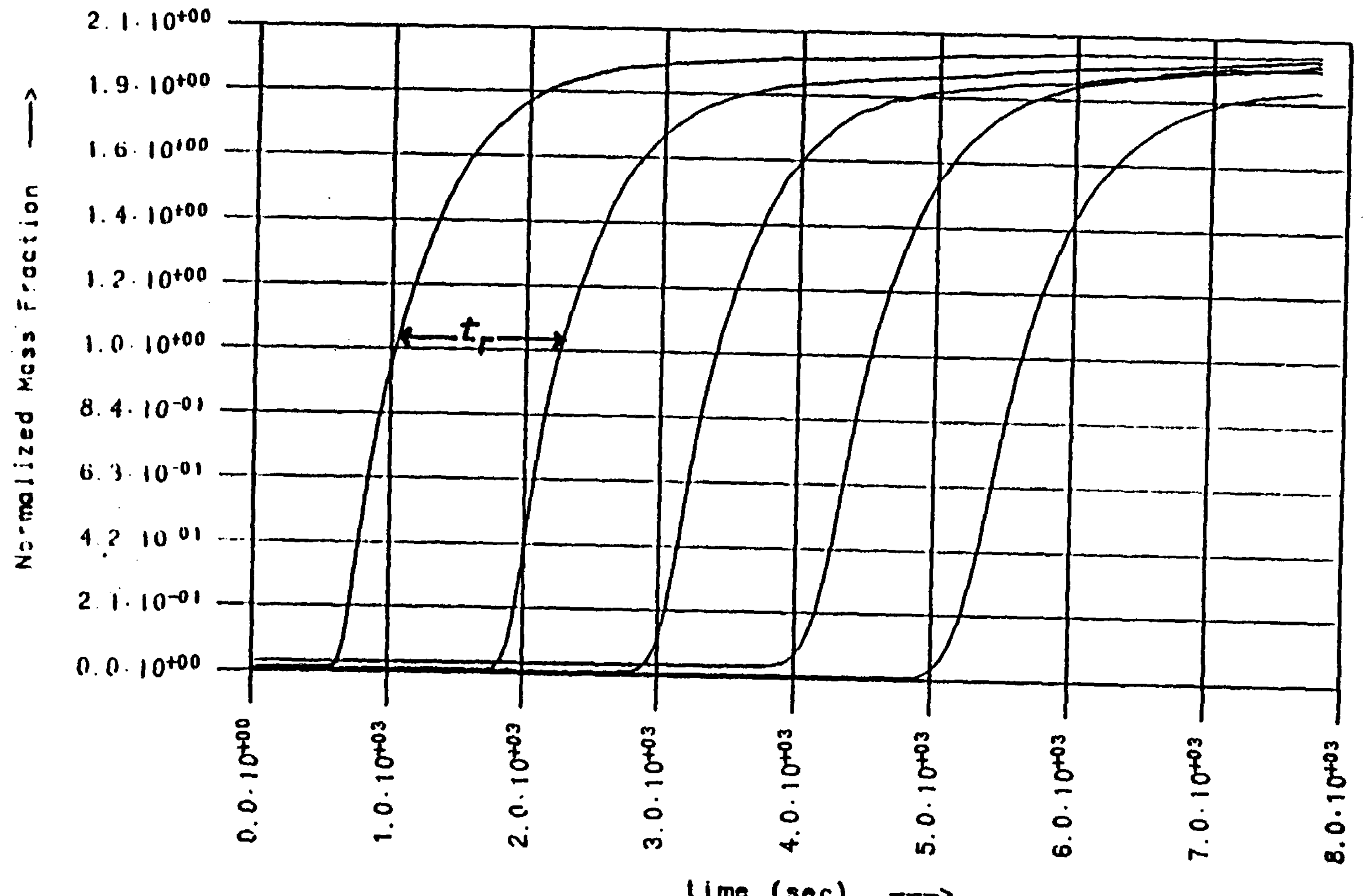
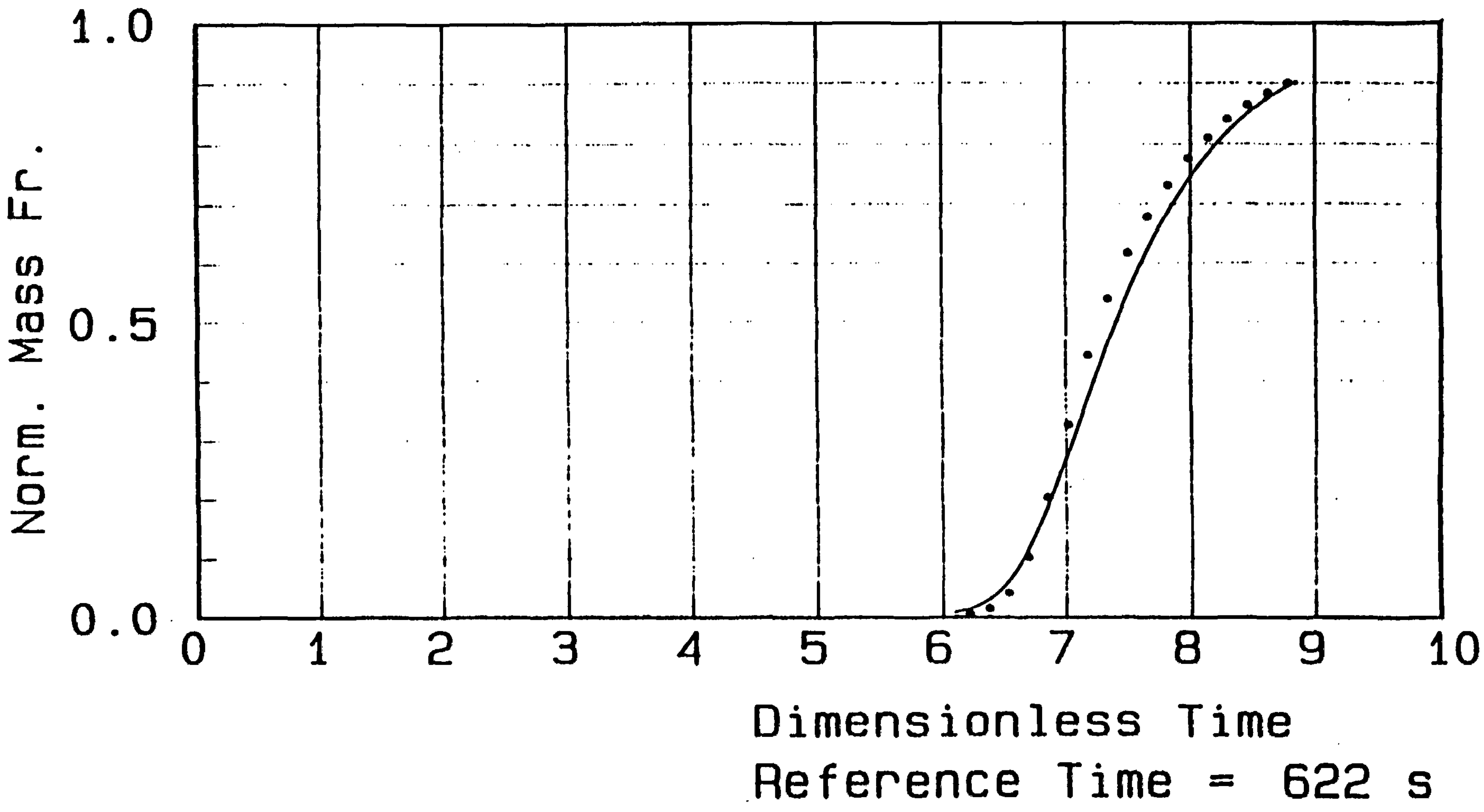
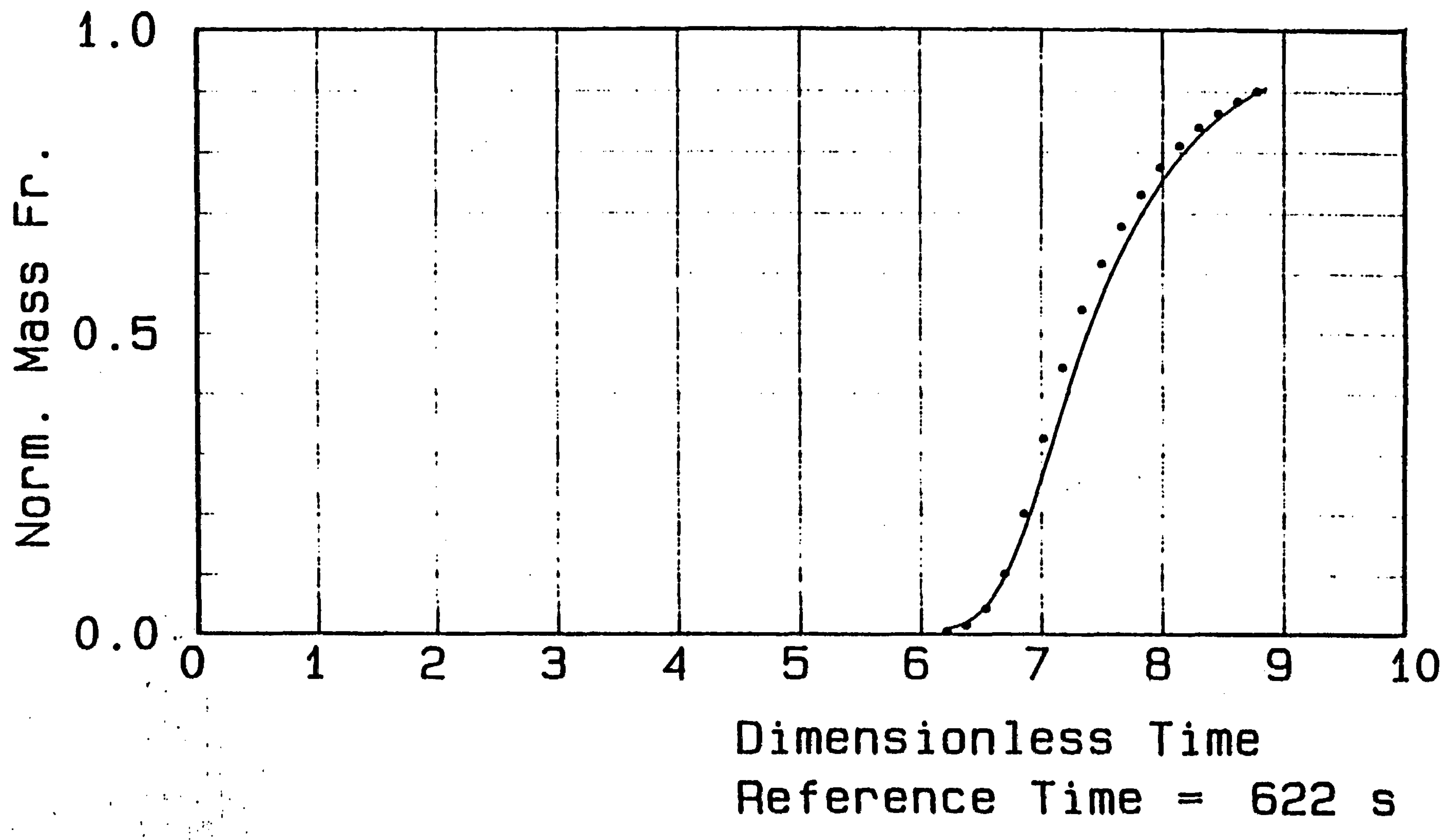


Figure 10. Breakthrough curves for low-concentration (ω_0 = 0.002) displacement experiments



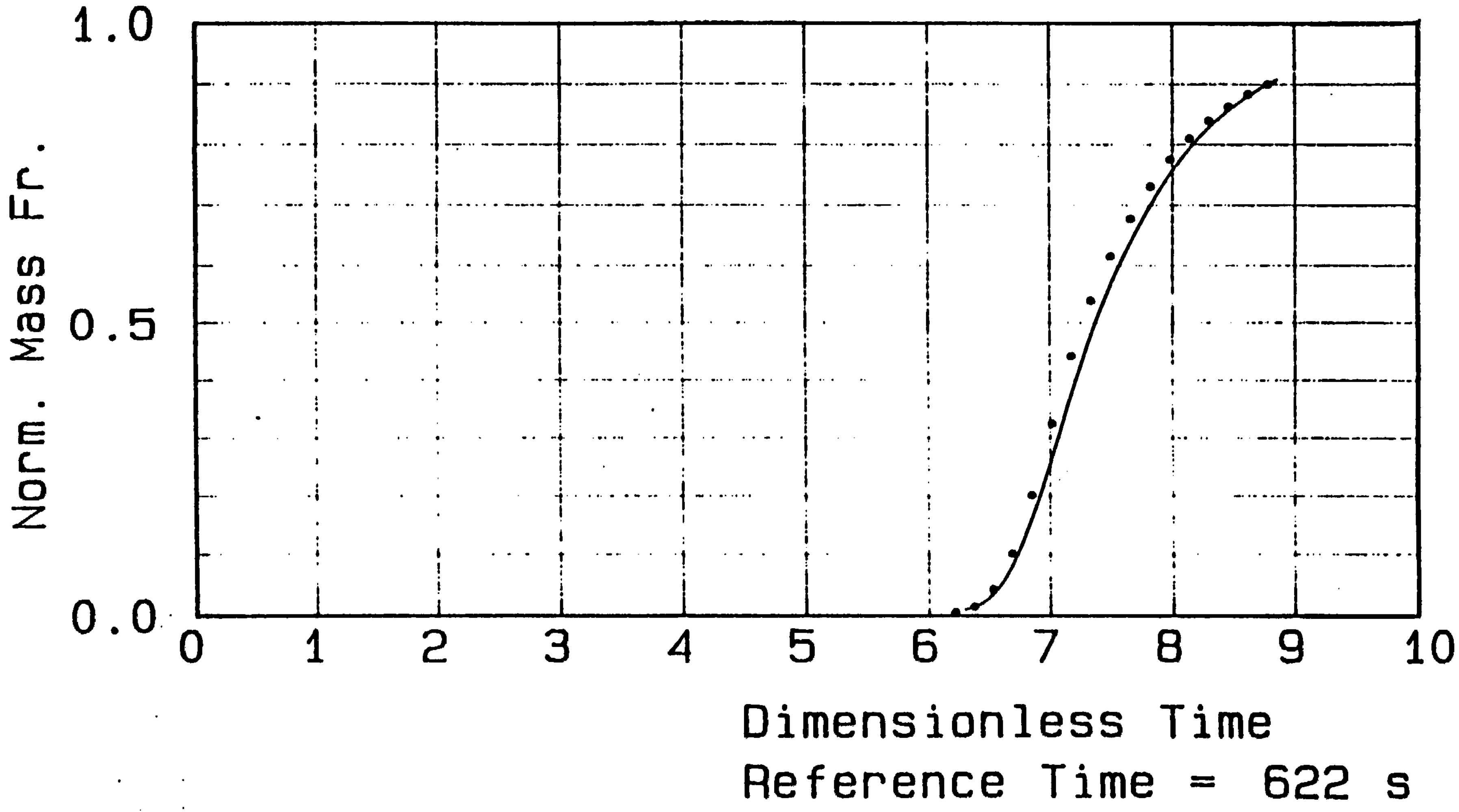
Low Concentration Experiment Number 1
dz = 1 mm dispersivity = 1 mm
channel number 29 z = 81 cm

Figure 11. Electrode 10



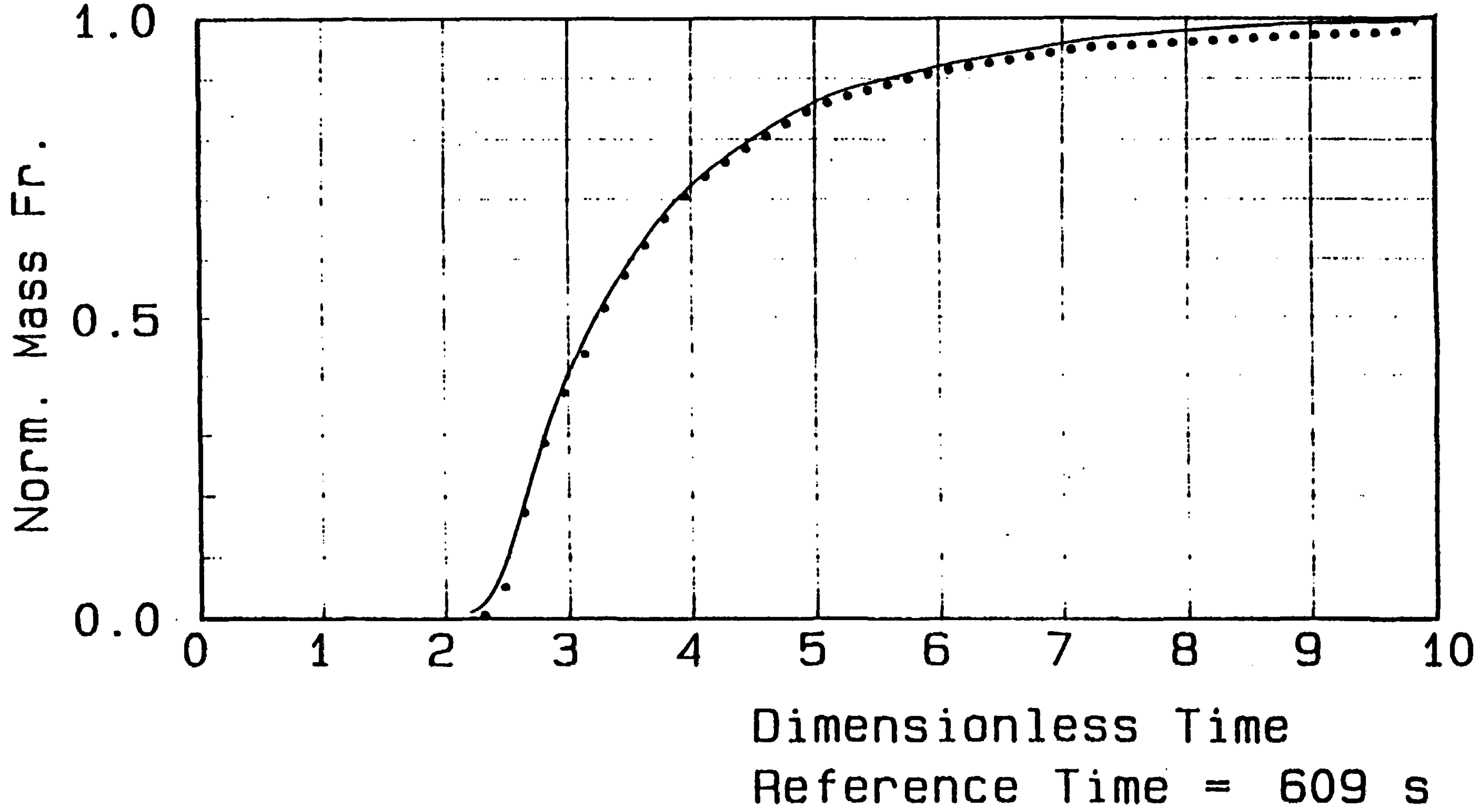
Low Concentration Experiment Number 1
dz = 1 mm dispersivity = 0.5 mm
channel number 29 z = 81 cm

Figure 12. Electrode 10



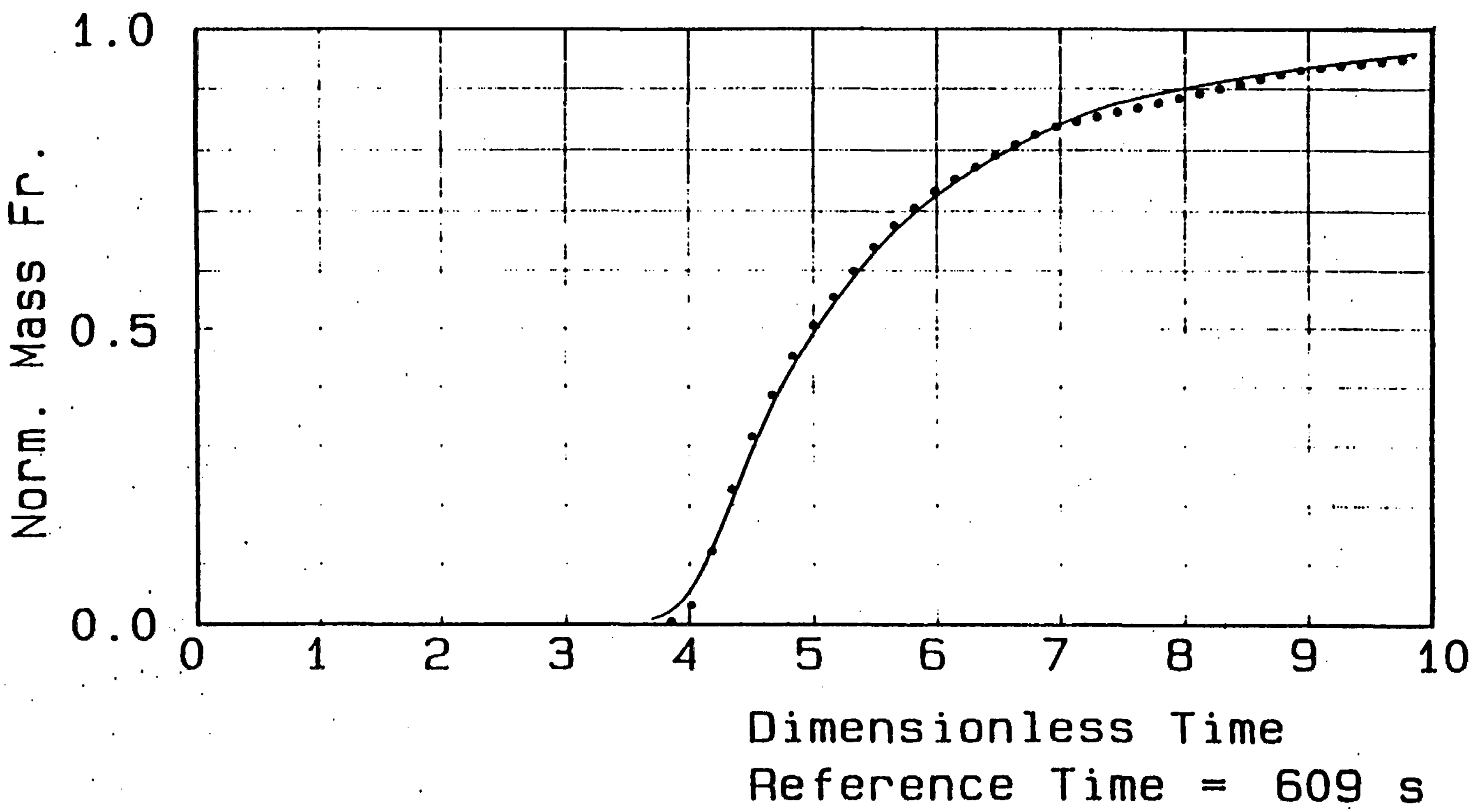
Low Concentration Experiment Number 1
dz = 1 mm dispersivity = 0.2 mm
channel number 29 z = 81 cm

Figure 13. Electrode 10



High Concentration Experiment Number 1
dz = 1 mm dispersivity = 0.2 mm
channel number 23 z = 27 cm

Figure 14. Electrode 4

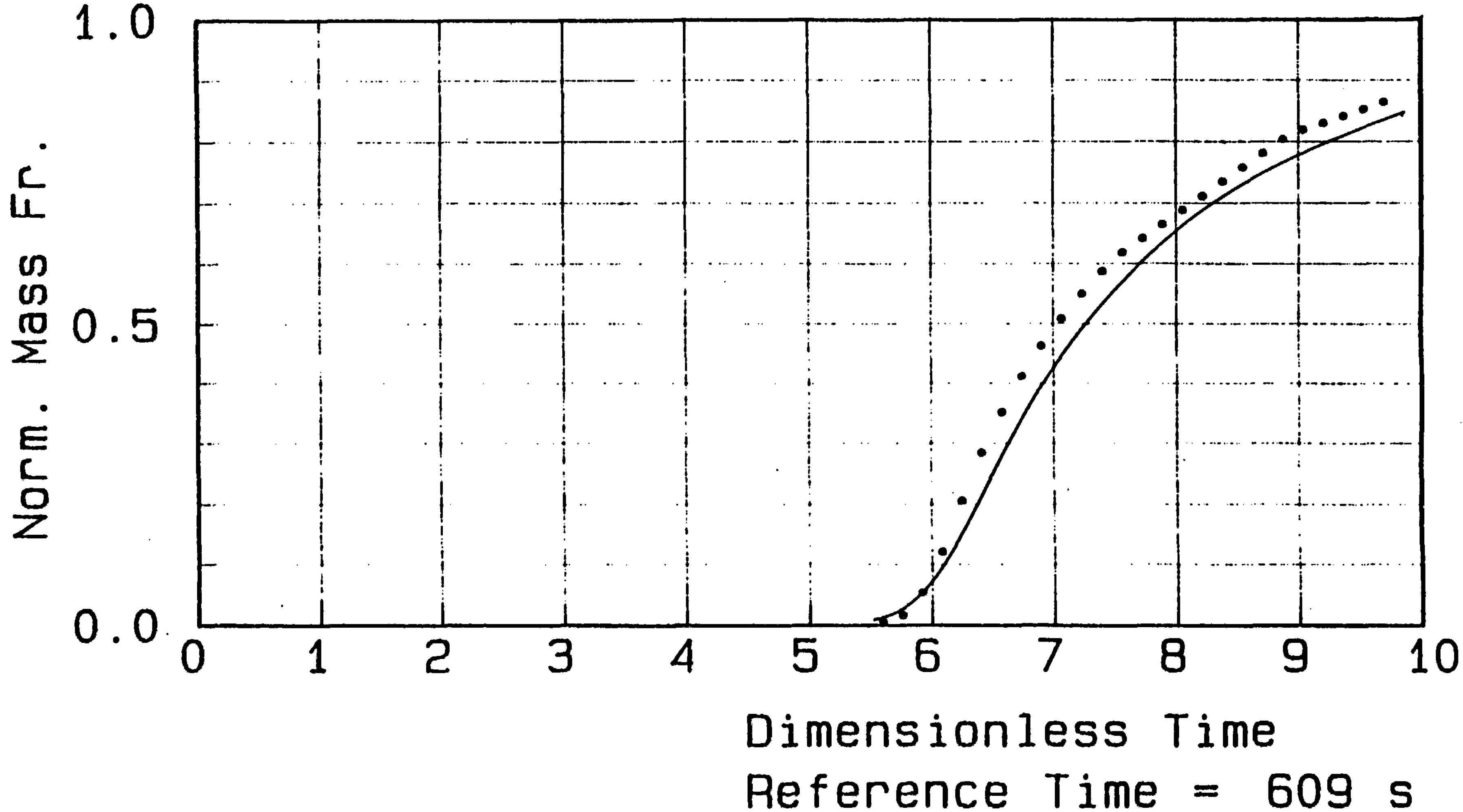


High Concentration Experiment Number 1

dz = 1 mm dispersivity = 0.2 mm

channel number 26 z = 54 cm

Figure 15. Electrode 7



High Concentration Experiment Number 1
dz = 1 mm dispersivity = 0.2 mm
channel number 29 z = 81 cm

Figure 16. Electrode 10