THE INTERNATIONAL HYDROCOIN PROJECT

GROUNDWATER HYDROLOGY MODELLING STRATEGIES FOR PERFORMANCE ASSESSMENT OF NUCLEAR WASTE DISPOSAL

BACKGROUND AND RESULTS

1987

The Coordinating Group of the HYDROCOIN Project
Swedish Nuclear Power Inspectorate (SKI)

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to article 1 of the Convention signed in Paris on 14th December, 1960, and which came into force on 30th September, 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

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NEA now groups all the European Member countries of OECD and Australia, Canada, Japan, and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objectives of NEA are to promote co-operation between its Member governments on the safety and regulatory aspects of nuclear development, and on assessing the future role of nuclear energy as a contributor to economic progress.

This is achieved by:

- *encouraging harmonisation of governements' regulatory policies and practices in the nuclear field, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
- *keeping under review the technical and economic characteristics of nuclear power growth and of the nuclear fuel cycle, and assessing demand and supply for the different phases of the nuclear fuel cycle and the potential future contribution of nuclear power to overall energy demand;*
- *developing exchanges of scientific and technical information on nuclear energy, particularly through participation in common services;*
- *setting up international research and development programmes and undertakings jointly organised and operated by OECD countries.*

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

Publié en français sous le titre :

PROJET INTERNATIONAL HYDROCOIN

FOREWORD

The International HYDROCOIN (Hydrologic Code Intercomparison) Project was started in May 1984. Fourteen organisations participate in the Project, with the Swedish Nuclear Power Inspectorate (SKI) as managing participant and the OECD Nuclear Energy Agency (NEA) taking part as a member of the Project secretariat. HYDROCOIN is concerned with the assessment of groundwater movements at potential nuclear waste disposal sites with the help of mathematical models and computer codes. The Project is divided into three levels. The objective of HYDROCOIN Level 1 is to verify the accuracy of groundwater flow codes. HYDROCOIN Level 2 and Level 3 are concerned with validation of hydrological models and uncertainty / sensitivity analysis, respectively.

This report, which has been prepared by the NEA Secretariat and SKI in consultation with the co-ordinating group of the HYDROCOIN Project summarises the background and objectives of the Project and presents the results of the work performed up to the middle of 1987. It is intended to provide general information on HYDROCOIN to interested parties beyond the group of directly involved specialists.

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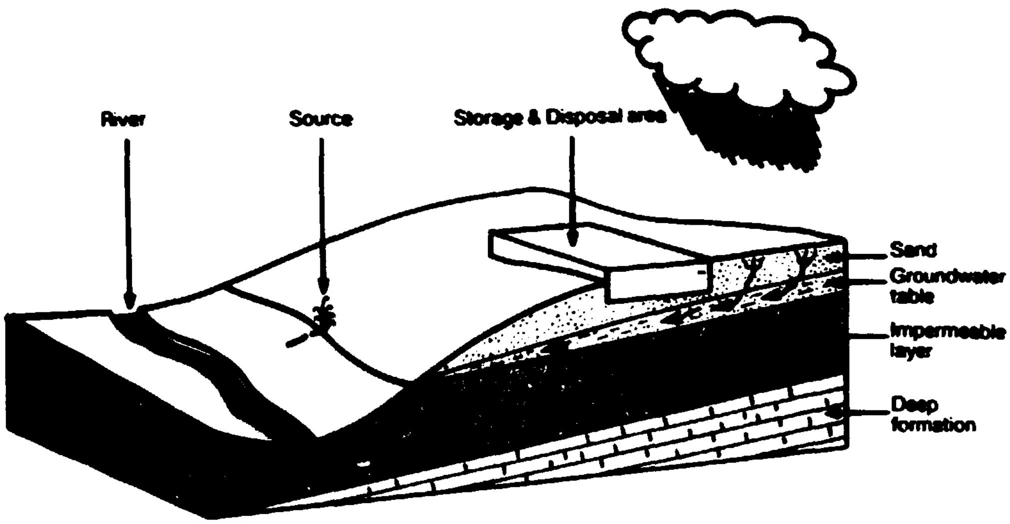
I

THE DISPOSAL OF NUCLEAR WASTE

Nuclear electricity generation give rise to radioactive waste which must be disposed of in a safe way. Some wastes have only a low concentration of radioactive elements that decay rather quickly. Other wastes are highly radioactive and contain long-lived radioactive elements. Before storage or disposal, the wastes are immobilised and encapsulated. Low-level waste with short-lived elements can be safely treated and disposed of in a rather simple way. Dumping into the sea or shallow ground burial has been or are being practised for the disposal of these wastes. Shallow underground disposal, for instance in rock caverns, will also be practised in the near future.

The most advanced treatment and disposal techniques are needed for the long-lived high-level waste. In this case the greatest part of the effort is directed towards developing safe methods for the disposal in stable geological formations deep underground.

Many different types of geological formations show favourable characteristics for long term isolation of radioactive wastes: salt, clays, shales, basalts, tuffs and crystalline rocks such as granite. The choice for a particular country depends to a large extent on the availability of such formations in that country. All countries with a nuclear power programme are involved in studies to find suitable geological formations for disposal of their wastes. Much of the Research and Development work is made in international co-operation. Timetables for site-selection and implementation of the disposal systems vary between countries. Repositories for low and medium level wastes are already in operation or being constructed in many countries. For the disposal of high-level wastes the first repositories are foreseen to be taken into operation around the turn of the century. The years up till then will be used for further research, site-selection studies and evaluation of disposal concepts and proposed sites.



Credit: ANDRA.

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Figures 1 and 2. **Examples of concepts for shallow disposal of low-level waste and deep disposal of high-level waste. In both cases knowledge about groundwater movements will be needed to evaluate the safety.**

II

THE QUESTION OF LONG-TERM SAFETY

The fundamental function of a disposal system is to contain and isolate the radioactive materials so they cause no undue harm to man or his environment, either now or in the future. This means that one is confronted with the problem of predicting the behaviour of the system over long time periods. It will not be necessary to predict the future behaviour in every detail. What is needed is to understand enough to be assured that no harmful releases will occur. To gain this level of understanding and to describe it to responsible authorities and the public is one of the major tasks in any nuclear waste disposal program.

The basis for an analysis of the safety is a good scientific understanding of all parts of the system. This encompasses for instance:

- The physical / chemical properties of the waste materials and canisters (the source);

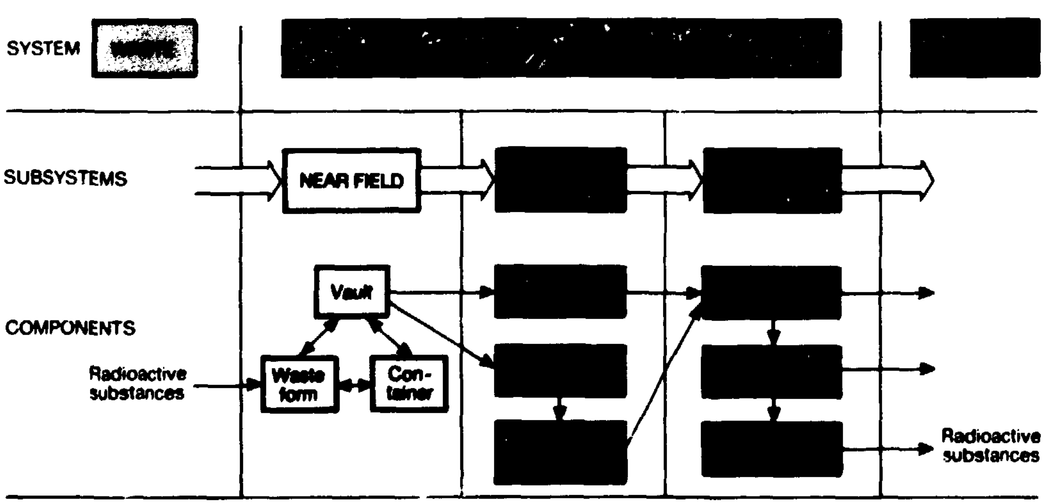


Figure 3. To understand the long-term safety of a waste isolation system a detailed assessment is needed of the performance of all its components.

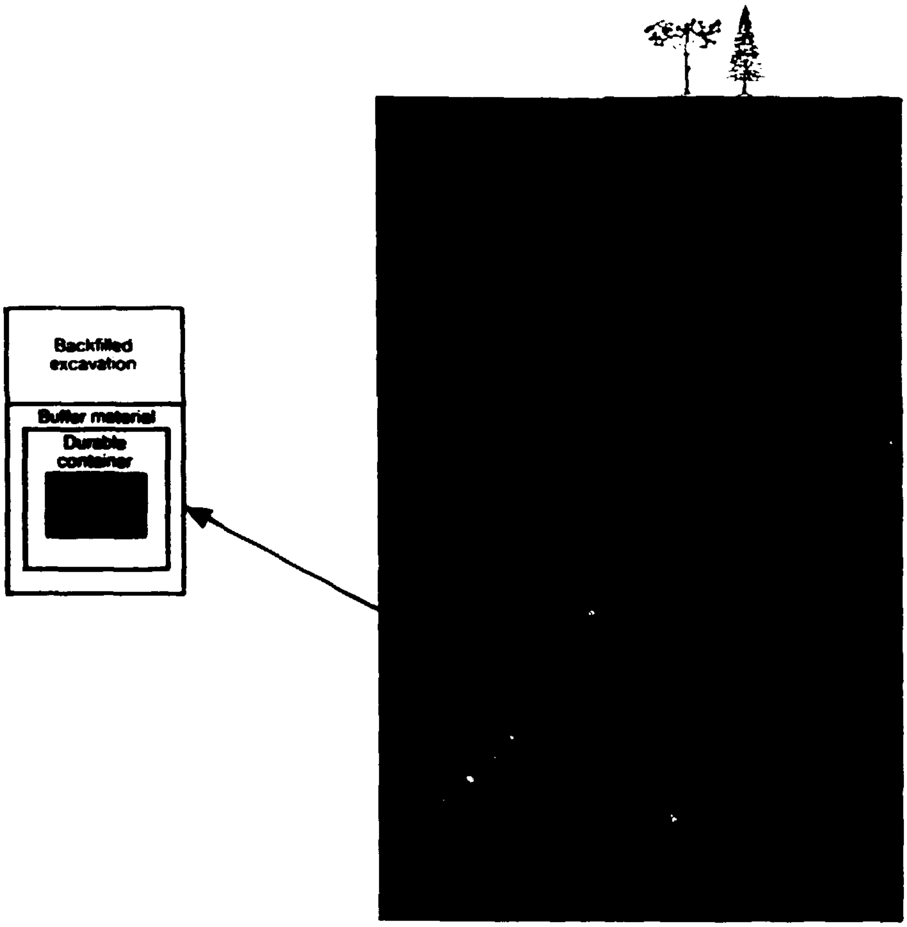


Figure 4. Schematic of natural and engineered barriers in a nuclear waste disposal system.

- The chemical interactions and transport phenomena within or close to the repository (the near-field);
- The chemical interactions and transport phenomena in the geological formation surrounding the repository (the far-field);
- The effects of dispersion and/or reconcentration of possible releases to the biosphere.

In all these areas research is performed through experiments and observations in laboratories or in the field. *Mathematical models* are developed to describe important processes that might occur. The large amount of data obtained from experiments and field tests are collected in a systematic way and stored in ***data bases.***

In a safety assessment the available information is used as appropriate as possible to assess the future effects of the repository on the environment. The quality of such a total system performance assessment and the relevance of its results will depend on:

- That all important events or processes that may influence the releases from the repository have been identified (scenarios);
- That the mathematical models give a correct description of these processes, at the level of detail needed for this particular purpose;
- That the input data used is representative of the actual site conditions and repository design, and finally;
- That the calculations and the interpretation of results are made in an appropriate way.

For the geological disposal of high-level waste no country has yet reached the stage of making a formal safety assessment for the licensing of a repository at a specific site. Extensive formal assessments of the feasability of implementing safe disposal have been carried out in some countries e.g. the Federal Republic of Germany, Sweden, Switzerland, and are planned in other countries e.g. Canada.

III

THE IMPORTANCE TO UNDERSTAND GROUNDWATER MOVEMENTS

Should radionuclides be released from an underground repository of nuclear waste, then the primary mechanism for transporting and spreading them will be groundwater movement. Further, the durability of the near-field barriers, like buffer materials and canisters, is dependent on the flow of water at the depth of the repository. Thus it is very important to gain adequate

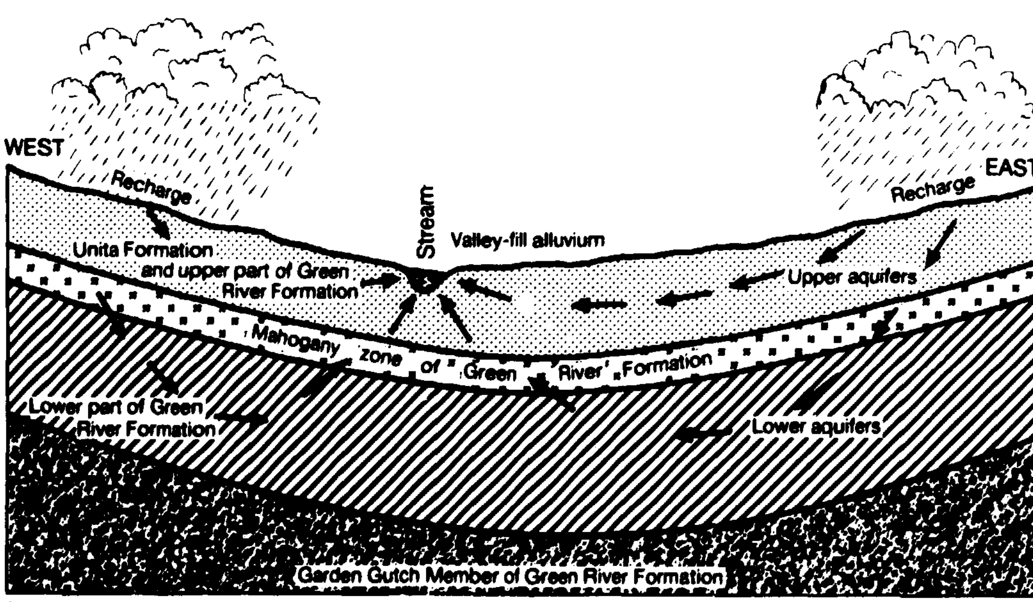


Figure 5. Groundwater in geological formations is formed by infiltration from rainfall and surfacewaters into the deeper formations. The figure shows a simplified scheme of the flow system at the Piceance and Yellow Creek drainage basins in Colorado. The arrows indicate pathways for the water. A case based on measurements in this region was included in HYDROCOIN, Level 2 for model validation attempts.

understanding of groundwater movements (hydrology) at potential repository sites. It is needed for analysing the safety and it can be used in selecting a proper site and repository design.

Different types of geological formations may have very different hydrological properties. As an example salt formations are normally impervious to water; in clay formations one may find a slow homogeneous water flow; and crystalline rocks most often show large inhomogeneties in groundwater movements.

The hydrological properties of a geological formation are studied through field observations and field tests. Precipitation, infiltration from the surface, local and regional geological features are basic elements of information needed. By measurements in deep boreholes and by observations in shafts and rock caverns further knowledge can be gained. A large experience is available from classical hydrology as applied in investigations for water or oil resources and for underground construction works. Further development of site investigation techniques and measurement techniques is also made to satisfy the needs to be able to characterise rocks at large depth with a very low flow of groundwater. One example is the International Stripa Project where experimental research on fractured crystalline rocks is being made since 1980 under the sponsorship of the OECD/NEA. Studies of groundwater movements is one of the major parts of this project.

IV

THE USE OF MODELS AND COMPUTER CODES

To take full advantage of the geological/hydrological information gathered in the field, a mathematical modelling of groundwater movements is needed. The modelling is based on a conceptual model of the geological formation

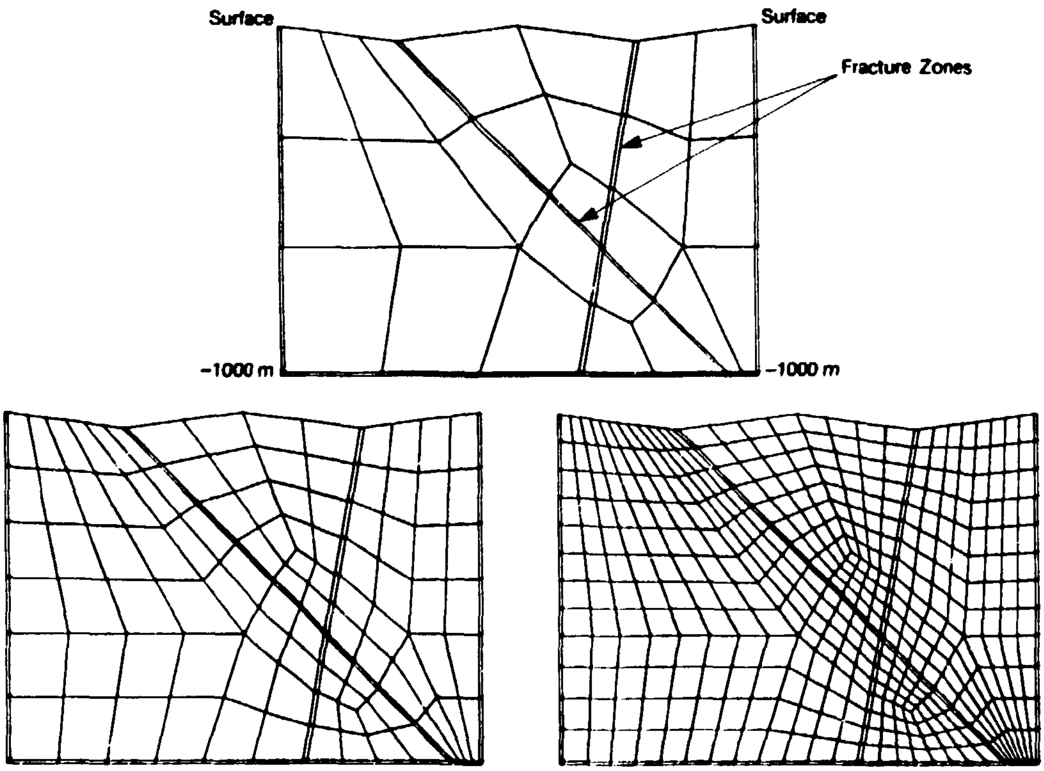
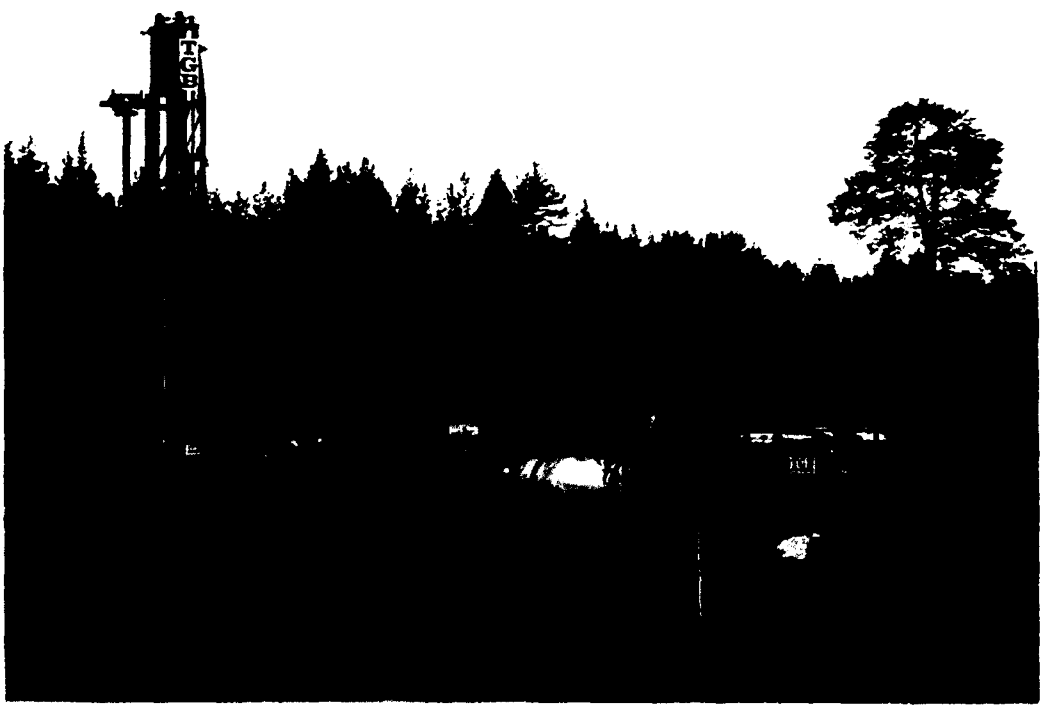


Figure 6. For solving the equations a mathematical method called the finite elements method is often used. The modelled domain is devided into a network of elements and the equations are solved by approximations within each element. The figure show a set of finite element networks (*meshes*) at three different levels of detail. (HYDROCOIN Level 1, case 2). The finest network will give the most accurate solution but it will also require more computer time.

considered and on classical expressions for the balance of mass and energy for the water flow within it. To be able to solve the resulting system of differential equations, input data on material properties as well as initial and boundary conditions are needed. The permeability of the rock to flowing water is an example of a material property that is needed. The level of the water table might be one of the boundary conditions.

In principle, by solving the equations, one can get to know the groundwater flow and its direction at any point in the formation. In practice this is only possible under very simplified assumptions compared to a real situation. In all realistic cases approximations will have to be used both when establishing the model and when solving the equations. For most practical purposes computer code techniques are used for solving the equations. In fact, the most advanced techniques in this field are often needed to perform the complex hydrological modelling of potential nuclear repository sites.



Credit: SKB.

Figure 7. The figure shows drilling activities in crystalline rocks at a site in Sweden. Measurements in drillholes of the water-flow resistance of the rock constitute an important part of the database for modelling of groundwater movements.

The hydrological modelling enters into several stages of a site evaluation

- Data from field tests and field observations often have to be evaluated with the help of and within the context of certain hydrological models.
- Local and regional groundwater movements are modelled under varying assumptions.
- The influence on groundwater movements of the construction of a repository in the formation, the heat emitted from the waste or the withdrawal from a fresh water well close to the site is simulated using hydrological modelling.
- It is also an area still under rapid development. New more complex models and approaches are developed and taken into practice as the tools for computer calculations are developing.

V

THE HYDROCOIN PROJECT

General aims

HYDROCOIN is an international project for studying groundwater hydrology modelling strategies. This means that it is concerned with how to use the modelling tools in an appropriate way. It deals with:

- The computer codes and how accurate they are (code verification);
- The capabilities of the hydrological models to describe field measurements and real world hydrological situations (model validation);
- The impact of various parameters and physical phenomena on the results (uncertainty and sensitivity analysis).

The overall aim is to gain further understanding of and confidence in the complex field of hydrological modelling of potential repository sites.

Approach and structure

HYDROCOIN brings together specialist in hydrological modelling from 10 countries. Together with the project Secretariat they have formulated a set of cases for modelling and calculation. Twice a year workshops (3-4 days) are held where results by the project teams are presented, compared and discussed and the further work is proposed.

Decisions concerning the project are taken in the Co-ordinating Group where each participating party is represented. The Co-ordinating Group meet directly after the workshops. In between the workshops the project teams make their calculations and send the results to the project Secretariat, which compiles and compares them for discussion at the next meeting.

Bringing together, in this way, specialists from several countries and having them to tackle the same set of modelling cases has been found to be very

Figure 8. HYDROCOIN level structure and brief case descriptions.

TIME SCHEDULE

HYDROCOIN started in 1984.
Calculations will be finalised in 1987.
Level 1 finalised; report printed end 1987.
Level 2 in progress; report printed mid 1988.
Level 3 in progress; report printed late 1988.

Figure 9. Timeschedule and reporting.

fruitful for the exchange of experiences and for furthering the understanding of hydrological modelling.

HYDROCOIN was started in 1984 and it will be finished in 1987. Six workshops have been held and one more is being planned.

The project is conducted at three successive levels.

Level 1 (code verification). At this level the numerical accuracies of the codes are studied. This is made by comparing results from numerical calculations by computer codes with analytical solutions (true mathematical solutions) in such cases where this is possible. It is also made by simply intercomparing results from codes using different numerical methods to solve the same problem. A secondary objective has been the exchange of ideas on methods for cost-effective but accurate computer code calculations and techniques for the further processing and presentation of the results.

Level 2 (model validation). At this level field or laboratory experiments are modelled. Some of the data from the experiments are used as input for the calculations. It is then studied how well the results from the model calculations represent the field or laboratory observations. By such exercises a better understanding is gained of the possibilities and limitations in using different hydrological models to describe real situations. It will help modellers to use their models in a cautious and prudent way and it will thus contribute to confidence building in the area of predictive modelling for safety assessment of nuclear waste disposal.

Level 3. At this level uncertainty and sensitivity analysis is being made. The cases used are some of those treated already at Level 1 or 2. By studying the impact on the results of varying the input parameter values and the assumptions made further knowledge is gained on the relevance and accuracy of the results provided by the models. It will also help in sorting out which information and what data from the field are most important to know in order to be able to make a correct modelling of the groundwater movements.

Level 1 results

The seven cases defined for Level 1 are all simplified versions of situations encountered in the assessment of groundwater movements at potential repository sites. Together they cover problems related to different types of formations (crystalline rocks, salt, clay ...) and to different phenomena (fracture flow, heat induced flow, flow induced by differences in density of the fluid ...). Two of the cases (case 1 and 4) have an exact mathematical solution that the computer code results can be compared to. In the other cases one has to intercompare the results from calculations by different computer codes.

The Level 1 of HYDROCOIN was finished during 1986 and the detailed results will be published at the end of 1987. A big effort was made by the participants on this level and in total 23 project teams have participated using 29 computer codes. Most of the cases have been treated by more than 10 teams. The calculated entities have been both scalars (groundwater pressure and temperature) and vectorial properties (groundwater velocities and pathways).

In general the agreement between the calculations has been satisfactory. The best agreement is obtained in calculating scalar units like groundwater pressure and temperature. Also for groundwater velocity fields and pathways there is a good agreement but to a less extent. The computer code methods to generate the pathways has to be selected with care and the HYDROCOIN Level 1 exercise indicate that there is a certain need to refine and improve these methods. A test case to compare and evaluate different methods for calculation of pathways was therefore included in the Level 3 of HYDROCOIN.

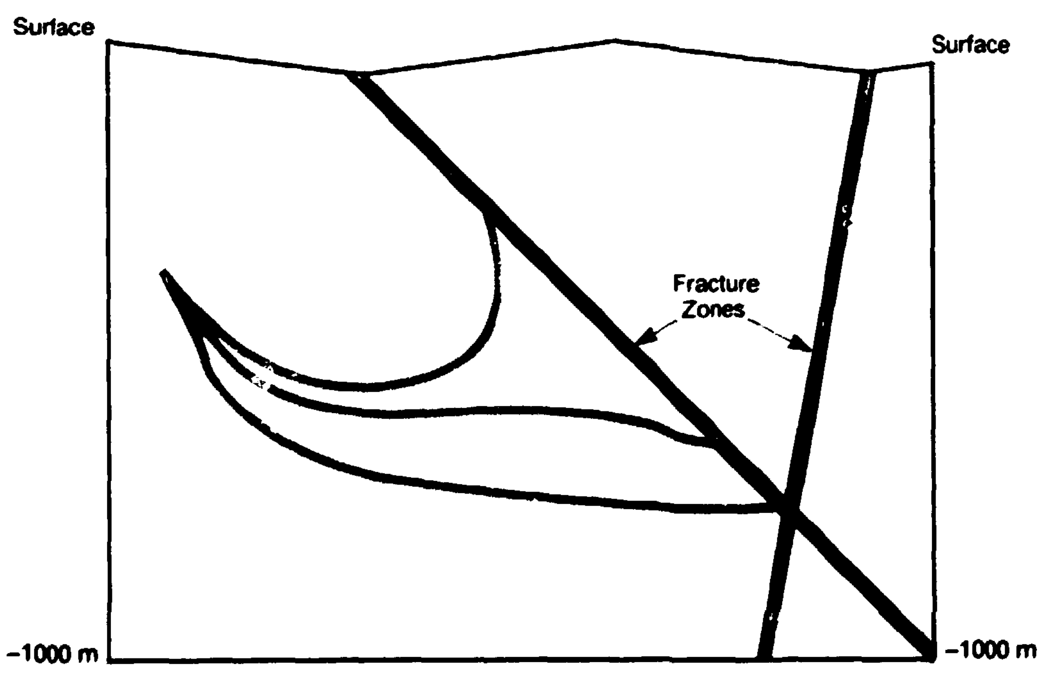


Figure 10. The figure shows the pathways for a *water-particle* starting at a defined position. *Different codes gave different results of groundwater flow pathways* (Level 1, case 2) *if the network of finite elements* (see Figure 6) was to coarse.

In two of the test cases (case 3 and 5) there are strong variations in material properties and flowfields over the domain considered. This makes modelling more difficult and there is a need for developing better methods for that kind of problems.

Finally, it should be pointed out that all the models used in HYDROCOIN Level 1 are based on the concept of equivalent porous media for description of the water flow through the formations considered. For fractured media, for instance, this concept is valid only to a certain level of detail. For the detailed description of real fractured and fractured porous media other concepts are under development (network models, ...).

Level 2 results

The five cases at Level 2 are directly taken from complex real world situations or laboratory experiments. A considerable effort was needed merely to formulate and define the cases for the modelling and validation exercise. This was done by one pilot-group for each case.

The objective of Level 2 is model validation. It is carried out by comparison of calculations with observations and experimental measurements.

Validation has many aspects. At least two were included and partially addressed within Level 2 of HYDROCOIN.

- Validation of the mathematical description of the physical processes involved in groundwater hydrology;
- The building of confidence that models are correctly applied in the sense that they give relevant answers to questions raised in the safety assessments of nuclear waste repositories.

The compilation of Level 2 results is not yet finalised but some general observations can be made.

Comprehensive data bases sufficient for validation of complex groundwater flow models are presently not available. There is a need for experiments specifically designed and planned for validation purposes. However, cases could be defined that have given much experience in how to approach model validation and that has provided confidence in many aspects of the modelling. Some previous experiences have been confirmed. Thus, the modelling of high-permeability pourous media cases are well in hand. Additional efforts are justified to validate the applicability of our characterization methods and our ability to model in deep hydrologic systems of low permeability.

Level 3 preliminary results

The seven cases defined for Level 3 are all, except one, extensions of cases used at Level 1 or 2. This means that the project teams can benefit from the basic work performed at the previous level when they do additional calculations to study the sensitivity and uncertainty due to variations in parameter values or interpretation of boundary conditions etc.

Potential nuclear repository sites will never be characterized in every detail. Further, over the time periods that have to be considered, some changes in geohydrological characteristics can take place. Therefore, it is clear that sensitivity and uncertainty analysis in hydrological assessments will be indispensable to obtain the full information needed in this respect for a correct analysis of the safety. Level 3 of HYDROCOIN will promote further insight and development in this respect.

VI

ORGANISATION OF THE INTERNATIONAL HYDROCOIN PROJECT

The study is directed by a Co-ordinating Group with one member from each participating organisation (Party) setting up the study. The Swedish Nuclear Power Inspectorate (SKI) acts as managing participant. A project Secretariat has, according to the agreement between the HYDROCOIN Parties, been set up by SKI in co-operation with the United Kingdom Atomic Energy Authority/Atomic Energy Research Establishment, Harwell (UKAEA/AERE), and with a certain economic support from the Nordic Liaison Committee for Atomic Energy (NKA). The Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA) participates in the Secretariat, Kemakta Consultants Co. participates in the Secretariat as principal investigator and the Institute for Energy Technology, Norway (IFE) participates as Nordic representative.

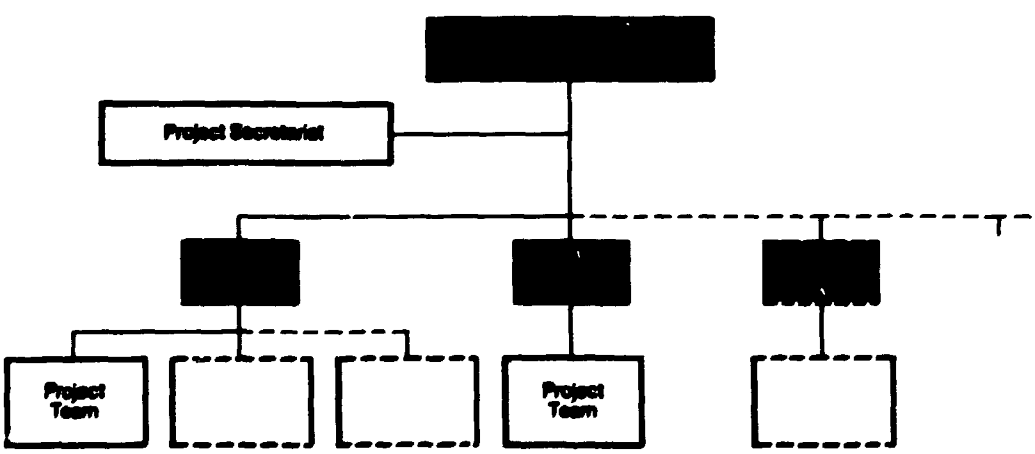


Figure 11. Survey of the organisation of HYDROCOIN.

The Parties organise project teams for the actual project work with model calculations. Each Party covers the costs for its participation in the study and is responsible for its project team or teams including computer cost, travelling expenses, etc.

At suitable time intervals depending upon the progress of the study, workshops are arranged, normally in conjunction with meetings of the Co-ordinating Group. During the workshops problem definitions and achieved results are discussed as a preparation for decisions in the Co-ordinating Group.

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HYDROCOIN Final Report Level 1 – Code verification. Published by OECD/NEA, Paris, 1987.

LIST OF PARTICIPATING PARTIES AND PROJECT TEAMS IN THE HYDROCOIN STUDY

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Gesellschaft für Strahlen- und Umweltforschung (GSF), Federal Republic of Germany	Technical University of Berlin
Technical Research Centre of Finland (VTT)	Technical Research Centre of Finland
Commissariat à l'Energie Atomique/ Institut de Protection et de Sûreté Nucléaire (CEA/IPSN), France	Commissariat à l'Energie Atomique Ecole Nationale Supérieure des Mines de Paris
Japan Atomic Energy Research Institute (JAERI)	Japan Atomic Energy Research Institute Hazamagumi Limited Okumura Limited University of Kyoto Central Research Institute of the Electric Power Industry
Rijksinstituut voor Volksgezondheid en Milieuhygiene (RIVM), the Netherlands	Rijksinstituut voor Volksgezondheid en Milieuhygiene
Swedish Nuclear Fuel and Waste Management Co. (SKB)	Royal Institute of Technology
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (NAGRA), Switzerland	Motor Columbus University of Neuchâtel
British Geological Survey (BGS)	British Geological Survey
UK Atomic Energy Authority/ Atomic Energy Research Establishment (UKAEA/AERE)	Atomic Energy Research Establishment Atkins Research & Development
US Department of Energy (USDOE)	Basalt Waste Isolation Project Salt Repository Project Nevada Nuclear Waste Storage Investigations Office of Waste Technology Development
US Nuclear Regulatory Commission (USNRC)	Nuclear Regulatory Commission Sandia National Laboratory
Swedish Nuclear Power Inspectorate (SKI)	Kemakta Consultant Co. (principal investigator)
Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA) (Observer and member of Secretariat)	

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