COMPARATIVE SITE-SPECIFIC CALCULATION OF THE MIGRATION OF RADIONUCLIDES RELEASED FROM A REPOSITORY IN ROCK-SALT

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ABSTRACT

The Netherlands' research program for geological disposal is intended to supply a basis for the selection of combinations of three factors, i.e., type of rock-salt formation, site, and disposal technique, in compliance with radiological standards. The disposal techniques under consideration are a mined repository or deep boreholes made from the surface, both in combination with cavities for low-level and medium-level waste. Available rock-salt types are bedded salt, salt domes, and intermediate forms. This paper deals with comparative rock-type specific calculations of potential radionuclide release from a repository in salt. The computer code METROPOL, recently developed by the RIVM, was used to model the groundwater flow under the specific geohydrological conditions in the porous rocks covering the rock-salt. The methodology used to perform potential migration calculations is illustrated for release from bedded salt and from a deep-lying salt dome. In the future, particularly in the latter case, the hydrological situation might create a flow system that is completely different from the present one.

INTRODUCTION

The first step in the safety assessment study on disposal of radioactive waste in rock-salt in The Netherlands concerns the selection of the optimal combination of rock-type, site, and disposal technique. An overview of the complete research program is presented in the paper by Vons in these proceedings (1). A hydrogeological study based on data from the literature and open-file reports made it clear that site-specific information is very scarce (2). Values for hydrogeological parameters could only be obtained by extrapolation of data combined with analyses of the sedimentary environment. Despite this limitation, an attempt was made to differentiate between type of formation and location. By the end of 1986, the geological studies had yielded a preliminary number of more than 30 locations where salt domes and salt pillows occur and two areas with salt beds more than 400 m thick (Fig.1).

SET-UP OF THE GEOHYDROLOGICAL MODEL STUDY

The objectives of the geohydrological model studies are to characterize the groundwater flow system, especially in aquifers directly overlying the rock-salt, and to determine potential migration pathways from the periphery of the salt formation to the surface. In view of the limitations of the available geohydrological data and the impossibility of carrying out model studies for each of the locations, several models each representing a group of locations are being constructed.

Calculations are performed for the following situations:

1. a S-N-running cross-section over bedded salt,
2. a 3-D model from the top of a deep-lying salt dome to the surface,
3. a 3-D model from the upper part of the flanks of a shallow-lying salt dome to the surface, and
4. a 3-D model from the top of a salt pillow to the surface.

In this paper the methodology of modeling and determining pathways is illustrated on the basis of the cross-section and the deep-lying salt dome.

The initial runs are carried out with water assigned one density value. Later, the model takes density differences into account. Finally, these models provide the boundary conditions (flow-rate, concentration, pressure) for local migration models.

METROPOL

For the investigation of subterranean radionuclide migration and of the influences of the uncertainties in the geological, hydrological, and geochemical input data on the modeling results, a numerical model simulating the flow processes was needed. Since many needs had to be met for geosphere transport modeling, such as the ability to handle several dissolved species and the interaction of nuclide migration, salinity, and sorption, which could not easily be incorporated into existing models, a new three-dimensional model of groundwater flow was developed. The package was called METROPOL, which stands for simulation method for the transport of pollutants. The METROPOL package now consists of several subpackages developed for mesh generation, computation of steady-state groundwater flow, simulation of transient flow, and the solution of coupled flow and transport equations. Special care was taken to treat correctly the flow of groundwater containing a solute in a high concentration (e.g. salt)(3,4). Furthermore, several postprocessing packages (particle tracking, plotting of computed results) are available.

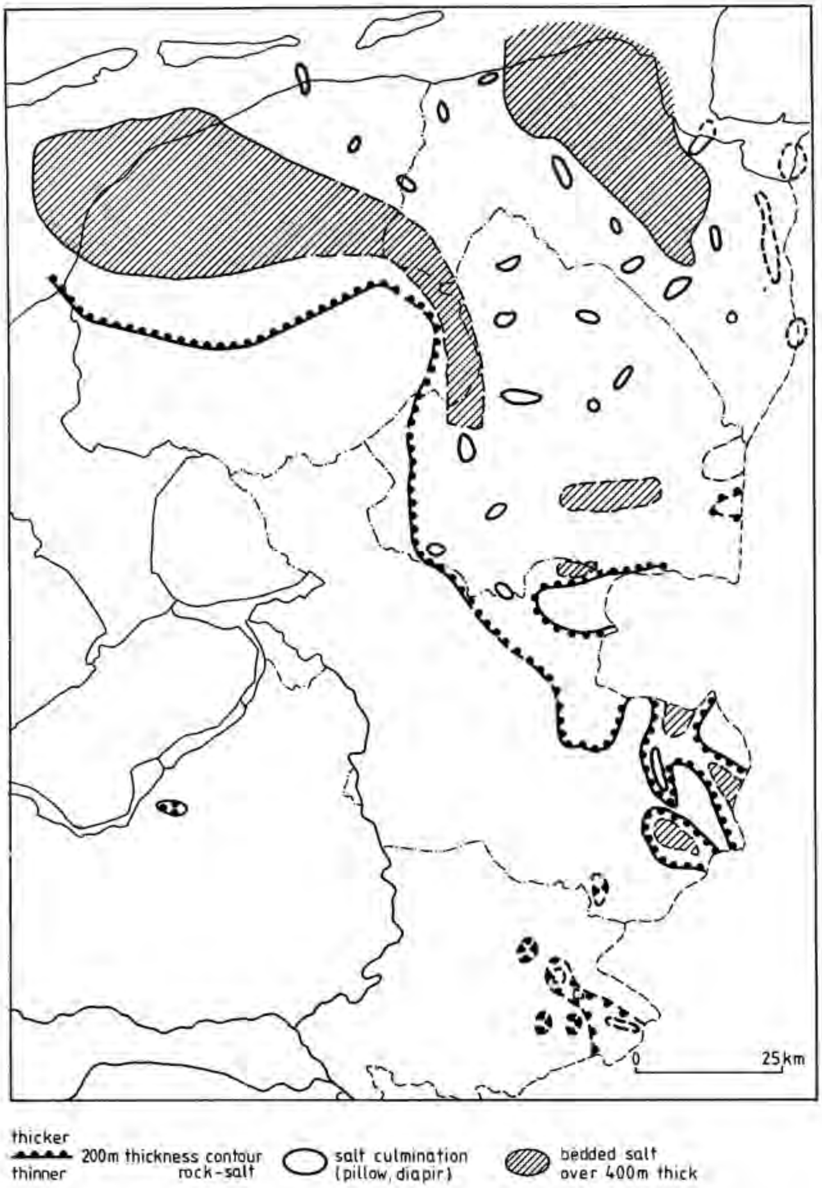

Fig.1. Inventory of rock-salt in the N.E. part of The Netherlands (5).

Particle tracking

The particle tracking facility that can be used as a postprocessor for METROPOL, enables one to get a quick impression of the main flow direction of the groundwater. For calculation of the flow rates with METROPOL use is made of a finite element formulation of Darcy´s law. These velocities in the nodal points of a mesh are used by the particle tracking package, which interpolates the nodal point velocities inside an element and uses an adaptive timestepping algorithm. This algorithm calculates a timestep taking *into* account the size of an element in the mesh and the velocity in that element.

THE REGIONAL MODEL

The model of the bedded salt has a length of 150 km (Fig.2) and starts at the outcrop of the Mesozoic. The salt layer dips down to a depth of 3 km. The profile is drawn over two salt domes; however, the model cross-section was displaced to avoid interruptions of the aquifers. For this orientational calculation the hydrological units are treated as homogeneous, although there are regional differences in permeability within a unit. Information about the geohydrological parameters was derived from Ref.2. The Triassic Buntsandstein shows substantial spread as to permeability and porosity but in general the aquifer properties are better developed than those of the Jurassic and the Cretaceous. Nevertheless, locally within the Cretaceous there are more permeable sandstone layers of limited thickness. Groundwater pressures are not known for Mesozoic strata; there are only indications of artesian conditions in the Triassic (2).

Schematization

The boundary conditions taken for the model are as follows. The sea-level and the piezometric head of the Quaternary system serve as upper boundary conditions. The right and left sides of the model are closed, but the boundary blocks on both sides are defined as highly permeable. These conditions create a hydrostatic pressure. The lower boundary (rock-salt) is impermeable, as are the front and back sides of the model.

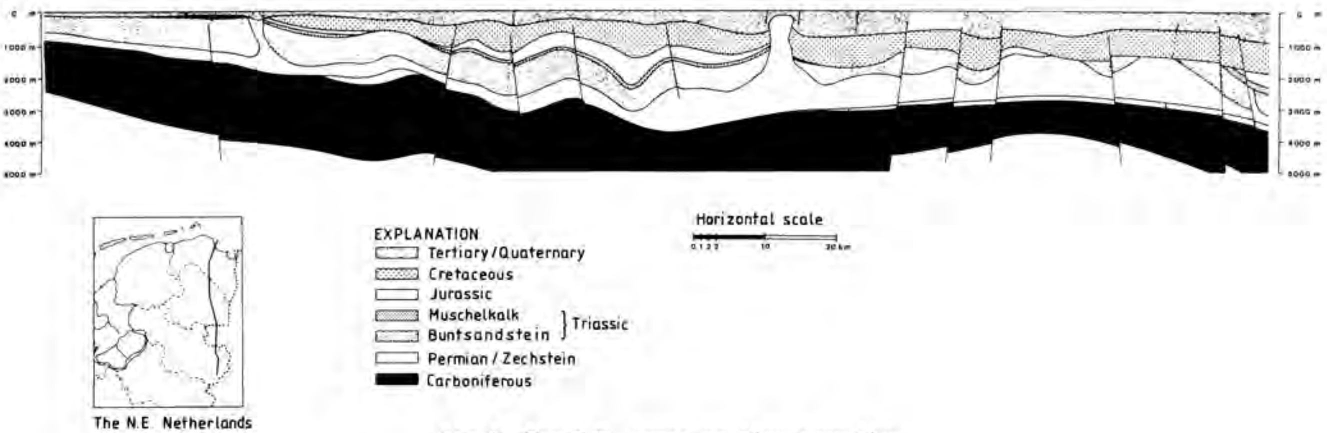

Fig.2. The S.N. cross-section over the bedded salt

The grid of this model consists of deformed cubes. This makes it possible to incorporate the shape of the geological layers in the model. Note that the grid in Fig.3 is exaggerated in the vertical direction.

Results

This model yielded values for flow velocities up to about 0.1 m/a in the aquifer adjacent to the bedded salt. These flow velocities are shown in Fig.3. The flow pattern seems to consist of three more or less separate systems. The highest velocities occur close to the surface and in the deepest layer. In between there is a flow domain with very small velocities, differing by a factor of 10 to 100. Fig. 4 shows the velocities on a logarithmic scale to give an impression of the direction of the velocities throughout the domain.

Particle tracking

The regional model was used to perform particle tracking for two starting points, one on the bedded salt in the Buntsandstein and the other at the position of a possible release point from a salt dome. The preliminary results show that a particle starting at the bottom of the model will not reach the surface (Fig.5). It leaves the model at the northern boundary (right side) after a travel time of 1.5 million years.

The particle starting at the top of the salt dome moves downward first and reaches the surface in a seepage zone after about 2.5 million years. The influence of the salt dome on the flow field is neglected in this regional model. The travel time of the latter particle depends strongly on the local groundwater flow pattern in the upper layers. This point requires further study with a more detailed model of the upper part of the regional model. An example of a local model of this kind is given in the next section.

The effect of grid refinement on the numerical results also remains to be studied.

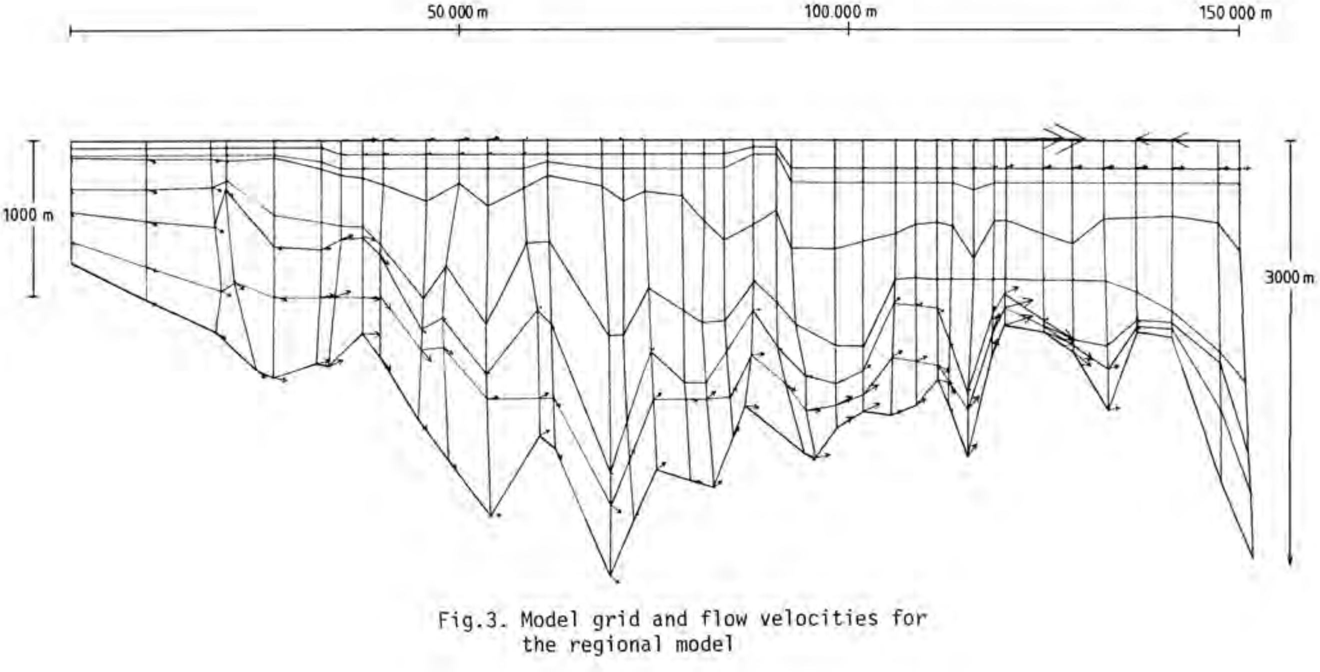

Fig.3. Model grid and flow velocities for the regional model

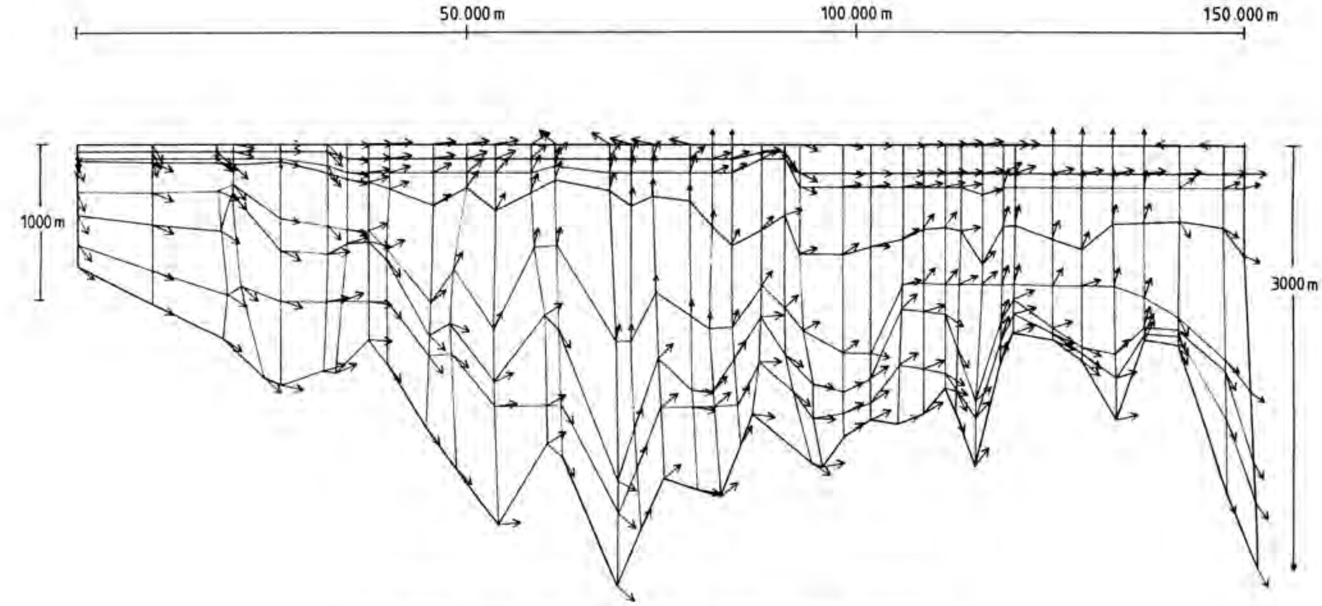

Fig.4. Flow velocities on a logarithmic scale for the regional model

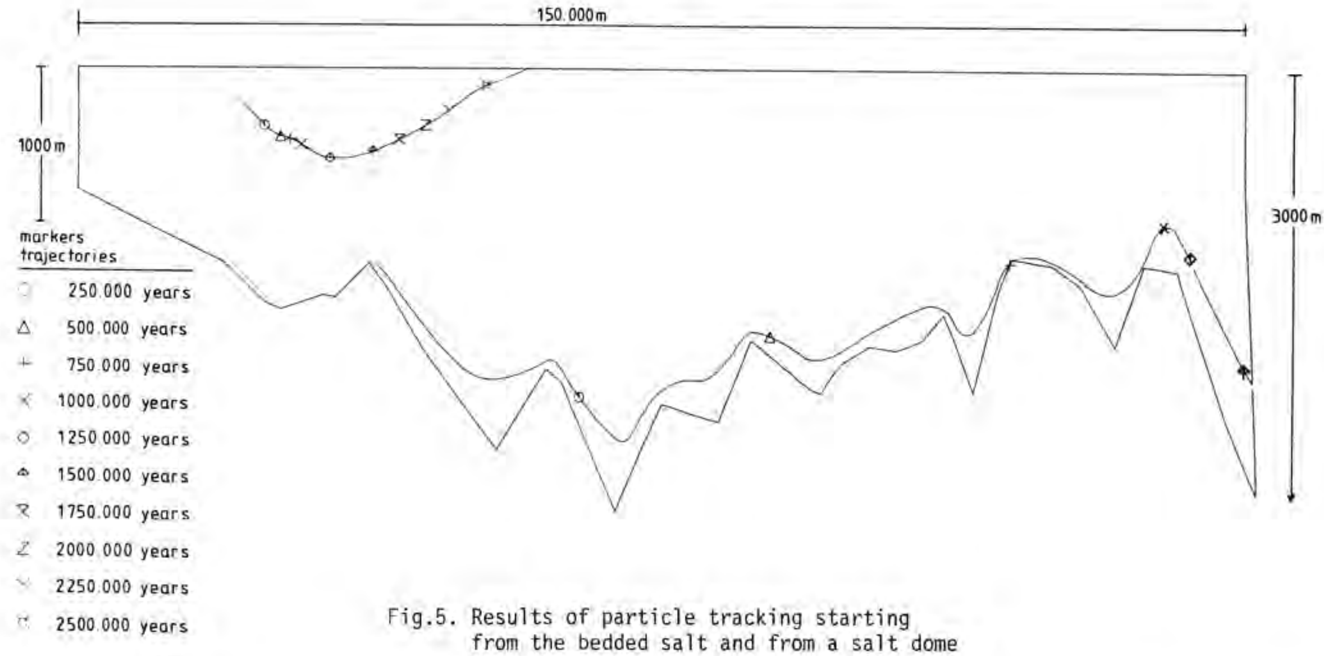

Fig.5. Results of particle tracking starting from the bedded salt and from a salt dome

SALT-DOME MODELS

Other models are being designed for groundwater flow in porous sediments overlying salt domes or pillows. A special category is formed by salt domes with a top less than 200 m below the surface. Only clayey sediments less than 100 m thick separate the top from fresh water in shallow aquifers. Lithologically, salt domes with a deep-lying top and salt pillows do not differ greatly with respect to the covering sediments.

As an example of the methodology, calculations are presented for a salt dome with its top at a depth of 800 m. Chalk of Cretaceous age overlies the top. The upper part of this Cretaceous chalk is probably more permeable than the deeper part. A continuous clay layer of the Lower Tertiary separates the Cretaceous chalk from the Eocene aquifer, which is a continuous sandy bed with a thickness of 100 m. The chalk contains almost-saturated brine. The TDS in the Eocene aquifer is generally over 100 g/l. Seismic information indicates a fault in the Cretaceous near the center of the salt dome. Since no data are available on the permeability of this fault, it was set arbitrarily at 100 times the permeability of the surrounding medium. The other data are derived from regional information and correlation with measurements elsewhere in the N.W. European Basin. It was not considered relevant to make a detailed model of the shallow aquifer system, which is interbedded with clay lenses. Because we expected extremely long travel times, there was no reason to take the present piezometric heads as top-boundary condition. With respect to the topographic differences in the N.E. part of The Netherlands, which are mainly due to gla-

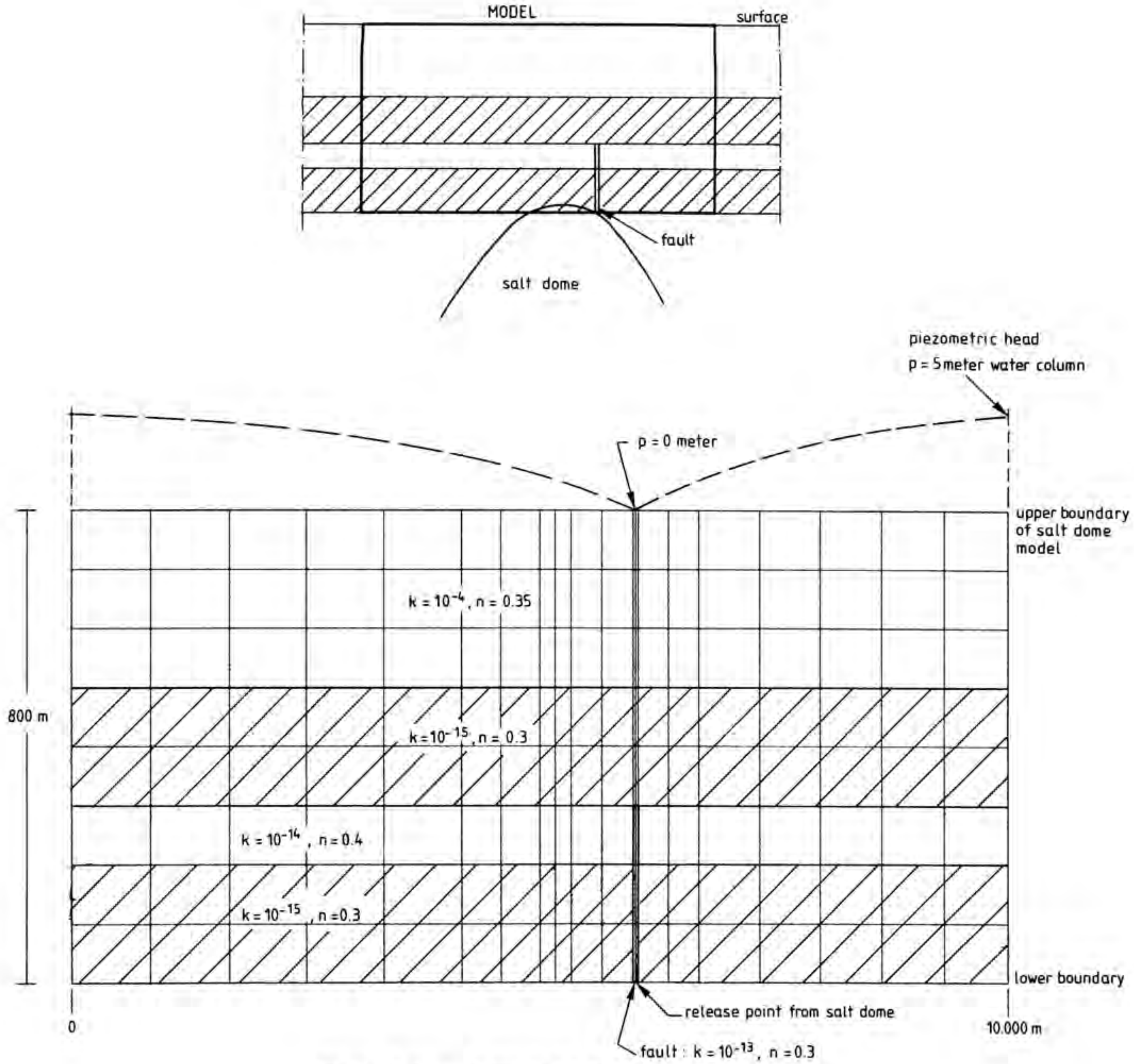

Fig.6. Set-up of the model for a salt dome with a deep-lying top

ciation, a gradient of 1/1000 is a high but not unrealistic value.

Schematization

The model comprises four layers differing as to permeability and porosity (see Fig. 6). Note that in this first example only the area above the salt dome is dealt with. The selected grid consists of rectangular blocks differing in size. The fault is modeled with much smaller blocks than the surrounding layers are. Two water-divides are placed 10 km apart, and, as a worst-case approach, the seepage zone is hypothetically placed just above the fault in the Cretaceous. The source term for the release of brine containing radionuclides is placed beneath this fault and the rate of this source term is set at 1 m^3/a.

Results

The plot of the velocity field (Fig.7) shows rather high velocities in the upper layer and none at all in the lower layers. In Fig. 8 the velocities are plotted on a logarithmic scale; this figure also shows velocities in the other layers, albeit much smaller ones. A better impression of the flow system can be obtained from this Figure.

Particle tracking

Figure 7 shows the pathway of the particle tracking as well. The particle moves straight from the source to the upper boundary. The travel time is about 170,000 years, and is significantly longer if the seepage zone is not located directly above the fault.

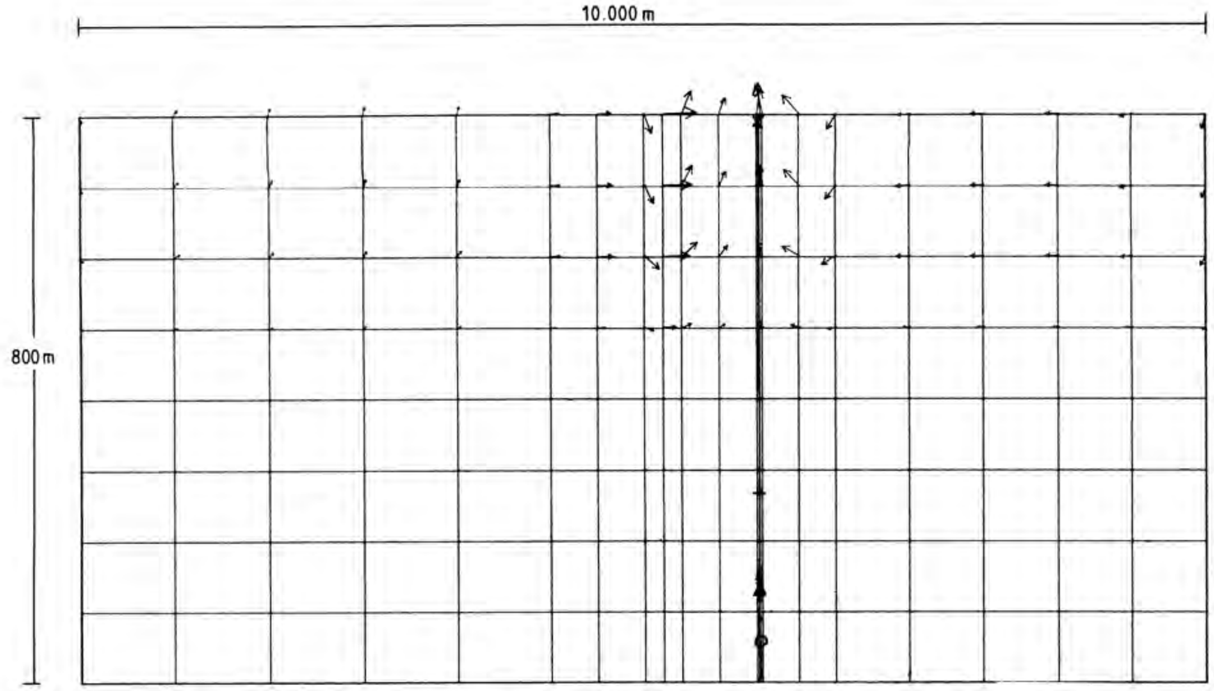

Fig.7. Model grid, flow velocities, and results of particle tracking for the salt dome model

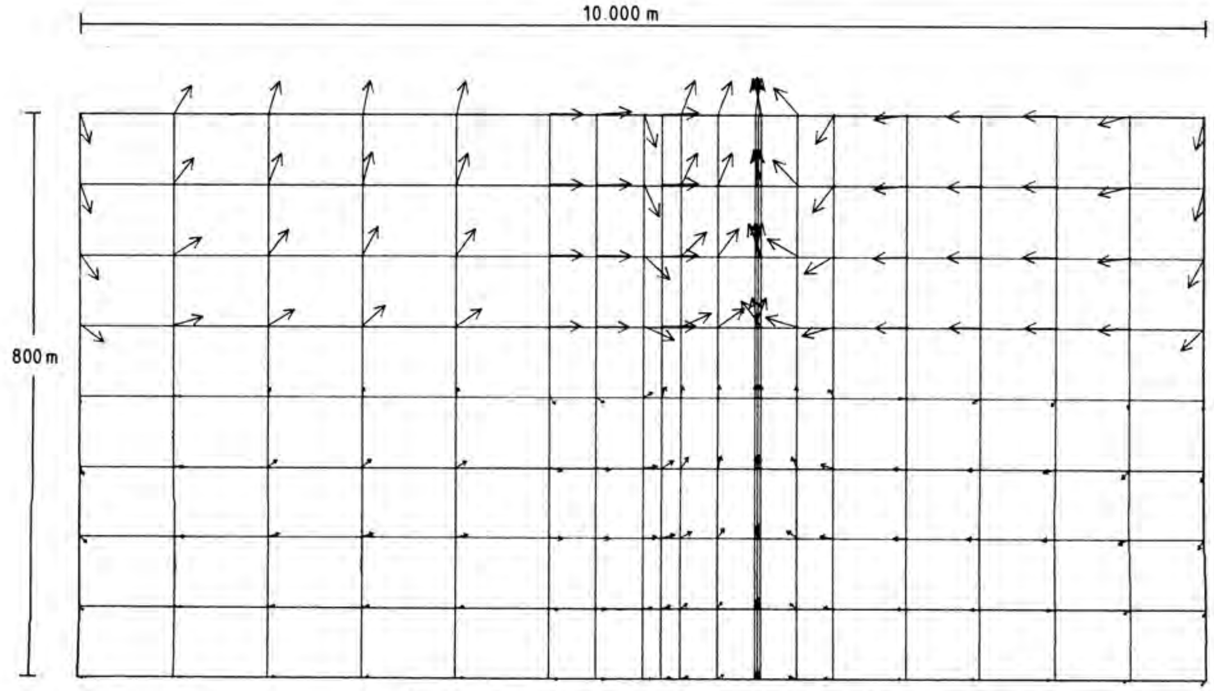

Fig.8. Flow velocities on a logarithmic scale for the salt dome model

CONCLUSIONS

The underground travel times calculated for several possible locations for a radio-active waste repository in rock-salt show that for particles starting at the bedded salt, that time might amount to more than a million years. This long duration is probably due to the favorable hydrological conditions in the North Sea Basin, where The Netherlands is situated. Small differences in height and the absence of deep-carving valleys form a hydrological environment dominated by very slow horizontal movement of groundwater. Release from deep-lying salt domes would lead, under worst-case conditions, to travel times of about 10^5 years.

These preliminary results show that the applied methodology makes comparison of formation types feasible. In these two hypothetical situations, however, the travel times are so long that any differences in the ultimate radiological consequences would probably be negligible.

FUTURE DEVELOPMENT

The runs discussed here were carried out with one density value for the fluid. The METROPOL version with variable density will be applied in due course. In a later stage of this study, nuclide migration calculations will be carried out on a local scale after the use of particle tracking to establish potential pathways of released radionuclides. For this purpose, some flow patterns in the large regional cross-section will be modeled in more detail.

The models presented here have a hypothetical source term at the upper boundary of the salt. The source term consists of an input of saturated brine released from a flooded repository by rock-mechanical processes. The definition of the source term will be provided by model calculations for migration of radionuclides inside the salt formation. These calculations are being carried out for a scenario describing intrusion of water into the repository and expulsion of contaminated brine, as well as for a scenario describing migration of brine inclusions in the salt toward the heat-producing waste, again followed by expulsion from the salt structure. For all scenarios the existence of a permeable and continuous anhydrite layer running from the repository toward the salt surface is obligatory.

The sensitivity of the groundwater flow system to sea-level variations requires evaluation too. In this context, the question of the usefulness of validating models incorporating groundwater pressures measured in boreholes is relevant, because of the possibility that the observations do not represent a steady state condition. Important sea-level changes related to ice ages, have occurred in the past. For situations with travel times of hundreds of thousands or millions of years, the use of an estimated average boundary condition seems acceptable, whereas for shorter travel times extreme situations need careful consideration. The boundary conditions applied for the salt dome case represent such an extreme.

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