ATTACHMENT 1

# The German Approach to the Disposal of Radioactive Wastes

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# THE GERMAN APPROACH TO THE DISPOSAL OF RADIOACTIVE WASTES

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## Abstract

In the Federal Republic of Germany the PTB is responsible for the construction and operation of the repositories in which radioactive wastes will be disposed of. Two repositories are planned:

- Gorleben (salt dome; for all types of radioactive wastes)
- Konrad (abandoned iron ore mine; for radioactive wastes with negligible thermal influence upon the host rock).

The safe operation of the repositories has to be demonstrated to the licensing authorities. These are the responsible Ministers of the Federal States (Länder) and the mining authorities. According to the "safety criteria for the disposal of radioactive wastes in a mine", the safety of a repository has to be demonstrated by a site specific safety assessment for the normal operation of a repository, for incidents in the operational phase, and the post-operational phase. These assessments result in waste acceptance requirements. The compliance of the waste packages to be disposed of with the waste acceptance requirements is checked with a waste package quality control either by random tests on waste packages or a qualification and inspection of waste conditioning processes.

Preliminary waste acceptance requirements have been set up for the planned Konrad repository. In the Kernforschungsanlage Jülich (KFA) a group for the quality control of radioactive waste has been established on behalf of the PTB. The application documents for Konrad have been completely submitted to the licensing authority. The operation of the Konrad repository is anticipated for the year 1990. Preliminary safety assessments have only been performed for the Gorleben site on the basis of model assumptions. These are planned to be updated in 1986/87 on the basis of the results of the site investigation from surface and on new data of the wastes to be disposed of.

Presently, the sinking of the two shafts is under way. This will be followed by an underground investigation of the salt dome, which will last until about 1992. The beginning of operation of this repository is planned for about the year 2000. According to the recent inquiries it will be possible by this approach to dispose of all arising radioactive wastes of the Federal Republic of Germany.

## 1. INTRODUCTION

In the Federal Republic of Germany the Physikalisch-Technische Bundesanstalt (PTB) is responsible for the construction and operation of the repositories in which radioactive wastes will be disposed of /1/. The PTB may make use of the services of third parties in order to construct or operate these facilities. For this task the Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH, DBE (German Company for the Construction and Operation of Repositories for Waste Material), was founded in 1979. It is directly supervised by federal authorities. The organization of the disposal of radioactive wastes is illustrated in Fig. 1.

Two repositories are planned (Fig. 2):

- Gorleben (salt dome; for all types of radioactive wastes)

- Konrad (abandoned iron ore mine; for radioactive wastes with negligible thermal influence upon the host rock).

Additionally, it is planned to inject tritium-containing water from the reprocessing of spent fuel into deep geological formations, especially porous sediments. A pre-examination of possible sites in Bavaria is under way.

From 1967 to 1978, the former Asse salt mine was used as a pilot repository within the scope of a licence limited in time. It now serves as the R+D facility whose work aims at determining above all the thermal and thermomechanical effects of the heat generating wastes. This information is required for the construction of the Gorleben repository.
The costs for work carried out in connection with the repositories are being paid by the waste producers according to the "Endlagervorausleistungs-Verordnung" (Advance Payment Ordinance), /2/. The total costs which will have accumulated until the repositories will be put into operation have been

estimated to be about $10^9$ DM for Konrad and about $2{,}6 \cdot 10^9$ DM for Gorleben.

The state of the planning and practical work carried out in connection with the repositories and the organisational measures taken indicate that it is possible to dispose of all radioactive wastes arising from the operation of nuclear power plants ând other facilities where radionuclides are used.

## 2. THE PLANNED REPOSITORIES

### 2.1 Gorleben

The Gorleben site is under investigation to check the suitability of the salt dome for the disposal of all types of radicactive wastes, especially heat-generating wastes. A comprehensive site investigation programme has been elaborated in cooperation with the Bundesanstalt für Geowissenschaften und Rohstoffe, BGR (Federal Institute of Geosciences and Natural Resources) /3/.

The investigations from above ground are almost terminated and the results were published in May 1983 in a summarizing interim report /4/.

These investigations were carried out in an area of roughly 300 $km^2$ and included:

- 129 hydrogeological exploratory drillings,
- 275 observation drillings, which have been expanded for use as ground water measuring locations,
- 1 well for pumping tests,
- 11 core drillings,
- more than 40 drillings sunk down to 80 m into the salt,
- 4 salt dome exploratory drillings of about 2000 m into the flanks of the salt dome, and

- an intensive seismic measuring programme.

Fig. 3 shows the exploration area and the locations of the hydrogeological investigations, the 4 salt dome exploratory drillings and 2 shaft pre-borings.

The resulting site-specific data include special information about

- the hydrogeological situation in the overlying and surrounding strata of the salt dome,
- the sorption data of radionuclides in Gorleben samples (sediment and waters) /5/,
- the geological situation in the caprock area,
- the existence and sequence of the various strata within the salt dome, and
- the locations for the shafts.

Figures 4 and 5 are sectional views of the overlying strata and the salt dome as examples of the results of the site investigation.

It was concluded from these results that the salt dome's suitability for waste disposal was confirmed and that those data which can only be obtained by an underground exploration are still lacking. For this purpose, two shafts must be sunk. The salt dome is to be explored by drillings from galleries of the exploratory mine into the surrounding rock /6/. An area of about 19 $km^2$ is to be investigated.

In July 1983, the Federal Government approved of the speedy commencement of the underground exploration.

The two shafts are being sunk by the Arbeitsgemeinschaft Schächte Gorleben, ASG (Gorleben shafts pool) making use of the "freezing technique". The work has been in progress since 1984. The preparation of the "freezing boreholes" began in May 1984 (Fig. 6). After the construction of a frost jacket the work on the sinking of the first shaft began in March 1986 (Fig. 7) and has now reached a depth of about 50 m. Work on the second shaft will be started in October 1986. The cumulative inventory of $\beta/\gamma$-emitters and of $\alpha$-emitters in the repository after 50 years of operation has been estimated on the basis of previous planning work to be in the order of magnitude of $10^{21}$ Bq and $10^{19}$ Bq, respectively /4, 7/. The annual data for the amounts of waste, the required host rock volume and activities are compiled in Table 1, /7/.

The heat-producing wastes are to be disposed of in boreholes (300 - 600 m deep). The other wastes will be emplaced in mined rooms (Fig. 8).

These planning data are currently being revised and will be updated in 1986/87 due to new developments in the data basis for radioactive wastes and the results of the site investigation.

## 2.2 Konrad

The Konrad mine is the most recent of all former iron ore pits in the Peine-Salzgitter area und has two shafts (Fig. 9). It is located in the south of the large iron ore sediment (Fig. 10) which was deposited about 150 million years ago during the Upper Jurassic (Malm). Ore Mining in 800 - 1300 m depth started in 1965 and was stopped in autumn 1976 for economic reasons. As the Konrad mine is very dry it was investigated from 1976 - 1982 by the Gesellschaft für Strahlen- und Umweltforschung mbH, GSF (Company for Radiation and Environment Research) for its potential suitability for the disposal of radioactive wastes. On the basis of the positive results of the GSF /8/ the PTB applied for the initiation of a plan-approval procedure on August 31, 1982 and submitted the completed documents on June 30, 1986 to the licensing authority.

In the meantime the PTB carried out supplementary work necessary to demonstrate the suitability of the mine in the course of the licensing procedure. This work included

- an underground exploration of the disposal areas,
- seismic measurements,
- one deep drilling,
- the development of a concept for the design and operation of the repository and a drafting of the facilities,
- the measurement of sorption data for radionuclides on Konrad samples (sediment and waters) /5/,
- the performance of safety assessments (for the normal operation of the mine, for incidents and for the post-operational phase), and
- the derivation of preliminary waste acceptance requirements.

As examples of the results of this supplementary work, a revised sectional view of the Konrad strata (Fig. 11), a diagram of the planned storage operations (Fig. 12), and a diagram of the anticipated waste emplacement areas (Fig. 13) are shown. In these areas presently under consideration it will be possible to dispose of about 650 000 $m^3$ of non heat generating waste packages in extended galleries with a cross-section of about 40 $m^2$ (Fig. 14).

The cumulative activity inventory of the Konrad mine at the end of its operation as a repository has been estimated. Accordingly, the activity of $\beta/\gamma$-emitters will be in the order of magnitude of $10^{18}$ Bq, and the activity of $\alpha$-emitters will be about $10^2$ times lower.

## 3. SAFETY REQUIREMENTS

### 3.1 Safety Criteria

The basic aspects which must be taken into account for the disposal of radioactive wastes are compiled in the "Safety Criteria" /9/ recommended by the Reactor Safety Commission in 1982 and announced by the Federal Ministry of the Interior in 1983. The following criteria are considered to be most important:

- The required safety of a repository constructed in a geological formation must be demonstrated by a site-specific safety analysis which includes the overall geological situation, the technical concept of the disposal mine and the waste packages.

- The objectives for the operation of a repository are prescribed by the German Atomic Energy Act /1/ and the German Radiation Protection Ordinance /10/.

- In the post-operational phase, the radionuclides which might reach the biosphere via the water path as a result of transport processes not completely excludable must not lead to individual dose rates which exceed the limiting values specified in § 45 of the German Radiation Protection Ordinance /10/ (30 mrem/a concept).

The safety criteria specify the scope of a site-specific safety analysis. The following aspects must be investigated (Fig. 15):

- In the operational phase of a repository, the radiation exposure of the personnel and of individuals in the environment of the facility to direct or scattered radiation as well as to radionuclides released via the air path or by liquid effluents must be judged.

- Additionally, the resulting effects of the heat generation per waste package must be analysed.

- In incident scenarios in the operational phase, mechanical and/or thermal impacts on the waste packages must be considered.

- In the post-operational phase of a repository, the radiation exposure of individuals in the biosphere due to radionuclides released from waste packages and transported via the water path is to be evaluated.

## 3.2 Development of Waste Acceptance Requirements and Quality Control

The PTB has developed a basic procedure (Fig. 16) to derive waste acceptance requirements /11, 12, 13, 14/ and a quality control programme to check compliance of waste packages with the waste acceptance requirements /12, 15, 16, 17, 18/.

The development of waste acceptance requirements (Fig. 16) is based on the characteristic properties of the waste, the layout of the disposal mine, and the geological situation at the envisaged site. With such a set of data it is possible to define preliminary waste acceptance requirements with a safety assessment in an iterative process between the waste producers and the operator of the repository. These are reviewed by the licensing authority, and waste acceptance requirements are established at the end of the licensing procedure.

The waste packages must fulfill the waste acceptance requirements. The waste producers are responsible for the quality of the waste packages. Compliance of the waste packages with the waste acceptance requirements must be checked by a waste package quality control. This can be done by a qualification of conditioning processes and subsequent controls and inspections or by a checking of waste packages with destructive or non-destructive tests. Additionally, checks of the documentation are necessary.

# 4. APPLICATION OF THE SAFETY CRITERIA

## 4.1 Gorleben

All existing assessments for the Gorleben site are based on model assumptions of the geology, the layout of the repository and the radioactive wastes. They were performed at the end of the seventies. Only the calculations of the long-term safety include parts of the hydrogeological investigations. Therefore, only weak points could be identified at this preliminary stage. All the assessments will have to be revised after the underground exploration. Additionally, the disposal of spent fuel will have to be allowed for in future plannings.

### 4.1.1 Normal Operation

In the normal operation of the repository significant releases from radioactive wastes could result from gaseous radionuclides and aerosols. In a preliminary assessment /11/ it was found that the release for H-3 from zircaloy -fuel element hulls fixed in concrete possibly could exceed the limits for the H-3 concentration in the air. Ranges of possibly tolerable average release rates of volatile radionuclides from waste packages have been derived from model calculations (Table 2), /19/.

The exposure to direct radiation can be adjusted to the required limits, e. g. by providing sufficient shieldings.

### 4.1.2 Incidents

The analysis of possible incidental events showed that mechanical or thermal impacts or a combination of both could be representative /11, 12/. The boundary conditions for these impacts will be evaluated within the scope of the anticipated updating of the preliminary assessments.

### 4.1.3 Thermal aspects

One of the main problems in the disposal of heat generating wastes is the influence of the dissipated heat on the waste package, the disposal area and the host rock.

The layout of the repository is based on a maximum temperature of 200 °C at the surface of the glass blocks of the vitrified fission product concentrate and 100 °C for cemented wastes /11, 12/. This limitation resulted from the chemical resistance of glass in brines and the cement properties, respectively. The disposal of these wastes has been planned to be carried out in deep boreholes (300 m-600 m). The limitation of the initial heat per waste package is e. g. dependent on the age of the waste, the distance and length of the boreholes, and the emplacement within the boreholes (longitudinal heat dilution) /12, 20/.

The temperature distribution in a host rock formation has been calculated on the basis of model assumptions for the Gorleben salt dome. The time dependence of the heat dissipation for a repository with deep boreholes (maximum temperature of 200 °C) is shown in Fig. 17 /12, 21/. It is very important that the highest temperatures occur only locally in the center of a borehole field and for a limited period of about 100 years (between 50 and 150 years after disposal). The temperature outside the disposal field stays below 100 °C. The natural temperature distribution in the host rock is almost obtained 5000 years after waste disposal.

The effects of this temperature distribution have been simulated with two independent numerical computer programmes /22, 23/. The thermal expansion of the salt induces a velocity field within the host rock (Fig. 18) /22/, which leads to a calculated uplift of 1,2 m above the repository 450 years after disposal (Fig. 19), /22/. From this first investigation no arguments could be found against this layout of the model repository. The final layout can only be carried out after the underground investigation when the questions relevant to geochemical, physical, chemical and rock mechanical aspects can be answered.

### 4.1.4 Long-Term Safety Assessment

The intrusion of the salt into the younger, overlying strata took place between the geological periods of Malm and Lower Cretaceous. As a result of diapirism, the salt layers are folded.

Detailed knowledge of the interior of the salt dome will only be available after its underground investigation. Possible incidents are therefore conservatively considered in theory for the long-term safety assessment. It is assumed that thermomechanical effects caused by heat-generating radioactive wastes can produce new pathways for waters in the anhydrite horizons in the post-operational phase of the repository (especially in the Hauptanhydrit). In this way water from the ground-water-bearing overlying strata could intrude into the repository area. Contaminated brines could be released back into the overlying strata on the same way due to the convergency of the rock salt /24/.

In the overlying strata of tertiary, especially quaternary geological age, the sorption of radionuclides will then influence the migration of the radionuclides in the flow of ground-water. Preliminary results from an R+D study on the consequences of such a scenario have been published /25/. The intrusion of waters into the repository area and the releases of contaminated waters are shown in Fig. 20. The calculated doses from these releases are shown in Fig. 21 /25/.

Some of the main results are

- that the intruding waters do not reach the disposal area for the vitrified fission product concentrates because of the thermal layout,

- that the calculated dose rates in the environment are dominated by Tc and Np,

- that the highest dose rates occur about 10 000 years after disposal, and

- that the requirements of the safety criteria /9/ are fulfilled.

Due to recent results of the investigation of the sorption behaviour of radionuclides in Gorleben samples /5/ it could be shown that the sorption data for Np and Tc are considerably higher than assumed in /25/. Therefore, the dose rates of these radionuclides will be of less importance.

## 4.2 Konrad

The site specific safety assessments for the planned Konrad repository have been terminated and the preliminary waste acceptance requirements developed /14, 26/. The completed application documents have been submitted to the licensing authority. Final waste acceptance requirements will be set up after the licensing procedure.

### 4.2.1 Normal Operation

This safety assessment includes the direct radiation of waste packages and releases of volatile radionuclides with air (direct) or water (indirect).

The analysis of the conditions showed that the operation of the repository is possible with a suitable layout of the facility (shielding of buildings, vehicles etc.), /27/.

The deduction of annual release rates of volatile radionuclides must ensure that the calculated potential exposures in the environment are below the limits given in the Radiation Protection Ordinance /10/ and that the inhalation dose for the staff is below 0,5 mSv/a. This relatively low value is an internal planning requirement and represents a largely unavoidable exposure. The annual release rates applied are given in Table 3. From these data it is possible to derive permissible concentrations of the volatile radionuclides in waste packages taking into account the different barriers which can be the waste form, the packaging, the backfill material and the closure building of the storage rooms /27/.

#### 4.2.2 Incidents

The first step in an incident analysis is the identification of "undesired" events. About 50 of such events were identified. They could be condensed to 3 radiologically representative incidents (Table 4).

In order to calculate the radiological consequences, the fractions of the activity released in the case of an incident must be determined. Those waste packages which have comparable release behaviours can be condensed to waste form groups (i. e. requirements for the waste form) and waste classes (i. e. requirements for the packaging). Thus the maximum permissible activity contents in waste packages can be calculated if the release fractions and the additional retentions are determined and if the maximum permissible exposure rates and the calculation modes are given /28/.

#### 4.2.3 Thermal Aspects

The planned Konrad repository is only intended for radioactive wastes with negligible heat generation. According to definition wastes are in compliance with this requirement if the thermal influence upon the host rock is less than $\Delta T$ 3K. The maximum permissible radionuclide inventory can be calculated for each waste package and can be derived if the temperature distribution in the repository is determined /29/.

### 4.2.4 Long-Term Safety Assessment

The geological horizon in which the waste will be disposed of, the so-called Korallenoolith (Oxford), including the iron ore, lies at a depth of about 800 m to 1300 m. It is covered by younger sediments, most of which have a very low permeability. In the scenario for the long-term safety assessment it is assumed that in the post-operational phase the mine will be filled with waters from the surrounding rocks which have a low permeability. The contaminated waters then follow the general flow of ground-water in a northerly direction. At a distance of more than 30 km from the repository the horizon of the Oxford approaches the surface. This pathway was modelled in the safety assessment considering the retardation of radionuclides by sorption /5/. Resulting individual dose rates have been calculated. Water transfer times are in the order of several 100 000 years. It could be shown for the anticipated radionuclide inventories that the calculated exposures are below the exposure limits /10/ and only the total amount of iodine in the repository should be limited.

According to the safety criteria /9/ it is necessary to predict with a site-specific safety assessment that the exposure limits of § 45 of the Radiation Protection Ordinance /10/ are not exceeded. This procedure seems only meaningful for such a period of time which allows a sufficiently exact prediction. This time span is in the order of magnitude of 10 000 years and the forecast for the geological conditions at the site of a repository are indicated with 1 000 000 years /30/.

## 4.2.5 Quality Control for Radioactive Wastes

The PTB has established a quality control group in the Kernforschungsanlage Jülich, KFA (Jülich Nuclear Research Establishment) to control compliance of the waste packages with the waste acceptance requirements. At present, the installations for the control of waste packages are being constructed. Additionally, waste conditioners have applied for the process qualification of 8 conditioning processes. 2 more applications have been announced.

It is the aim to have enough checked waste packages available when the Konrad mine will be ready for operation as a repository.

# 5. CONCLUSIONS

The present state of the work on the repository projects reveals that the F. R. of Germany plays a leading role in managing waste disposal. Detailed information is in particular available on the data for radioactive wastes /26/ and the anticipated sites. Additionally, necessary site-specific information is under investigation.

Safety assessments which are preliminary for the Gorleben site have been performed and preliminary waste acceptance requirements derived for Konrad. This considerable technical know-how which has been compiled with contractors and in cooperation with various institutes and universities is available and will be used for the anticipated updating of the safety assessments for the Gorleben site.

The state of the planning and construction work for the repositories indicates that it will be possible to dispose of all radioactive wastes produced, in particular as their volumes will decrease as a result of new conditioning techniques.

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| | Waste volume produced per annum | | Repository volume required per annum | | Activity inventory of yearly produced waste | |
|---|---|---|---|---|---|---|
| | $m^3$ | % | $m^3$ | % | Bq | % |
| Reprocessing | $1{,}25 \cdot 10^4$ | 39,0 | $6{,}45 \cdot 10^6$ | 97,6 | $21{,}20 \cdot 10^{18}$ | 99,99 |
| HLW portion | $1{,}5 \cdot 10^2$ | 0,5 | $5{,}28 \cdot 10^6$ | 79,9 | $17{,}02 \cdot 10^{18}$ | 80,4 |
| Nuclear power | $1{,}62 \cdot 10^4$ | 50,4 | $1{,}28 \cdot 10^5$ | 1,95 | $21{,}16 \cdot 10^{14}$ | |
| Research centres | $2{,}21 \cdot 10^3$ | 6,8 | $1{,}64 \cdot 10^4$ | 0,25 | $8{,}14 \cdot 10^{13}$ | 0,01 |
| Industry | $5{,}63 \cdot 10^2$ | 1,7 | $5{,}36 \cdot 10^3$ | 0,1 | | |
| Collecting depots of the federal states | $7{,}31 \cdot 10^2$ | 2,3 | $6{,}82 \cdot 10^3$ | 0,1 | $34{,}04 \cdot 10^{12}$ | |

Table 1: Prospective quantity of radioactive waste for long-term repository planning

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Nuclide | H-3 | C-14 | Kr-85 | Ru-106 | J-129 | Rn-220 | Rn-222 |
| Non-bore-hole technique | $3\cdot10^{-3\pm1}$ | $2\cdot10^{-3\pm1}$ | $1\cdot10^{-3\pm1}$ | $5\cdot10^{-6\pm1}$ | $1\cdot10^{-6\pm1}$ | $1.10^{-5\pm1}$ | $5.10^{-5\pm1}$ |
| Bore-hole technique | $5\cdot10^{-2^{+0}_{-1}}$ | $4\cdot10^{-2^{+0}_{-1}}$ | $3\cdot10^{-2^{+0}_{-1}}$ | $6\cdot10^{-5^{+0}_{-1}}$ | $2\cdot10^{-5^{+0}_{-1}}$ | $2\cdot10^{-4^{+0}_{-1}}$ | $1\cdot10^{-3^{+0}_{-1}}$ |

Table 2: Preliminary maximum permissable mean annual release rates per waste package for volatile individual radionuclides (release rates in Ci/a waste package).

| Radionuclide/ Group of Radionuclides | Release Rates Bq/Year | |
|---|---|---|
| H - 3 | 1,48 E13 | |
| C - 14 | 3,7 E11 | |
| I - 129 | 7,4 E 6 | via |
| Rn - 222 | 1,85 E12 | air |
| aerosols (T1/2>10d) | | |
| $\beta/\gamma$-emitters | 7,4 E 7 | |
| $\alpha$-emitters | 3,7 E 6 | |
| H - 3 | 7,4 E12 | via |
| other radionuclides | 7,4 E 8 | water |

Table 3: Release rates of the repository applied for

Drop of a waste package during handling from 3 m height, onto the floor of the hall (above ground),

Drop of a waste package during emplacement in the chamber from 5 m height and

Collision of a vehicle resulting in a fire during waste transport in a transport gallery. For the fire, a fire temperature of 800 °C for 1 hour is assumed.

Table 4: Assumed Incidents (Konrad)

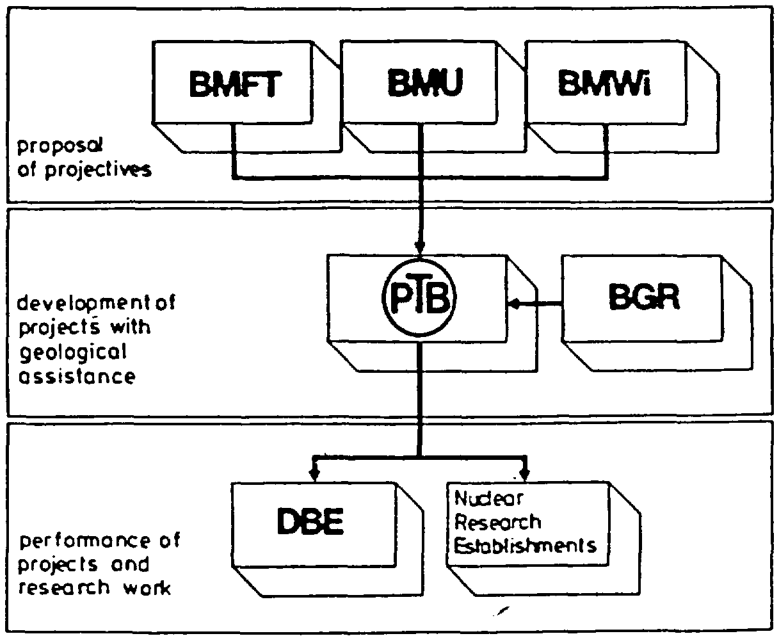



Figure 1: Responsibilities

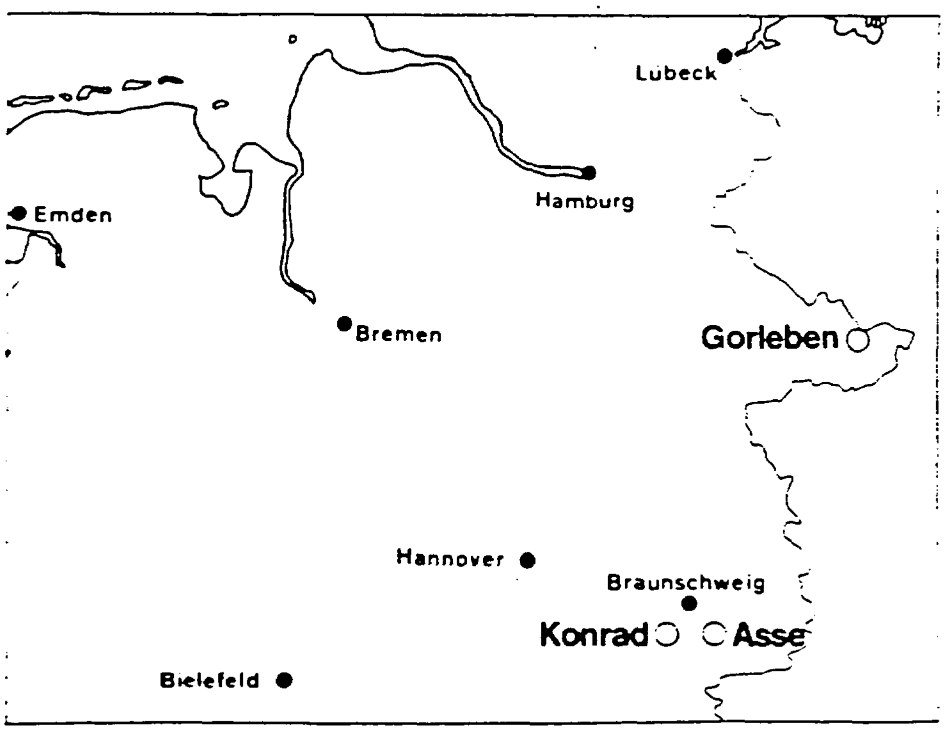



Figure 2: Locations of the sites

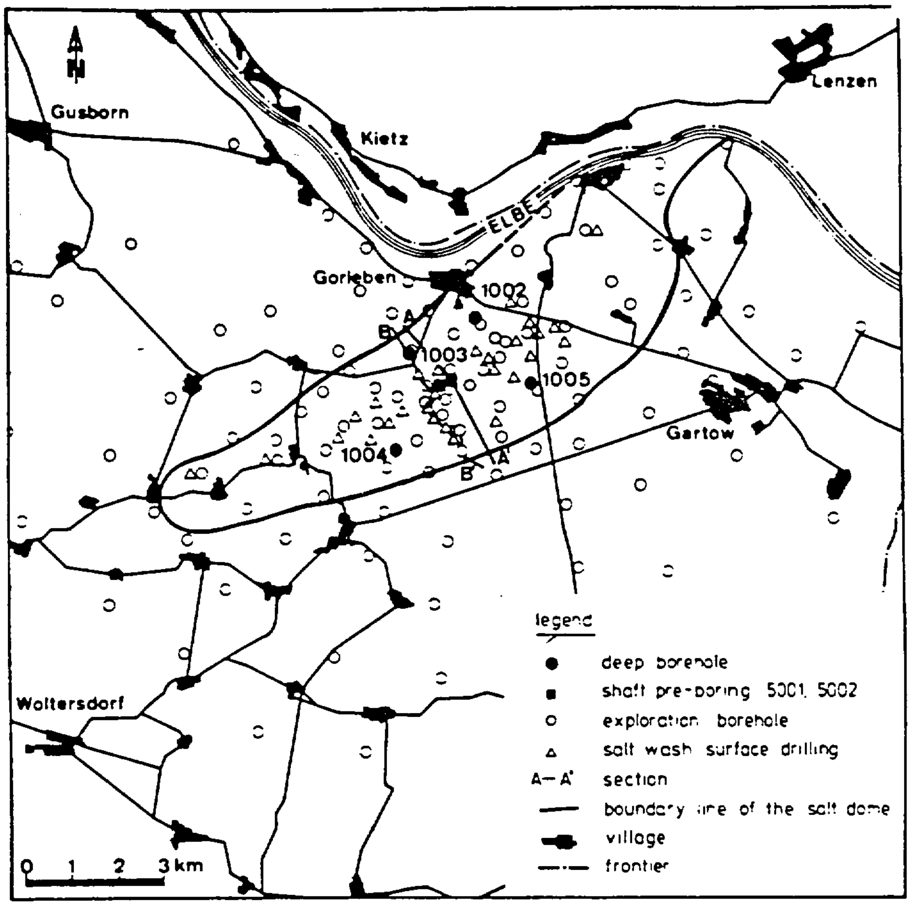



Figure 3: Locations for exploratory drill holes

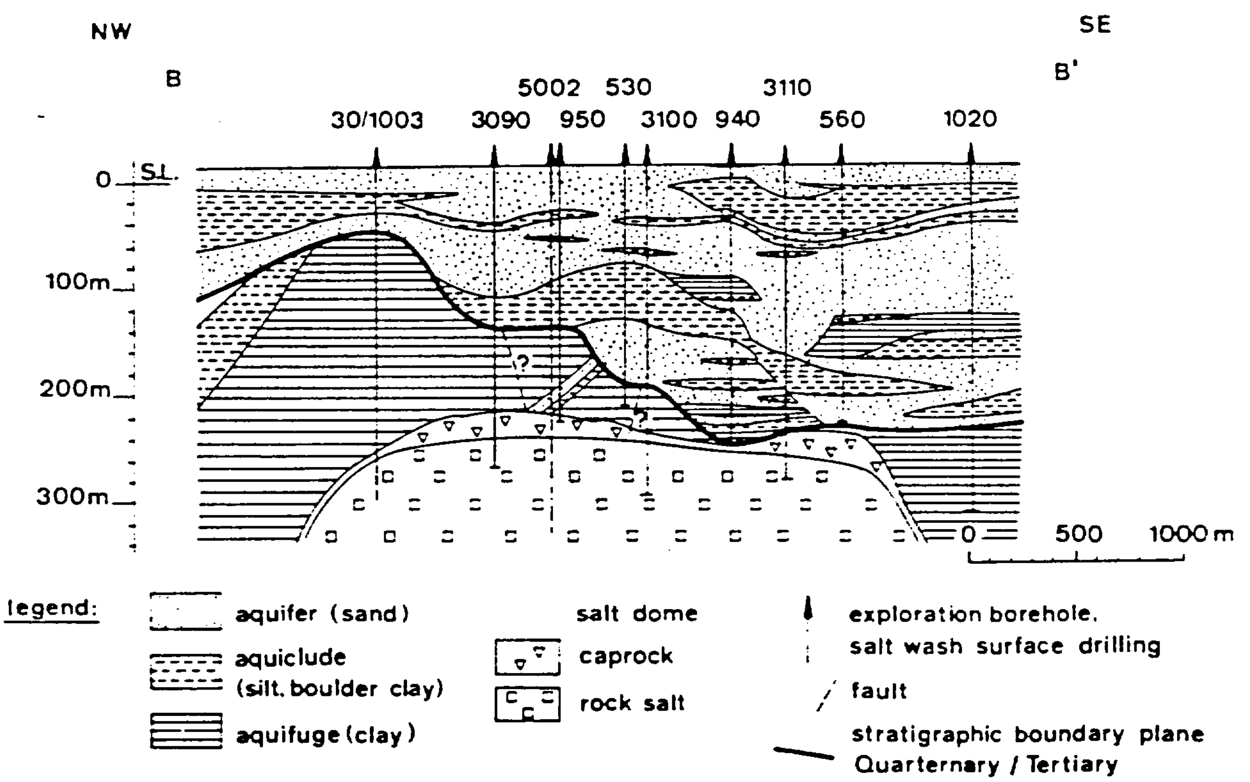



Figure 4: Geological section of the overlying strata in the channel area

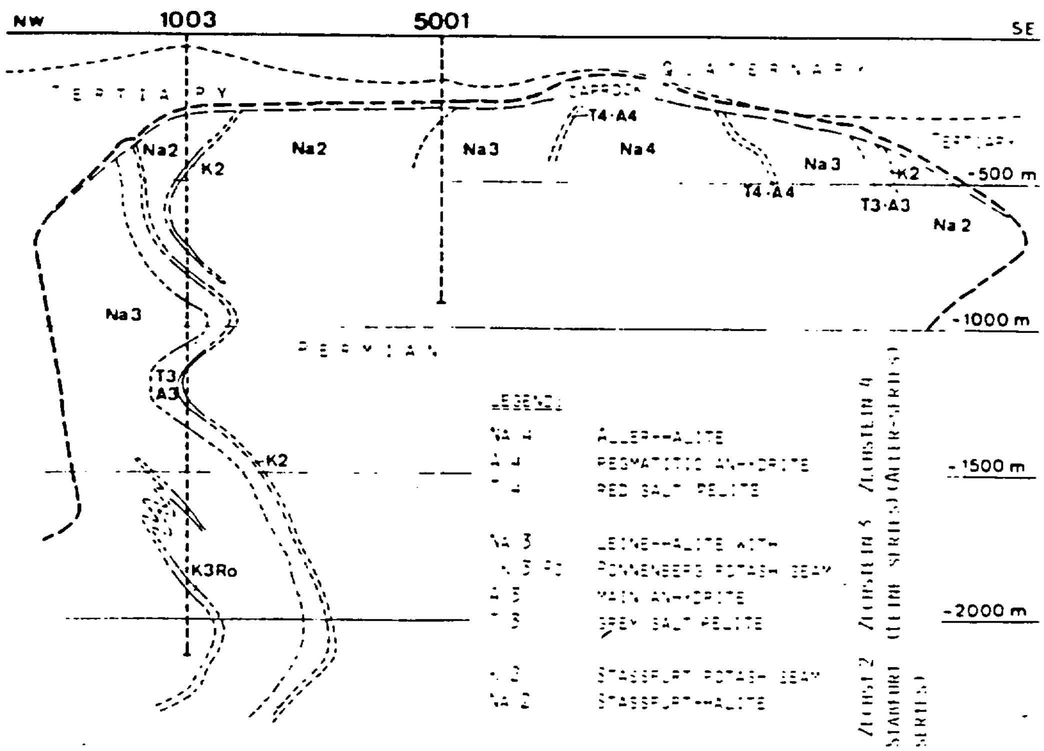



Figure 5: Section of salt dome

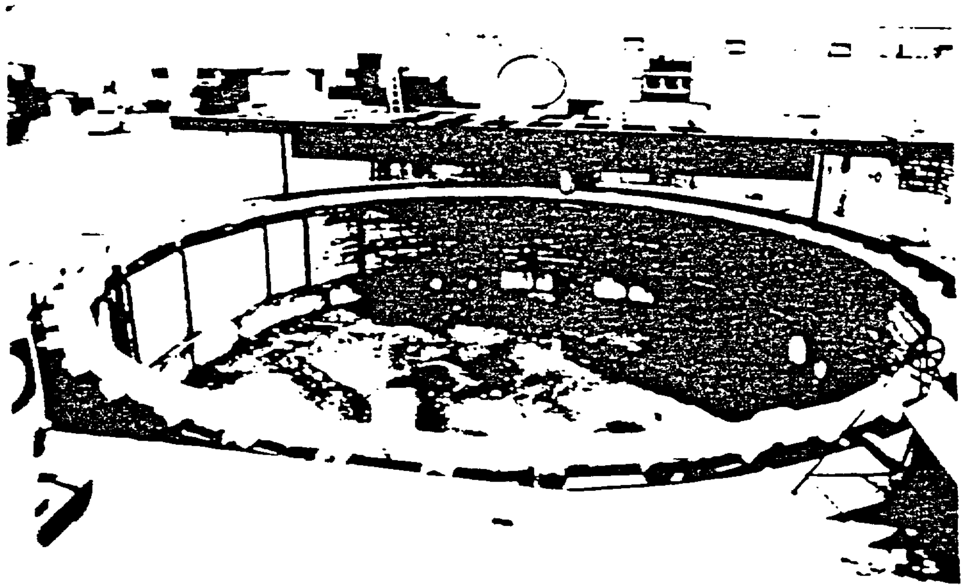


Figure 6: Sinking of the shafts by "freezing technique" (Gorleben)

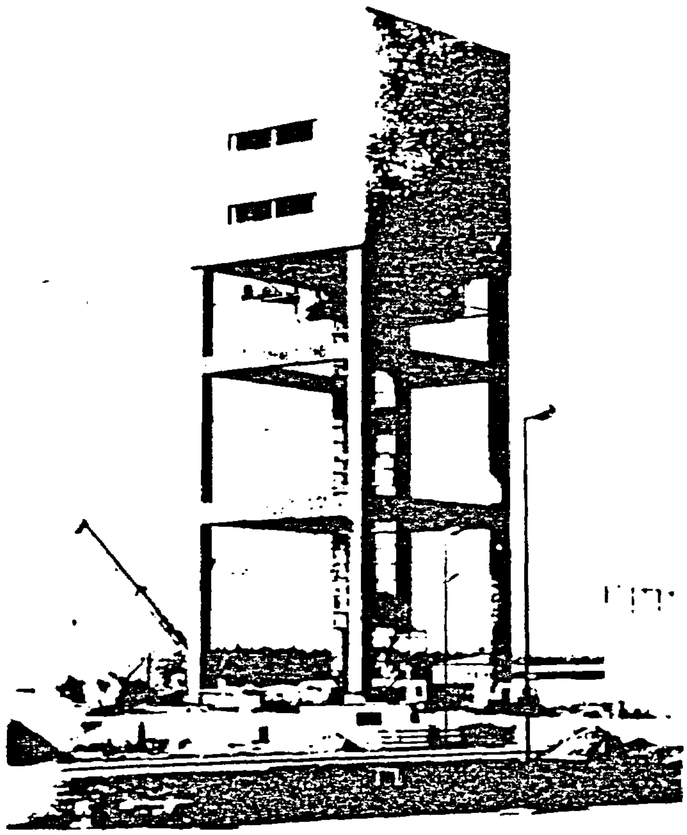


Figure 7: Hoist frame Gorleben

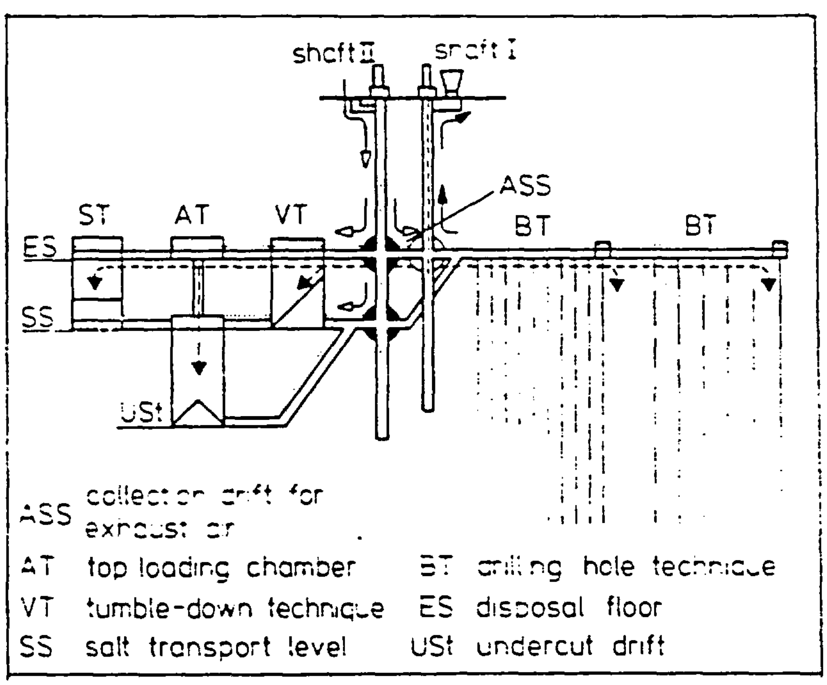



Figure 8: Schematical scope of the planned mine

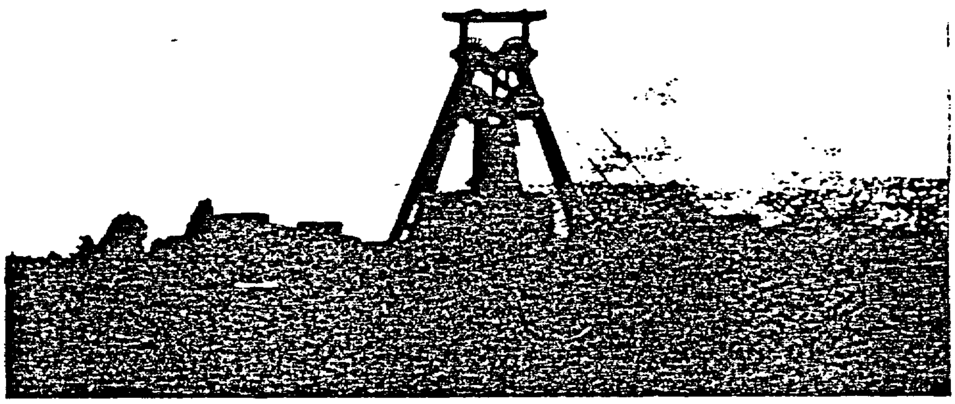


Figure 9: Hoist frame Konrad

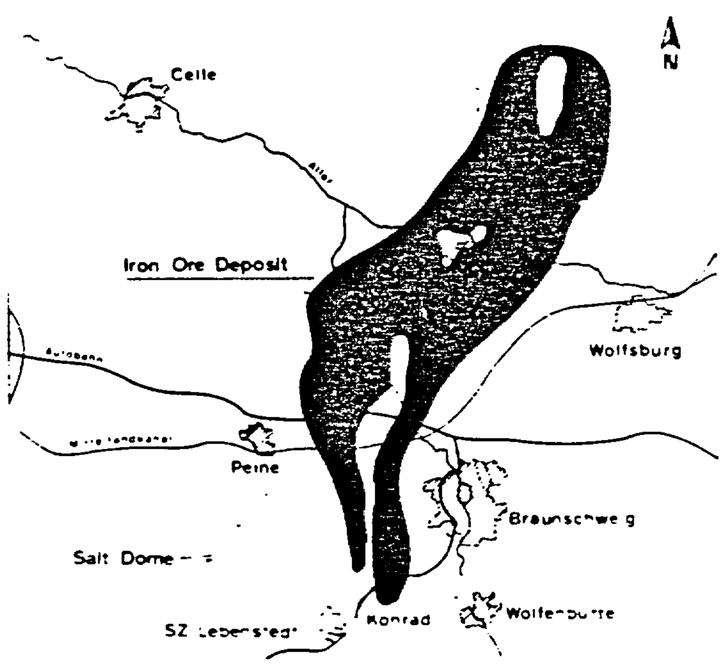



Figure 10: The iron ore deposit "Gifhorner Trog"

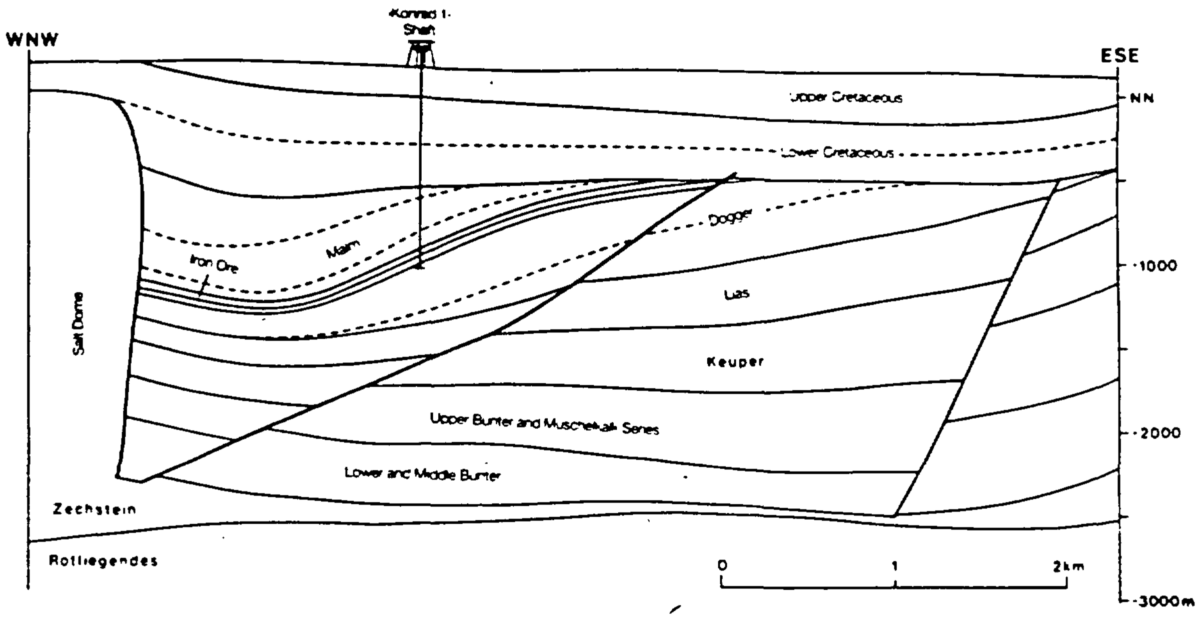



Figure 11: Cross-section through the Konrad iron ore deposit

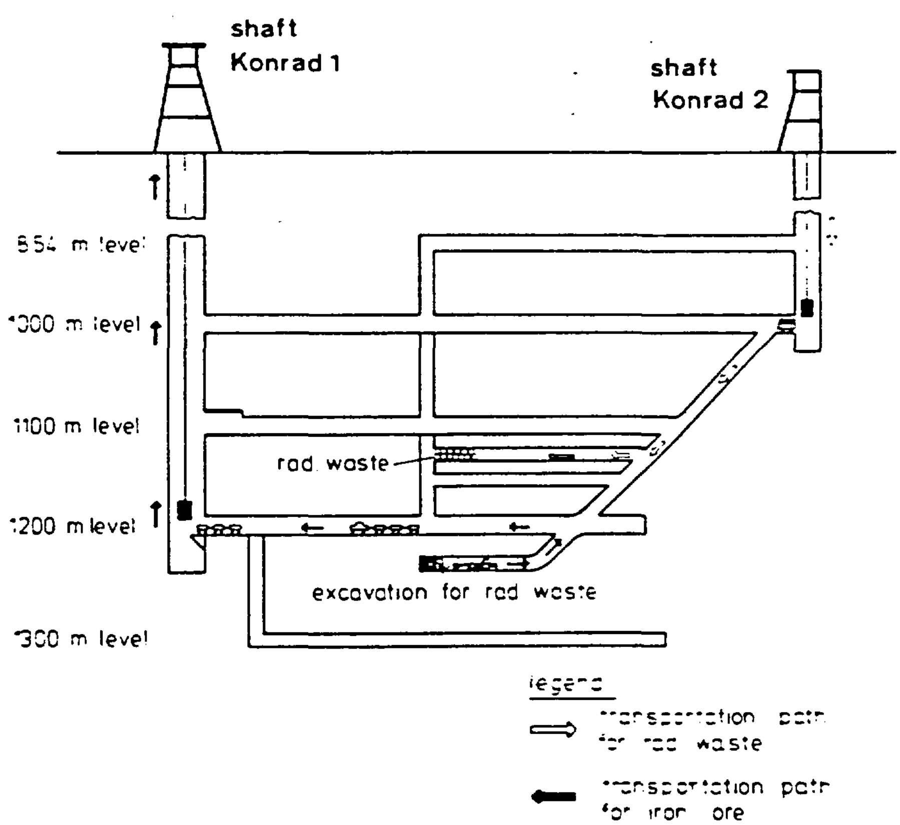



Figure 12: Principle of underground transportation

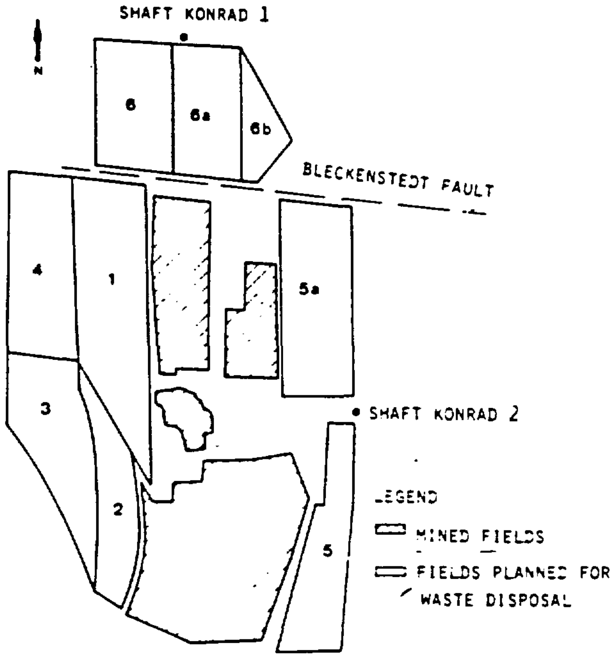



Figure 13: Fields for waste disposal (Konrad)

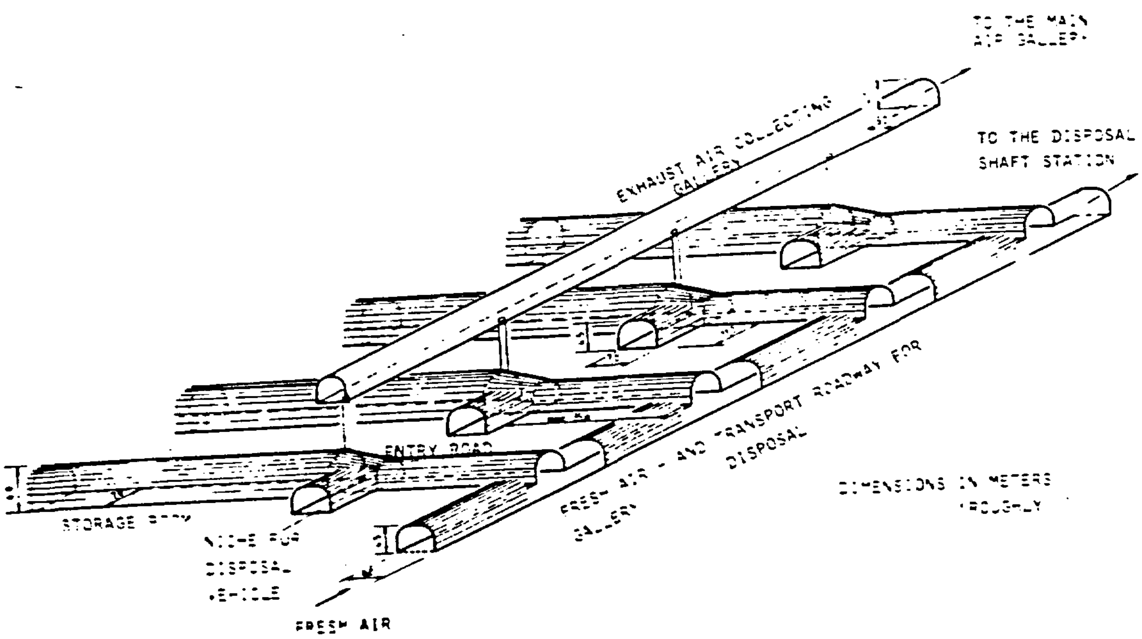



Figure 14: Principles of waste emplacement (Konrad)

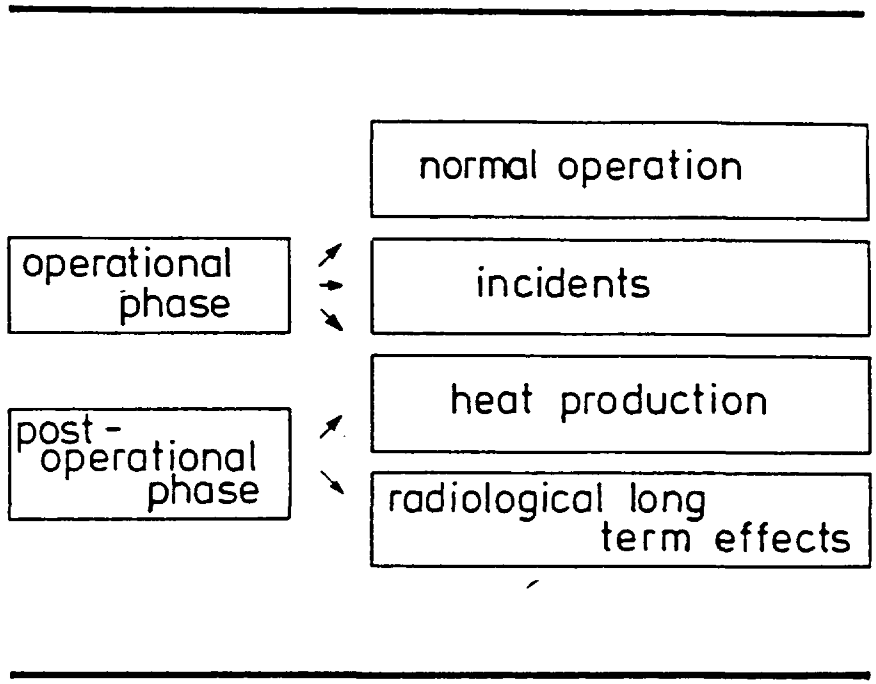



Figure 15: Safety assessments

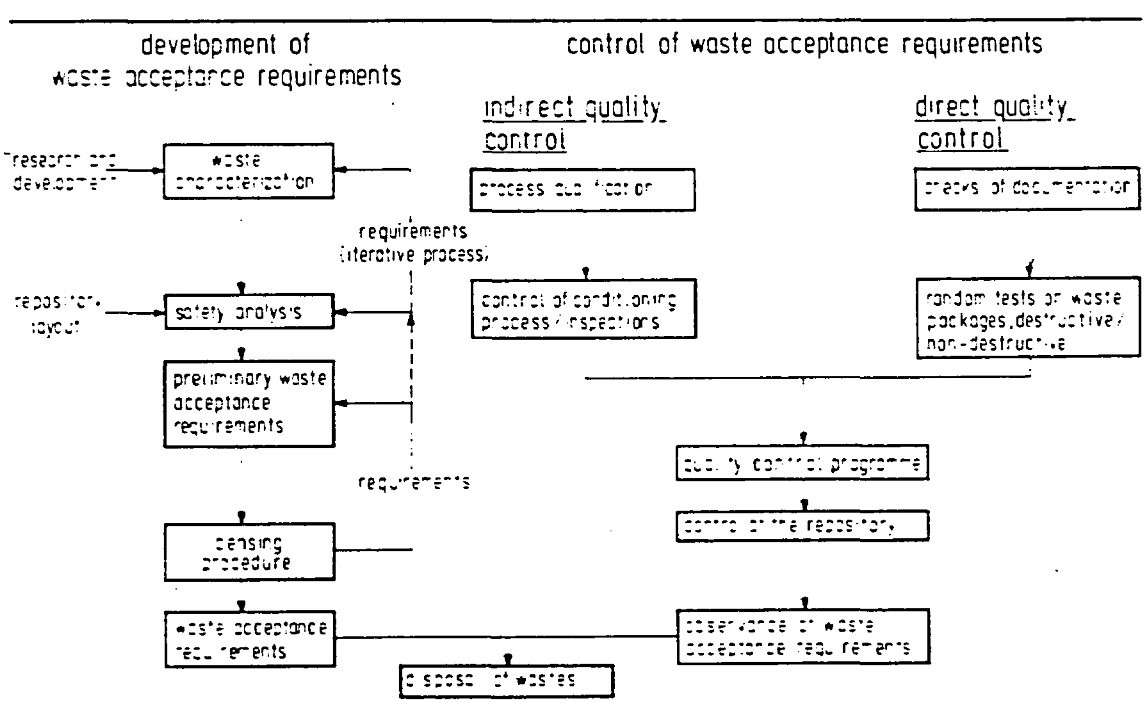
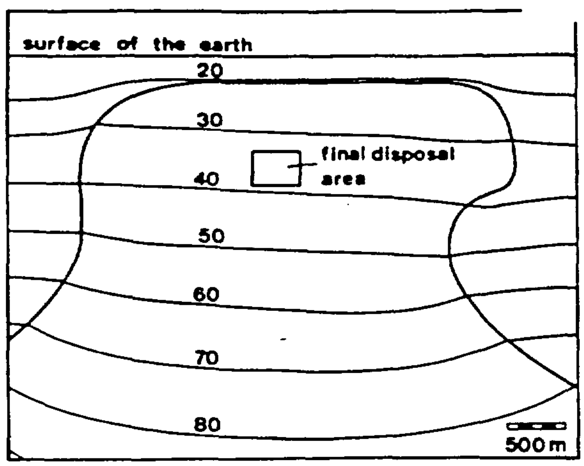
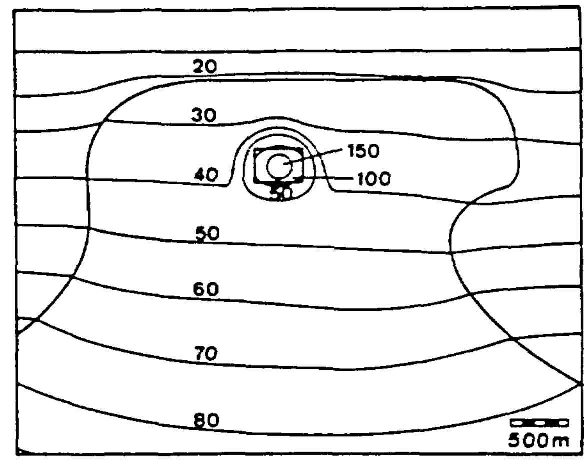


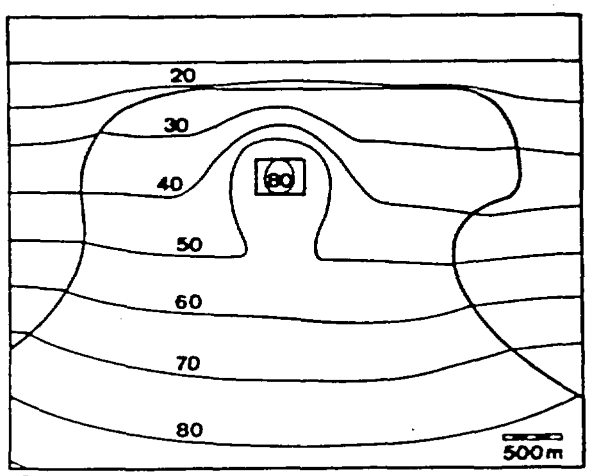

Figure 16: Principles of development and control of waste acceptance requirements



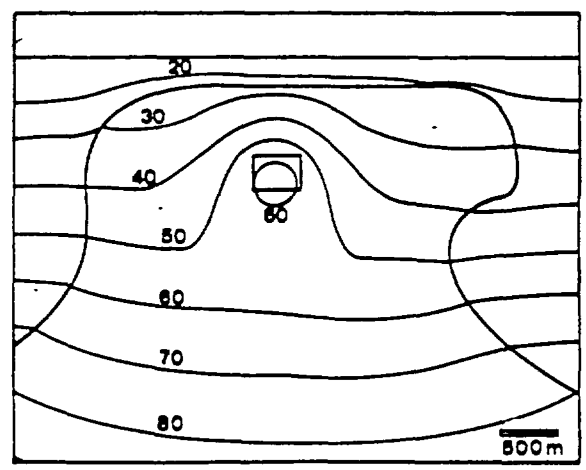

Rock Temperatures in the Model Salt Dome before HAW-Disposal



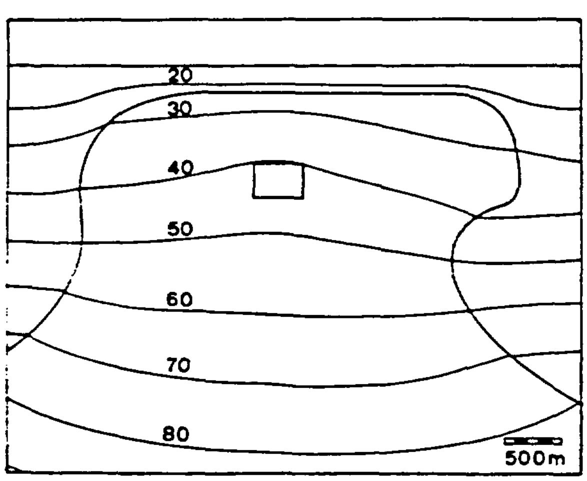

Rock Temperatures in the Model Salt Dome 100 Years after HAW-Disposal




Rock Temperatures in the Model Salt Dome 500 Years after HAW-Diposal

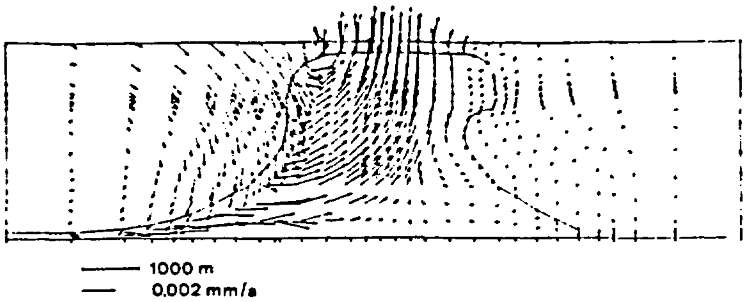



Rock Temperatures in the Model Salt Dome 1000 Years after HAW-Disposal

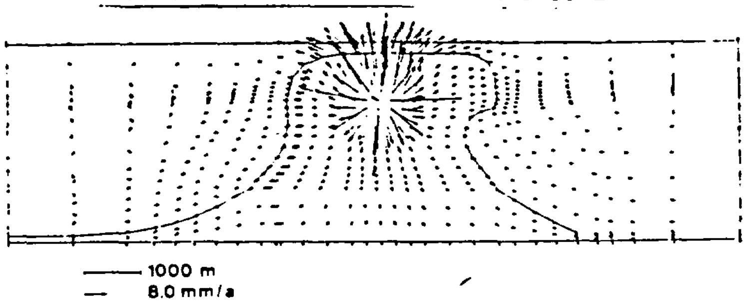



Rock Temperatures in the Model Salt Dome 5000 Years after HAW-Disposal

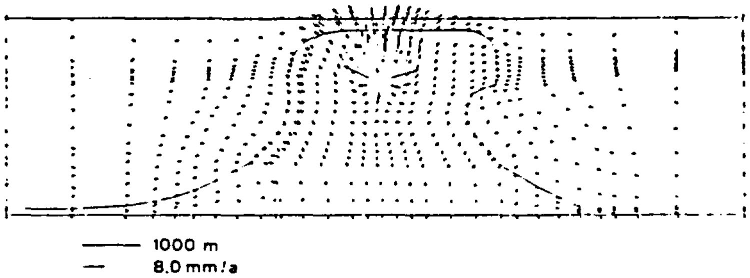
Figure 17: Calculated temperature distribution in a model salt dome



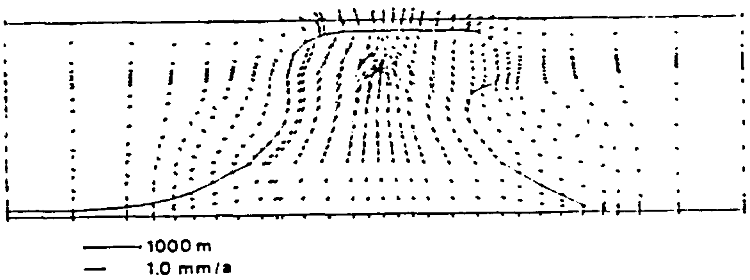

VELOCITY FIELD BEFORE HAW-DISPOSAL



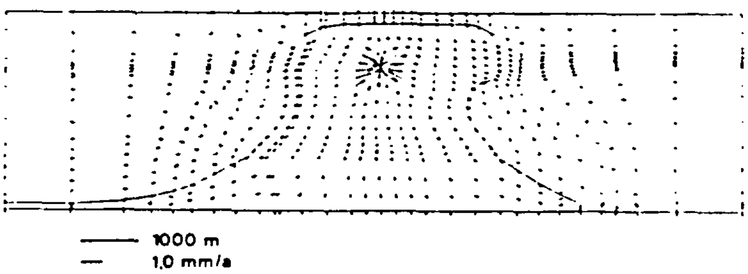

VELOCITY FIELD 20 YEARS AFTER HAW-DISPOSAL




VELOCITY FIELD 50 YEARS AFTER HAW-DISPOSAL




VELOCITY FIELD 115 YEARS AFTER HAW DISPOSAL




VELOCITY FIELD 450 YEARS AFTER HAW-DISPOSAL

Figure 18

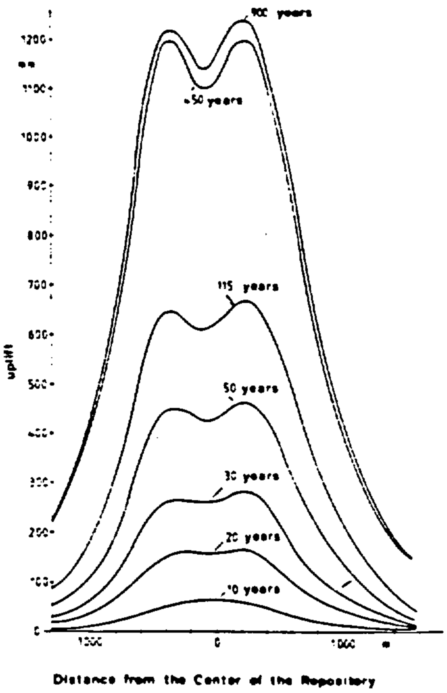



Figure 19: Uplift above the repository

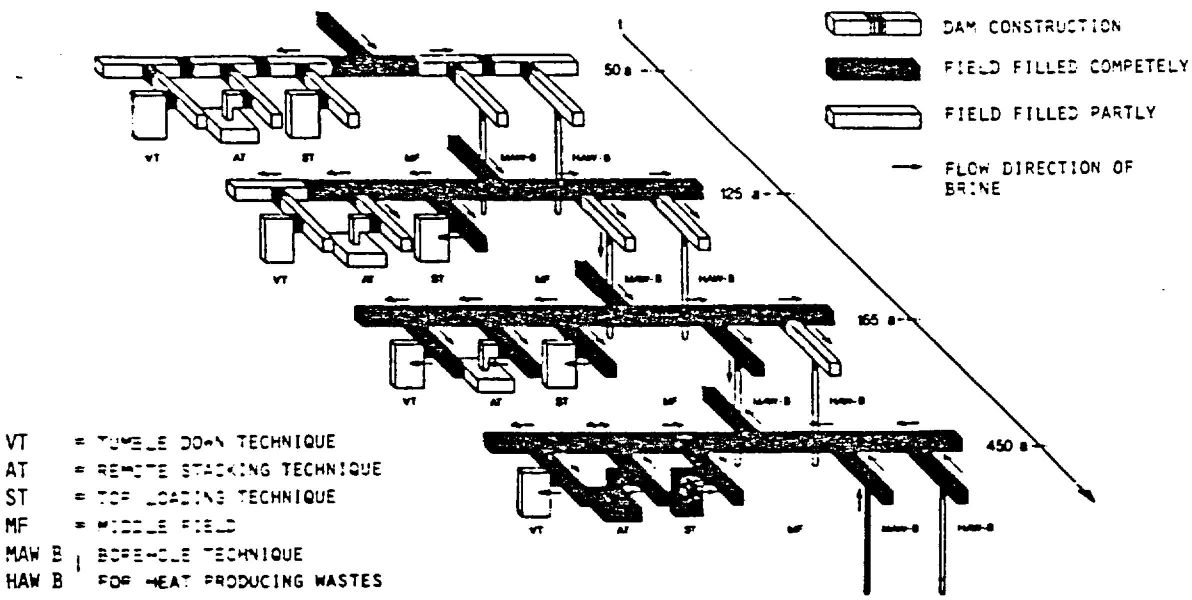



Figure 20: Time schedule of brine flow

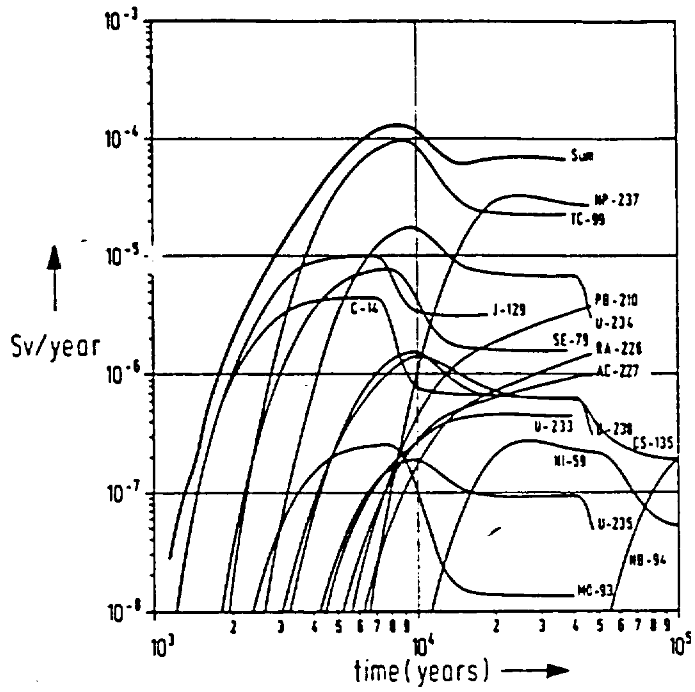



Figure 21: Contribution of some radionuclides to potential and total radiation exposure as a function of time

# CURRENT STATUS OF THE GORLEBEN PROJECT

Donald E. Clark, International Representative
U.S. Salt Repository Project
Braunschweig, FRG
August 17, 1987

## Summary

The Gorleben Project in the Federal Républic of Germany (FRG) represents an important national effort to develop a nuclear waste repository in salt. Although the Gorleben formation is a salt dome and the leading candidate U.S. salt site (Deaf Smith County, Texas) is in bedded salt, there are many similarities between the programs for disposal of nuclear waste in salt in both countries. For example, the shaft sinking technique being used at Gorleben, which involves ground freezing on a massive scale, will also be used at the Deaf Smith site. Also, the issues to be resolved by site characterization are expected to be similar (e.g., thermomechanical behavior of rock salt under repository-like conditions, and so on).

A May 1987 construction accident in one of the two shafts being sunk at Gorleben has aroused concern and opposition within the FRG to the current repository development program. In particular, antinuclear groups are exploiting this accident to the maximum extent possible, as though the incident could be taken to be a general indictment of nuclear power (in the FRG, granting of an operating license for a nuclear power plant is contigent upon demonstration that there is a solution to the problem of nuclear waste disposal). The accident has also provoked concern in the U.S.A. where questions have been raised about the viability of the shaft sinking technique.

This report, which is intended to provide a general overview of the current state of the Gorleben Project, has had the benefit of input from cognizant FRG personnel, in particular from the Physikalisch-Technische Bundesanstalt (PTB).

## Introduction

The Gorleben salt dome, situated in a remote area in the northeastern part of the Federal Republic of Germany (FRG), is being investigated as a candidate nuclear waste repository. For this purpose, two large-diameter shafts (excavation diameters of about 10 meters -- nearly 33 feet) are being sunk to depths of 850 to 900 meters (2,790 to 2,950 feet). In the region of the shafts, the top of the salt dome formation is at a depth of about 250 meters. Since water-bearing and incompetent rock layers lie above this salt formation, a freeze shaft sinking technique is being used for the shaft construction. Thus, a giant frost body, which extends down into the salt formation, is produced by means of a large-scale freezing operation at each shaft location. This is a well-established technique for shaft sinking through aquifer layers, and it permits excavation to proceed without inflow of water into the shaft.

As the shafts are being sunk through the frozen layers, preliminary wall linings (concrete blocks) are emplaced in sections having vertical dimensions of about 6-12 meters. Then, a final water-tight lining is constructed in each of the shafts. Extending upwards from a depth of about 260 meters, this permanent sealed liner system reduces the inner diameter to 7.5 meters (about 25 feet). Once the permanent liner is in place, the ground is thawed and a normal excavation procedure is followed to penetrate further into the salt formation (no liner is needed in the salt dome itself).

When the shafts are completed, they will be linked underground by means of a drift (they are 400 meters -- about 1,300 feet--apart) at the 840 meter level. Then, an extensive underground exploration program will be undertaken at this level in order to characterize the salt dome and determine its suitability as a nuclear waste disposal site. More than 25 kilometers (15 miles) of exploratory galleries will be constructed, along with the drilling of more than 50 kilometers of underground reconnaisance boreholes. Fan drilling will be done to test the salt prior to driving of all main and cross drifts. The drifts will be approximately 3 meters by 6 meters, for a cross-sectional area of 18 square meters (about 190 square feet). This program will entail exploration of an area comprising 18 square kilometers (about 6.9 square miles).

The characterization phase at Gorleben is expected to last several years, after which a site-specific license application will be prepared and submitted to the state licensing authority (State of Lower Saxony). If a license for nuclear waste disposal is granted, the Gorleben disposal level will be constructed at a depth 30 meters below the site exploration level, i.e., at a depth of 870 meters (2,850 feet). From this level, it is intended that certain waste packages will be emplaced in vertical boreholes drilled to even greater depths of 300-600 meters (985-1,870 feet). Other waste packages would be simply emplaced in galleries at the 870 meter level and backfilled with salt.

The development of Gorleben as a candidate nuclear waste repository site has been underway for several years. Extensive exploration of the region by surface drilling began in April 1979. Surface facilities for the exploration phase were completed and shaft excavation was begun in 1986. By the spring of 1987, shafts #1 and #2 had reached depths of 239 meters and 27 meters, respectively. In shaft #1, this was approximately to the depth of the caprock layer which overlies the salt dome.

Construction Accident at Gorleben

On May 12, 1987, an accident occurred in the Gorleben shaft #1, which is now having an impact on the overall site development schedule. Seven miners were at the bottom of the shaft, approximately 239 meters (740 feet) below the surface, at the time of the accident. A number of steel support rings had been placed over the preliminary liner in the lower 14 meter section of the shaft to provide additional resistance to the ground pressure of a clay layer. Unexpectedly, one of the support rings broke and fell to the bottom of the shaft, a distance of about 5 meters, striking six of the miners. One of the miners was severely injured and died two days later.

After the accident, and with evidence of a continuing pressure buildup on the other steel support rings, it was decided that the situation could be best stabilized by filling the affected part of the shaft (lower 14 meters) with a lean concrete plug. The support concrete will enable either a new lining or a lining reinforcement to be installed at a later date.

At the time of the accident, a changeover of excavation mode was underway at shaft #2, so no excavation activity was being conducted there. Since the accident, there has been no further excavation activity at either shaft pending completion of a technical investigation of the shaft #1 incident and its ramifications for further shaft sinking. Coincidently, a pause at shaft #2 had been previously planned to allow for complete freezing of an upper level clay layer.

Because of the loss of life, there is also an investigation by the prosecuting attorney's office as to the cause, possible liability, etc. (of course, this is quite comparable to the situation in the U.S.A. or elsewhere whenever there has been loss of life due to an industrial accident). This investigation is continuing and probably will not be concluded for several weeks at the earliest.

The exact cause of the Gorleben accident is still under investigation. The clay layer immediately above the caprock exhibited an unexpected and non-uniform convergence. It was not predicted that the inward directed pressure of this clay layer would be sufficient to break a support ring. When all of the data have been analyzed and the probable cause of this accident has been determined, a recovery plan and schedule to continue excavation of shaft #1 into the salt formation will be issued, and approval will be sought for a restart of the shaft sinking operations.

Current Situation

As noted above, the investigation into details of the accident and resulting loss of life that was undertaken by the prosecuting attorney's office is continuing. The geological and geomechanical conditions contributing to the accident are being investigated by the Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR), who will present their findings to the PTB. At the same time, a technical analysis of the conditions contributing to this accident and a recovery plan are being developed by the shaft-sinking corporation, ASG. (The ASG is a joint venture company formed specifically for work on the Gorleben project.) The report and recovery plan will be submitted to the Deutsche Gesellschaft zum Bau und Betrieb von Endlagern fuer Abfallstoffe (DBE) and PTB. It is expected that the report and recommended recovery plan will be issued prior the end of this calendar year, and excavation work in shaft #1 should begin again early in 1988.

The conditions at shaft #2 should soon be at a state where continued excavation could again be started. The technical consensus appears to be such as to recommend that excavation begin at an early date. However, the predominant political views seem to be that this should not occur before the situation at shaft #1 has been completely analyzed and agreement has been reached on the procedure to be followed for further excavation of shaft #1.

On August 12, 1987, the Federal Minister of the Environment, Nature Conservation and Nuclear Safety, Dr. K. Toepfer, visited the Gorleben site and expressed his view that consideration of the continued shaft sinking work at shaft #2 should be decoupled from that for shaft #1. Thus, it may be possible that shaft sinking will be started on shaft #2 sometime this fall, prior to the end of the year, although this is still not a certainty. Dr. Toepfer has instructed PTB to reevaluate the probability for significant water inflow through the shaft into the repository during the operational phase. This is considered to be a catastrophic event, but one of negligible chance for occurring; in light of the new data and behavior of this clay layer, this probability needs to be reassessed.

The accident at Gorleben is considered to be a construction related incident only. It is non-nuclear -- the nuclear function of this facility is still years ahead in the future -- and has no real connection with the viability of the option for disposing of nuclear waste in salt.

Critics in the FRG have claimed that this industrial accident is the result of a flawed site decision and that other disposal options should be explored. Responsible FRG officials do not accept this argument and intend to further pursue site exploration at Gorleben. Nor do they lack confidence in the freeze shaft sinking technique. In short, plans are to continue along the previously chosen path for development of the Gorleben site.

## Comments on Freeze Shaft Sinking

A few comments on freeze shaft sinking are provided as follows:

A) General

1. Freezing is indeed a proven and widely used technology for shaft sinking in unstable water-bearing ground. Using freezing as a construction tool down to depths of as much as 600 meters (nearly 2,000 feet), numerous mine shafts -- worldwide more that 400 -- have been successfully sunk mainly in the FRG, Belgium, the Netherlands, England, Poland, Russia, Canada, and China. Recent projects in the U.S.A. are shafts for the Jefferson Island Salt Mine (1), the Weeks Island Replacement Mine (2), the Elkhart Coal Mine (3), and the White County No: 1 Coal Mine (2).

2. The basic principle of ground freezing is very simple: By means of circulating a cooling agent (generally a salt solution) through a set of pipes surrounding the later excavation zone, the ground temperature is lowered well below the point where the water contained in its pores and/or fissures freezes. Thus, the ground around the later shaft is stabilized and at the same time made impervious, forming a cylinder of frozen material, the so-called "ice wall". Under its protection, shaft sinking can be executed under dry and stable conditions. The ice wall is maintained until the relevant section of the shaft is sunk and finally lined.

3. The particular advantages of the freezing technology for shaft sinking are:

- its application is only little dependent on the specific ground conditions (sufficient water provided)

- it ensures total and reliable sealing of the ground around the shaft (provided the temperatures applied are low enough)

- it does not at all contaminate or permanently affect the groundwater otherwise (the ice wall will thaw by the natural flow of heat after the freezing operation is stopped).

B) Specific

1. During the shaft-sinking operations, freezing is influencing the environment only in the immediate vicinity of the shaft and only to an insignificant extent (changing water into ice). After completion of the shaft, there is no ongoing impact. In particular, there is no adverse effect on the aquifers and the groundwater in them at all.

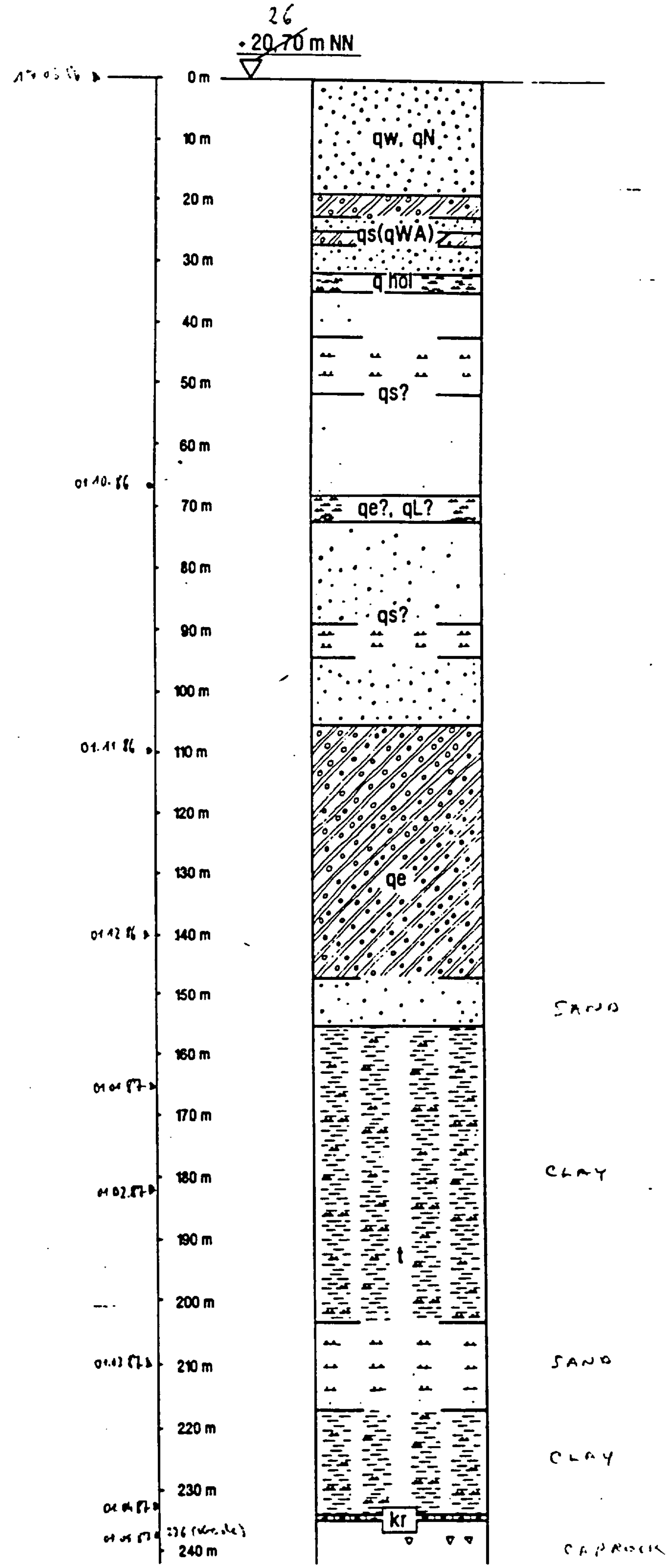
2. As explained above, for mine shafts to be sunk through unstable water-bearing ground, freezing is long since a standard technology. It is not true that a considerable percentage of freeze shafts failed during construction or after completion. To the contrary, in the past 30 years, no disastrous failure has been reported in the western world, and freezing has proven to be the most reliable method for shaft sinking under difficult geological and hydrological conditions.

3. The accident in the Gorleben shaft #1 is neither related to the freezing technology in general nor to the freezing operations in particular. The accident was the result of an unexpectedly high non-uniform ground pressure in a clay layer immediately on top of the caprock.

   Heavy non-uniform ground pressures as encountered at Gorleben are not at all to be expected at the Deaf Smith County site. In Texas, shaft sinking has to deal with bedded salt under a flat and rather homogeneous overburden, whereas, at Gorleben, the shafts have to be sunk into a salt dome with an overburden which has undergone considerable tectonic movements and strain, and is therefore rather inhomogeneous.

dec

# Schacht 1


26
+ 20,70 m NN
0 m
10 m
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40 m
50 m
60 m
70 m
80 m
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110 m
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180 m
190 m
200 m
210 m
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230 m
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qw, qN
qs(qWA)
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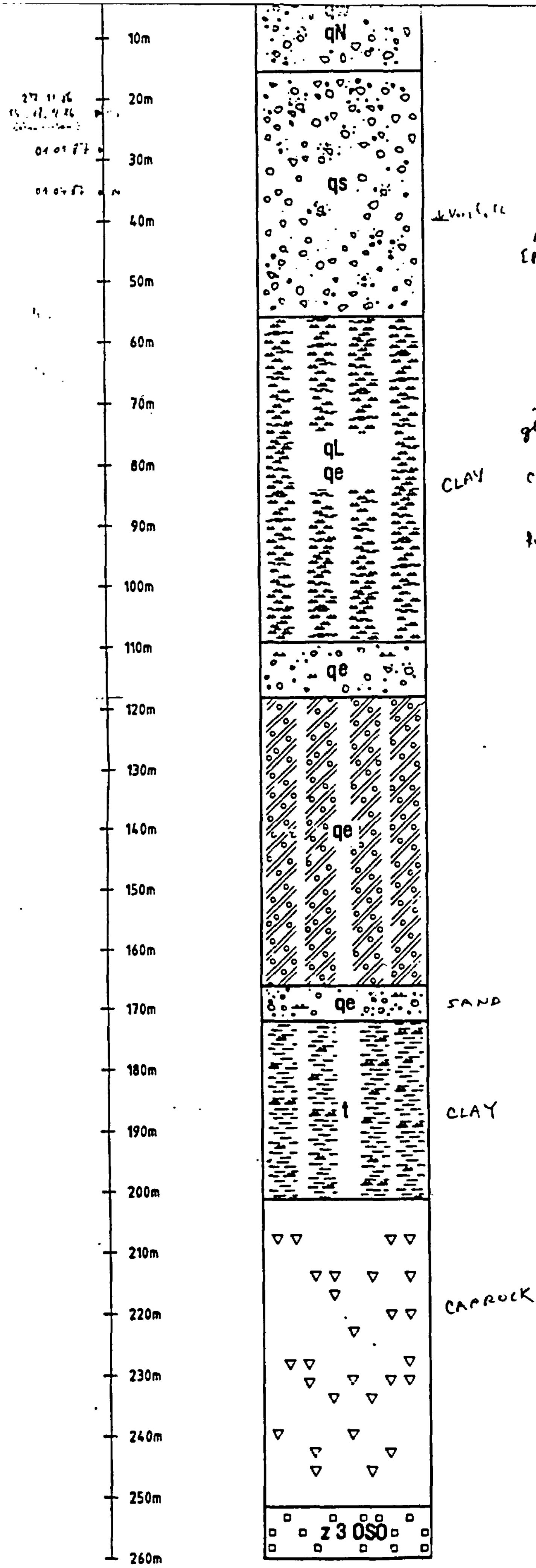
qs?
qe?, qL?
qs?
qe
t
kr
SAND
CLAY
SAND
CLAY
CAPROCK




# Lithologie

- fine gravel; sandy — Kies, sandig
- sand, gritty, silty [poor quality] clay — Sand, kiesig, schluffig
- silt [poor quality] clay; argillaceous — Schluff, tonig
- clay, silty [poor quality] clay — Ton, schluffig
- glacial marl, boulder clay — Geschiebemergel
- CAP ROCK — Hutgesteine
- ROCK SALT — Steinsalz

# Stratigraphie

| | |
|---|---|
| qw, qN | Weichsel- Kaltzeit, Niederterras |
| qs | Saale- Kaltzeit |
| qL | Lauenburger Ton |
| qe | Elster- Kaltzeit |
| t | Tertiär (ungegliedert) |
| z3 OSO | Oberes Orangesalz |

Physikalisch-Technische Bundesanstalt

Bergwerk zur Erkundung des Salzstockes Gorleben

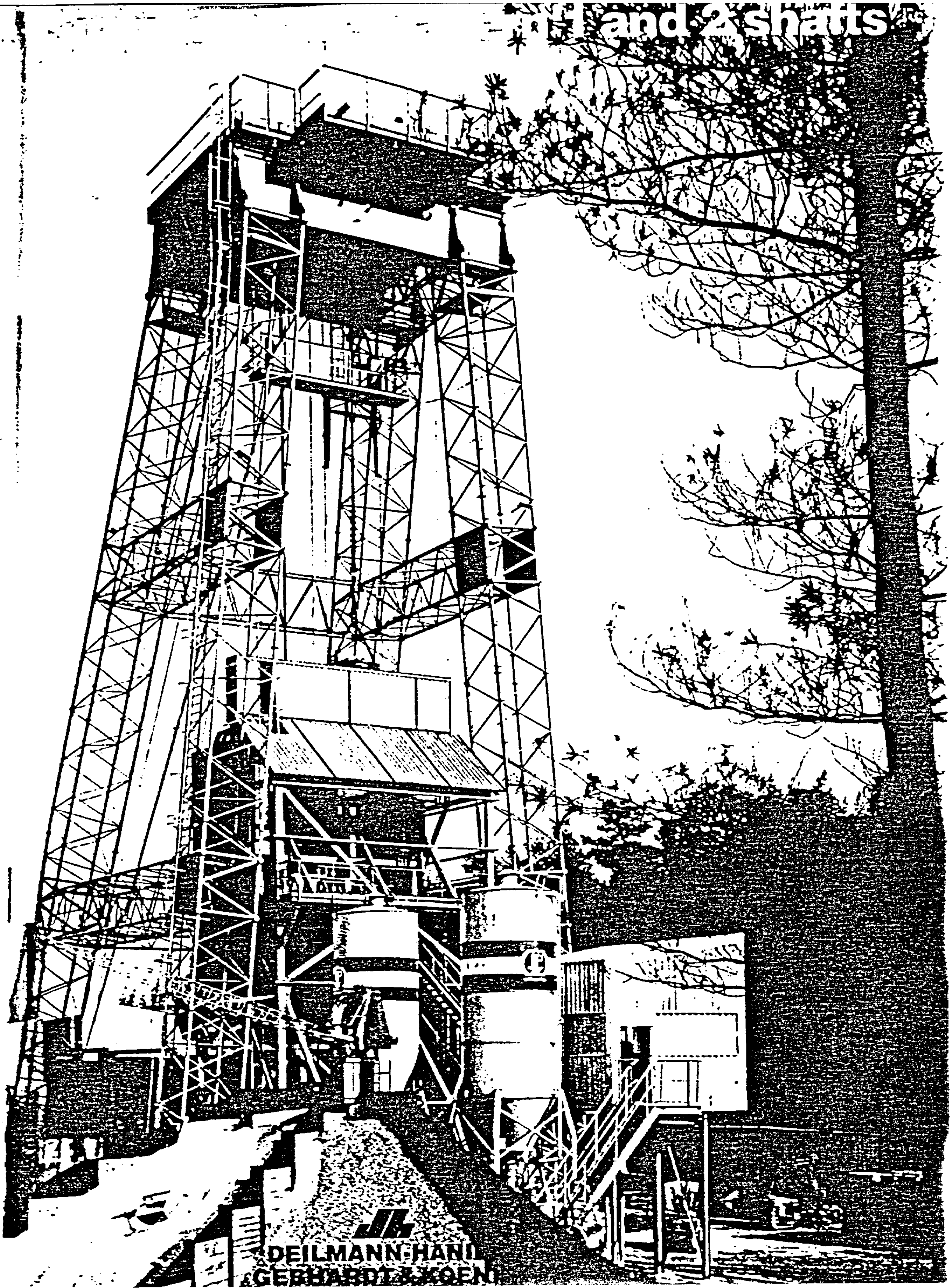
Schacht 2

| | Datum | Name |
|---|---|---|
| | 4.9.1985 | Ahlers |
| | Aug. 1985 | Karg |
| | 16.9.85 | Bundrock |

Maßstab 1:50 / 1:500 — Anlage 2-

Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH (DBE) — P - G

ATTACHMENT 4


1 and 2 shafts
DEILMANN-HANI
GERHARDT & KOEN

# Coal under the Haard

Exploration drilling has revealed vast coal reserves of the order of 500 mio. tons under the 'Haard' forest recreational area, north of Recklinghausen in the state of North-Rhine Westphalia, Federal Republic of Germany. The deposit consists of high grade coal at depths varying from 800 to 1,200 m.

Bergbau AG Lippe — a wholly owned subsidiary of Ruhrkohle AG — is planning to develop these coal deposits as the reserves of the present Haard Colliery — formerly Ewald Fortsetzung and General Blumenthal Colliery will soon be exhausted.

The exploitation of the Haard coal reserves emphasizes Ruhrkohle AG's policy, and commitment to the continued securual of the nations future energy supplies. This development will also provide employment for approximately [illegible].000 people.

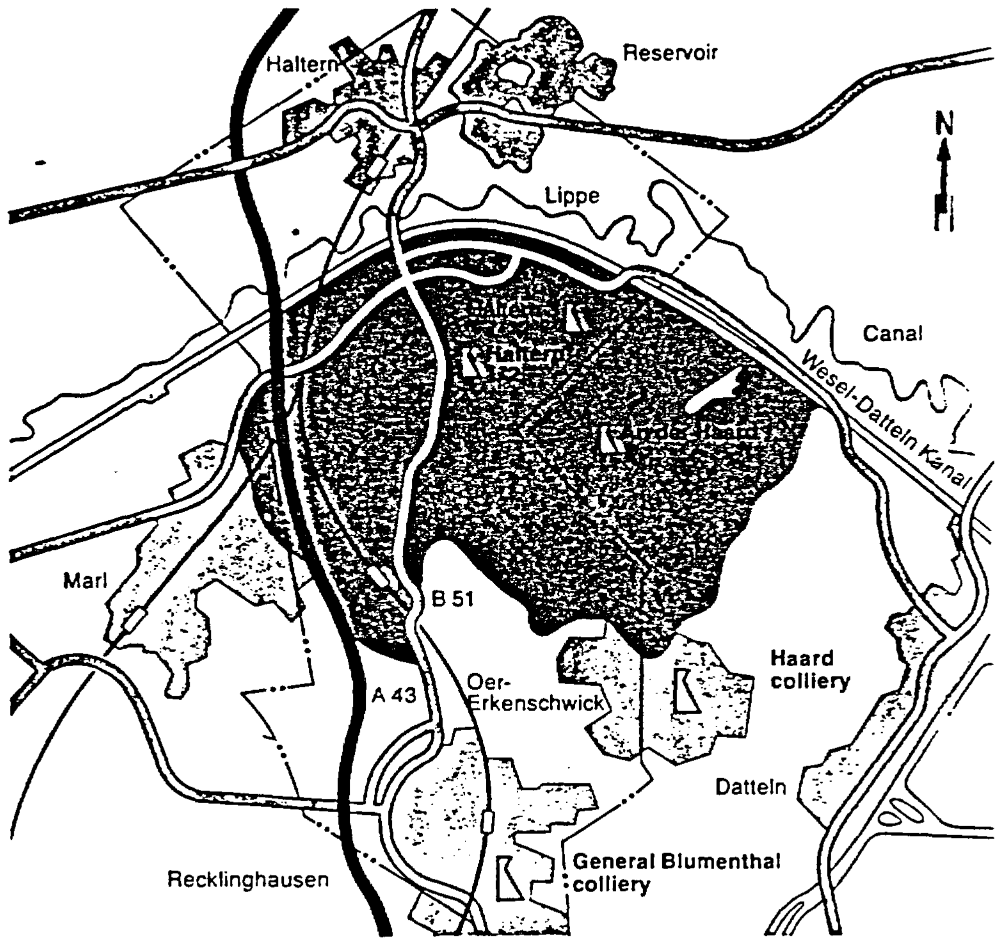
To extract the coal in this area a total of [illegible] shafts will be required. Sinking of the first shaft — An der Haard 1 — began at the end of 1977. Upon completion, in July 1981, it was handed over to the Haard Colliery.

The Haltern 1 and 2 shafts are the focal point of the Haltern mine which forms a part of General Blumenthal Colliery. They are located in the centre of the future 'take area' of the Haltern mine.

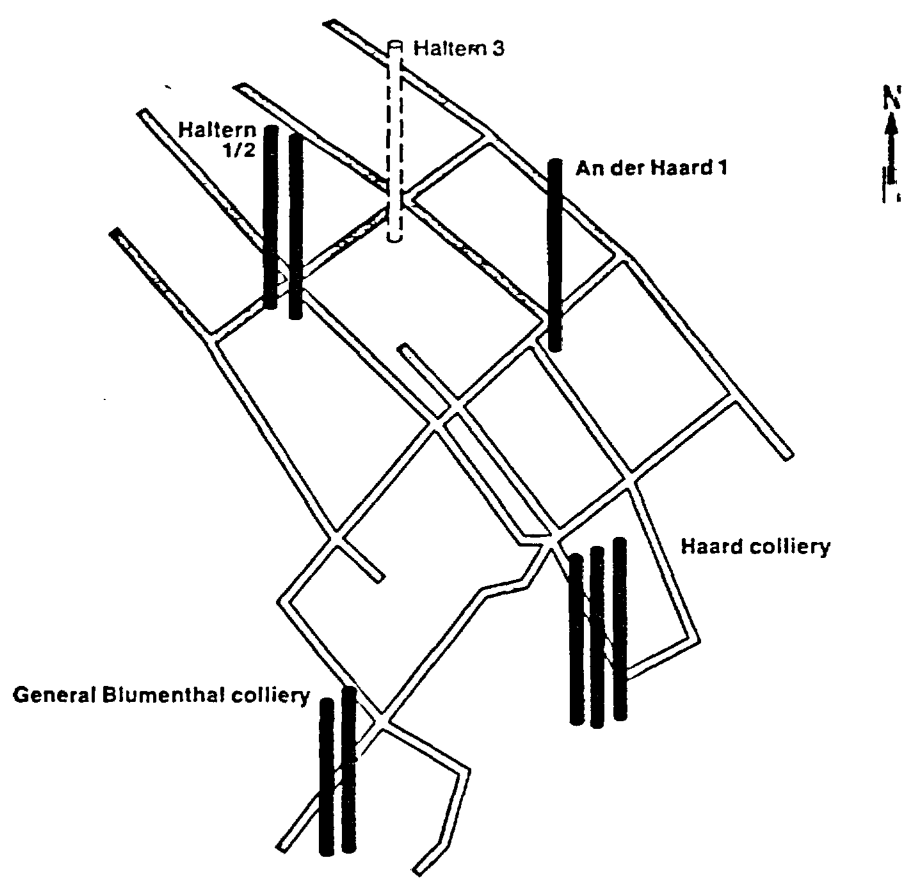
The shafts will improve the working and ventilation conditions in the mine by minimizing the time for personnel transportation to the faces and by considerably reducing the ventilation circuits.

The 'Haard' region is a popular recreational area for the densely populated northern Ruhr region. As a result of detailed planning minimum surface disturbance is anticipated.

Careful choice of the surface installations will ensure that they blend into the surrounding landscape. The entire set-up of the surface facilities is relatively small as the new shafts will only provide ventilation, manriding and material handling facilities. Mineral handling will not occur at these sites but all coal production will proceed via a large underground haulage system to production shafts situated outside the recreational area.



Haard/Haltern development area



Planned mine development

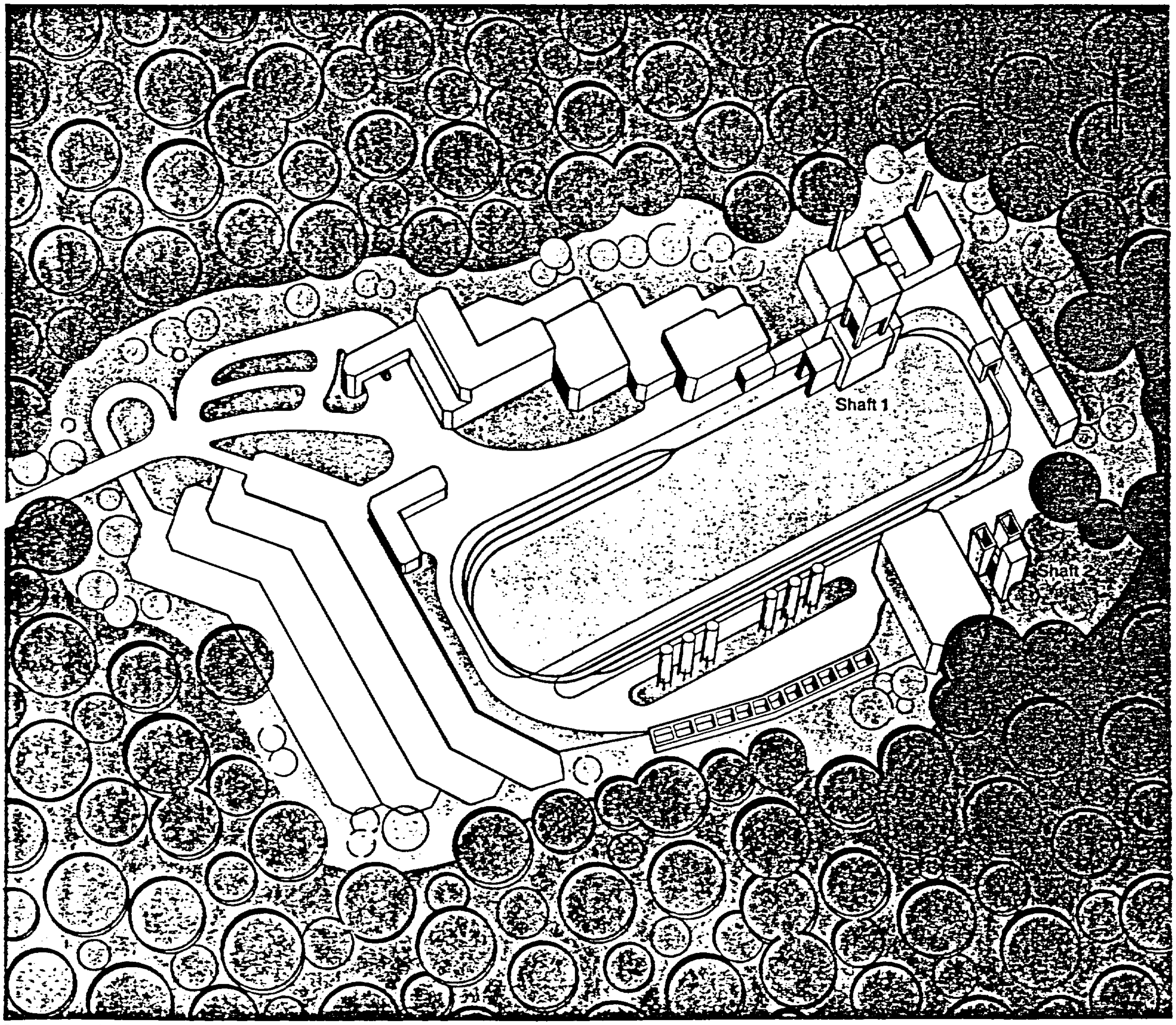
# The Haltern 1 and 2 shafts

Because of service and ventilation requirements the Haltern 1 and 2 shafts will have a finished diameter of 8.0 m. No 1 shaft with a total depth of 1,133 m will serve as a downcast shaft and be used for manriding and material handling. Three shaft insets at depths of 850 m, 980 m and 1,100 m will be constructed to connect the shaft to the mine. A full-face tunnelling machine driving from Blumenthal No 8 shaft is already operating on the 980 m level and will reach the Haltern 1 and 2 shafts in 1982. It will be the No 1 shaft equipped with steel buntons and guides, a main hoisting system with a 3 deck cage as well as an auxiliary hoist, both balanced by counterweights.

Pipes and cables will provide the colliery with the necessary services.

The surface facilities will be built in several construction phases according to the underground mining activity. Initially, approximately 1,000 miners will be hoisted daily. After full production is achieved in the Haard coalfield – approximately early 1990 – up to 3,500 miners will daily enter the mine through the No 1 shaft. Furthermore, 20,000 $m^3$/min of fresh air will be circulated through it.

No 2 shaft with a total depth of 1,017 m will serve as an upcast shaft, and two insets will connect the shaft to the existing mine. No equipping is necessary in the shaft.




Planned surface facilities. Haltern 1/2

Knowledge of the stratigraphy and rock characteristics of the strata are fundamental in determining the shaft sinking technique. Therefore, in the vicinity of No 1 shaft an exploratory test hole was drilled to a depth of 900 m. In the critical horizons, at depths of 20 - 300 m and 600 - 900 m, continuous cores were taken for more detailed inspection to aid the design teams.

Geotechnical investigations, laboratory analyses of the acquired samples and in-situ drill stem tests as well as geophysical logging in the exploratory hole gave the following results:

To a depth of 130 m lie the Halterner Sands and the calcareous sands of the Wulfener facies, they are unconsolidated dense, fine to medium quicksands with low cohesion.

The Recklinghauser Sandy Marl extends to a depth of 250 m. To a depth of approximately 190 m this layer is characterized by unconsolidated, fine clayey sands which tend to run when water saturated. Layers of hard calcareous sandstone approximately 20 cm thick occur within the sands. These hard layers form approximately 25 % of the Recklinghauser Sandy Marl.

Below 190 m the consolidation of the sandy marl increases with depth, with a corresponding reduction in pore volume and water content. Below a depth of 210 m the rock is considered to be competent.

The Emscher Marl from 250 - 650 m is characterized as a medium hard formation with no fissures. The Turon and Cenoman beds are lightly fissured medium hard to hard limestones.

Rock characteristics of the Emscher Marl, Turon and Cenoman are well documented from previous shaft sinking experience in the northern and eastern Ruhr area. Core investigations did not indicate any significant peculiarities or anomalies that might cause problems during sinking operations.

From a depth of 45 m the Halterner Sands, the calcareous sands of the Wulfener facies and the upper portion of the unconsolidated Recklinghauser Sandy Marls are fully water saturated. Below a depth of 210 m pore water is not present. However, fissure water may be encountered in the lower portion of the Recklinghauser Sandy Marls.

As a rule, water has to be anticipated in the fissures of the Turon and Cenoman beds. However, cores taken from these layers indicated that the fissures tend to be predominantly closed: i. e. not connected to an open system. At the interface between the Turon and Cenoman beds at a depth of 810 m drilling fluid was lost and core recovery was poor. This would suggest an open joint system and water would therefore have to be expected at this depth.

| Stratigraphy | Description and classification of rock | Classification for shaft sinking | Depth in m |
|---|---|---|---|
| | **Halterner sands**<br>fine to medium sands | unconsolidated, unstable, waterbearing (below 15 m depth) running sands | |
| | **Wulfener facies**<br>calcareous fine to medium sands | | 130 |
| | **Recklinghauser sandy marl**<br>fine marly sands to fine sandy marl | little consolidated, consolidation increasing with depth, unstable, waterbearing | 210 |
| | | competent, possible fissure water | 250 |
| **Santon and Coniac** | **Emscher marl**<br>Clay marl, initially fine sandy, then silty fine grained clay marl | competent, dry | [illegible] |
| **Turon** | **Calcareous marl and limestone**<br>partly clayey | competent, possible fissure water | |
| **Cenoman** | **Essener Grünsand** sandy limestone and fine grained sandstone | little consolidated to competent, dry | 845 |
| **Carbon** | **Lower coal measures** | | |

Strata profile

# Sinking of the shafts

The results of the exploratory test boring provided the main data for the conceptual design of the shafts. Due to the unstable ground to an extending depth of 210 m a special technique has to be applied to temporarily secure and stabilize these layers during sinking and lining operations. Through the water bearing zones a watertight lining will be installed to avoid any inflow of water or running sands. As fissure water might be encountered in the Turon and Cenoman beds, suitable precautionary measures must be taken during shaft sinking.

Coal production, employing the caving system, will begin in the immediate vicinity of the shafts. Resultant strata movements may well affect the final shaft lining. Therefore, it is required to design and construct that lining in such a way that it will stay watertight in the waterbearing unstable strata and its possible damage in the competent rock will be kept to a minimum. Both shafts will receive identical linings.

## 1. Securing and stabilization of the unstable strata

When evaluating special construction methods one has to differentiate between the zones above and below the water table which at this site is at a depth of 45 m approximately.

Below the water table the well known ground freezing technique will be used for stabilization and groundwater control. Above the water table an alternative construction technique has to be applied as the moisture content (3 - 4 %) is insufficient to enable effective ground stabilization by freezing.

### 1.1 Section from surface to 45 m

Securing of the shaft to a depth of 32 m is achieved by a secant pile wall, a construction technique used extensively in civil engineering for open excavation support systems. This wall consists of a series of bored, cast-in-place, lean concrete piles, 0,70 m in diameter with a 0,10 m overlap. Every alternate pile contains a steel beam as the main bearing element. The overlapping piles will transfer the loads due to the surrounding earth onto the main bearing piles.

Dry drilling procedures with flight augers are used to construct the piles. The depth to which this technique is applicable is limited due to the possible deviation of the piles with increasing depth.

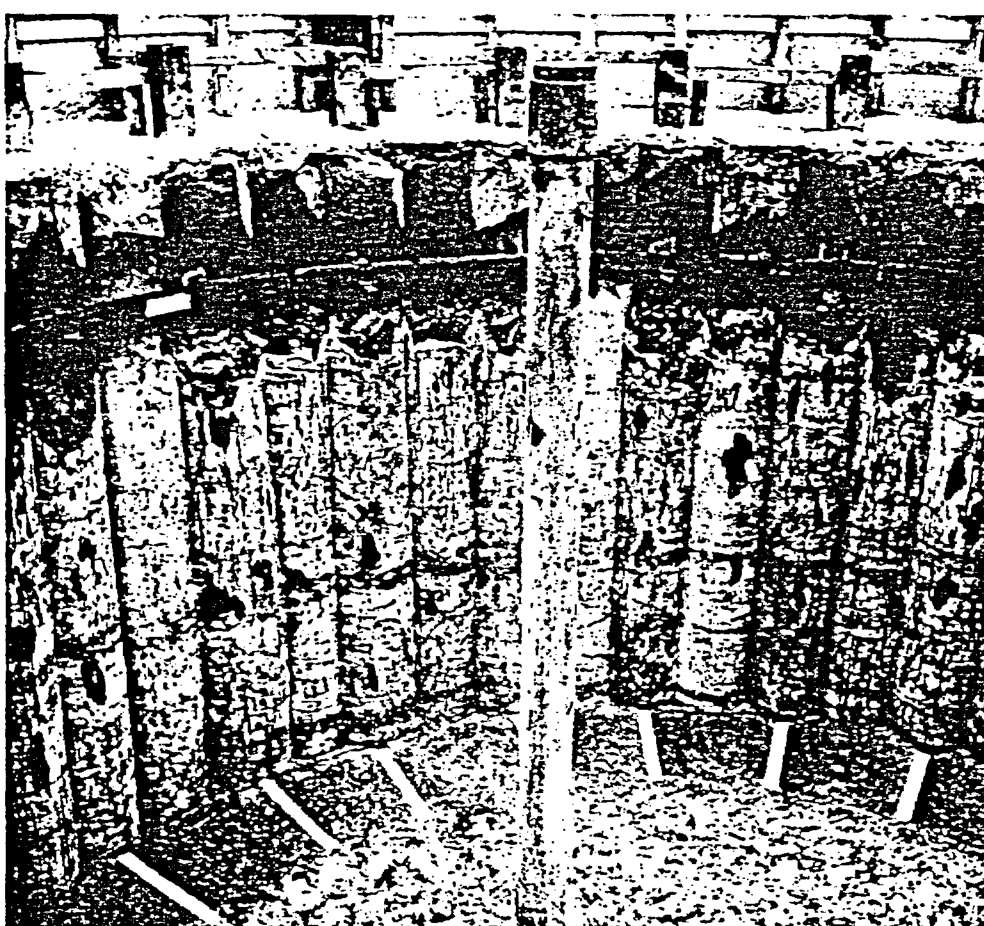
Below the pile wall to the top of the water table the shaft is secured with liner plates, i. e. thin rectangular steel plates, flanged on all four edges, punched with oversize holes for bolting and curved to the shaft. The liner plates are grouted in-place to establish firm contact with the ground. Additional strength is afforded by the installation of ring beams during sinking operations.

The size of the ring beams and the plate thickness – in this case 6.1 mm – is governed by the estimated loading to which they will be exposed. The section from the surface to the top of the watertight lining – here 38 m – is called the foreshaft.

### 1.2 Section between 45 m and 210 m

The ground freezing method will be used to stabilize the unstable waterbearing soils, to a depth of approximately 210 m, during shaft sinking and installation of the permanent lining. The principle of ground freezing is the use of refrigeration to convert in-situ pore water to ice. This ice becomes a bonding agent, fusing adjacent particles of soil to increase their combined strength and make them impervious. A cylindrical freeze wall is formed around the periphery of the planned excavation. This provides a stable support and ground water control system which enables safe sinking of the shaft. Ground freezing has been successfully utilized in shaft sinking over several decades. The extensive experience available and the reliability of this method enables detailed planning of time and economic factors.

39 refrigeration pipes are equally spaced on a 15.0 m diameter circle to create the freeze wall for each of the Haltern No 1 and No 2 shafts. The pipes are spaced 1.21 m apart at the surface. The refrigeration pipes extend to a depth of at least 217 m to tie the freeze wall safely into the competent sandy marl.



Secant pile wall for foreshaft

To ensure a positive and more or less uniform closure of the freeze wall it is essential to drill the refrigeration pipe holes accurately minimizing any deviation. The target area for the bore holes is defined by two concentric circles around the centre of the shaft, of 14,5 m and 15,5 m diameter resp. In addition, the spacing between two adjacent bore holes should not exceed 1.60 m to 1.95 m depending on depth. Continous alignment controls during drilling operations and – if required – the use of directional drilling tools to correct excessive deviations guarantee that the holes will remain within the specified limits.

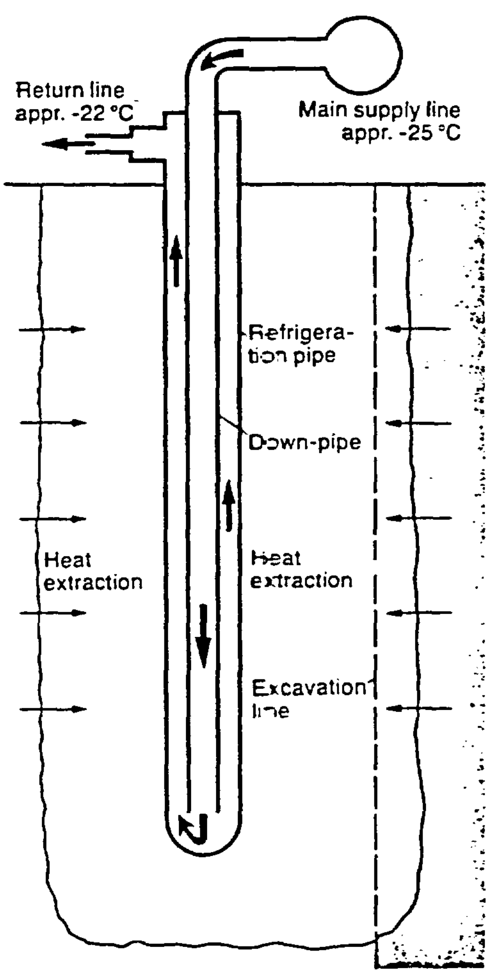
5"-refrigeration pipes will be installed in these bore holes to a depth of 217 m. 3"-PE down-pipes will be lowered into them. The refrigeration pipes will be connected to the main manifold lines, and a coolant – usually calcium chloride brine – at an approximate temperature of −25 °C will be pumped through the circuit. Circulation of the cold brine through the system causes a continuous extraction of heat from the ground.

Initially, a cylinder of frozen ground is formed around each refrigeration pipe. The frozen cylinders grow with time and when they merge a continuous freeze wall is formed. The freeze wall will then have to thicken with time at least to the required thickness according to the structural design. In general, the freeze wall thickness has to be increased with depth as the lateral pressures are also growing.

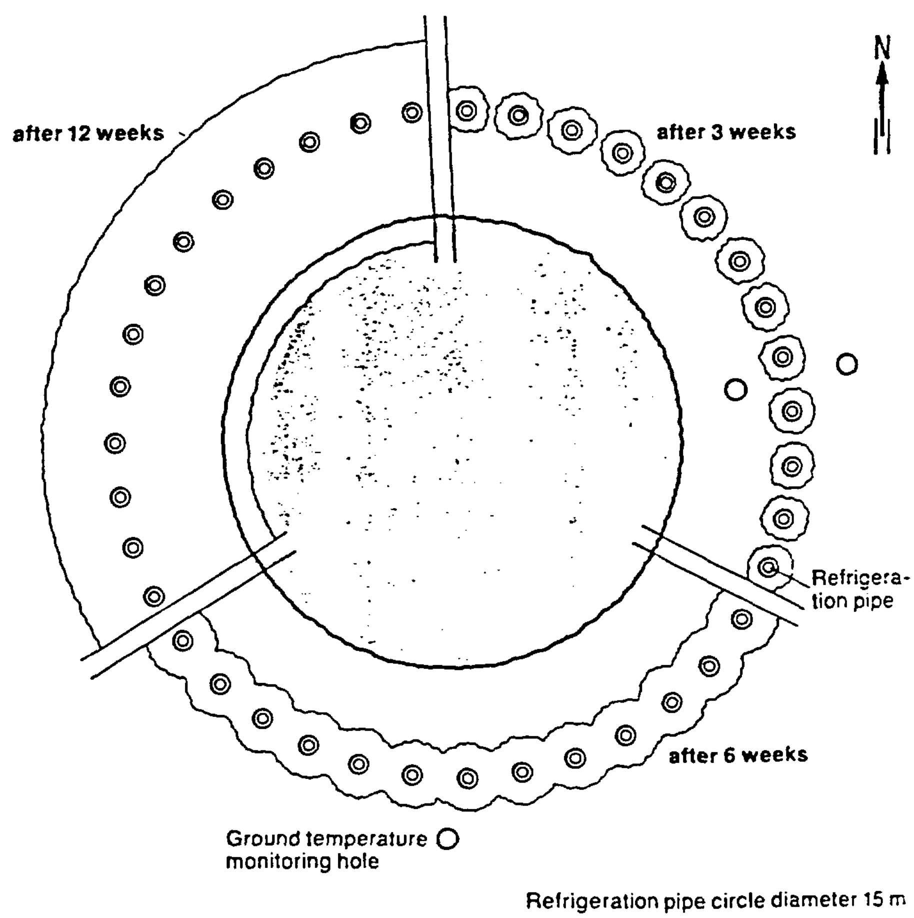
The refrigeration station used on this project consists of 3 units with screw compressors and has a total capacity of 4.7 mio. kJ/h at a brine temperature of − 25 °C. During the prefreezing period – the time from the start of freezing until a continuous freeze wall is formed – the refrigeration plants will operate under full load. Later on, it is necessary to control the freezing process so that as much as possible of the area to be excavated remains unfrozen in order to facilitate the mucking operations.

Of course, at the same time the ice wall thickness must be maintained according to the structural design.

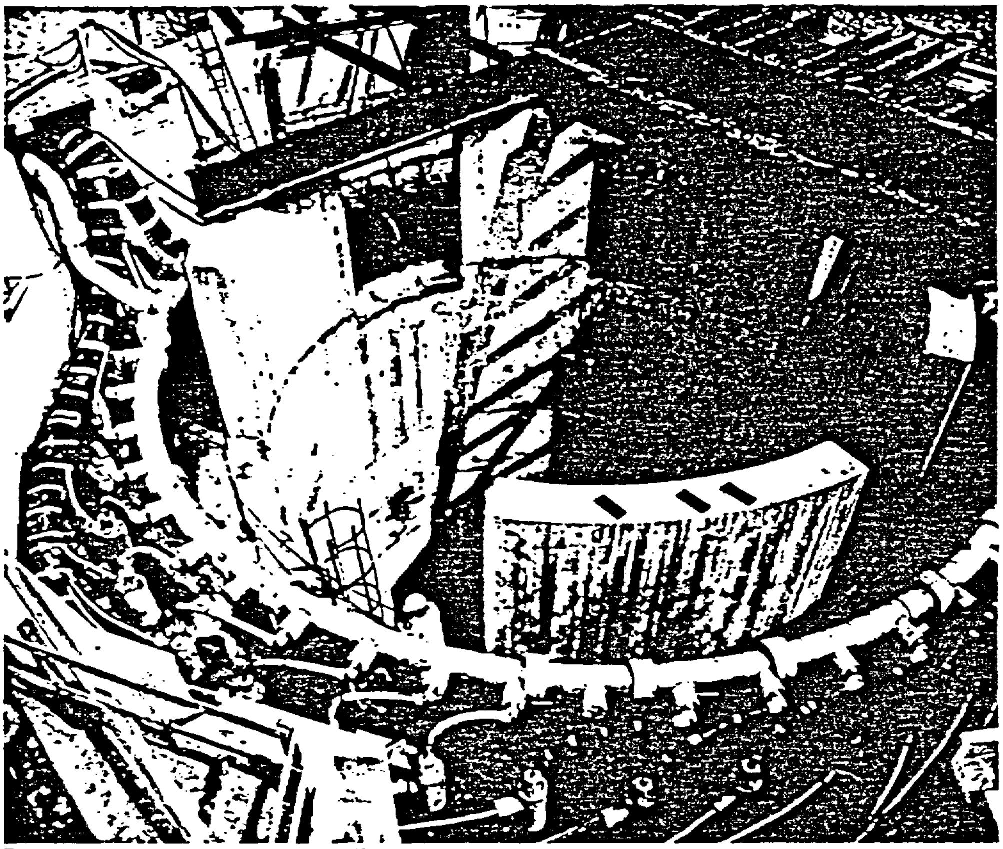
As the sinking of both shafts is staggered by about a year and a half, simultaneous freezing was not required, thereby minimizing the refrigeration plant capacity to be installed.



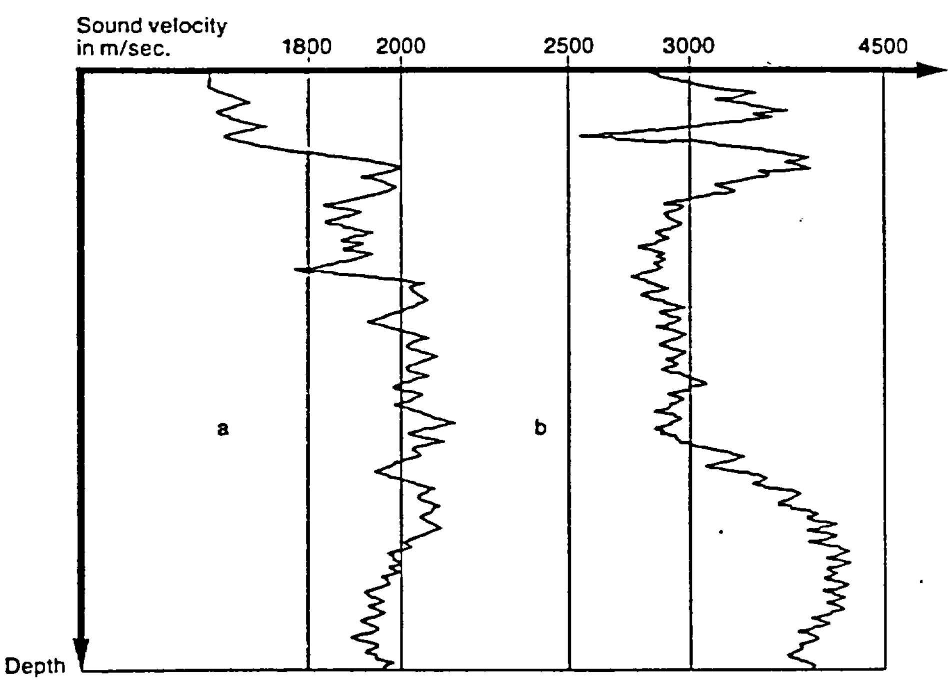

Brine circulatory system




Freeze wall formation



Freeze cellar containing main manifold system




Velocity of ultrasonic waves
a unfrozen soil
b frozen soil

Example of ultrasonic measurement

## 1.3 Monitoring of the freezing process

Special measurement techniques will be used to monitor the freezing process. Temperatures of the brine in the main supply line to the shaft as well as the return temperature in each individual refrigeration pipe are regularly measured and recorded. Pressure and flow rates are also monitored in the main brine supply line. Furthermore, the brine flow in each refrigeration pipe will be checked once daily and adjusted if required. Ground temperatures at critical locations are continuously measured in 3 temperature monitoring holes.

In addition ultrasonic measurements are used to check the progress, the extent and the continuity of the freeze wall. The principle underlying this method is the appreciable increase in the velocity of ultrasonic sound waves when passing through ice as opposed to water.
The data gained from all the measurements and their development with time will provide information on the shape and condition of the freeze wall, such as

- wall thickness
- wall temperatures which determine the strength of the frozen soil
- possible irregularities

Causes of such irregularities may be previously unknown local changes in ground conditions or lateral ground water movements affecting the uniform advance of the freeze wall. Precise evaluation and interpretation of the measured data will enable conclusions to be drawn as to possible cause of irregularities and to suggest the necessary remedial action that should be taken.

## 1.4 Thawing of the freeze wall

After the final watertight lining has been installed in the frozen section of the shaft, the freezing process can be terminated. Natural thawing, as opposed to the application of heat from external sources, will be employed. When the thawing process has progressed sufficiently the PE down-pipes will be pulled and the refrigeration pipes, which will remain in the ground, will be backfilled with cement grout.

# 2. Sinking and lining in the unstable strata

## 2.1 Excavation of foreshaft to 38 m depth

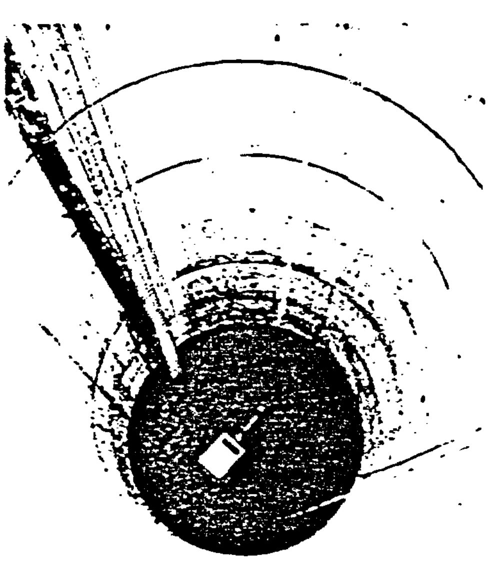
The shaft will be sunk to a depth of 38 m as an open excavation. To a depth of 32 m the preliminary support system consists of bored secant concrete piles. A hydraulic loader is used at the shaft bottom for mucking and loading. The muck will be hoisted to the surface in buckets attached to a crane. As sinking advances steel ring beams are installed to support the pile wall.

Below the pile wall the excavation diameter is increased and steel liner plates are used for temporary support. The sand is carefully trimmed to the excavation line and when a 0.5 or 1.0 m high section of ground has been exposed liner plates are immediately installed and grouted in-place.

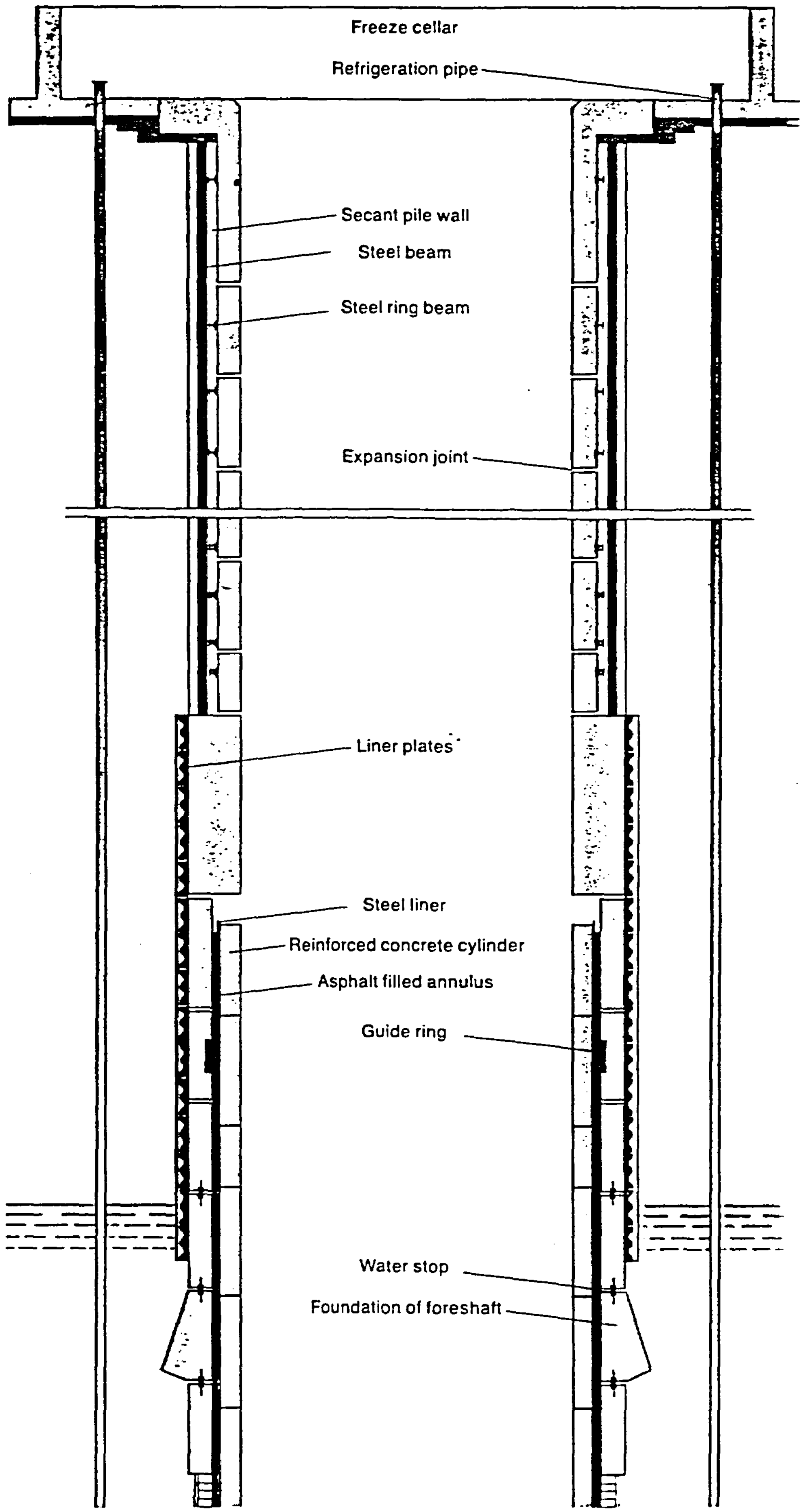
## 2.2 Final lining of foreshaft to 38 m depth

Above the water table a watertight lining is not necessary. A reinforced concrete lining to withstand the lateral earth pressure will suffice.

This lining with an inner diameter of 8.0 m and a wall thickness of 0.6 m to a depth of 32 m and 1.2 m from 32 to 38 m will be poured in 3 m sections from the bottom up with a jump form after the shaft has been sunk to 38 m depth.



View of Haltern 1 foreshaft




Lining of foreshaft

### 2.3 Shaft sinking below 38 m depth

After completion of the foreshaft the normal shaft sinking equipment, i. e. sinking headframe, bobbin hoist, winches etc. will be installed. However, resumption of sinking operations below 38 m depth is dependent on the freeze wall progress. Before sinking below the water table, which corresponds to the top of the freeze wall, can commence one has to ensure that the freeze wall is completely closed for watertightness and has its required thickness according to the structural design.

The shaft excavation is secured with liner plates to a depth of 45 m, below which the freeze wall will be the primary support system. Mucking and loading is achieved with a 0.8 $m^3$ capacity cactus grab, mounted on a fully rotational frame, suspended from the 2-deck sinking stage. A 5 $m^3$ bucket is used for the muck removal.

Where shaft sinking proceeds under the protection of the freeze wall the preliminary lining need not be installed immediately. This is because the surrounding soil is frozen and will secure the shaft for an extended period of time without any additional support. Hence, the preliminary lining will be installed in longer sections. Careful excavation of the frozen ground is necessary to avoid undue stress or strain on the refrigeration pipes leading to possible leakage or rupturing. Should the calcium chloride brine come into contact with the frozen ground it would act like a de-icing salt weakening the freeze wall locally.

The following techniques are therefore employed to avoid damage:

- loosening of the ground with jackhammers
- controlled blasting

Working with jackhammers is limited to neat profiling of the final excavation line. Smooth blasting techniques with limited length of a shaft round and limited amount of explosives are applied otherwise.

The preliminary calculations of the advance and thickness of the freeze wall based on geotechnical data from laboratory tests as well as temperature and ultrasonic measurements, will be verified by temperature measurements taken at the shaft wall; these results being supplemented by careful visual inspection of the frozen wall.

### 2.4 Preliminary lining below 38 m

The preliminary lining from 38-57 m consists of reinforced concrete, 0.6 m thick according to the structural design. Because of anticipated strata movements during subsequent mining activity, the concrete will not be placed in a continuous pour but will be poured in 3 m sections with waterstops to allow for some flexibility.

Below a depth of 57 m a "flexible" preliminary lining, consisting of 0.3 m thick prefabricated concrete blocks, is installed to minimize damage due to the expected ground movements. The flexibility of the lining is achieved by placing chip boards between the concrete blocks, in the horizontal and vertical joints. These chip boards can be compressed to approximately 40-50 % of their original thickness with almost no lateral strain which could cause spalling of concrete from the blocks.

8 mm thick chip boards were chosen for this project. With approximately 150 vertical joints distributed around the perimeter and assuming a uniform lateral pressure from the outside, a maximum contraction of the perimeter of approximately 0.50 m is possible, which corresponds to a reduction in diameter of 0.15 m. If the compressive strength, approximately 55 N/mm$^2$, of the concrete blocks is exceeded due to excessive strata movements, only small pieces will spall and get into the annular space filled with asphalt.

The prefabricated concrete blocks will be installed in 10-12 m sections. Each section has a small conical bearing set – also made of concrete blocks – resting on the frozen soil. A mortar layer, 0.05 m thick, provides intimate contact between the concrete blocks and the frozen ground.

Installation of the preliminary flexible lining constructed with prefabricated concrete blocks

## 2.5 Watertight lining in the frozen shaft section

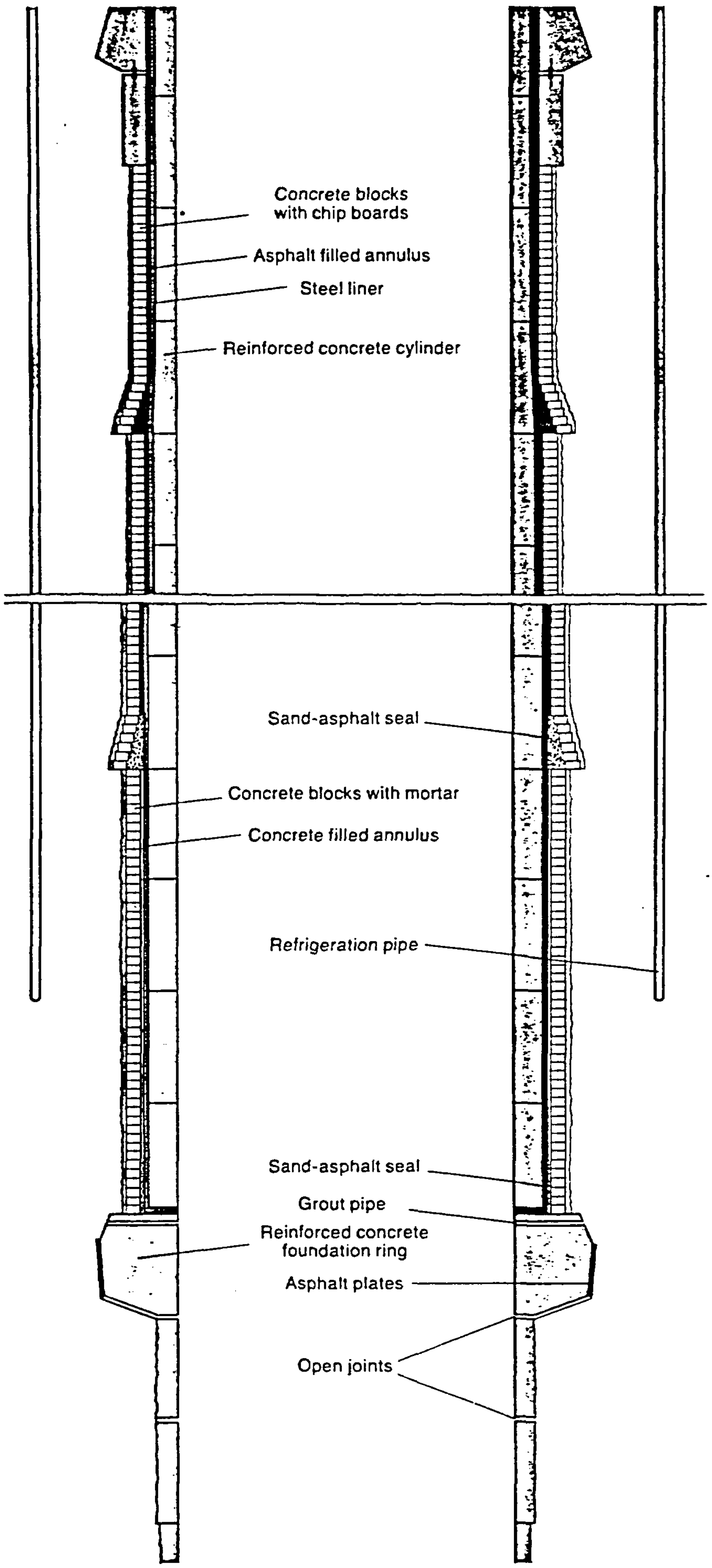
The expected strata movements due to subsequent mining activities in the immediate proximity of the shaft require, in the frozen shaft section, a lining which – despite the deformations which may occur – will not leak or loose its load bearing strength. This is particularly important as a failure of the associated inrush of the quick sands could have disastrous consequences for the shaft and mine. Therefore, the final lining is constructed so as to tolerate considerable deformations without being damaged and without loosing its watertightness.

Between the preliminary and final lining an annulus is left which will be filled with asphalt having the physical properties of a viscous fluid. The asphalt layer separates the final lining from the surrounding strata allowing relative movements between the two. It also represents a zone of protection as lateral ground movements will only have an immediate influence on the final lining once they exceed the width of the asphalt layer.

The final lining is supported by a foundation ring made of reinforced concrete ($f_c$= 6,400 psi) just below the frozen shaft section at a depth of 224 m. This foundation ring is 3.00 m high, 1.90 m wide and has to transfer the loads of the watertight lining into the strata. Immediately below, two 3 m high and 0,50 m thick reinforced concrete rings will be placed to take up the lateral rock pressure activated underneath the foundation.

The final lining consists of a structurally reinforced concrete cylinder ($f_c$= 5,00-6,400 psi). The wall thickness is increased from top to bottom as the lateral pressures, due to the soil and water, increase. The concrete thickness at the top of the watertight lining is 0.53 m, and will be increased in 5 stages to a final thickness of 0.75 m at the top of the foundation ring. The reinforcement will be increased accordingly from top to bottom.

The width of the asphalt layer between the watertight lining and the preliminary lining is 0.15 . Twelve metres of the annulus immediately above the main bearing ring are backfilled with concrete rather than asphalt to achieve the required fixation of the final lining.
A special seal is placed between the asphalt and the concrete backfill.




Lining in the frozen shaft section

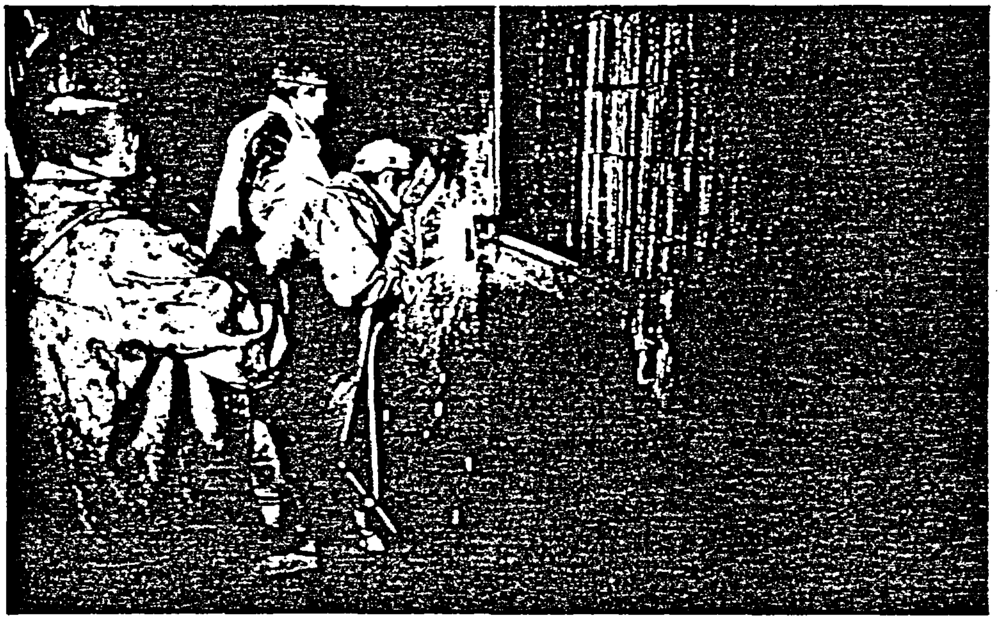
On the top, the watertight lining ends at a depth of 39 m, a point well above the existing ground water table. A guide system is to be installed which will only allow vertical movements of the lining at this location.

A 4-deck stage is used for the installation of the watertight lining. Its upper two decks serve to erect the steel liner which is composed of 3.6 m high segments five of which form a complete ring. Each steel segment will be lowered into the shaft and put in place with an auxiliary hoisting system. All welding is done in-situ. Ultrasonic techniques are used to check the integrity of the field welds.

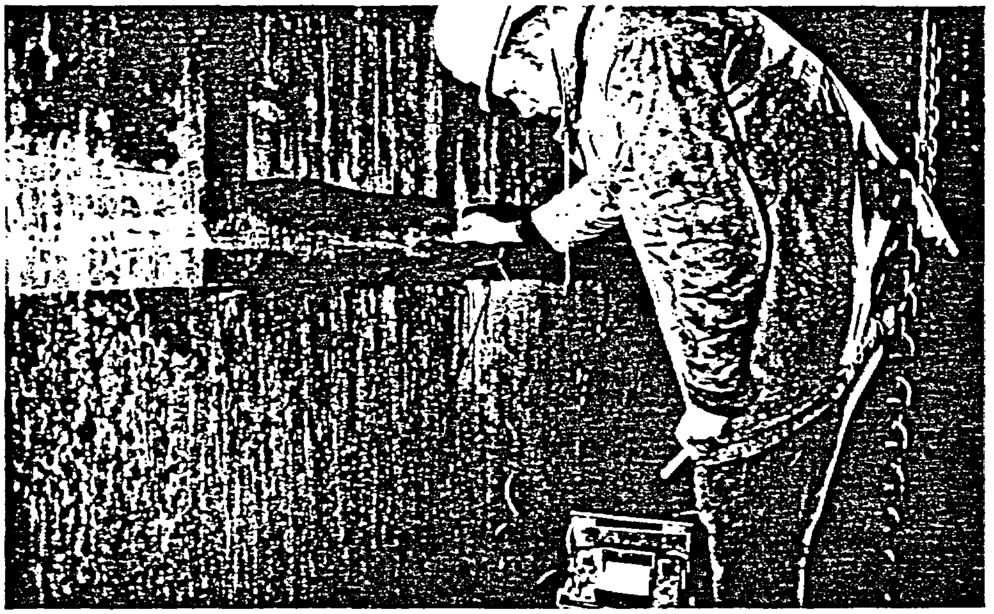
The pouring of the concrete cylinder is done from the two lower decks of the stage using a steel jump form. The reinforcement is, in form of "cages", prefabricated on the surfaces. Five cages form the reinforcement for each pour. They are lowered to the stage separately, installed and tied together.

The steel liner and the inner concrete cylinder will be installed sequentially in lifts of 3.6 m.

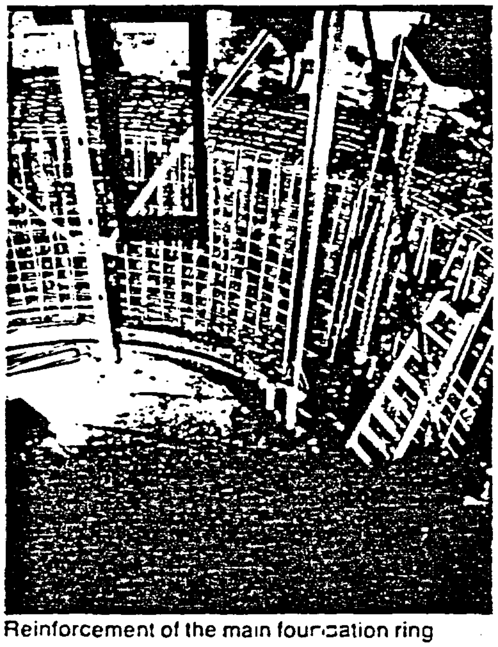
Backfilling the annulus between the preliminary and the final lining with asphalt is executed in two sections using a slick line. The asphalt is made of a special bitumen with finely crushed limestone as a filler to achieve the required density of 1.3 g/cm$^3$, and is poured into the annulus at an approximate temperature of 130 °C at which its viscosity is low.



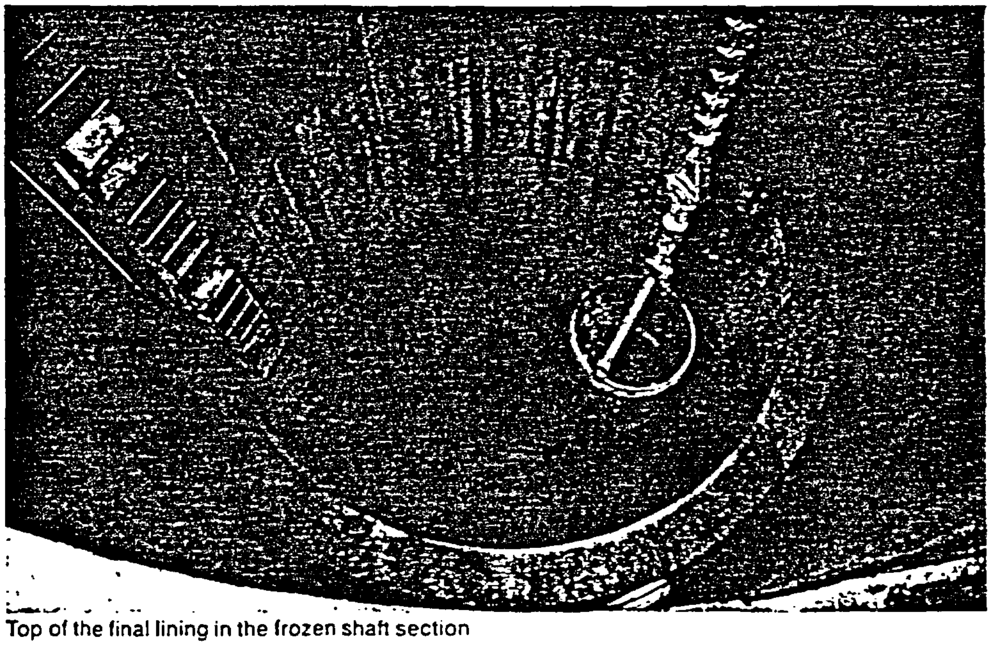
Field welding of steel liner segments



Examination of field welding with ultrasonic device

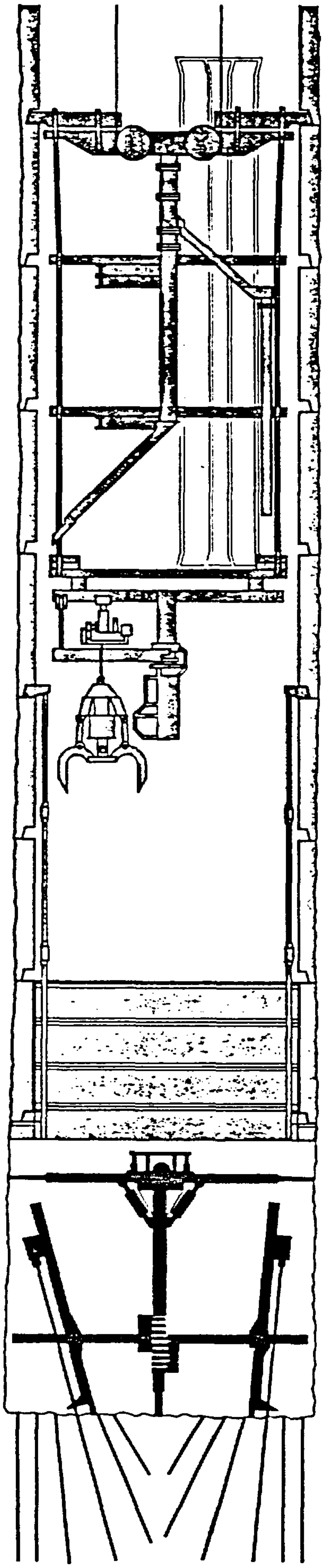


Reinforcement of the main foundation ring



Top of the final lining in the frozen shaft section

# 3. Sinking and lining in competent rock



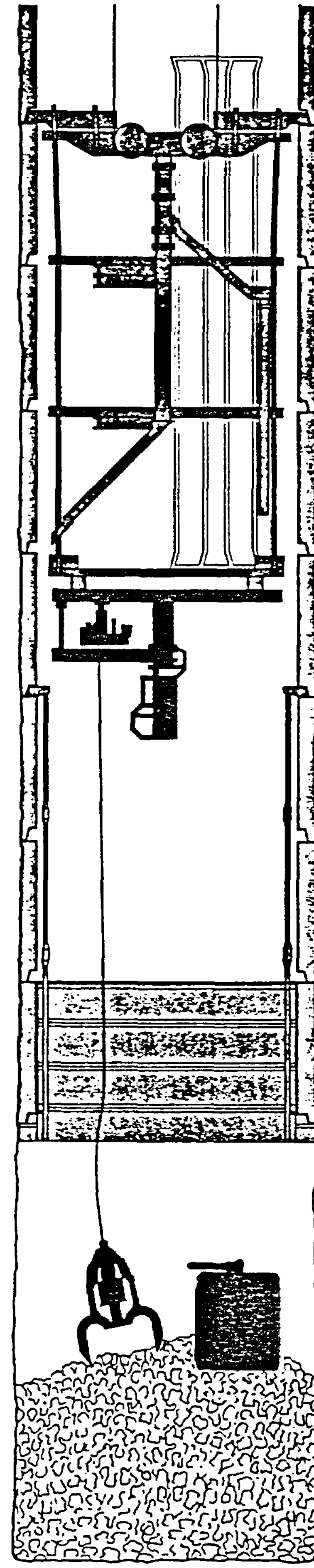
Drilling of a shaft round

### 3.1 Sinking

The application of special shaft sinking methods is not required in the competent rock below a depth of 220 m and also in the coal measure strata. Hence, conventional drill and blast techniques are used to sink the shaft. Sinking and lining is done alternatively and sequentially. Past experience in similar rock has shown that 8 m of shaft can be left unsupported till the final lining has to be installed. To drill the blast holes a shaft drill jumbo specially designed and manufactured by Deilmann-Haniel is used. The jumbo comprises of a central column with 4 booms capable of being swung through 360° in a horizontal plane. Rotary percussion drills are used. The muck buckets with a 5 $m^3$ capacity are loaded by a 5 blade cactus grab with a 0.8 $m^3$ capacity. The grab is attached to the sinking stage on a fully rotational frame so as to reach almost all of the shaft floor.

Shaft drill jumbo

Cactus grab

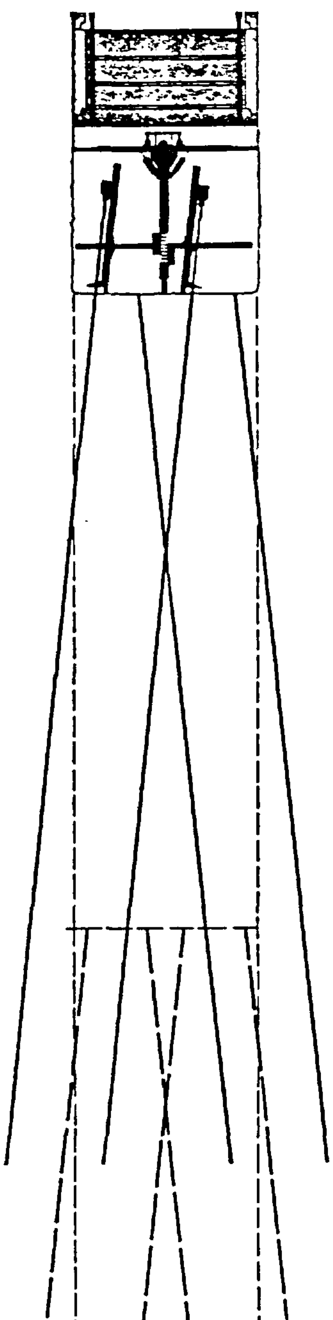


Mucking

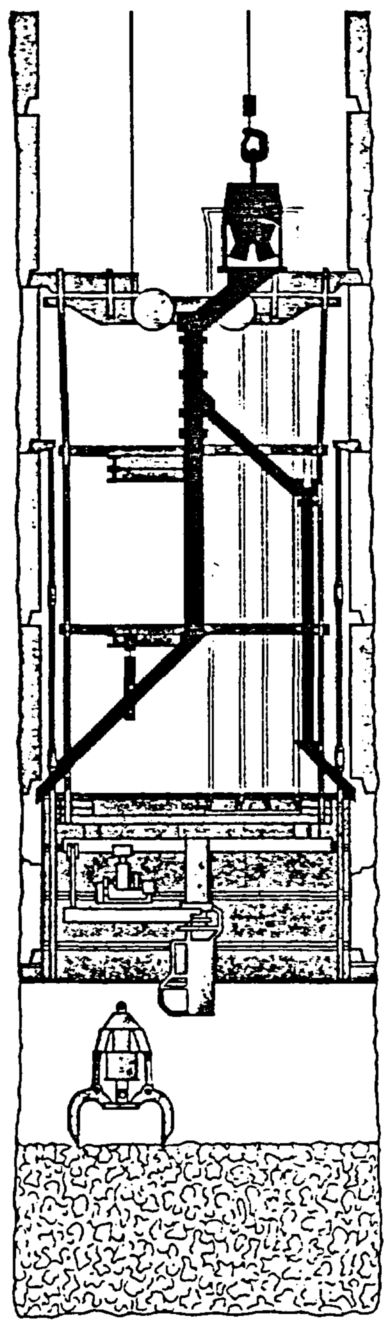
Systematic advance probe drilling through the Turon and Cenoman formations will be carried out to detect any fissure water. The probe drilling will be done in 35 m sections with an 8 - 12 m overlap.

Should water be encountered, cement grouting will take place to reduce water inflows to an extent that shaft sinking through these formations can proceed safely and almost unhindered.

Concrete bucket



Systematic probe drilling from shaft bottom



Pouring of a lift

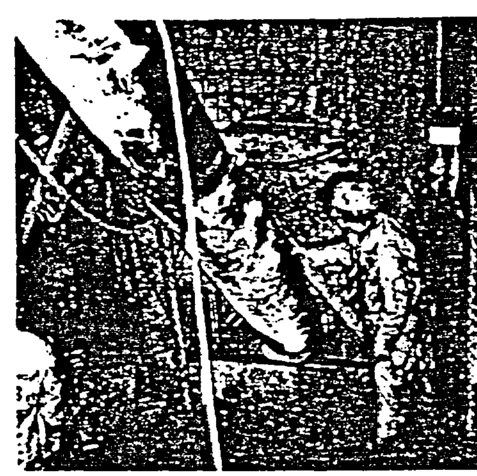
## 3.2 Lining

The lining in the competent rock of the overburden as well as in the coal measures is of concrete ($f_c$= 3,500 psi) with a wall thickness of at least 0.40 m. A light reinforcing mat is placed at the inside of the concrete lining. This reinforcing mat will avoid spalling of large chunks of the concrete when the expected high stress and strains occur during later mining activity.

The concrete is poured in 4.2 m lifts. The lifts are separated from each other by a continuous 0.30 m wide joint which is only closed on the side exposed to the rock by a 0.07 m thick concrete curtain. Apart from this, the joints which are used during shaft sinking for the support of the sinking stage will remain open. The separation of the lining into single concrete rings will allow a certain amount of yield in the vertical direction. This lining system will minimize damage, due to high compressive and tensile strains in the surrounding rock, brought about by mining activity. Furthermore, any future repair work can be more easily executed.

A 4.2 m high steel formwork will be used following sequentially the sinking operation. The formwork is placed on a curb ring. The curb ring is suspended from hanging rods, 13.5 m long, which are fixed to anchor plates placed on the already cured concrete above.

A 4-deck stage is used for the installation of the lining. Once the stage is in position and fixed, one complete ring can be poured without changing its position.



Rotating concrete delivery chute

# 4. Sinking schedule

In November 1978 the shaft sinking contract for Haltern No 1 shaft was awarded to the consortium, consisting of Deilmann-Haniel and its fully owned subsidiary Gebhardt & Koenig.

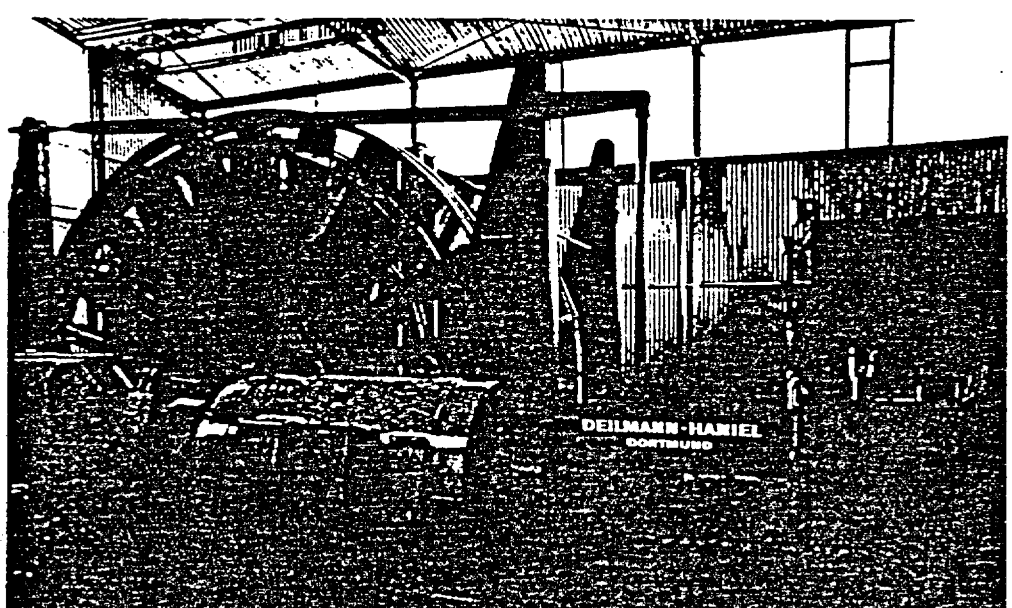
After completion of an access road and preparation on the shaft site, actual work in the field started with the construction of the freeze cellar, shaft collar to a depth of 9 m and various surface facilities required for the sinking of the shaft. The refrigeration pipe holes were drilled in 3 months. After completion of the foreshaft to a depth of 38 m and installation of machinery and equipment required for shaft sinking, excavation was resumed in February 1980.

Meanwhile the consortium, Deilmann-Haniel and Gebhardt & Koenig, was also awarded the contract to sink the Haltern No 2 shaft. This contract was awarded as a follow up to the An der Haard No 1 shaft contract. Upon completion of this shaft in the summer of 1981, the personnel, machinery and sinking equipment has been moved to the Haltern No 2 shaft site.

The first bucket at the Haltern No 1 shaft and the turning of the first sod at Haltern No 2 was celebrated with a ceremony on February 25, 1981.

It is scheduled to hand over the completed Haltern No 1 shaft to the owners, Berbau AG Lippe, in mid 1983 and Haltern No 2 shaft in spring of 1984.






Double bobbin hoist for sinking

Hoist control room

# Technical data on machinery and equipment used for sinking one shaft

## Shaft sinking installations

**Hoist**
2-drum Bobin with 2 x 800 kW driving output (5 kV)
rated load (capacity): 5-$m^3$ buckets

**Headframe**
light tubular steel construction
height: 36 m
base: 18 x 14 m
weight: 95 to
total of max. load: appr. 200 to

**Muck tipping frame**
base: 8 m x 6.5 m
height: 15 m
automatic bucket tipping device

**Sinking stage**
4-deck stage, weight 40 to
stage ropes = guide ropes for hoisting

**Stage winches**
4 drum winches, lifting capacity 35 to each,
max. rope storage on each drum: 3,500 m with 40 mm rope dia

**Compressed air**
3 compressors
with a total output of 75 $m^3$/min.

**Shaft drill jumbo**
Deilmann-Haniel System
centre column with 4 booms

**Mucker**
0.8-$m^3$ cactus grab on fully rotational frame

**Concrete forms**
collapsible steel form
height: 4.20 m
curb ring suspended on 8 steel rods
total weight: appr. 25 to

**Concrete batch plant**
pan mixer, 1,500 l capacity
proportioning system for cement and aggregates 3 size grains,
0-2, 8-16, 16-32 mm
transportation of concrete into shaft width drop bottom buckets, 2.5 $m^3$ capacity

## Ground freezing installations

**Refrigeration plants**
2 screw-compressors with a capacity of 1.7 mio. kJ/h ea. at − 25°C brine temperature, installed power 2 x 355 kW

1 screw-compressor with a capacity of 1.3 mio. kJ/h at − 25°C brine temperature, installed power 250 kW

**Coolant**
calcium chloride brine with a concentration of 30° Be.
brine freezing point appr. − 40°C
circulating brine volume appr. 120 $m^3$

**Brine pumps**
4 centrifugal pumps with a pump capacity of 2 $m^3$/min. each at a pressure of 4 bar
total pumping capacity: approx. 480 $m^3$/h

**Refrigeration pipes**
seamless steel pipes St 52
127 x 6.43 mm with Omega-connections

**Down-pipes**
polyethylene pipes 75 x 4.3 mm

**Ground freezing monitoring devices**
45 permanent temperature sensors in the brine supply- and return lines. continuously recording

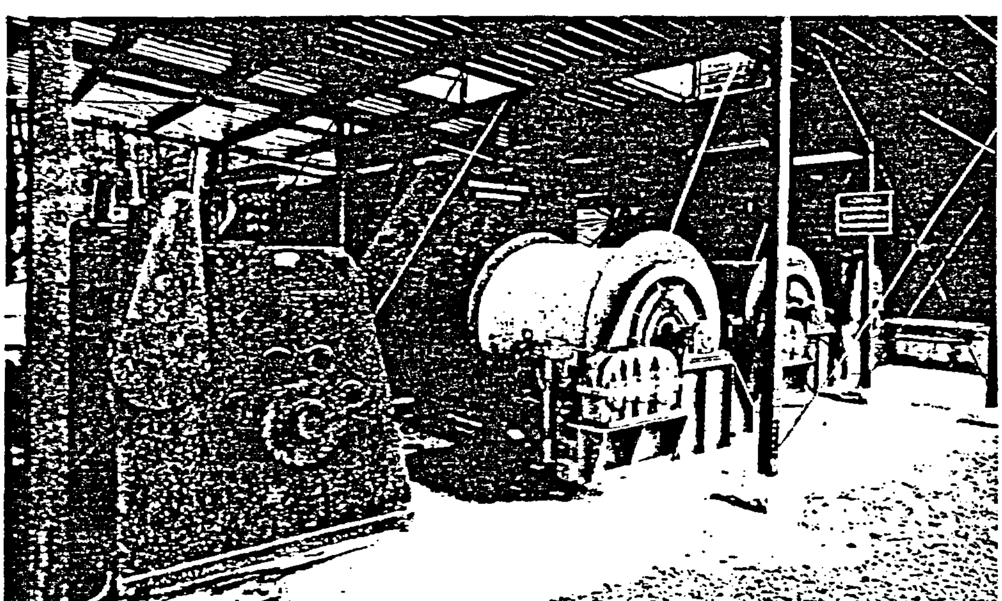
2 mobile single temperature sensors to check ground temperatures anywhere in the ground temperature monitoring holes

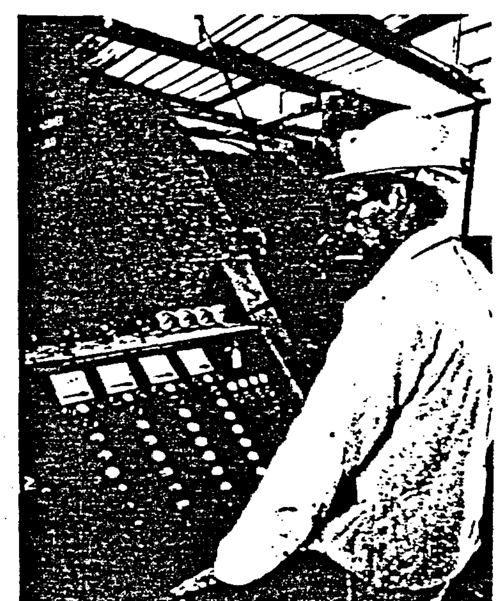
3 permanently installed temperature sensors string to check ground temperatures in the ground temperature monitoring holes at critical strata locations

1 flow meter in the brine supply line

device to measure the brine flow in the return line of each refrigeration pipe

Various installations are common to both shafts


Winches for the sinking stage


Control panel for stage winches

Publisher:
Joint venture
Schächte Haltern 1/2
DEILMANN-HANIEL
GEBHARDT & KOENIG
Postfach 130220
Haustenbecke 1
D-4600 Dortmund 13
Telefon 231/28910

Designed by:
Design-Studio Alfred Kilian
Düsseldorf
Printed by:
Druckerei Grüßner
Krefeld

WM Record File
106-

WM Project 16
Docket No.
PDR ✓
LPDR ✓ (S)

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J Linehan | Gillen Carlson
Wastler
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WM Project 16

Docket No.

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LPDR ✓ (5)

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JCG

**Department of Energy**
Salt Repository Project Office
110 North 25 Mile Avenue
Hereford, Texas 79045


October 21, 1987

Mr. John J. Linehan
Section Leader, Salt Section
Repository Projects Branch
Division of Waste Management, MS 623-SS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Linehan:

SUBJECT: MONTHLY REPORT (AUGUST) FROM DON CLARK

Enclosed for your information is the monthly activity report of Mr. Don Clark, who is the Salt Repository Project Representative in the Federal Republic of Germany. He is stationed in Braunschweig at the Company for Radiation and Environmental Research/Institute for Underground Storage (GSF/IfT), which is relatively close to the Asse Mine, the Konrad Mine, and the Gorleben potential repository site. This report covers the month of August 1987.

Please let me know if you have questions about the enclosed material.

Sincerely,

J. O. Neff

J.O. Neff
Project Manager
Salt Repository Project Office

SRPO:KKW:max:1179KW

Enclosure:
Monthly Report from Don Clark,
August 1987

cc: K. Wu, SRPO
R. Lahoti, SRPO
S. Heston, SRPO
G. Appel, SRPO
D. Smith, TxNWPO
P. Niedzielski-Eichner, WDIC

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# SRP REPRESENTATIVE TO THE FEDERAL REPUBLIC OF GERMANY (FRG)

Donald E. Clark

Monthly Report for August 1987

## Summary

During this reporting period, close contact was maintained with the situation at the Gorleben candidate salt repository. Excavation activities at Gorleben have been halted due to the construction accident that occurred there in May 1987. A summary report on the current status of the Gorleben project was prepared and submitted to the SRP. Also, additional information on the freeze shaft sinking technique used at Gorleben is being gathered. A German shaft-sinking company has been contacted and arrangements have been made to observe the installation of a permanent liner in a shaft similar to the two that are being constructed at Gorleben. Assistance has been given to both U.S. and FRG personnel for the planning of upcoming meetings and visits.

## Introduction

Beginning in early 1987, the long-term assignment of a representative of the Salt Repository Project (SRP) to the nuclear waste disposal program in the Federal Republic of Germany (FRG) was established as part of the ongoing interactions between the two countries under the U.S./FRG Bilateral Agreement (Waste Management). Through day-to-day contacts and close association of a technically cognizant SRP representative with key aspects of the FRG program, the objective of having a systematic exchange of pertinent programmatic information and data on the nuclear waste disposal programs of both countries is being realized. During this reporting period, additional valuable contacts with key FRG personnel were established and continued, and direct communication with SRP management was maintained.

## PTB and DBE -- Two Key Organizations in FRG Radioactive Waste Disposal Program

Regular contact is being maintained with the Physikalisch Technische Bundesanstalt (PTB) in Braunschweig and the Deutsche Gesellschaft zum Bau und Betrieb von Endlagern fuer Abfallstoffe (DBE) in Peine. The PTB has responsibility to ensure that federal installations are constructed and operated for the long-term storage and disposal of radioactive waste. In turn, the PTB has contracted with the DBE to design, construct, and operate the federal disposal facilities.

Two candidate repository sites have been selected in the FRG. The Gorleben site, a salt dome, would serve for the disposal of all types of radioactive waste but, most importantly, for vitrified high-level waste (HLW) and spent nuclear fuel. The Konrad site, an abandoned iron ore mine, would serve for the disposal of non-heat-producing wastes. A good summary paper of the German approach is included as Attachment 1 ("The German Approach to the Disposal of Radioactive Wastes" by Ernst Warnecke).

Through regular contacts with the PTB and DBE, current and authoritative information on the FRG disposal program is being obtained and transmitted back to the SRP. This includes photographs and other public information materials, much of which should be very useful to the SRP in providing an overview of the FRG program to interested parties.

## The Situation at Gorleben

A summary status report on the Gorleben project was prepared and submitted to the SRP (see Attachment 2). At this time, the broad consensus of cognizant FRG experts is that the accident is not related to questions as to the suitability of the Gorleben salt dome for nuclear waste disposal. However, the occurrence of this unexpected event has resulted in much criticism of the FRG waste disposal program on the part of various antinuclear and opposition political groups. As in the U.S.A., various unsubstantiated and erroneous accounts have appeared in the press, and the public information offices have been busy trying to correct all of the misinformation. The overall impact on the German schedule for the exploration and later licensing of the Gorleben site is not yet known, though it now appears that the slippage will extend into the next calendar year.

A copy of schematic drawings of shafts #1 and #1 at Gorleben showing the approximate lithological structures for each is contained in Attachment 3. The principal clay layers for shaft #1 are at depths of about 70 meters, 160-200 meters, and 220-240 meters. For shaft #2, clay layers will be encountered at depths of about 60-110 meters and 170-200 meters.

Attachment 4 is a copy of a photograph taken in the bottom of shaft #1 at Gorleben a week or two prior to the accident. It shows workers at a level about three meters above where the shaft was sunk at the time of the accident. The steel support ring which broke and fell to the bottom of the shaft is the one that is in between the ring marked with an "8" and the one that is darker in color, according to sources in the FRG.

More information concerning the Gorleben accident will be transmitted to the SRP as it becomes available.

## Freeze Shaft Sinking Construction

The freeze shaft sinking construction technique being used at Gorleben is well established. Published information on this technique is being gathered and transmitted to the SRP. A copy was obtained of a very good German book on this subject, "Handbook of Freeze Shaft Construction in Mining", edited by Dr.-Ing. Joachim Klein. An English translation is being made of two important chapters in this handbook.

Contact was made with a German company which has had extensive experience with the freeze shaft sinking technique. This is the Deilmann-Haniel (D-H) Company with headquarters in Dortmund, FRG. Through a joint venture company, ASG, formed with the Thyssen-Schachtbau Company, D-H is also involved in the shaft construction work at Gorleben. An informative and attractive brochure describing the sinking of the Haltern 1 and 2 shafts was obtained from D-H and is included as Attachment 5.

Arrangements have been made to visit a D-H shaft sinking project in the FRG and to observe installation of the final liner in the frozen portion of the shaft. There is only a narrow window of time during which the visit can be made and this will occur in early September.

## Assistance for Planning of Upcoming Meetings and Visits

Assistance is routinely provided to both U.S. and FRG personnel for the planning of upcoming meetings and visits, as appropriate. A U.S./FRG workshop on geochemistry is scheduled to be held in

Albuquerque, New Mexico in September 1987. Several German representatives will attend this workshop and assistance was provided to them and U.S. counterparts in planning for this meeting and the making of other arrangements. Similarly, assistance was given for planning of visits to the FRG by U.S. representatives. A local meeting on geochemistry is planned in Braunschweig in early September in connection with an international conference on actinide chemistry and migration behavior which is scheduled to be held in mid-September in Munich.

A visit by U.S. nationals under sponsorship of the National Conference of State Legislators (NCSL) is planned for October 1-2, 1987. This is part of an orientation tour of several European radioactive waste management sites and will include visits to the Konrad and Asse mines, as well as discussions with licensing authority representatives of the State of Lower Saxony. Most of the group of 25-30 persons are legislators and staff from the states currently being considered by DOE as potential hosts for the first HLW repository or the Monitored Retreivable Storage (MRS) facility, i.e., from Texas, Nevada, Washington, and Tennessee. A considerable effort will be required to coordinate this this visit with the Germans and to make it a success for all concerned.

Planned Activities for September 1987

A visit will be made to the D-H Company and installation of the final liner will be observed in a frozen shaft. Locally, a meeting on geochemistry with Dr. Paul Cloke of ONWI will be held in Braunschweig. Participation is planned at the international conference to be held in Munich on September 14-18. The title of this conference is "Chemistry and Migration Behavior of Actinides and Fission Products in the Geosphere". Further plans will be made to accomodate visits by U.S. and FRG representatives, as appropriate, and to participate in the NCSL tour of European waste management sites. And, close contact will be maintained with PTB and DBE, particularly with respect to any developments concerning Gorleben.

Attachments

1. Paper by Ernst Warnecke, "The German Approach to the Disposal of Radioactive Wastes"

2. Summary report by D. E. Clark on current status of the Gorleben project

3. Schematic drawings of Gorleben shafts #1 and #2

4. Photograph of workers in bottom of Gorleben shaft #1

5. D-H brochure describing the sinking of Haltern 1 and 2 shafts

dec

attachments (5)

ATTACHMENT 1

# The German Approach to the Disposal of Radioactive Wastes

Ernst Warnecke
Physikalisch-Technische Bundesanstalt
Bundesallee 100

D-3300 Braunschweig

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61pp

Finnish-German Seminar on Nuclear Waste Management
Otaniemi, Espoo, Finland
September 23-25, 1986

# THE GERMAN APPROACH TO THE DISPOSAL OF RADIOACTIVE WASTES

Ernst Warnecke
Physikalisch-Technische Bundesanstalt
Bundesallee 100
D-3300 Braunschweig, Federal Republic of Germany

## Abstract

In the Federal Republic of Germany the PTB is responsible for the construction and operation of the repositories in which radioactive wastes will be disposed of. Two repositories are planned:

- Gorleben (salt dome; for all types of radioactive wastes)
- Konrad (abandoned iron ore mine; for radioactive wastes with negligible thermal influence upon the host rock).

The safe operation of the repositories has to be demonstrated to the licensing authorities. These are the responsible Ministers of the Federal States (Länder) and the mining authorities. According to the "safety criteria for the disposal of radioactive wastes in a mine", the safety of a repository has to be demonstrated by a site specific safety assessment for the normal operation of a repository, for incidents in the operational phase, and the post-operational phase. These assessments result in waste acceptance requirements. The compliance of the waste packages to be disposed of with the waste acceptance requirements is checked with a waste package quality control either by random tests on waste packages or a qualification and inspection of waste conditioning processes.
Preliminary waste acceptance requirements have been set up for the planned Konrad repository. In the Kernforschungsanlage Jülich (KFA) a group for the quality control of radioactive waste has been established on behalf of the PTB. The application documents for Konrad have been completely submitted to the licensing authority. The operation of the Konrad repository is anticipated for the year 1990. Preliminary safety assessments have only been performed for the Gorleben site on the basis of model assumptions. These are planned to be updated in 1986/87 on the basis of the results of the site investigation from surface and on new data of the wastes to be disposed of.

Presently, the sinking of the two shafts is under way. This will be followed by an underground investigation of the salt dome, which will last until about 1992. The beginning of operation of this repository is planned for about the year 2000. According to the recent inquiries it will be possible by this approach to dispose of all arising radioactive wastes of the Federal Republic of Germany.

## 1. INTRODUCTION

In the Federal Republic of Germany the Physikalisch-Technische Bundesanstalt (PTB) is responsible for the construction and operation of the repositories in which radioactive wastes will be disposed of /1/. The PTB may make use of the services of third parties in order to construct or operate these facilities. For this task the Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH, DBE (German Company for the Construction and Operation of Repositories for Waste Material), was founded in 1979. It is directly supervised by federal authorities. The organization of the disposal of radioactive wastes is illustrated in Fig. 1.

Two repositories are planned (Fig. 2):

- Gorleben (salt dome; for all types of radioactive wastes)

- Konrad (abandoned iron ore mine; for radioactive wastes with negligible thermal influence upon the host rock).

Additionally, it is planned to inject tritium-containing water from the reprocessing of spent fuel into deep geological formations, especially porous sediments. A pre-examination of possible sites in Bavaria is under way.

From 1967 to 1978, the former Asse salt mine was used as a pilot repository within the scope of a licence limited in time. It now serves as the R+D facility whose work aims at determining above all the thermal and thermomechanical effects of the heat generating wastes. This information is required for the construction of the Gorleben repository.
The costs for work carried out in connection with the repositories are being paid by the waste producers according to the "Endlagervorausleistungs-Verordnung" (Advance Payment Ordinance), /2/. The total costs which will have accumulated until the repositories will be put into operation have been

estimated to be about $10^9$ DM for Konrad and about $2,6 \cdot 10^9$ DM for Gorleben.

The state of the planning and practical work carried out in connection with the repositories and the organisational measures taken indicate that it is possible to dispose of all radioactive wastes arising from the operation of nuclear power plants and other facilities where radionuclides are used.

## 2. THE PLANNED REPOSITORIES

### 2.1 Gorleben

The Gorleben site is under investigation to check the suitability of the salt dome for the disposal of all types of radioactive wastes, especially heat-generating wastes. A comprehensive site investigation programme has been elaborated in cooperation with the Bundesanstalt für Geowissenschaften und Rohstoffe, BGR (Federal Institute of Geosciences and Natural Resources) /3/.

The investigations from above ground are almost terminated and the results were published in May 1983 in a summarizing interim report /4/.

These investigations were carried out in an area of roughly 300 $km^2$ and included:

- 129 hydrogeological exploratory drillings,
- 275 observation drillings, which have been expanded for use as ground water measuring locations,
- 1 well for pumping tests,
- 11 core drillings,
- more than 40 drillings sunk down to 80 m into the salt,
- 4 salt dome exploratory drillings of about 2000 m into the flanks of the salt dome, and

- an intensive seismic measuring programme.

Fig. 3 shows the exploration area and the locations of the hydrogeological investigations, the 4 salt dome exploratory drillings and 2 shaft pre-borings.

The resulting site-specific data include special information about

- the hydrogeological situation in the overlying and surrounding strata of the salt dome,
- the sorption data of radionuclides in Gorleben samples (sediment and waters) /5/,
- the geological situation in the caprock area,
- the existence and sequence of the various strata within the salt dome, and
- the locations for the shafts.

Figures 4 and 5 are sectional views of the overlying strata and the salt dome as examples of the results of the site investigation.

It was concluded from these results that the salt dome's suitability for waste disposal was confirmed and that those data which can only be obtained by an underground exploration are still lacking. For this purpose, two shafts must be sunk. The salt dome is to be explored by drillings from galleries of the exploratory mine into the surrounding rock /6/. An area of about 19 $km^2$ is to be investigated.

In July 1983, the Federal Government approved of the speedy commencement of the underground exploration.

The two shafts are being sunk by the Arbeitsgemeinschaft Schächte Gorleben, ASG (Gorleben shafts pool) making use of the "freezing technique". The work has been in progress since 1984. The preparation of the "freezing boreholes" began in May 1984 (Fig. 6). After the construction of a frost jacket the work on the sinking of the first shaft began in March 1986 (Fig. 7) and has now reached a depth of about 50 m. Work on the second shaft will be started in October 1986. The cumulative inventory of $\beta/\gamma$-emitters and of $\alpha$-emitters in the repository after 50 years of operation has been estimated on the basis of previous planning work to be in the order of magnitude of $10^{21}$ Bq and $10^{19}$ Bq, respectively /4, 7/. The annual data for the amounts of waste, the required host rock volume and activities are compiled in Table 1, /7/.

The heat-producing wastes are to be disposed of in boreholes (300 - 600 m deep). The other wastes will be emplaced in mined rooms (Fig. 8).

These planning data are currently being revised and will be updated in 1986/87 due to new developments in the data basis for radioactive wastes and the results of the site investigation.

## 2.2 Konrad

The Konrad mine is the most recent of all former iron ore pits in the Peine-Salzgitter area und has two shafts (Fig. 9). It is located in the south of the large iron ore sediment (Fig. 10) which was deposited about 150 million years ago during the Upper Jurassic (Malm). Ore Mining in 800 - 1300 m depth started in 1965 and was stopped in autumn 1976 for economic reasons. As the Konrad mine is very dry it was investigated from 1976 - 1982 by the Gesellschaft für Strahlen- und Umweltforschung mbH, GSF (Company for Radiation and Environment Research) for its potential suitability for the disposal of radioactive wastes. On the basis of the positive results of the GSF /8/ the PTB applied for the initiation of a plan-approval procedure on August 31, 1982 and submitted the completed documents on June 30, 1986 to the licensing authority.

In the meantime the PTB carried out supplementary work necessary to demonstrate the suitability of the mine in the course of the licensing procedure. This work included

- an underground exploration of the disposal areas,
- seismic measurements,
- one deep drilling,
- the development of a concept for the design and operation of the repository and a drafting of the facilities,
- the measurement of sorption data for radionuclides on Konrad samples (sediment and waters) /5/,
- the performance of safety assessments (for the normal operation of the mine, for incidents and for the post-operational phase), and
- the derivation of preliminary waste acceptance requirements.

As examples of the results of this supplementary work, a revised sectional view of the Konrad strata (Fig. 11), a diagram of the planned storage operations (Fig. 12), and a diagram of the anticipated waste emplacement areas (Fig. 13) are shown. In these areas presently under consideration it will be possible to dispose of about 650 000 $m^3$ of non heat generating waste packages in extended galleries with a cross-section of about 40 $m^2$ (Fig. 14).

The cumulative activity inventory of the Konrad mine at the end of its operation as a repository has been estimated. Accordingly, the activity of $\beta/\gamma$-emitters will be in the order of magnitude of $10^{18}$ Bq, and the activity of $\alpha$-emitters will be about $10^2$ times lower.

## 3. SAFETY REQUIREMENTS

### 3.1 Safety Criteria

The basic aspects which must be taken into account for the disposal of radioactive wastes are compiled in the "Safety Criteria" /9/ recommended by the Reactor Safety Commission in 1982 and announced by the Federal Ministry of the Interior in 1983. The following criteria are considered to be most important:

- The required safety of a repository constructed in a geological formation must be demonstrated by a site-specific safety analysis which includes the overall geological situation, the technical concept of the disposal mine and the waste packages.

- The objectives for the operation of a repository are prescribed by the German Atomic Energy Act /1/ and the German Radiation Protection Ordinance /10/.

- In the post-operational phase, the radionuclides which might reach the biosphere via the water path as a result of transport processes not completely excludable must not lead to individual dose rates which exceed the limiting values specified in § 45 of the German Radiation Protection Ordinance /10/ (30 mrem/a concept).

The safety criteria specify the scope of a site-specific safety analysis. The following aspects must be investigated (Fig. 15):

- In the operational phase of a repository, the radiation exposure of the personnel and of individuals in the environment of the facility to direct or scattered radiation as well as to radionuclides released via the air path or by liquid effluents must be judged.

- Additionally, the resulting effects of the heat generation per waste package must be analysed.

- In incident scenarios in the operational phase, mechanical and/or thermal impacts on the waste packages must be considered.

- In the post-operational phase of a repository, the radiation exposure of individuals in the biosphere due to radionuclides released from waste packages and transported via the water path is to be evaluated.

## 3.2 Development of Waste Acceptance Requirements and Quality Control

The PTB has developed a basic procedure (Fig. 16) to derive waste acceptance requirements /11, 12, 13, 14/ and a quality control programme to check compliance of waste packages with the waste acceptance requirements /12, 15, 16, 17, 18/.

The development of waste acceptance requirements (Fig. 16) is based on the characteristic properties of the waste, the layout of the disposal mine, and the geological situation at the envisaged site. With such a set of data it is possible to define preliminary waste acceptance requirements with a safety assessment in an iterative process between the waste producers and the operator of the repository. These are reviewed by the licensing authority, and waste acceptance requirements are established at the end of the licensing procedure.

The waste packages must fulfill the waste acceptance requirements. The waste producers are responsible for the quality of the waste packages. Compliance of the waste packages with the waste acceptance requirements must be checked by a waste package quality control. This can be done by a qualification of conditioning processes and subsequent controls and inspections or by a checking of waste packages with destructive or non-destructive tests. Additionally, checks of the documentation are necessary.

## 4. APPLICATION OF THE SAFETY CRITERIA

### 4.1 Gorleben

All existing assessments for the Gorleben site are based on model assumptions of the geology, the layout of the repository and the radioactive wastes. They were performed at the end of the seventies. Only the calculations of the long-term safety include parts of the hydrogeological investigations. Therefore, only weak points could be identified at this preliminary stage. All the assessments will have to be revised after the underground exploration. Additionally, the disposal of spent fuel will have to be allowed for in future plannings.

#### 4.1.1 Normal Operation

In the normal operation of the repository significant releases from radioactive wastes could result from gaseous radionuclides and aerosols. In a preliminary assessment /11/ it was found that the release for H-3 from zircaloy -fuel element hulls fixed in concrete possibly could exceed the limits for the H-3 concentration in the air. Ranges of possibly tolerable average release rates of volatile radionuclides from waste packages have been derived from model calculations (Table 2), /19/.

The exposure to direct radiation can be adjusted to the required limits, e. g. by providing sufficient shieldings.

#### 4.1.2 Incidents

The analysis of possible incidental events showed that mechanical or thermal impacts or a combination of both could be representative /11, 12/. The boundary conditions for these impacts will be evaluated within the scope of the anticipated updating of the preliminary assessments.

### 4.1.3 Thermal aspects

One of the main problems in the disposal of heat generating wastes is the influence of the dissipated heat on the waste package, the disposal area and the host rock.

The layout of the repository is based on a maximum temperature of 200 °C at the surface of the glass blocks of the vitrified fission product concentrate and 100 °C for cemented wastes /11, 12/. This limitation resulted from the chemical resistance of glass in brines and the cement properties, respectively. The disposal of these wastes has been planned to be carried out in deep boreholes (300 m-600 m). The limitation of the initial heat per waste package is e. g. dependent on the age of the waste, the distance and length of the boreholes, and the emplacement within the boreholes (longitudinal heat dilution) /12, 20/.

The temperature distribution in a host rock formation has been calculated on the basis of model assumptions for the Gorleben salt dome. The time dependence of the heat dissipation for a repository with deep boreholes (maximum temperature of 200 °C) is shown in Fig. 17 /12, 21/. It is very important that the highest temperatures occur only locally in the center of a borehole field and for a limited period of about 100 years (between 50 and 150 years after disposal). The temperature outside the disposal field stays below 100 °C. The natural temperature distribution in the host rock is almost obtained 5000 years after waste disposal.

The effects of this temperature distribution have been simulated with two independent numerical computer programmes /22, 23/. The thermal expansion of the salt induces a velocity field within the host rock (Fig. 18) /22/, which leads to a calculated uplift of 1,2 m above the repository 450 years after disposal (Fig. 19), /22/. From this first investigation no arguments could be found against this layout of the model repository. The final layout can only be carried out after the underground investigation when the questions relevant to geochemical, physical, chemical and rock mechanical aspects can be answered.

#### 4.1.4 Long-Term Safety Assessment

The intrusion of the salt into the younger, overlying strata took place between the geological periods of Malm and Lower Cretaceous. As a result of diapirism, the salt layers are folded.

Detailed knowledge of the interior of the salt dome will only be available after its underground investigation. Possible incidents are therefore conservatively considered in theory for the long-term safety assessment. It is assumed that thermomechanical effects caused by heat-generating radioactive wastes can produce new pathways for waters in the anhydrite horizons in the post-operational phase of the repository (especially in the Hauptanhydrit). In this way water from the ground-water-bearing overlying strata could intrude into the repository area. Contaminated brines could be released back into the overlying strata on the same way due to the convergency of the rock salt /24/.

In the overlying strata of tertiary, especially quaternary geological age, the sorption of radionuclides will then influence the migration of the radionuclides in the flow of ground-water. Preliminary results from an R+D study on the consequences of such a scenario have been published /25/. The intrusion of waters into the repository area and the releases of contaminated waters are shown in Fig. 20. The calculated doses from these releases are shown in Fig. 21 /25/.

Some of the main results are

- that the intruding waters do not reach the disposal area for the vitrified fission product concentrates because of the thermal layout,

- that the calculated dose rates in the environment are dominated by Tc and Np,

- that the highest dose rates occur about 10 000 years after disposal, and

- that the requirements of the safety criteria /9/ are fulfilled.

Due to recent results of the investigation of the sorption behaviour of radionuclides in Gorleben samples /5/ it could be shown that the sorption data for Np and Tc are considerably higher than assumed in /25/. Therefore, the dose rates of these radionuclides will be of less importance.

## 4.2 Konrad

The site specific safety assessments for the planned Konrad repository have been terminated and the preliminary waste acceptance requirements developed /14, 26/. The completed application documents have been submitted to the licensing authority. Final waste acceptance requirements will be set up after the licensing procedure.

### 4.2.1 Normal Operation

This safety assessment includes the direct radiation of waste packages and releases of volatile radionuclides with air (direct) or water (indirect).

The analysis of the conditions showed that the operation of the repository is possible with a suitable layout of the facility (shielding of buildings, vehicles etc.), /27/.

The deduction of annual release rates of volatile radionuclides must ensure that the calculated potential exposures in the environment are below the limits given in the Radiation Protection Ordinance /10/ and that the inhalation dose for the staff is below 0,5 mSv/a. This relatively low value is an internal planning requirement and represents a largely unavoidable exposure. The annual release rates applied are given in Table 3. From these data it is possible to derive permissible concentrations of the volatile radionuclides in waste packages taking into account the different barriers which can be the waste form, the packaging, the backfill material and the closure building of the storage rooms /27/.

#### 4.2.2 Incidents

The first step in an incident analysis is the identification of "undesired" events. About 50 of such events were identified. They could be condensed to 3 radiologically representative incidents (Table 4).

In order to calculate the radiological consequences, the fractions of the activity released in the case of an incident must be determined. Those waste packages which have comparable release behaviours can be condensed to waste form groups (i. e. requirements for the waste form) and waste classes (i. e. requirements for the packaging). Thus the maximum permissible activity contents in waste packages can be calculated if the release fractions and the additional retentions are determined and if the maximum permissible exposure rates and the calculation modes are given /28/.

#### 4.2.3 Thermal Aspects

The planned Konrad repository is only intended for radioactive wastes with negligible heat generation. According to definition wastes are in compliance with this requirement if the thermal influence upon the host rock is less than $\Delta T$ 3K. The maximum permissible radionuclide inventory can be calculated for each waste package and can be derived if the temperature distribution in the repository is determined /29/.

### 4.2.4 Long-Term Safety Assessment

The geological horizon in which the waste will be disposed of, the so-called Korallenoolith (Oxford), including the iron ore, lies at a depth of about 800 m to 1300 m. It is covered by younger sediments, most of which have a very low permeability. In the scenario for the long-term safety assessment it is assumed that in the post-operational phase the mine will be filled with waters from the surrounding rocks which have a low permeability. The contaminated waters then follow the general flow of ground-water in a northerly direction. At a distance of more than 30 km from the repository the horizon of the Oxford approaches the surface. This pathway was modelled in the safety assessment considering the retardation of radionuclides by sorption /5/. Resulting individual dose rates have been calculated. Water transfer times are in the order of several 100 000 years. It could be shown for the anticipated radionuclide inventories that the calculated exposures are below the exposure limits /10/ and only the total amount of iodine in the repository should be limited.

According to the safety criteria /9/ it is necessary to predict with a site-specific safety assessment that the exposure limits of § 45 of the Radiation Protection Ordinance /10/ are not exceeded. This procedure seems only meaningful for such a period of time which allows a sufficiently exact prediction. This time span is in the order of magnitude of 10 000 years and the forecast for the geological conditions at the site of a repository are indicated with 1 000 000 years /30/.

### 4.2.5 Quality Control for Radioactive Wastes

The PTB has established a quality control group in the Kernforschungsanlage Jülich, KFA (Jülich Nuclear Research Establishment) to control compliance of the waste packages with the waste acceptance requirements. At present, the installations for the control of waste packages are being constructed. Additionally, waste conditioners have applied for the process qualification of 8 conditioning processes. 2 more applications have been announced.

It is the aim to have enough checked waste packages available when the Konrad mine will be ready for operation as a repository.

## 5. CONCLUSIONS

The present state of the work on the repository projects reveals that the F. R. of Germany plays a leading role in managing waste disposal. Detailed information is in particular available on the data for radioactive wastes /26/ and the anticipated sites. Additionally, necessary site-specific information is under investigation.

Safety assessments which are preliminary for the Gorleben site have been performed and preliminary waste acceptance requirements derived for Konrad. This considerable technical know-how which has been compiled with contractors and in cooperation with various institutes and universities is available and will be used for the anticipated updating of the safety assessments for the Gorleben site.

The state of the planning and construction work for the repositories indicates that it will be possible to dispose of all radioactive wastes produced, in particular as their volumes will decrease as a result of new conditioning techniques.

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| | Waste volume produced per annum | | Repository volume required per annum | | Activity inventory of yearly produced waste | |
|---|---|---|---|---|---|---|
| | $m^3$ | % | $m^3$ | % | Bq | % |
| Reprocessing | $1{,}25 \cdot 10^4$ | 39,0 | $6{,}45 \cdot 10^6$ | 97,6 | $21{,}20 \cdot 10^{18}$ | 99,99 |
| HLW portion | $1{,}5 \cdot 10^2$ | 0,5 | $5{,}28 \cdot 10^6$ | 79,9 | $17{,}02 \cdot 10^{18}$ | 80,4 |
| Nuclear power | $1{,}62 \cdot 10^4$ | 50,4 | $1{,}28 \cdot 10^5$ | 1,95 | $21{,}16 \cdot 10^{14}$ | |
| Research centres | $2{,}21 \cdot 10^3$ | 6,8 | $1{,}64 \cdot 10^4$ | 0,25 | $8{,}14 \cdot 10^{13}$ | 0,01 |
| Industry | $5{,}63 \cdot 10^2$ | 1,7 | $5{,}36 \cdot 10^3$ | 0,1 | | |
| Collecting depots of the federal states | $7{,}31 \cdot 10^2$ | 2,3 | $6{,}82 \cdot 10^3$ | 0,1 | $34{,}04 \cdot 10^{12}$ | |

Table 1: Prospective quantity of radioactive waste for long-term repository planning

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Nuclide | H-3 | C-14 | Kr-85 | Ru-106 | J-129 | Rn-220 | Rn-222 |
| Non-bore-hole technique | $3 \cdot 10^{-3 \pm 1}$ | $2 \cdot 10^{-3 \pm 1}$ | $1 \cdot 10^{-3 \pm 1}$ | $5 \cdot 10^{-6 \pm 1}$ | $1 \cdot 10^{-6 \pm 1}$ | $1 \cdot 10^{-5 \pm 1}$ | $5 \cdot 10^{-5 \pm 1}$ |
| Bore-hole technique | $5 \cdot 10^{-2 {}^{+0}_{-1}}$ | $4 \cdot 10^{-2 {}^{+0}_{-1}}$ | $3 \cdot 10^{-2 {}^{+0}_{-1}}$ | $6 \cdot 10^{-5 {}^{+0}_{-1}}$ | $2 \cdot 10^{-5 {}^{+0}_{-1}}$ | $2 \cdot 10^{-4 {}^{+0}_{-1}}$ | $1 \cdot 10^{-3 {}^{+0}_{-1}}$ |

Table 2: Preliminary maximum permissable mean annual release rates per waste package for volatile individual radionuclides (release rates in Ci/a waste package).

| Radionuclide/ Group of Radionuclides | Release Rates Bq/Year | |
|---|---|---|
| H - 3 | 1,48 E13 | |
| C - 14 | 3,7 E11 | |
| I - 129 | 7,4 E 6 | via |
| Rn - 222 | 1,85 E12 | air |
| aerosols (T1/2>10d) | | |
| $\beta/\gamma$-emitters | 7,4 E 7 | |
| $\alpha$-emitters | 3,7 E 6 | |
| H - 3 | 7,4 E12 | via |
| other radionuclides | 7,4 E 8 | water |

Table 3: Release rates of the repository applied for

Drop of a waste package during handling from 3 m height, onto the floor of the hall (above ground),

Drop of a waste package during emplacement in the chamber from 5 m height and

Collision of a vehicle resulting in a fire during waste transport in a transport gallery. For the fire, a fire temperature of 800 °C for 1 hour is assumed.

Table 4: Assumed Incidents (Konrad)

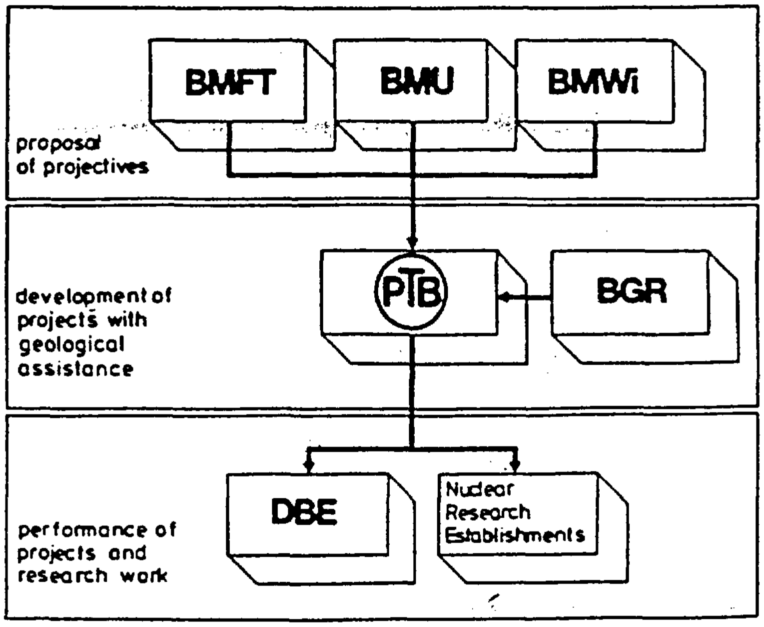



Figure 1: Responsibilities

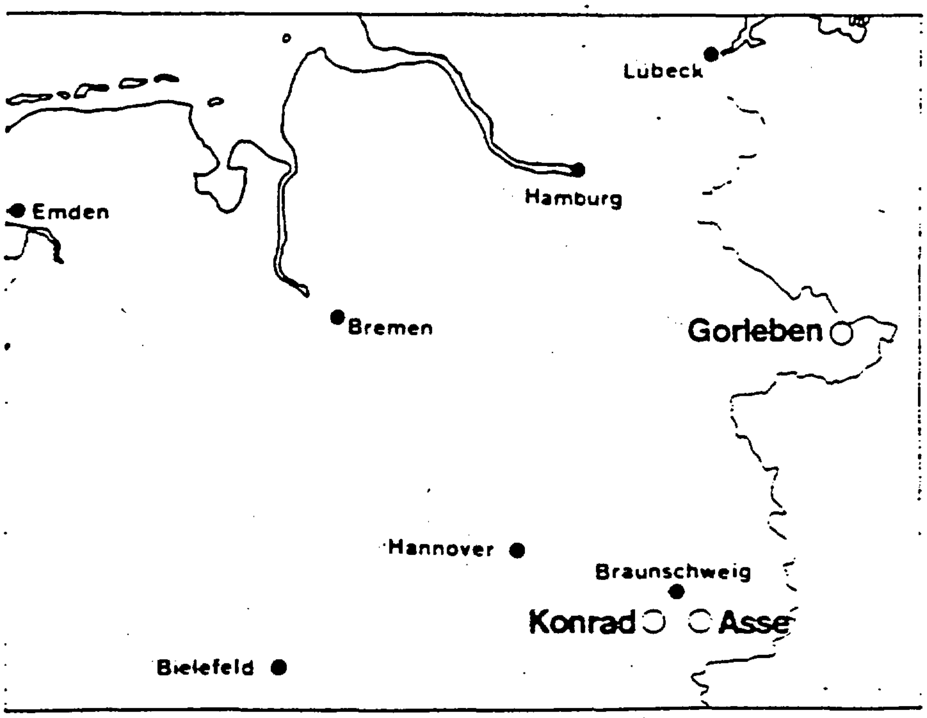



Figure 2: Locations of the sites

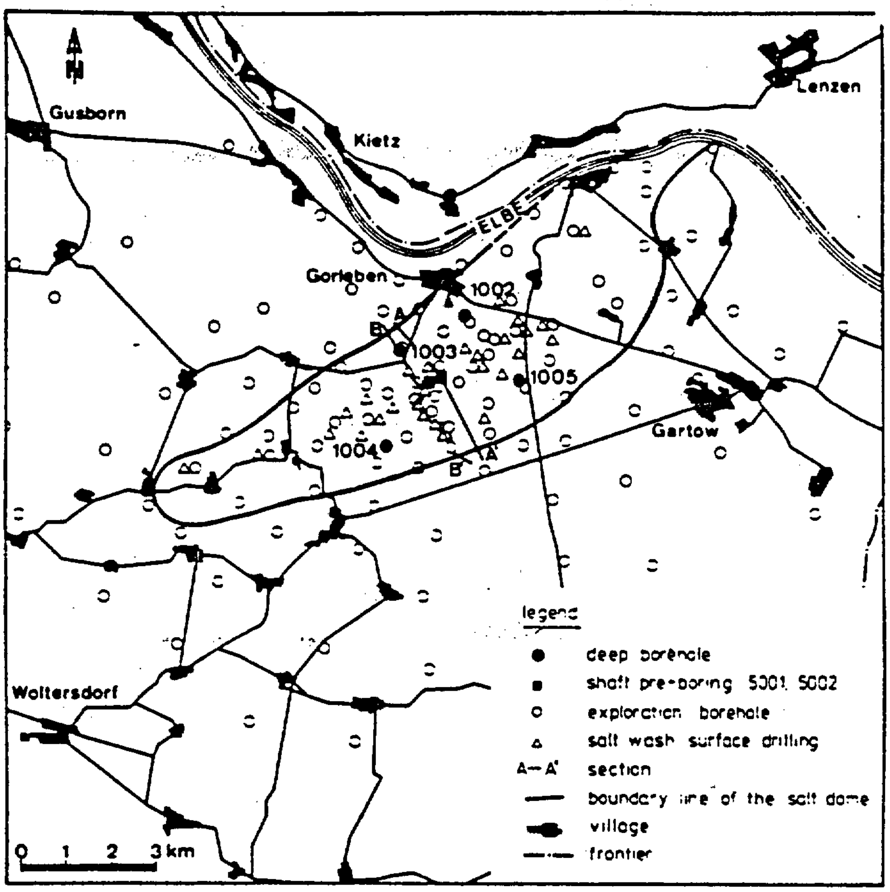



Figure 3: Locations for exploratory drill holes

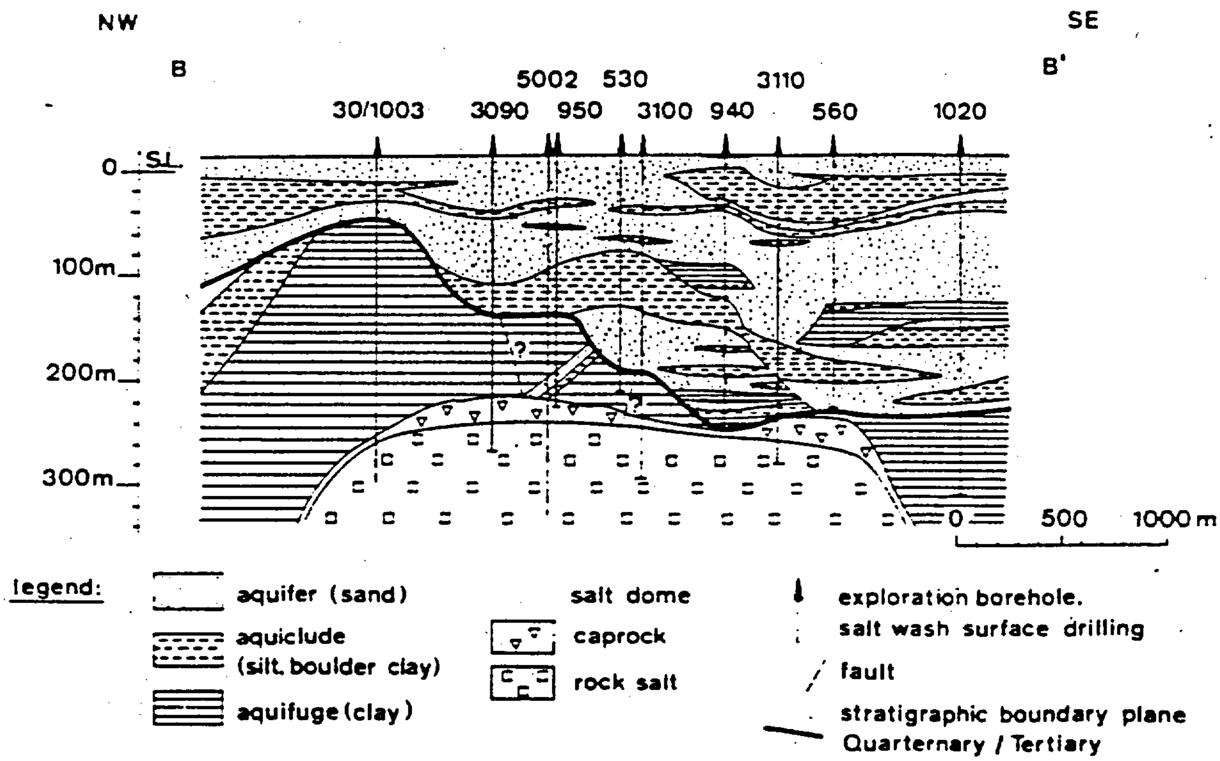



Figure 4: Geological section of the overlying strata in the channel area

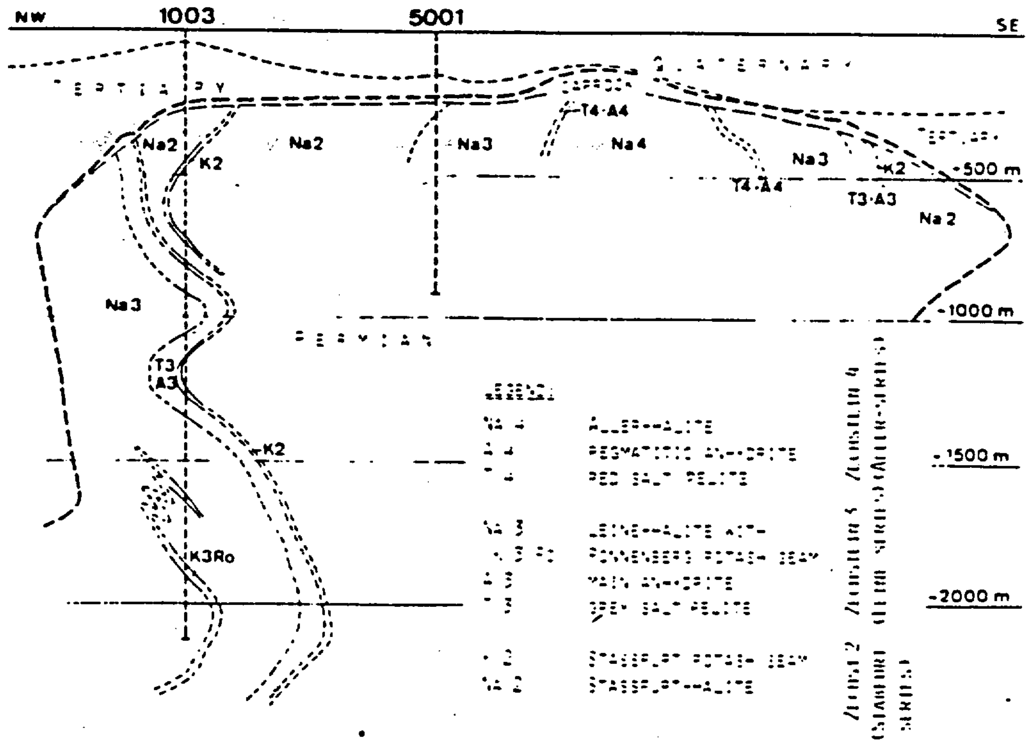



Figure 5: Section of salt dome

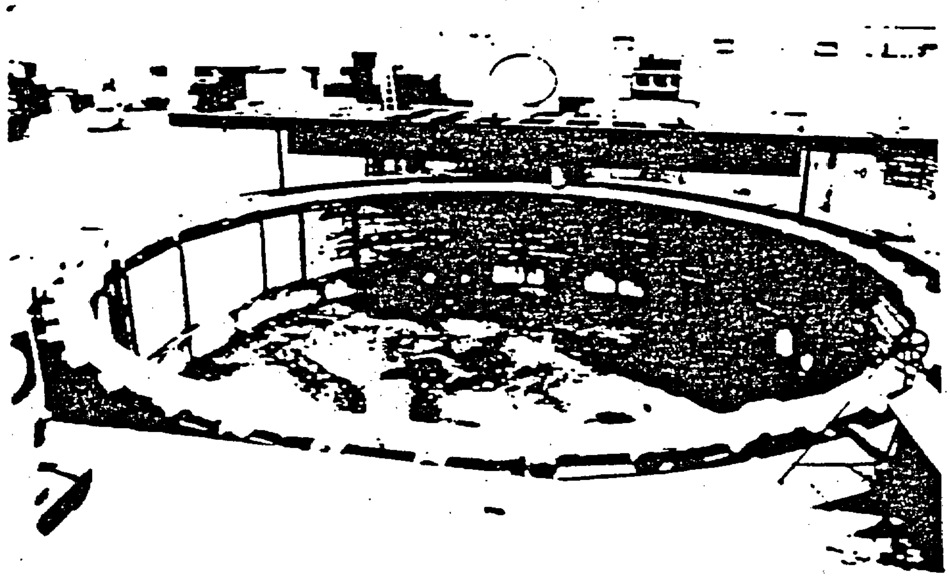


Figure 6: Sinking of the shafts by "freezing technique" (Gorleben)

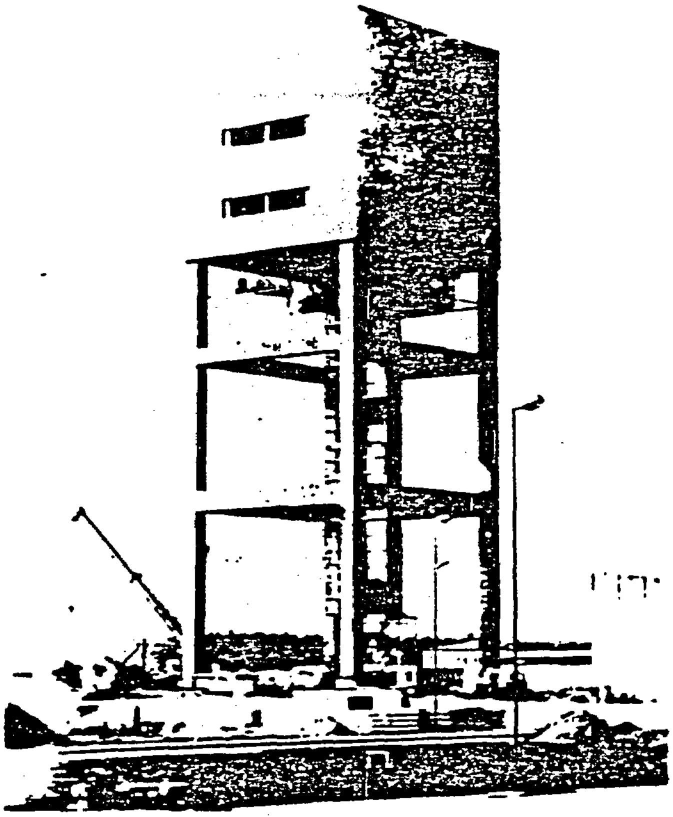


Figure 7: Hoist frame Gorleben

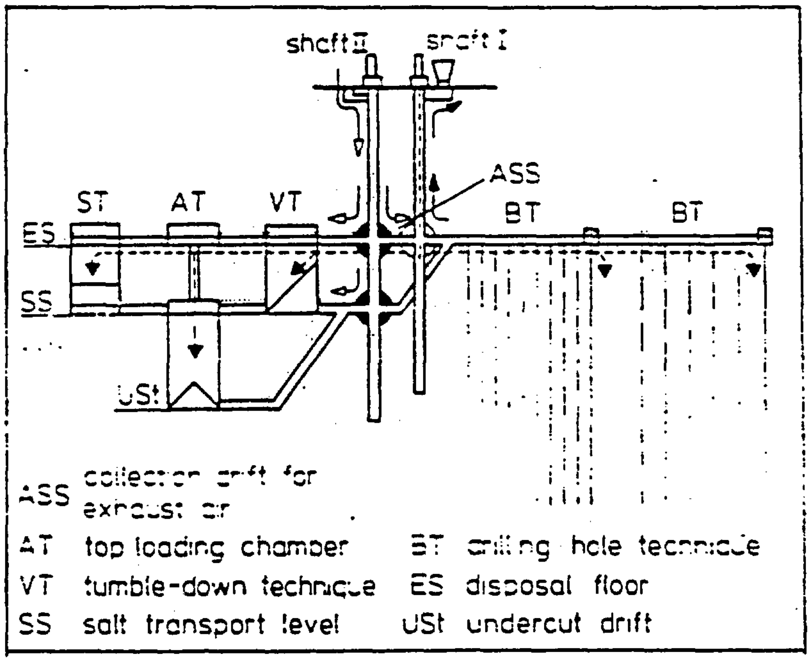



Figure 8: Schematical scope of the planned mine

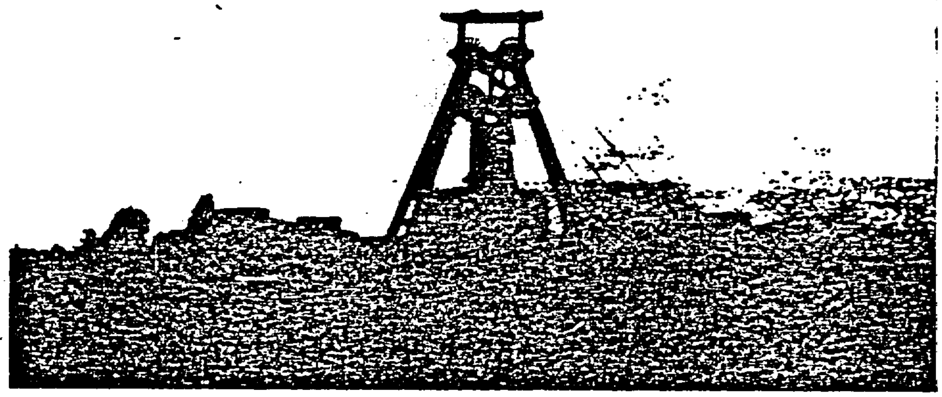


Figure 9: Hoist frame Konrad

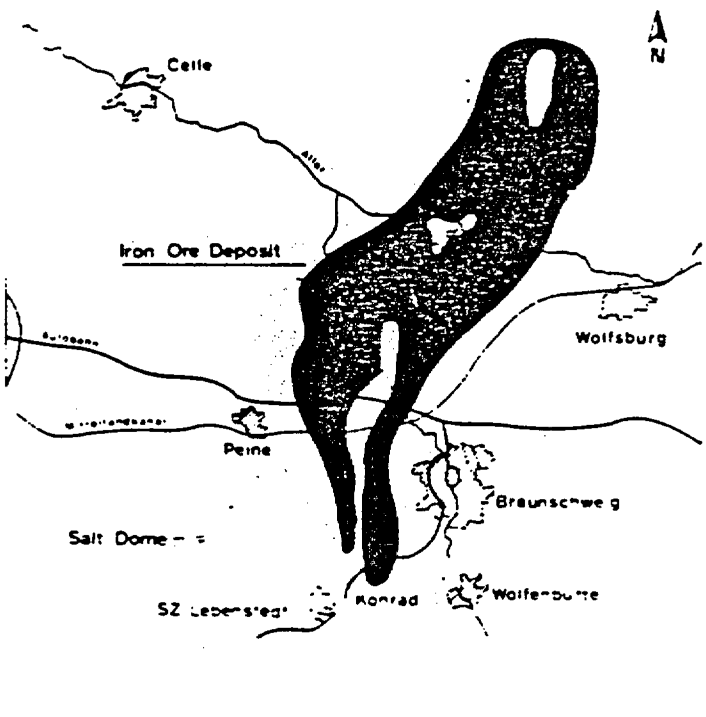



Figure 10: The iron ore deposit "Gifhorner Trog"

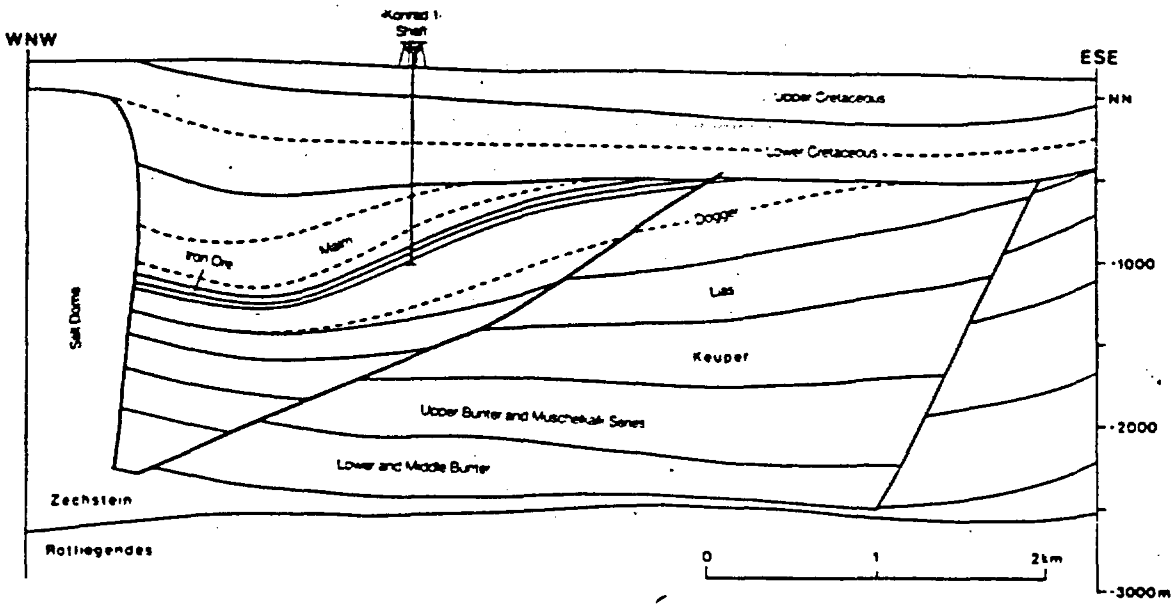



Figure 11: Cross-section through the Konrad iron ore deposit

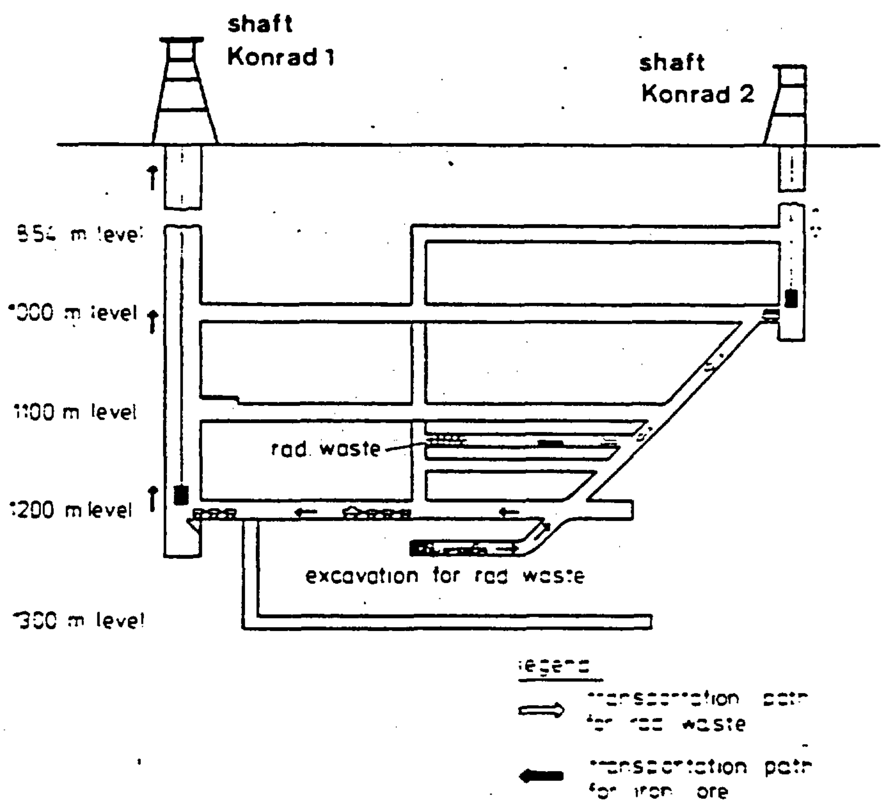



Figure 12: Principle of underground transportation

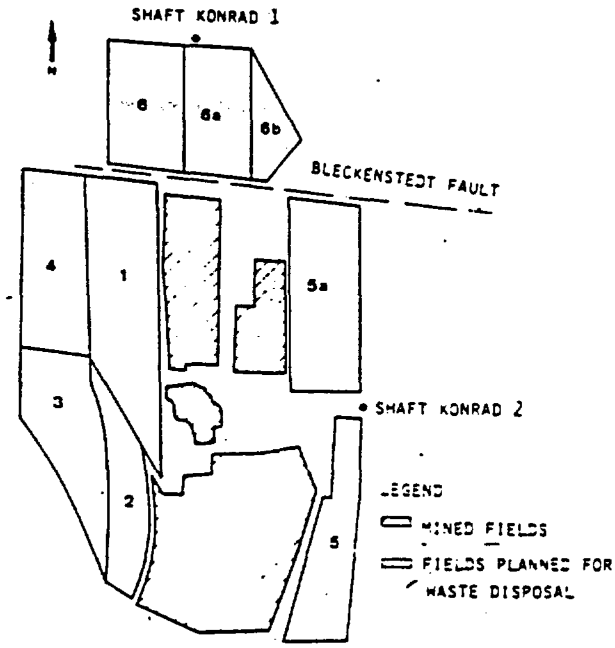



Figure 13: Fields for waste disposal (Konrad)

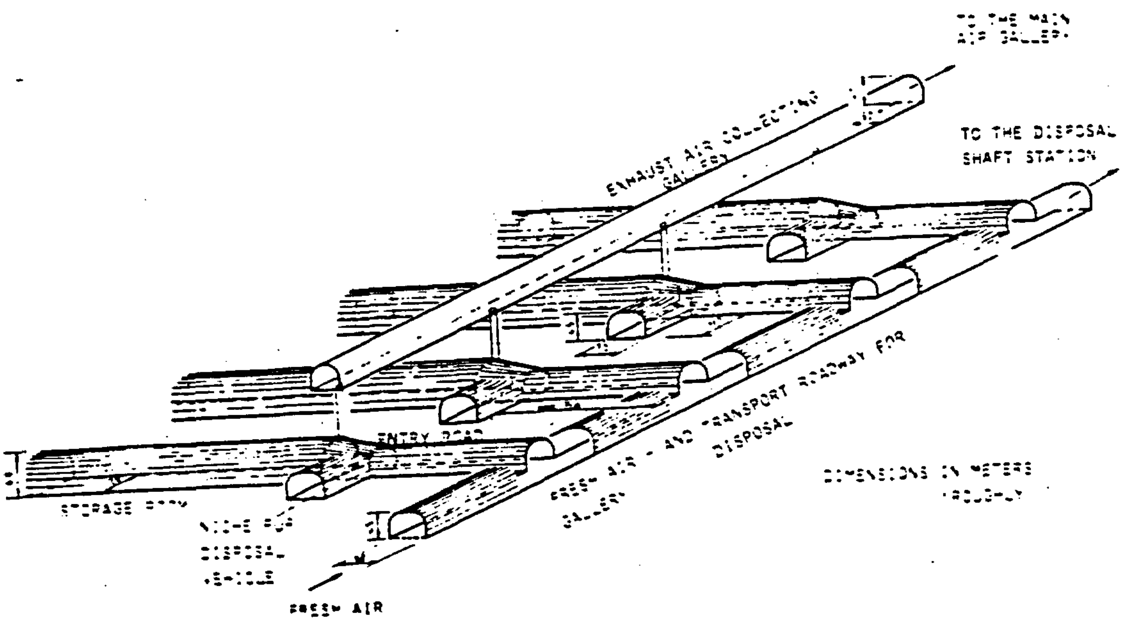



Figure 14: Principles of waste emplacement (Konrad)

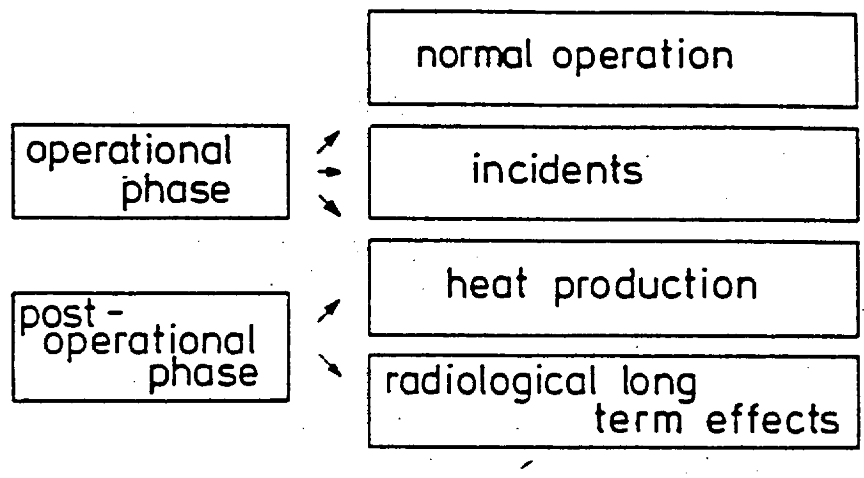



Figure 15: Safety assessments

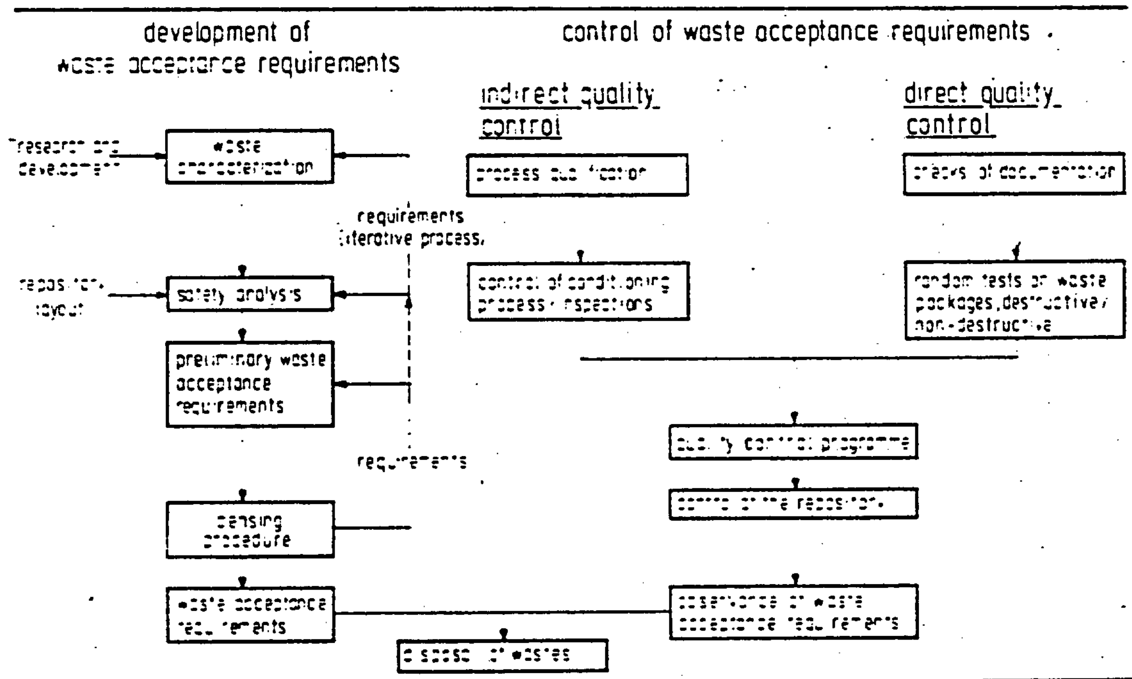
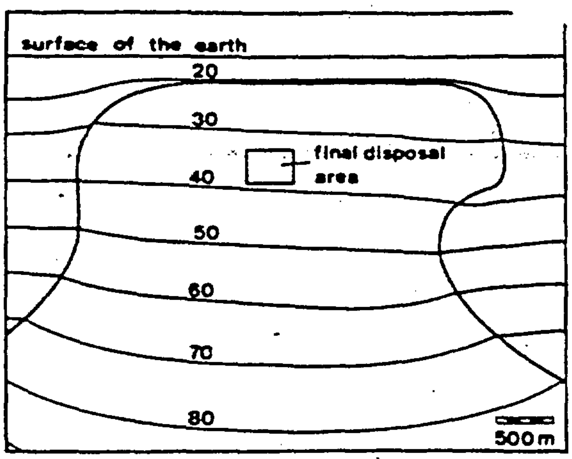
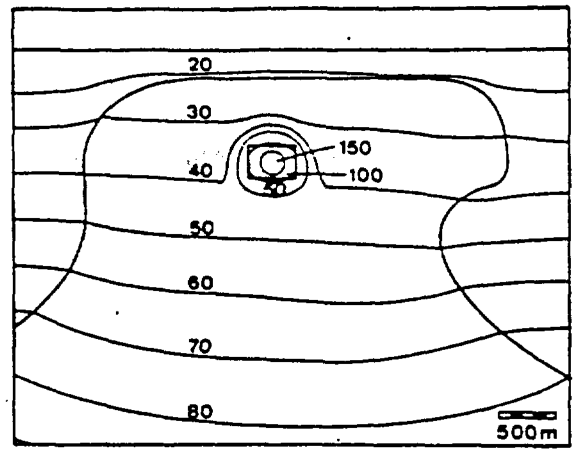


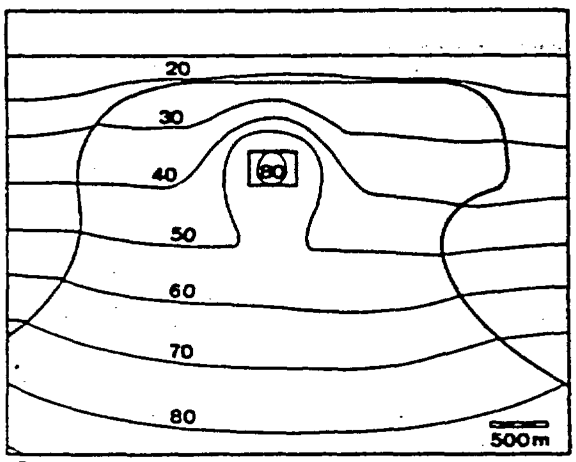

Figure 16: Principles of development and control of waste acceptance requirements



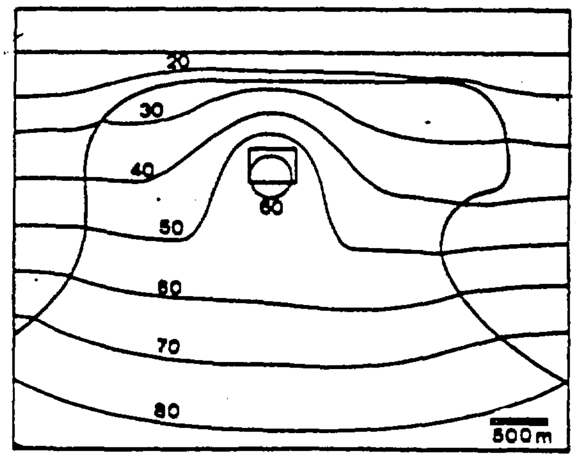

Rock Temperatures in the Model Salt Dome before HAW-Disposal



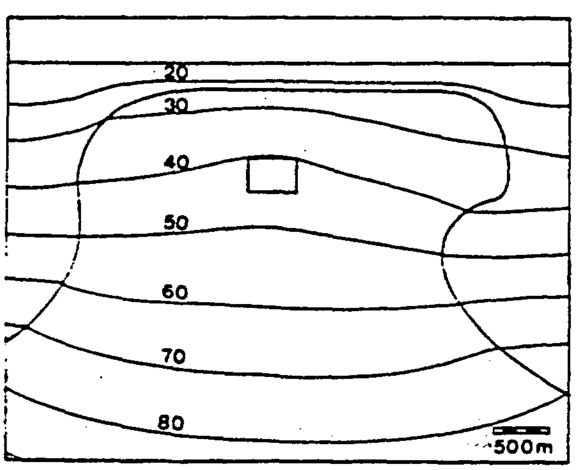

Rock Temperatures in the Model Salt Dome 100 Years after HAW-Disposal




Rock Temperatures in the Model Salt Dome 500 Years after HAW-Diposal

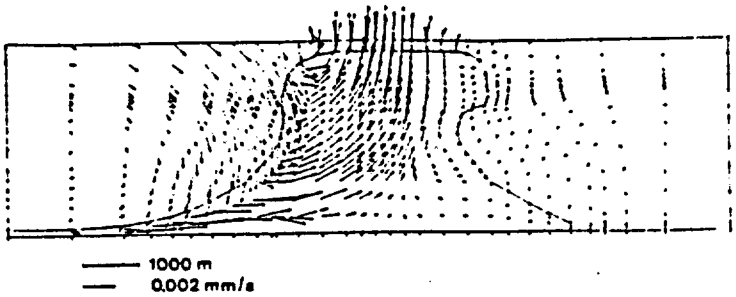



Rock Temperatures in the Model Salt Dome 1000 Years after HAW-Disposal

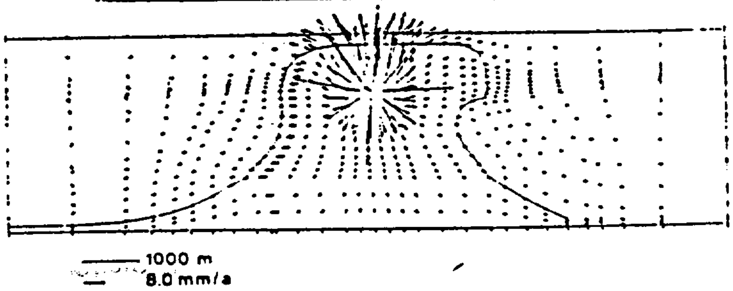



Rock Temperatures in the Model Salt Dome 5000 Years after HAW-Disposal

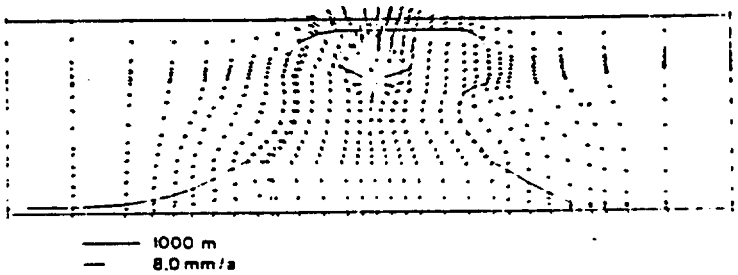
Figure 17: Calculated temperature distribution in a model salt dome



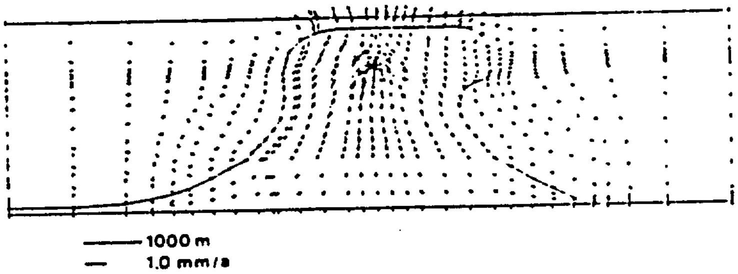

VELOCITY FIELD BEFORE HAW-DISPOSAL



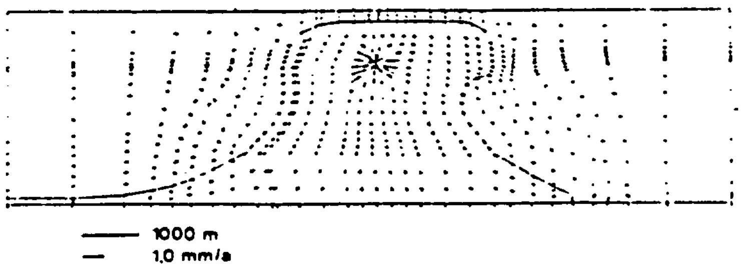

VELOCITY FIELD 20 YEARS AFTER HAW-DISPOSAL




VELOCITY FIELD 50 YEARS AFTER HAW-DISPOSAL




VELOCITY FIELD 115 YEARS AFTER HAW DISPOSAL




VELOCITY FIELD 450 YEARS AFTER HAW-DISPOSAL

Figure 18

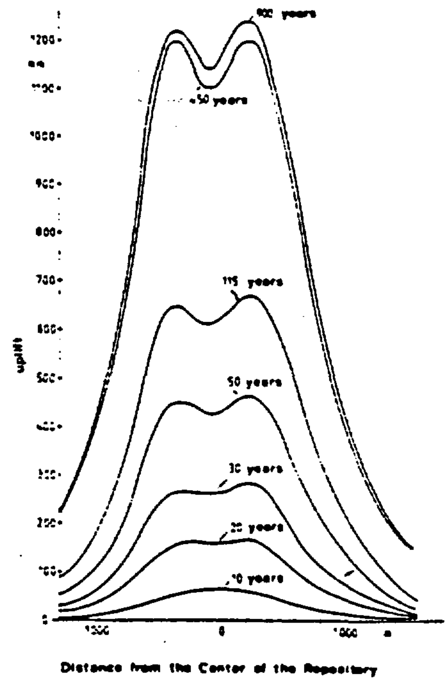


Figure 19: Uplift above the repository

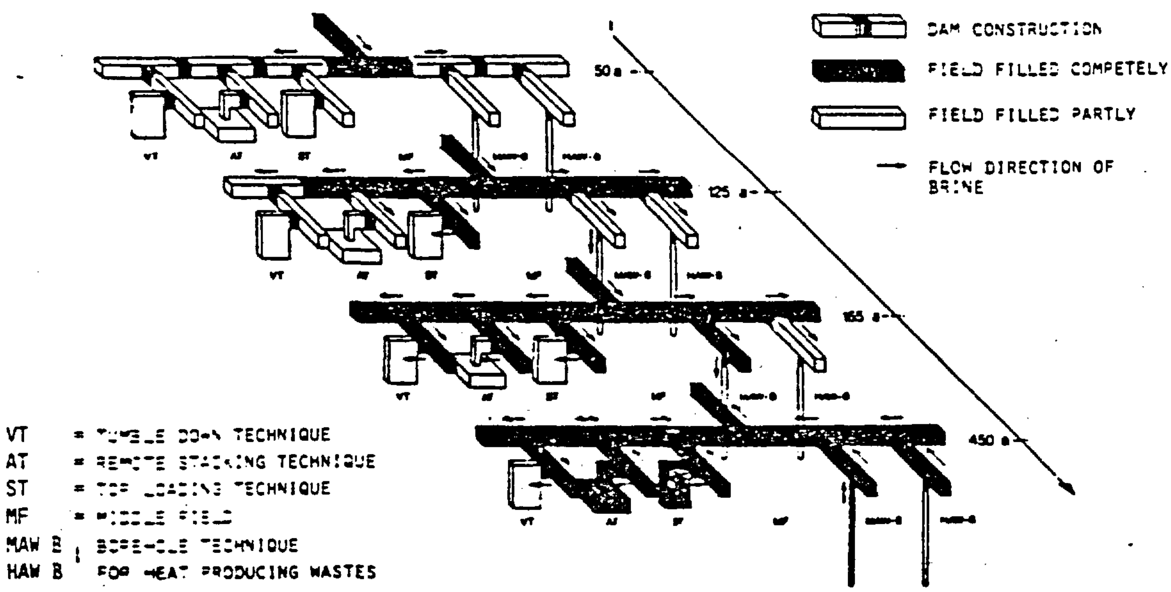


Figure 20: Time schedule of brine flow

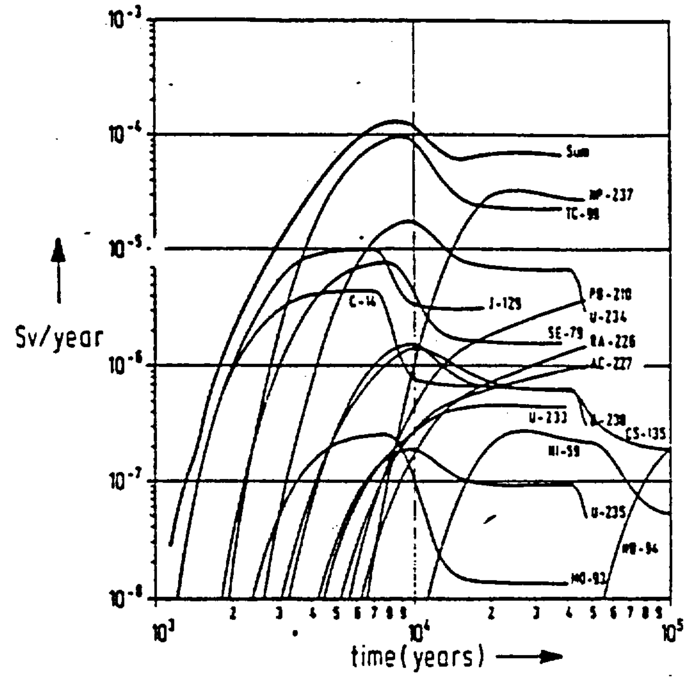



Figure 21: Contribution of some radionuclides to potential and total radiation exposure as a function of time

CURRENT STATUS OF THE GORLEBEN PROJECT

Donald E. Clark, International Representative
U.S. Salt Repository Project
Braunschweig, FRG
August 17, 1987

Summary

The Gorleben Project in the Federal Républic of Germany (FRG) represents an important national effort to develop a nuclear waste repository in salt. Although the Gorleben formation is a salt dome and the leading candidate U.S. salt site (Deaf Smith County, Texas) is in bedded salt, there are many similarities between the programs for disposal of nuclear waste in salt in both countries. For example, the shaft sinking technique being used at Gorleben, which involves ground freezing on a massive scale, will also be used at the Deaf Smith site. Also, the issues to be resolved by site characterization are expected to be similar (e.g., thermomechanical behavior of rock salt under repository-like conditions, and so on).

A May 1987 construction accident in one of the two shafts being sunk at Gorleben has aroused concern and opposition within the FRG to the current repository development program. In particular, antinuclear groups are exploiting this accident to the maximum extent possible, as though the incident could be taken to be a general indictment of nuclear power (in the FRG, granting of an operating license for a nuclear power plant is contigent upon demonstration that there is a solution to the problem of nuclear waste disposal). The accident has also provoked concern in the U.S.A. where questions have been raised about the viability of the shaft sinking technique.

This report, which is intended to provide a general overview of the current state of the Gorleben Project, has had the benefit of input from cognizant FRG personnel, in particular from the Physikalisch-Technische Bundesanstalt (PTB).

Introduction

The Gorleben salt dome, situated in a remote area in the northeastern part of the Federal Republic of Germany (FRG), is being investigated as a candidate nuclear waste repository. For this purpose, two large-diameter shafts (excavation diameters of about 10 meters -- nearly 33 feet) are being sunk to depths of 850 to 900 meters (2,790 to 2,950 feet). In the region of the shafts, the top of the salt dome formation is at a depth of about 250 meters. Since water-bearing and incompetent rock layers lie above this salt formation, a freeze shaft sinking technique is being used for the shaft construction. Thus, a giant frost body, which extends down into the salt formation, is produced by means of a large-scale freezing operation at each shaft location. This is a well-established technique for shaft sinking through aquifer layers, and it permits excavation to proceed without inflow of water into the shaft.

As the shafts are being sunk through the frozen layers, preliminary wall linings (concrete blocks) are emplaced in sections having vertical dimensions of about 6-12 meters. Then, a final water-tight lining is constructed in each of the shafts. Extending upwards from a depth of about 260 meters, this permanent sealed liner system reduces the inner diameter to 7.5 meters (about 25 feet). Once the permanent liner is in place, the ground is thawed and a normal excavation procedure is followed to penetrate further into the salt formation (no liner is needed in the salt dome itself).

When the shafts are completed, they will be linked underground by means of a drift (they are 400 meters -- about 1,300 feet-- apart) at the 840 meter level. Then, an extensive underground exploration program will be undertaken at this level in order to characterize the salt dome and determine its suitability as a nuclear waste disposal site. More than 25 kilometers (15 miles) of exploratory galleries will be constructed, along with the drilling of more than 50 kilometers of underground reconnaisance boreholes. Fan drilling will be done to test the salt prior to driving of all main and cross drifts. The drifts will be approximately 3 meters by 6 meters, for a cross-sectional area of 18 square meters (about 190 square feet). This program will entail exploration of an area comprising 18 square kilometers (about 6.9 square miles).

The characterization phase at Gorleben is expected to last several years, after which a site-specific license application will be prepared and submitted to the state licensing authority (State of Lower Saxony). If a license for nuclear waste disposal is granted, the Gorleben disposal level will be constructed at a depth 30 meters below the site exploration level, i.e., at a depth of 870 meters (2,850 feet). From this level, it is intended that certain waste packages will be emplaced in vertical boreholes drilled to even greater depths of 300-600 meters (985-1,870 feet). Other waste packages would be simply emplaced in galleries at the 870 meter level and backfilled with salt.

The development of Gorleben as a candidate nuclear waste repository site has been underway for several years. Extensive exploration of the region by surface drilling began in April 1979. Surface facilities for the exploration phase were completed and shaft excavation was begun in 1986. By the spring of 1987, shafts #1 and #2 had reached depths of 239 meters and 27 meters, respectively. In shaft #1, this was approximately to the depth of the caprock layer which overlies the salt dome.

Construction Accident at Gorleben

On May 12, 1987, an accident occurred in the Gorleben shaft #1, which is now having an impact on the overall site development schedule. Seven miners were at the bottom of the shaft, approximately 239 meters (740 feet) below the surface, at the time of the accident. A number of steel support rings had been placed over the preliminary liner in the lower 14 meter section of the shaft to provide additional resistance to the ground pressure of a clay layer. Unexpectedly, one of the support rings broke and fell to the bottom of the shaft, a distance of about 5 meters, striking six of the miners. One of the miners was severely injured and died two days later.

After the accident, and with evidence of a continuing pressure buildup on the other steel support rings, it was decided that the situation could be best stabilized by filling the affected part of the shaft (lower 14 meters) with a lean concrete plug. The support concrete will enable either a new lining or a lining reinforcement to be installed at a later date.

At the time of the accident, a changeover of excavation mode was underway at shaft #2, so no excavation activity was being conducted there. Since the accident, there has been no further excavation activity at either shaft pending completion of a technical investigation of the shaft #1 incident and its ramifications for further shaft sinking. Coincidently, a pause at shaft #2 had been previously planned to allow for complete freezing of an upper level clay layer.

Because of the loss of life, there is also an investigation by the prosecuting attorney's office as to the cause, possible liability, etc. (of course, this is quite comparable to the situation in the U.S.A. or elsewhere whenever there has been loss of life due to an industrial accident). This investigation is continuing and probably will not be concluded for several weeks at the earliest.

The exact cause of the Gorleben accident is still under investigation. The clay layer immediately above the caprock exhibited an unexpected and non-uniform convergence. It was not predicted that the inward directed pressure of this clay layer would be sufficient to break a support ring. When all of the data have been analyzed and the probable cause of this accident has been determined, a recovery plan and schedule to continue excavation of shaft #1 into the salt formation will be issued, and approval will be sought for a restart of the shaft sinking operations.

## Current Situation

As noted above, the investigation into details of the accident and resulting loss of life that was undertaken by the prosecuting attorney's office is continuing. The geological and geomechanical conditions contributing to the accident are being investigated by the Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR), who will present their findings to the PTB. At the same time, a technical analysis of the conditions contributing to this accident and a recovery plan are being developed by the shaft-sinking corporation, ASG. (The ASG is a joint venture company formed specifically for work on the Gorleben project.) The report and recovery plan will be submitted to the Deutsche Gesellschaft zum Bau und Betrieb von Endlagern fuer Abfallstoffe (DBE) and PTB. It is expected that the report and recommended recovery plan will be issued prior the end of this calendar year, and excavation work in shaft #1 should begin again early in 1988.

The conditions at shaft #2 should soon be at a state where continued excavation could again be started. The technical consensus appears to be such as to recommend that excavation begin at an early date. However, the predominant political views seem to be that this should not occur before the situation at shaft #1 has been completely analyzed and agreement has been reached on the procedure to be followed for further excavation of shaft #1.

On August 12, 1987, the Federal Minister of the Environment, Nature Conservation and Nuclear Safety, Dr. K. Toepfer, visited the Gorleben site and expressed his view that consideration of the continued shaft sinking work at shaft #2 should be decoupled from that for shaft #1. Thus, it may be possible that shaft sinking will be started on shaft #2 sometime this fall, prior to the end of the year, although this is still not a certainty. Dr. Toepfer has instructed PTB to reevaluate the probability for significant water inflow through the shaft into the repository during the operational phase. This is considered to be a catastrophic event, but one of negligible chance for occurring; in light of the new data and behavior of this clay layer, this probability needs to be reassessed.

The accident at Gorleben is considered to be a construction related incident only. It is non-nuclear -- the nuclear function of this facility is still years ahead in the future -- and has no real connection with the viability of the option for disposing of nuclear waste in salt.

Critics in the FRG have claimed that this industrial accident is the result of a flawed site decision and that other disposal options should be explored. Responsible FRG officials do not accept this argument and intend to further pursue site exploration at Gorleben. Nor do they lack confidence in the freeze shaft sinking technique. In short, plans are to continue along the previously chosen path for development of the Gorleben site.

## Comments on Freeze Shaft Sinking

A few comments on freeze shaft sinking are provided as follows:

A) General

1. Freezing is indeed a proven and widely used technology for shaft sinking in unstable water-bearing ground. Using freezing as a construction tool down to depths of as much as 600 meters (nearly 2,000 feet), numerous mine shafts -- worldwide more that 400 -- have been successfully sunk mainly in the FRG, Belgium, the Netherlands, England, Poland, Russia, Canada, and China. Recent projects in the U.S.A. are shafts for the Jefferson Island Salt Mine (1), the Weeks Island Replacement Mine (2), the Elkhart Coal Mine (3), and the White County No: 1 Coal Mine (2).

2. The basic principle of ground freezing is very simple: By means of circulating a cooling agent (generally a salt solution) through a set of pipes surrounding the later excavation zone, the ground temperature is lowered well below the point where the water contained in its pores and/or fissures freezes. Thus, the ground around the later shaft is stabilized and at the same time made impervious, forming a cylinder of frozen material, the so-called "ice wall". Under its protection, shaft sinking can be executed under dry and stable conditions. The ice wall is maintained until the relevant section of the shaft is sunk and finally lined.

3. The particular advantages of the freezing technology for shaft sinking are:

- its application is only little dependent on the specific ground conditions (sufficient water provided)

- it ensures total and reliable sealing of the ground around the shaft (provided the temperatures applied are low enough)

- it does not at all contaminate or permanently affect the groundwater otherwise (the ice wall will thaw by the natural flow of heat after the freezing operation is stopped).

B) <u>Specific</u>

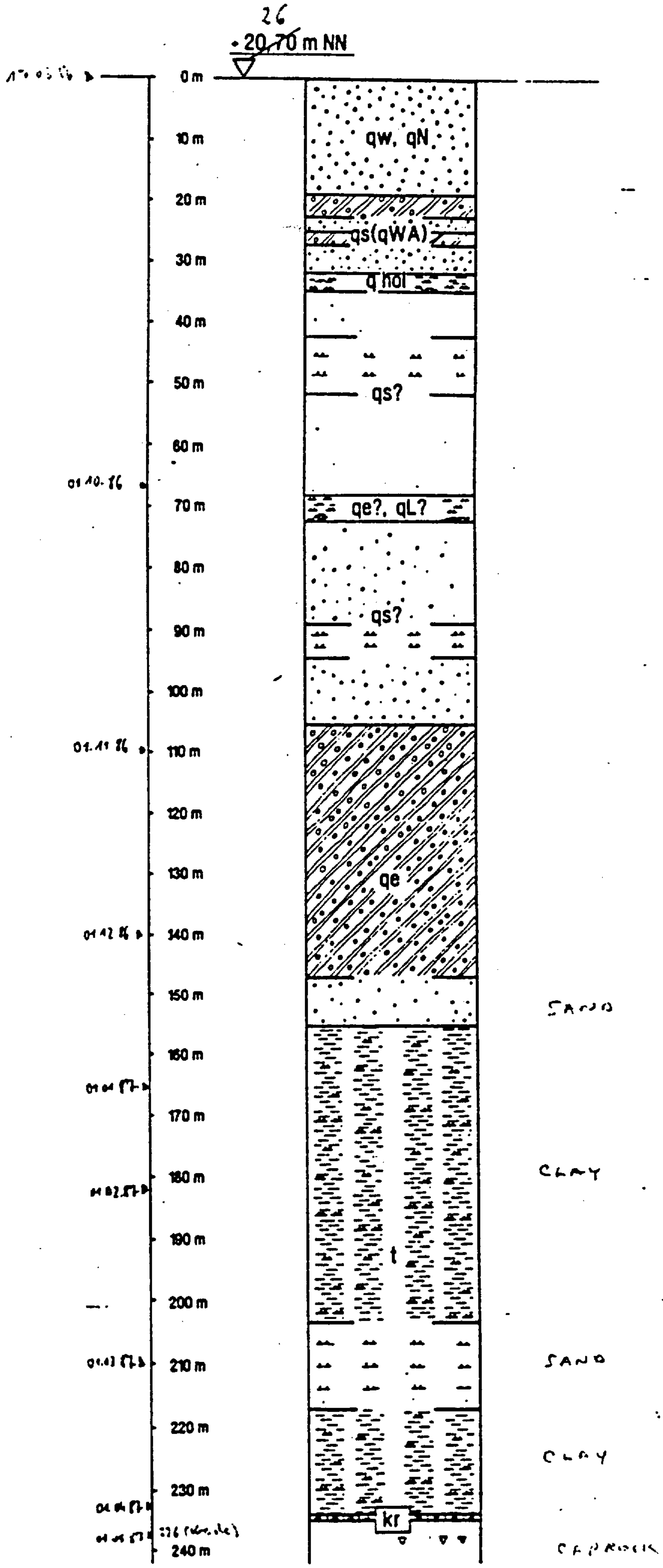
1. During the shaft-sinking operations, freezing is influencing the environment only in the immediate vicinity of the shaft and only to an insignificant extent (changing water into ice). After completion of the shaft, there is no ongoing impact. In particular, there is no adverse effect on the aquifers and the groundwater in them at all.

2. As explained above, for mine shafts to be sunk through unstable water-bearing ground, freezing is long since a standard technology. It is not true that a considerable percentage of freeze shafts failed during construction or after completion. To the contrary, in the past 30 years, no disastrous failure has been reported in the western world, and freezing has proven to be the most reliable method for shaft sinking under difficult geological and hydrological conditions.

3. The accident in the Gorleben shaft #1 is neither related to the freezing technology in general nor to the freezing operations in particular. The accident was the result of an unexpectedly high non-uniform ground pressure in a clay layer immediately on top of the caprock.

   Heavy non-uniform ground pressures as encountered at Gorleben are not at all to be expected at the Deaf Smith County site. In Texas, shaft sinking has to deal with bedded salt under a flat and rather homogeneous overburden, whereas, at Gorleben, the shafts have to be sunk into a salt dome with an overburden which has undergone considerable tectonic movements and strain, and is therefore rather inhomogeneous.

dec


26
20,70 m NN
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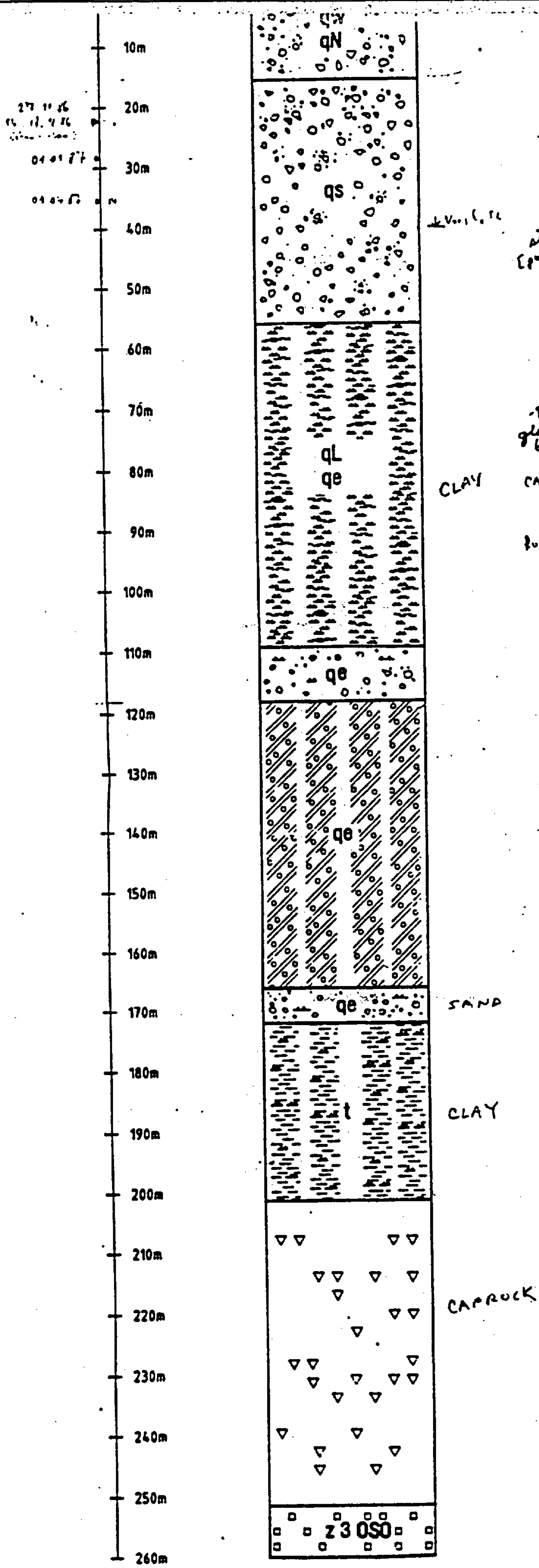
CAPROCK




# Lithologie

| | |
|---|---|
| fine gravel; sandy | Kies, sandig |
| sand, gritty, silty [poor-quality] clay | Sand, kiesig, schluffig |
| silt [poor-quality] clay; argillaceous | Schluff, tonig |
| clay, silty [poor-quality] clay | Ton, schluffig |
| glacial marl, boulder clay | Geschiebemergel |
| CAP ROCK | Hutgesteine |
| ROCK SALT | Steinsalz |

# Stratigraphie

| | |
|---|---|
| qw, qN | Weichsel- Kaltzeit, Niederterras |
| qs | Saale- Kaltzeit |
| qL | Lauenburger Ton |
| qe | Elster- Kaltzeit |
| t | Tertiär (ungegliedert) |
| z3 OSO | Oberes Orangesalz |

Physikalisch-Technische Bundesanstalt

Projekt: Bergwerk zur Erkundung des Salzstockes Gorleben

Schacht 2

| | Datum | Name |
|---|---|---|
| | 4. 9. 1985 | Ahlers |
| | Aug. 1985 | Karg |
| | 16.2.85 | Bundrock |

1:50 / 1:500

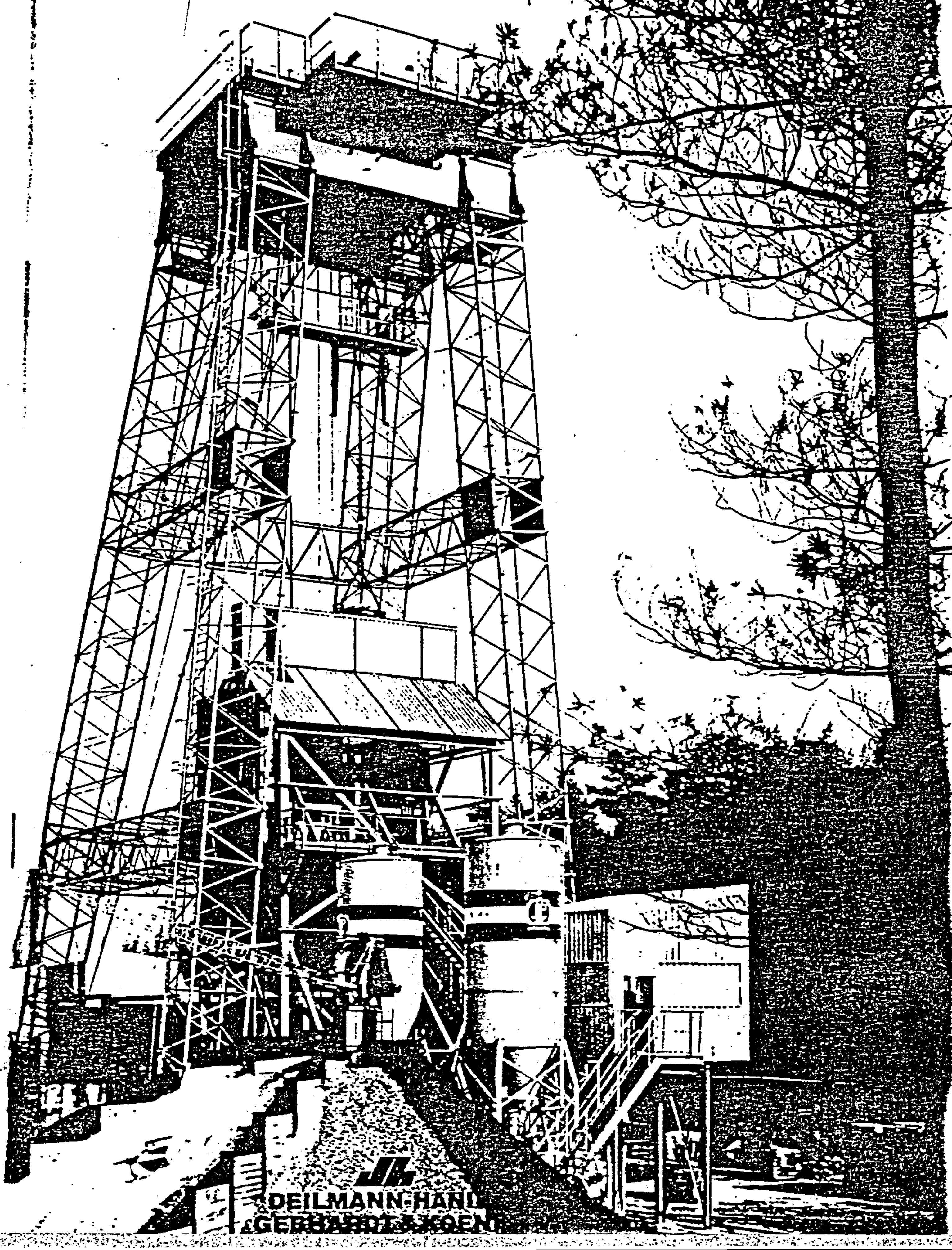
2 -

Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH (DBE)

P - G

ATTACHMENT 4

## 1 and 2 shafts



# Coal under the Haard

Exploration drilling has revealed vast coal reserves of the order of 500 mio. tons under the 'Haard' forest recreational area, north of Recklinghausen in the state of North-Rhine Westphalia, Federal Republic of Germany. The deposit consists of high grade coal at depths varying from 800 to 1,200 m.

Bergbau AG Lippe — a wholly owned subsidiary of Ruhrkohle AG – is planning to develop these coal deposits as the reserves of the present Haard Colliery – formerly Ewald Fortsetzung and General Blumenthal Colliery will soon be exhausted.

The exploitation of the Haard coal reserves emphasizes Ruhrkohle AG's policy, and commitment to the continued secural of the nations future energy supplies. This development will also provide employment for approximately [illegible].000 people.

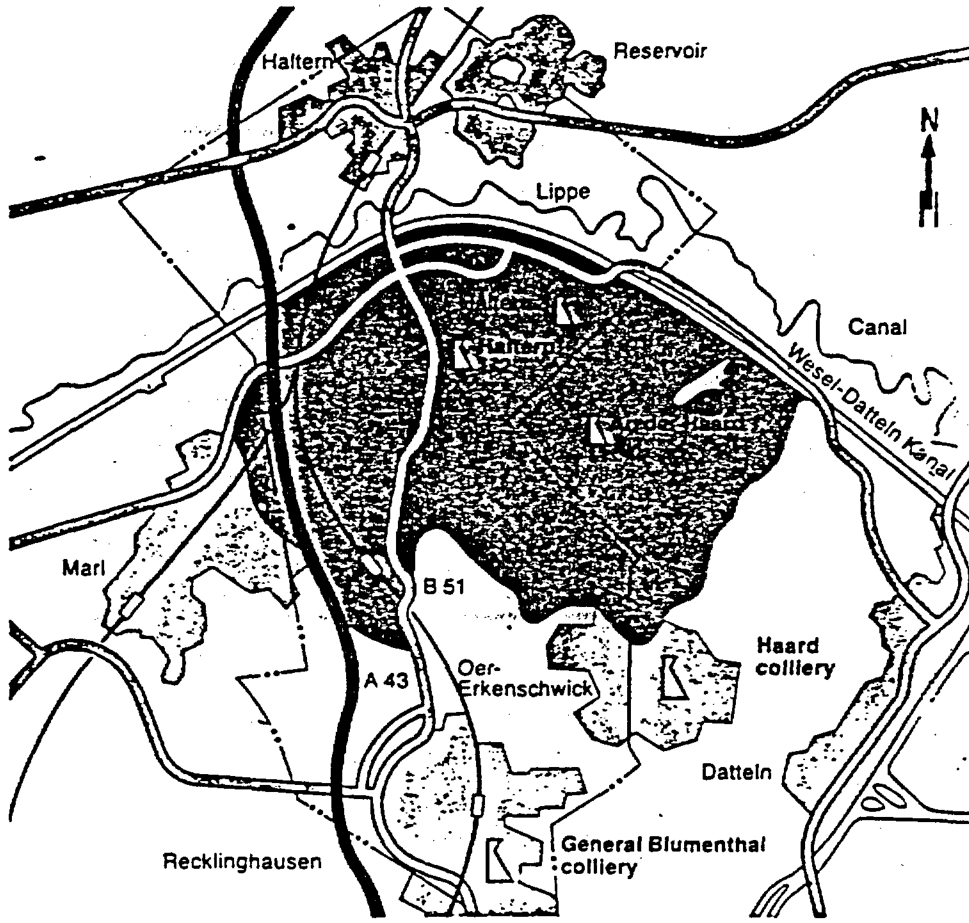
To extract the coal in this area a total of 4 shafts will be required. Sinking of the first shaft – An der Haard 1 – began at the end of 1977. Upon completion, in July 1981, it was handed over to the Haard Colliery.

The Haltern 1 and 2 shafts are the focal point of the Haltern mine which forms a part of General Blumenthal Colliery. They are located in the centre of the future 'take area' of the Haltern mine.

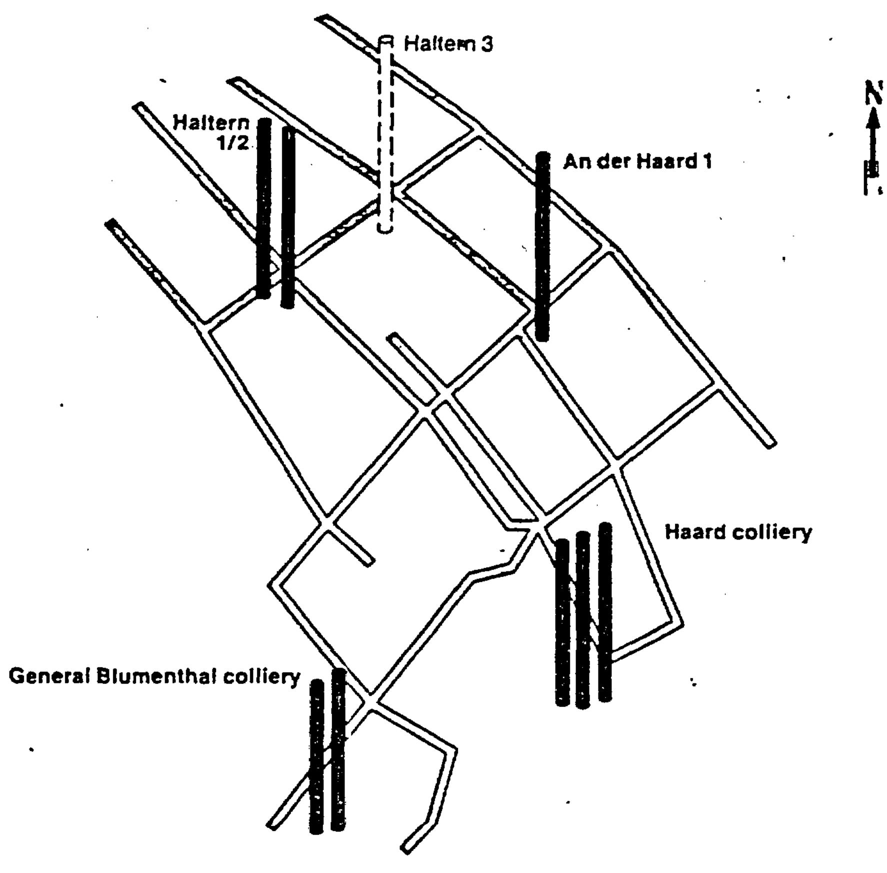
The shafts will improve the working and ventilation conditions in the mine by minimizing the time for personnel transportation to the faces and by considerably reducing the ventilation circuits.

The 'Haard' region is a popular recreational area for the densely populated northern Ruhr region. As a result of detailed planning minimum surface disturbance is anticipated.

Careful choice of the surface installations will ensure that they blend into the surrounding landscape. The entire set-up of the surface facilities is relatively small as the new shafts will only provide ventilation, manriding and material handling facilities. Mineral handling will not occur at these sites but all coal production will proceed via a large underground haulage system to production shafts situated outside the recreational area.




Haard/Haltern development area



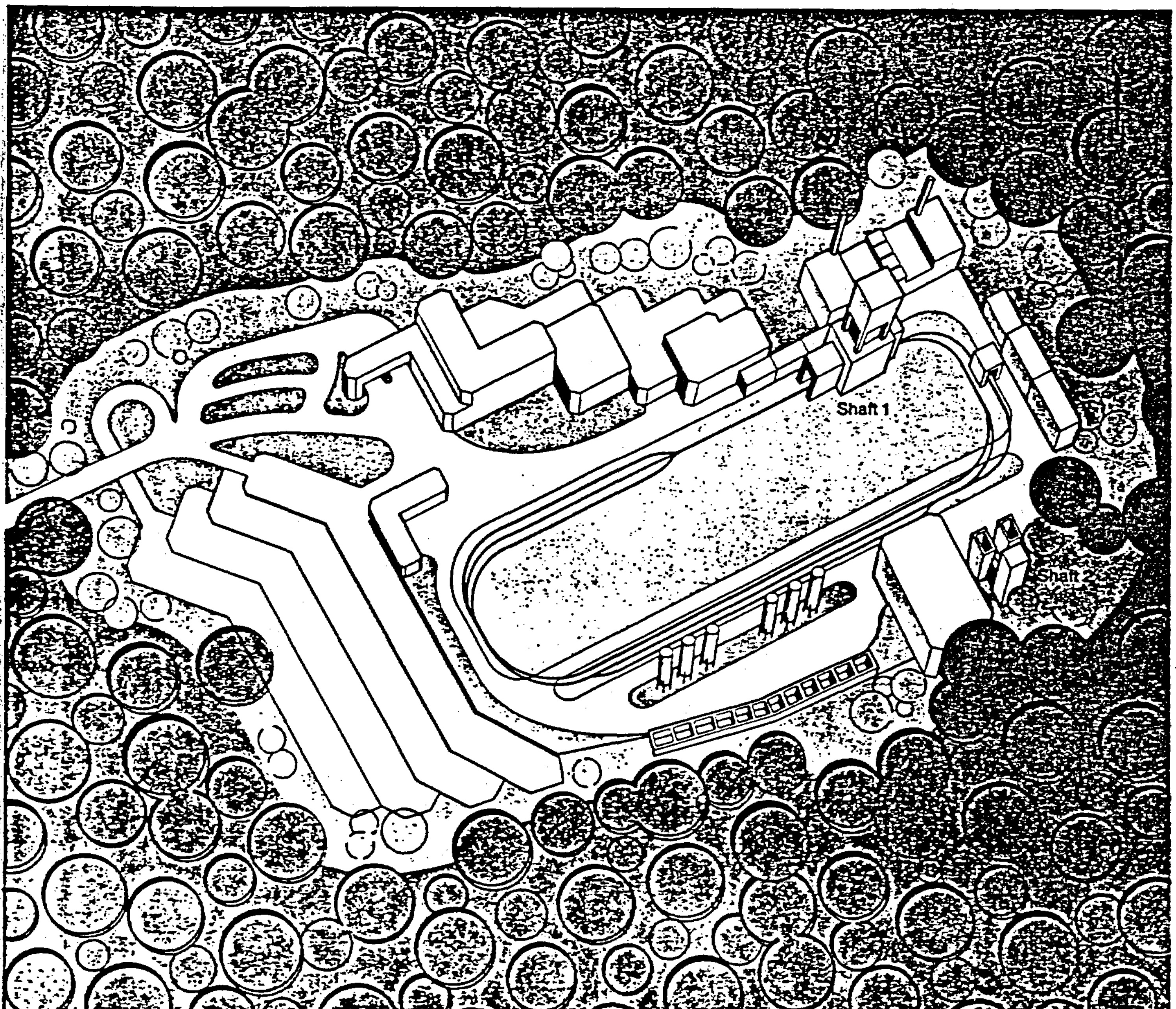
# The Haltern 1 and 2 shafts

Because of service and ventilation requirements the Haltern 1 and 2 shafts will have a finished diameter of 8.0 m. No 1 shaft with a total depth of 1,133 m will serve as a downcast shaft and be used for manriding and material handling. Three shaft insets at depths of 850 m, 980 m and 1,100 m will be constructed to connect the shaft to the mine. A full-face tunnelling machine driving from Blumenthal No 8 shaft is already operating on the 980 m level and will reach the Haltern 1 and 2 shafts in 1982. It will be the No 1 shaft equipped with steel buntons and guides, a main hoisting system with a 3 deck cage as well as an auxiliary hoist, both balanced by counterweights.

Pipes and cables will provide the colliery with the necessary services.

The surface facilities will be built in several construction phases according to the underground mining activity. Initially, approximately 1,000 miners will be hoisted daily. After full production is achieved in the Haard coalfield – approximately early 1990 – up to 3,500 miners will daily enter the mine through the No 1 shaft. Furthermore, 20,000 $m^3$/min of fresh air will be circulated through it.

No 2 shaft with a total depth of 1,017 m will serve as an upcast shaft, and two insets will connect the shaft to the existing mine. No equipping is necessary in the shaft.




Planned surface facilities. Haltern 1/2

# Geology

Knowledge of the stratigraphy and rock characteristics of the strata are fundamental in determining the shaft sinking technique. Therefore, in the vicinity of No 1 shaft an exploratory test hole was drilled to a depth of 900 m. In the critical horizons, at depths of 20 - 300 m and 600 - 900 m, continuous cores were taken for more detailed inspection to aid the design teams.

Geotechnical investigations, laboratory analyses of the acquired samples and in-situ drill stem tests as well as geophysical logging in the exploratory hole gave the following results:

To a depth of 130 m lie the Halterner Sands and the calcareous sands of the Wulfener facies, they are unconsolidated dense, fine to medium quicksands with low cohesion.

The Recklinghauser Sandy Marl extends to a depth of 250 m. To a depth of approximately 190 m this layer is characterized by unconsolidated, fine clayey sands which tend to run when water saturated. Layers of hard calcareous sandstone approximately 20 cm thick occur within the sands. These hard layers form approximately 25 % of the Recklinghauser Sandy Marl.

Below 190 m the consolidation of the sandy marl increases with depth, with a corresponding reduction in pore volume and water content. Below a depth of 210 m the rock is considered to be competent.

The Emscher Marl from 250 - 650 m is characterized as a medium hard formation with no fissures. The Turon and Cenoman beds are lightly fissured medium hard to hard limestones.

Rock characteristics of the Emscher Marl, Turon and Cenoman are well documented from previous shaft sinking experience in the northern and eastern Ruhr area. Core investigations did not indicate any significant peculiarities or anomalies that might cause problems during sinking operations.

From a depth of 45 m the Halterner Sands, the calcareous sands of the Wulfener facies and the upper portion of the unconsolidated Recklinghauser Sandy Marls are fully water saturated. Below a depth of 210 m pore water is not present. However, fissure water may be encountered in the lower portion of the Recklinghauser Sandy Marls.

As a rule, water has to be anticipated in the fissures of the Turon and Cenoman beds. However, cores taken from these layers indicated that the fissures tend to be predominantly closed: i. e. not connected to an open system. At the interface between the Turon and Cenoman beds at a depth of 810 m drilling fluid was lost and core recovery was poor. This would suggest an open joint system and water would therefore have to be expected at this depth.

| Stratigraphy | Description and classification of rock | Classification for shaft sinking | Depth in m |
|---|---|---|---|
| | **Halterner sands**<br>fine to medium sands | unconsolidated, unstable, waterbearing (below 15 m depth) running sands | |
| | **Wulfener facies**<br>calcareous fine to medium sands | | 130 |
| | **Recklinghauser sandy marl**<br>fine marly sands to fine sandy marl | little consolidated, consolidation increasing with depth, unstable, waterbearing | 210 |
| | | competent, possible fissure water | 250 |
| **Santon and Coniac** | **Emscher marl**<br>Clay marl, initially fine sandy, then silty fine grained clay marl | competent, dry | [illegible] |
| **Turon** | **Calcareous marl and limestone**<br>partly clayey | competent, possible fissure water | |
| **Cenoman** | **Essener Grünsand sandy limestone and fine grained sandstone** | little consolidated to competent, dry | 845 |
| **Carbon** | **Lower coal measures** | | |

Strata profile

# Sinking of the shafts

The results of the exploratory test boring provided the main data for the conceptual design of the shafts. Due to the unstable ground to an extending depth of 210 m a special technique has to be applied to temporarily secure and stabilize these layers during sinking and lining operations. Through the water bearing zones a watertight lining will be installed to avoid any inflow of water or running sands. As fissure water might be encountered in the Turon and Cenoman beds, suitable precautionary measures must be taken during shaft sinking.

Coal production, employing the caving system, will begin in the immediate vicinity of the shafts. Resultant strata movements may well affect the final shaft lining. Therefore, it is required to design and construct that lining in such a way that it will stay watertight in the waterbearing unstable strata and its possible damage in the competent rock will be kept to a minimum. Both shafts will receive identical linings.

## 1. Securing and stabilization of the unstable strata

When evaluating special construction methods one has to differentiate between the zones above and below the water table which at this site is at a depth of 45 m approximately.

Below the water table the well known ground freezing technique will be used for stabilization and groundwater control. Above the water table an alternative construction technique has to be applied as the moisture content (3-4 %) is insufficient to enable effective ground stabilization by freezing.

### 1.1 Section from surface to 45 m

Securing of the shaft to a depth of 32 m is achieved by a secant pile wall, a construction technique used extensively in civil engineering for open excavation support systems. This wall consists of a series of bored, cast-in-place, lean concrete piles, 0,70 m in diameter with a 0,10 m overlap. Every alternate pile contains a steel beam as the main bearing element. The overlapping piles will transfer the loads due to the surrounding earth onto the main bearing piles.

Dry drilling procedures with flight augers are used to construct the piles. The depth to which this technique is applicable is limited due to the possible deviation of the piles with increasing depth.

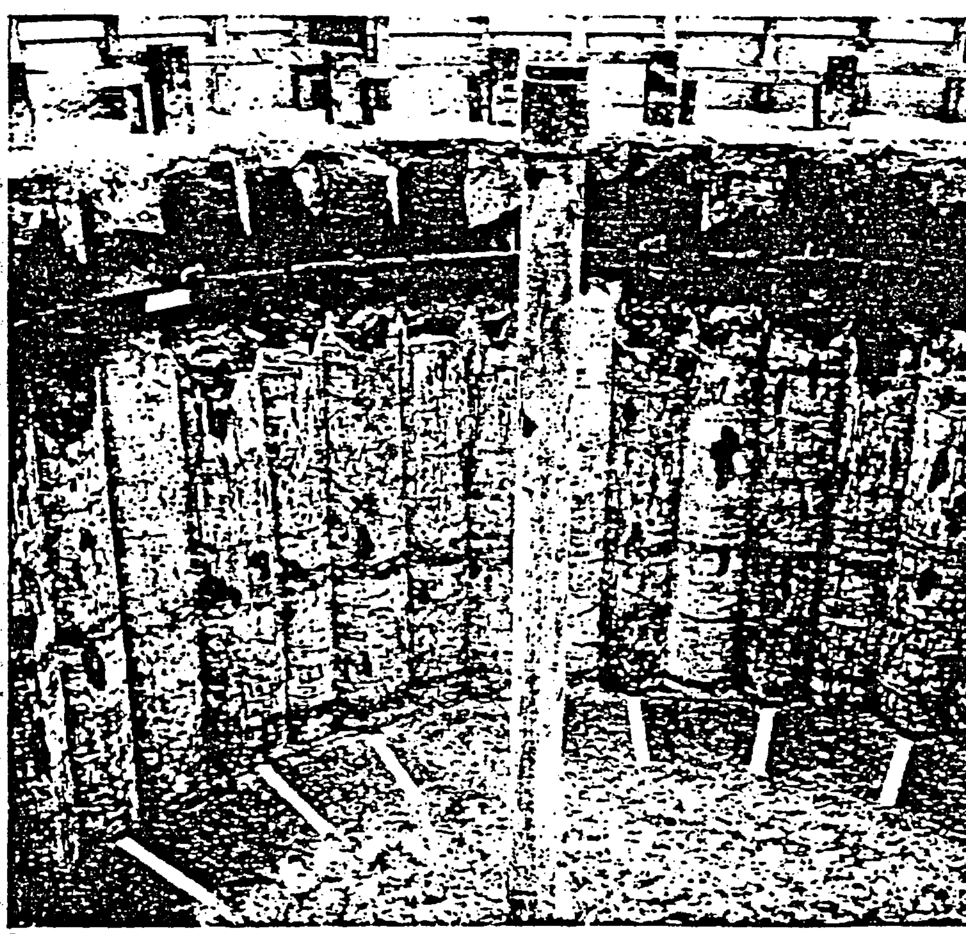
Below the pile wall to the top of the water table the shaft is secured with liner plates, i. e. thin rectangular steel plates, flanged on all four edges, punched with oversize holes for bolting and curved to the shaft. The liner plates are grouted in-place to establish firm contact with the ground. Additional strength is afforded by the installation of ring beams during sinking operations.

The size of the ring beams and the plate thickness – in this case 6.1 mm – is governed by the estimated loading to which they will be exposed. The section from the surface to the top of the watertight lining – here 38 m – is called the foreshaft.

### 1.2 Section between 45 m and 210 m

The ground freezing method will be used to stabilize the unstable waterbearing soils, to a depth of approximately 210 m, during shaft sinking and installation of the permanent lining. The principle of ground freezing is the use of refrigeration to convert in-situ pore water to ice. This ice becomes a bonding agent, fusing adjacent particles of soil to increase their combined strength and make them impervious. A cylindrical freeze wall is formed around the periphery of the planned excavation. This provides a stable support and ground water control system which enables safe sinking of the shaft. Ground freezing has been successfully utilized in shaft sinking over several decades. The extensive experience available and the reliability of this method enables detailed planning of time and economic factors.

39 refrigeration pipes are equally spaced on a 15.0 m diameter circle to create the freeze wall for each of the Haltern No 1 and No 2 shafts. The pipes are spaced 1.21 m apart at the surface. The refrigeration pipes extend to a depth of at least 217 m to tie the freeze wall safely into the competent sandy marl.



*Secant pile wall for foreshaft*

To ensure a positive and more or less uniform closure of the freeze wall it is essential to drill the refrigeration pipe holes accurately minimizing any deviation. The target area for the bore holes is defined by two concentric circles around the centre of the shaft, of 14,5 m and 15,5 m diameter resp. In addition, the spacing between two adjacent bore holes should not exceed 1.60 m to 1.95 m depending on depth. Continous alignment controls during drilling operations and – if required – the use of directional drilling tools to correct excessive deviations guarantee that the holes will remain within the specified limits.

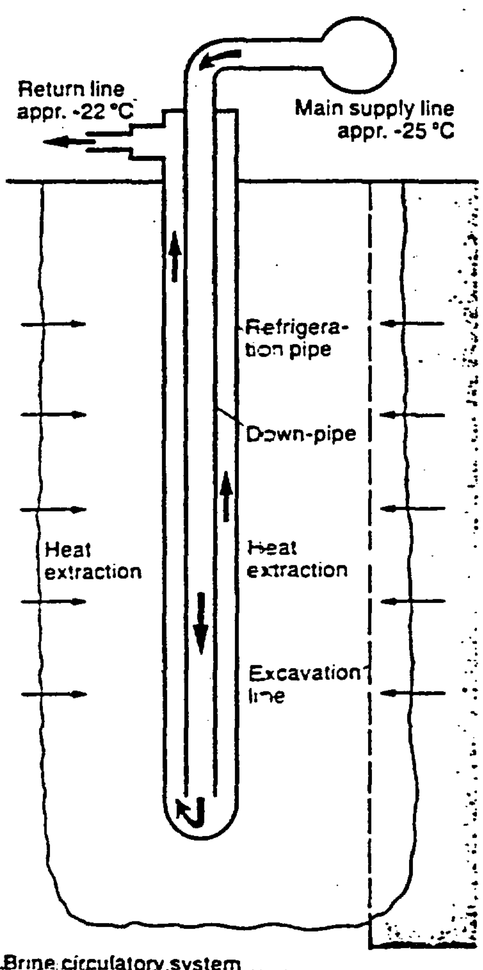
5"-refrigeration pipes will be installed in these bore holes to a depth of 217 m. 3"-PE down-pipes will be lowered into them. The refrigeration pipes will be connected to the main manifold lines, and a coolant – usually calcium chloride brine – at an approximate temperature of −25°C will be pumped through the circuit. Circulation of the cold brine through the system causes a continuous extraction of heat from the ground.

Initially, a cylinder of frozen ground is formed around each refrigeration pipe. The frozen cylinders grow with time and when they merge a continuous freeze wall is formed. The freeze wall will then have to thicken with time at least to the required thickness according to the structural design. In general, the freeze wall thickness has to be increased with depth as the lateral pressures are also growing.

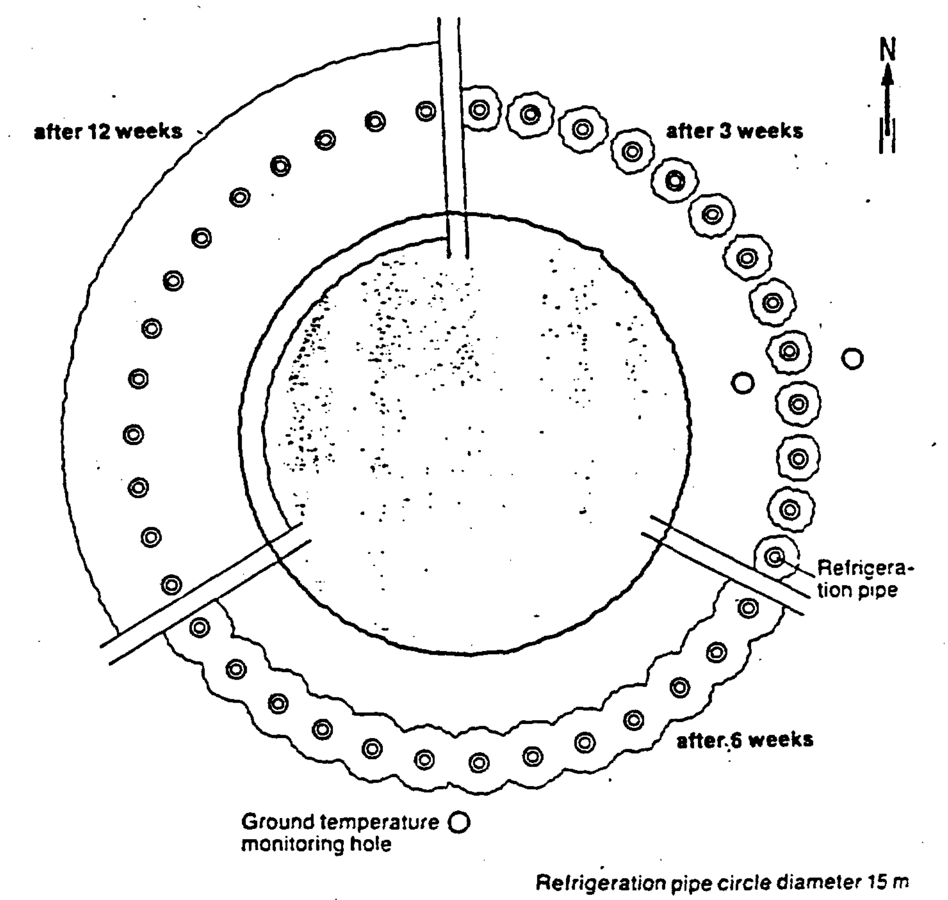
The refrigeration station used on this project consists of 3 units with screw compressors and has a total capacity of 4.7 mio. kJ/h at a brine temperature of −25°C. During the prefreezing period – the time from the start of freezing until a continuous freeze wall is formed – the refrigeration plants will operate under full load. Later on, it is necessary to control the freezing process so that as much as possible of the area to be excavated remains unfrozen in order to facilitate the mucking operations.

Of course, at the same time the ice wall thickness must be maintained according to the structural design.

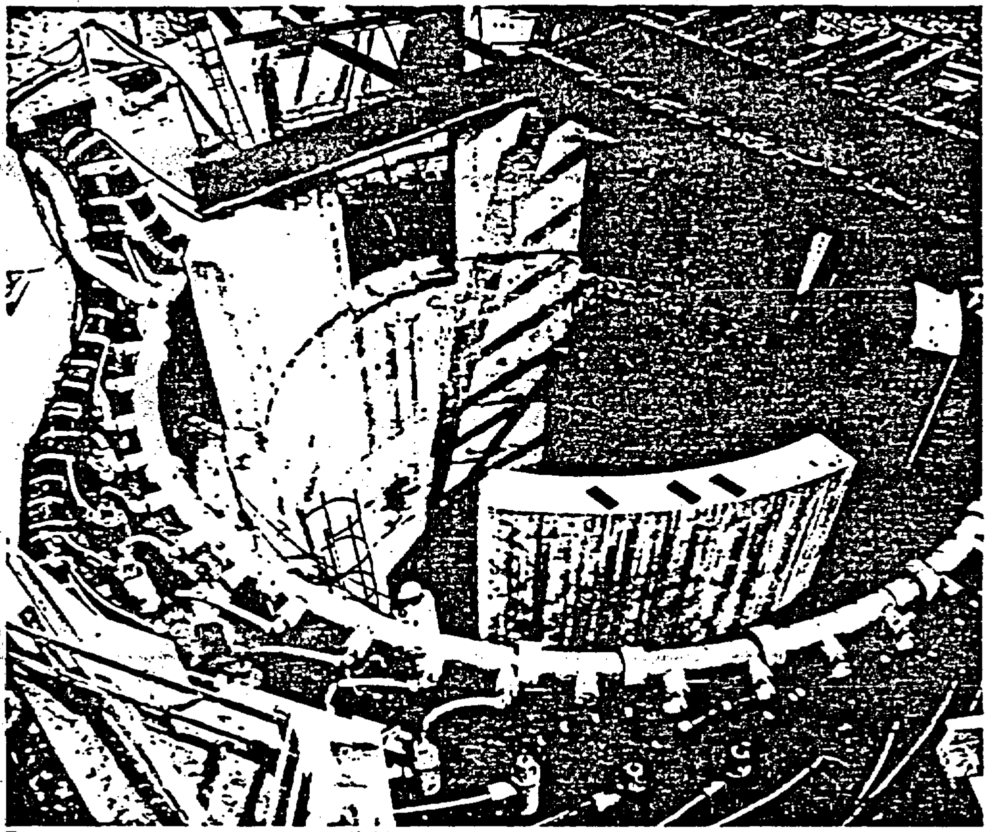
As the sinking of both shafts is staggered by about a year and a half, simultaneous freezing was not required, thereby minimizing the refrigeration plant capacity to be installed.

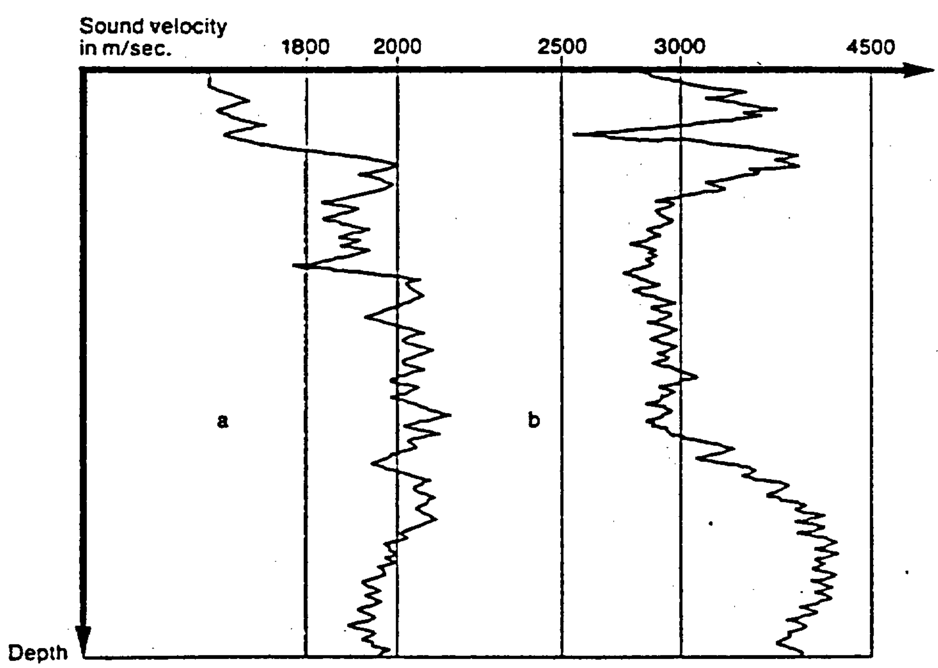



Brine circulatory system




Freeze wall formation


Freeze cellar containing main manifold system



Velocity of ultrasonic waves
a unfrozen soil
b frozen soil

Example of ultrasonic measurement

1.3 Monitoring of the freezing process

Special measurement techniques will be used to monitor the freezing process. Temperatures of the brine in the main supply line to the shaft as well as the return temperature in each individual refrigeration pipe are regularly measured and recorded. Pressure and flow rates are also monitored in the main brine supply line. Furthermore, the brine flow in each refrigeration pipe will be checked once daily and adjusted if required. Ground temperatures at critical locations are continuously measured in 3 temperature monitoring holes.

In addition ultrasonic measurements are used to check the progress, the extent and the continuity of the freeze wall. The principle underlying this method is the appreciable increase in the velocity of ultrasonic sound waves when passing through ice as opposed to water.
The data gained from all the measurements and their development with time will provide information on the shape and condition of the freeze wall, such as

- wall thickness
- wall temperatures which determine the strength of the frozen soil
- possible irregularities

Causes of such irregularities may be previously unknown local changes in ground conditions or lateral ground water movements affecting the uniform advance of the freeze wall. Precise evaluation and interpretation of the measured data will enable conclusions to be drawn as to possible cause of irregularities and to suggest the necessary remedial action that should be taken.

1.4 Thawing of the freeze wall

After the final watertight lining has been installed in the frozen section of the shaft, the freezing process can be terminated. Natural thawing, as opposed to the application of heat from external sources, will be employed. When the thawing process has progressed sufficiently the PE down-pipes will be pulled and the refrigeration pipes, which will remain in the ground, will be backfilled with cement grout.

# 2. Sinking and lining in the unstable strata

### 2.1 Excavation of foreshaft to 38 m depth

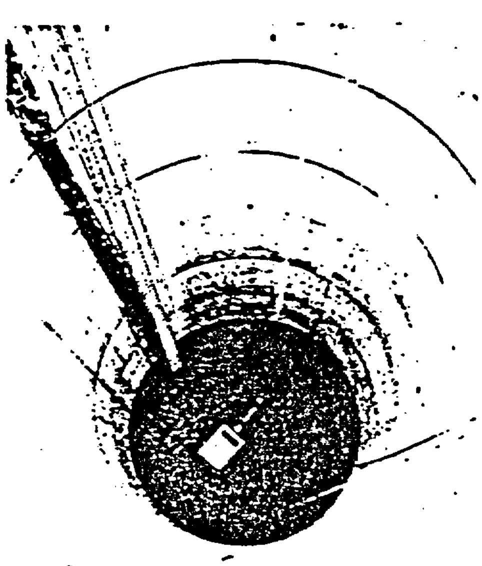
The shaft will be sunk to a depth of 38 m as an open excavation. To a depth of 32 m the preliminary support system consists of bored secant concrete piles. A hydraulic loader is used at the shaft bottom for mucking and loading. The muck will be hoisted to the surface in buckets attached to a crane. As sinking advances steel ring beams are installed to support the pile wall.

Below the pile wall the excavation diameter is increased and steel liner plates are used for temporary support. The sand is carefully trimmed to the excavation line and when a 0.5 or 1.0 m high section of ground has been exposed liner plates are immediately installed and grouted in-place.

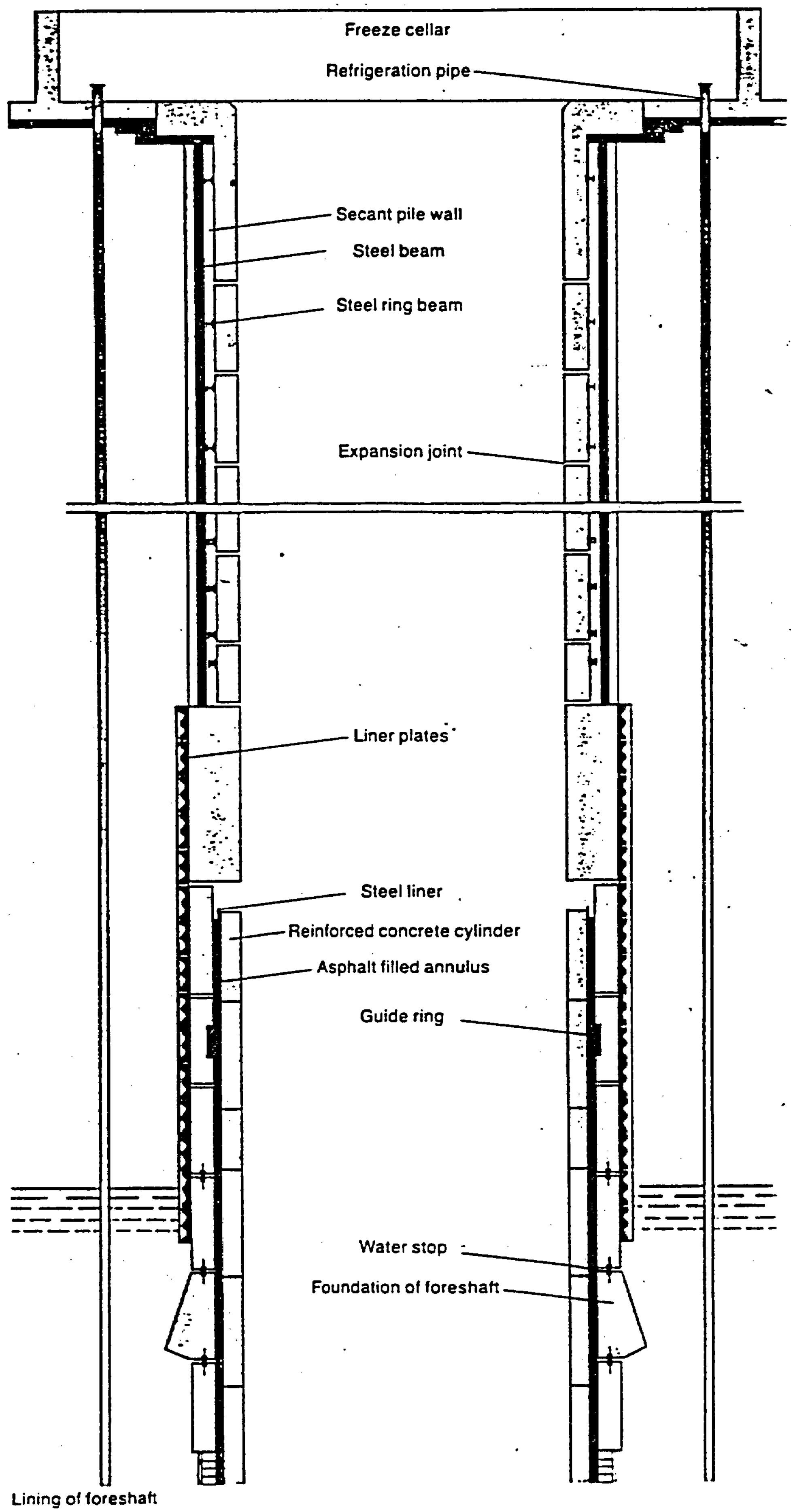
### 2.2 Final lining of foreshaft to 38 m depth

Above the water table a watertight lining is not necessary. A reinforced concrete lining to withstand the lateral earth pressure will suffice.

This lining with an inner diameter of 8.0 m and a wall thickness of 0.6 m to a depth of 32 m and 1.2 m from 32 to 38 m will be poured in 3 m sections from the bottom up with a jump form after the shaft has been sunk to 38 m depth.



View of Haltern 1 foreshaft




Lining of foreshaft

### 2.3 Shaft sinking below 38 m depth

After completion of the foreshaft the normal shaft sinking equipment, i. e. sinking headframe, bobbin hoist, winches etc. will be installed. However, resumption of sinking operations below 38 m depth is dependent on the freeze wall progress. Before sinking below the water table, which corresponds to the top of the freeze wall, can commence one has to ensure that the freeze wall is completely closed for watertightness and has its required thickness according to the structural design.

The shaft excavation is secured with liner plates to a depth of 45 m, below which the freeze wall will be the primary support system. Mucking and loading is achieved with a 0.8 $m^3$ capacity cactus grab, mounted on a fully rotational frame, suspended from the 2-deck sinking stage. A 5 $m^3$ bucket is used for the muck removal.

Where shaft sinking proceeds under the protection of the freeze wall the preliminary lining need not be installed immediately. This is because the surrounding soil is frozen and will secure the shaft for an extended period of time without any additional support. Hence, the preliminary lining will be installed in longer sections. Careful excavation of the frozen ground is necessary to avoid undue stress or strain on the refrigeration pipes leading to possible leakage or rupturing. Should the calcium chloride brine come into contact with the frozen ground it would act like a de-icing salt weakening the freeze wall locally.

The following techniques are therefore employed to avoid damage:

- loosening of the ground with jackhammers
- controlled blasting

Working with jackhammers is limited to neat profiling of the final excavation line. Smooth blasting techniques with limited length of a shaft round and limited amount of explosives are applied otherwise.

The preliminary calculations of the advance and thickness of the freeze wall based on geotechnical data from laboratory tests as well as temperature and ultrasonic measurements, will be verified by temperature measurements taken at the shaft wall; these results being supplemented by careful visual inspection of the frozen wall.

### 2.4 Preliminary lining below 38 m

The preliminary lining from 38 - 57 m consists of reinforced concrete, 0.6 m thick according to the structural design. Because of anticipated strata movements during subsequent mining activity, the concrete will not be placed in a continuous pour but will be poured in 3 m sections with waterstops to allow for some flexibility.

Below a depth of 57 m a "flexible" preliminary lining, consisting of 0.3 m thick prefabricated concrete blocks, is installed to minimize damage due to the expected ground movements. The flexibility of the lining is achieved by placing chip boards between the concrete blocks, in the horizontal and vertical joints. These chip boards can be compressed to approximately 40 - 50 % of their original thickness with almost no lateral strain which could cause spalling of concrete from the blocks.

8 mm thick chip boards were chosen for this project. With approximately 150 vertical joints distributed around the perimeter and assuming a uniform lateral pressure from the outside, a maximum contraction of the perimeter of approximately 0.50 m is possible, which corresponds to a reduction in diameter of 0.15 m. If the compressive strength, approximately 55 N/$mm^2$, of the concrete blocks is exceeded due to excessive strata movements, only small pieces will spall and get into the annular space filled with asphalt.

The prefabricated concrete blocks will be installed in 10 - 12 m sections. Each section has a small conical bearing set – also made of concrete blocks – resting on the frozen soil. A mortar layer, 0.05 m thick, provides intimate contact between the concrete blocks and the frozen ground.

Installation of the preliminary flexible lining constructed with prefabricated concrete blocks

## 2.5 Watertight lining in the frozen shaft section

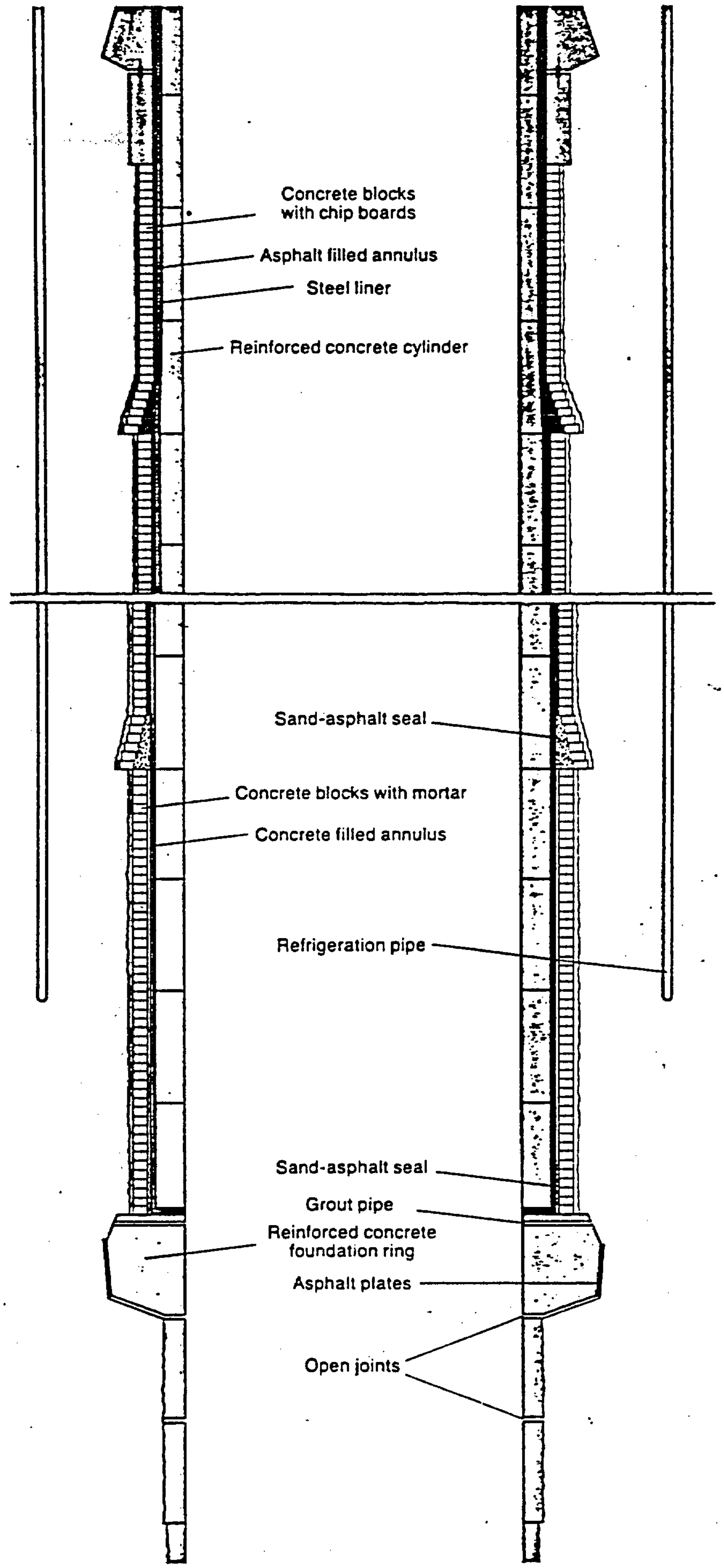
The expected strata movements due to subsequent mining activities in the immediate proximity of the shaft require, in the frozen shaft section, a lining which – despite the deformations which may occur – will not leak or loose its load bearing strength. This is particularly important as a failure of the associated inrush of the quick sands could have disastrous consequences for the shaft and mine. Therefore, the final lining is constructed so as to tolerate considerable deformations without being damaged and without loosing its watertightness.

Between the preliminary and final lining an annulus is left which will be filled with asphalt having the physical properties of a viscous fluid. The asphalt layer separates the final lining from the surrounding strata allowing relative movements between the two. It also represents a zone of protection as lateral ground movements will only have an immediate influence on the final lining once they exceed the width of the asphalt layer.

The final lining is supported by a foundation ring made of reinforced concrete ($f_c$= 6,400 psi) just below the frozen shaft section at a depth of 224 m. This foundation ring is 3.00 m high, 1.90 m wide and has to transfer the loads of the watertight lining into the strata. Immediately below, two 3 m high and 0.50 m thick reinforced concrete rings will be placed to take up the lateral rock pressure activated underneath the foundation.

The final lining consists of a structurally reinforced concrete cylinder ($f_c$= 5,00-6,400 psi). The wall thickness is increased from top to bottom as the lateral pressures, due to the soil and water, increase. The concrete thickness at the top of the watertight lining is 0.53 m, and will be increased in 5 stages to a final thickness of 0.75 m at the top of the foundation ring. The reinforcement will be increased accordingly from top to bottom.

The width of the asphalt layer between the watertight lining and the preliminary lining is 0.15 . Twelve metres of the annulus immediately above the main bearing ring are backfilled with concrete rather than asphalt to achieve the required fixation of the final lining.
A special seal is placed between the asphalt and the concrete backfill.




Lining in the frozen shaft section

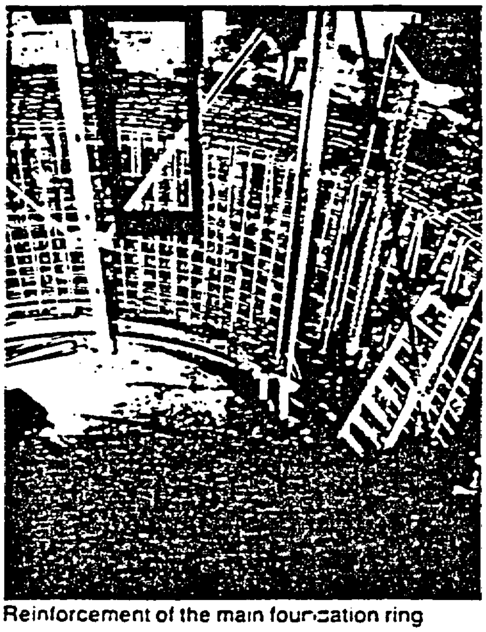
On the top, the watertight lining ends at a depth of 39 m, a point well above the existing ground water table. A guide system is to be installed which will only allow vertical movements of the lining at this location.

A 4-deck stage is used for the installation of the watertight lining. Its upper two decks serve to erect the steel liner which is composed of 3.6 m high segments five of which form a complete ring. Each steel segment will be lowered into the shaft and put in place with an auxiliary hoisting system. All welding is done in-situ. Ultrasonic techniques are used to check the integrity of the field welds.

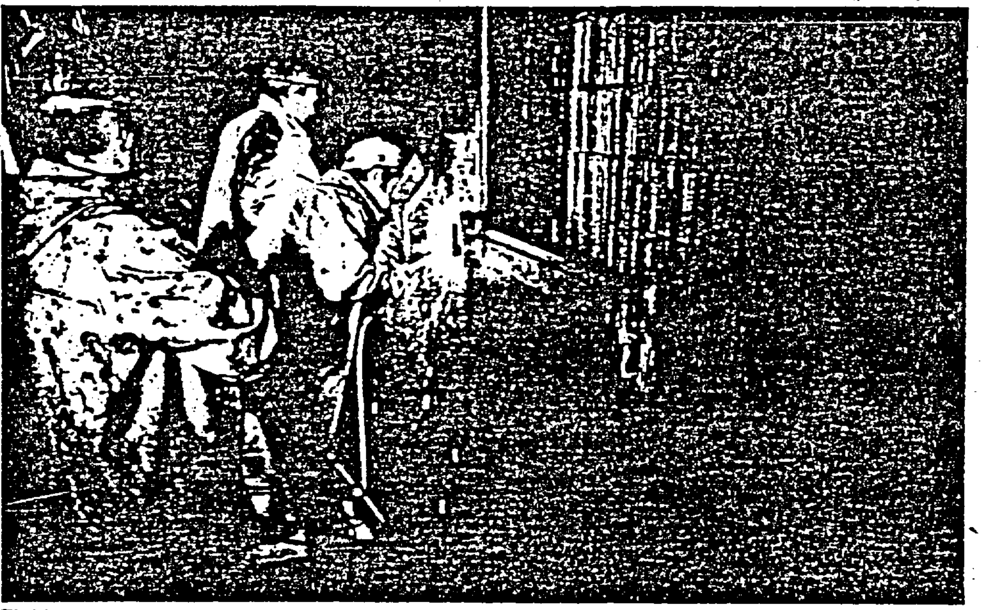
The pouring of the concrete cylinder is done from the two lower decks of the stage using a steel jump form. The reinforcement is, in form of "cages", prefabricated on the surfaces. Five cages form the reinforcement for each pour. They are lowered to the stage separately, installed and tied together.

The steel liner and the inner concrete cylinder will be installed sequentially in lifts of 3.6 m.

Backfilling the annulus between the preliminary and the final lining with asphalt is executed in two sections using a slick line. The asphalt is made of a special bitumen with finely crushed limestone as a filler to achieve the required density of 1.3 g/cm³, and is poured into the annulus at an approximate temperature of 130 °C at which its viscosity is low.

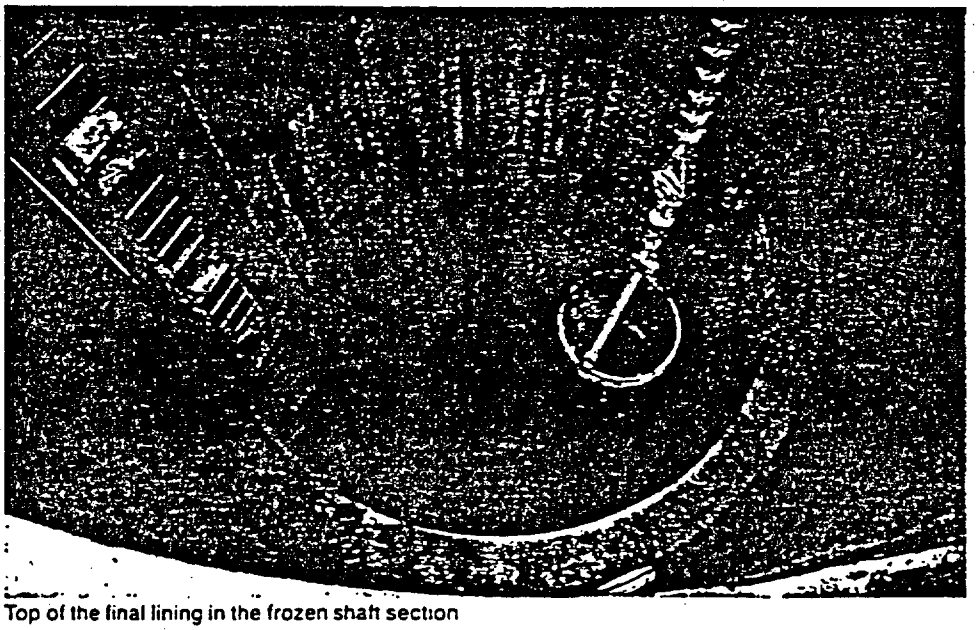


Reinforcement of the main foundation ring



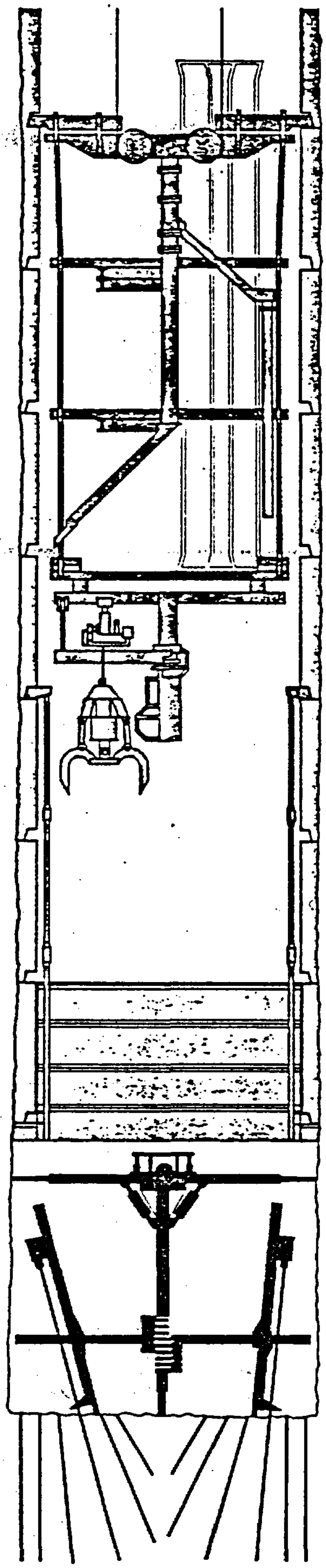
Field welding of steel liner segments

Examination of field welding with ultrasonic device



Top of the final lining in the frozen shaft section

# 3. Sinking and lining in competent rock



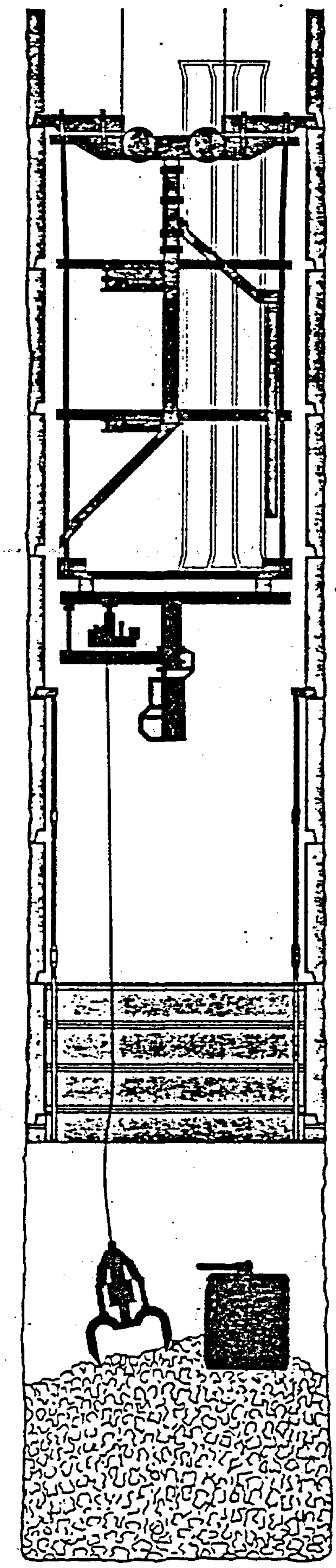
Drilling of a shaft round

## 3.1 Sinking

The application of special shaft sinking methods is not required in the competent rock below a depth of 220 m and also in the coal measure strata. Hence, conventional drill and blast techniques are used to sink the shaft. Sinking and lining is done alternatively and sequentially. Past experience in similar rock has shown that 8 m of shaft can be left unsupported till the final lining has to be installed. To drill the blast holes a shaft drill jumbo specially designed and manufactured by Deilmann-Haniel is used. The jumbo comprises of a central column with 4 booms capable of being swung through 360° in a horizontal plane. Rotary percussion drills are used. The muck buckets with a 5 $m^3$ capacity are loaded by a 5 blade cactus grab with a 0.8 $m^3$ capacity. The grab is attached to the sinking stage on a fully rotational frame so as to reach almost all of the shaft floor.

Shaft drill jumbo

Cactus grab

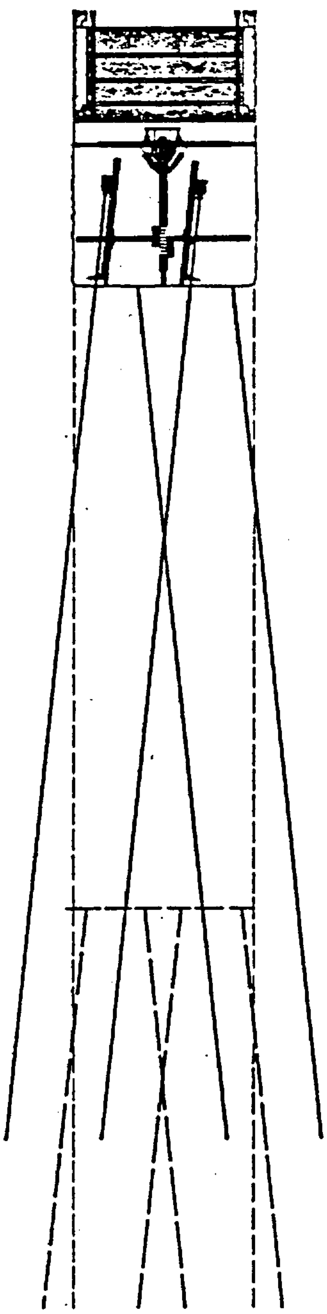


Mucking

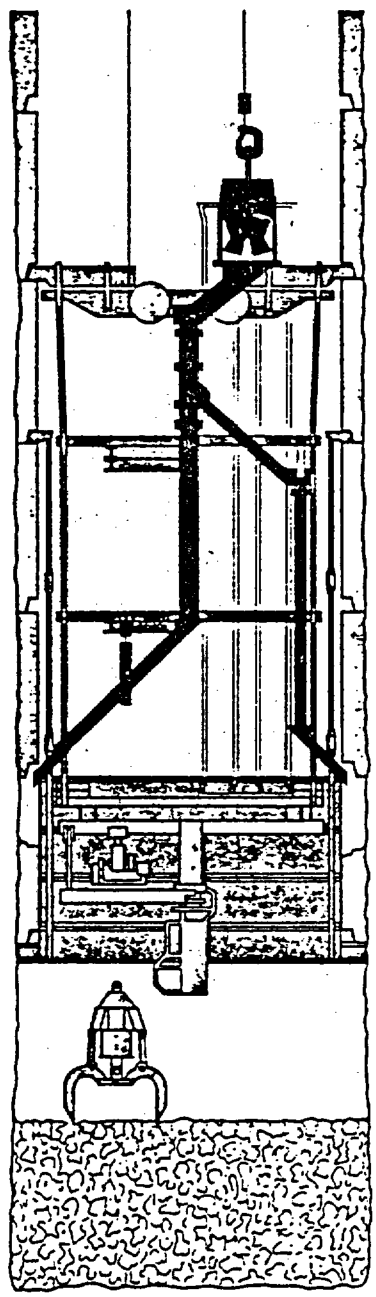
Systematic advance probe drilling through the Turon and Cenoman formations will be carried out to detect any fissure water. The probe drilling will be done in 35 m sections with an 8 - 12 m overlap.

Should water be encountered, cement grouting will take place to reduce water inflows to an extent that shaft sinking through these formations can proceed safely and almost unhindered.

Concrete bucket



Systematic probe drilling from shaft bottom



Pouring of a lift

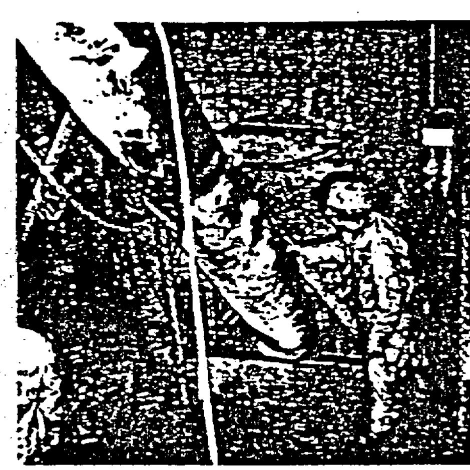
## 3.2 Lining

The lining in the competent rock of the overburden as well as in the coal measures is of concrete ($f_c$= 3,500 psi) with a wall thickness of at least 0.40 m. A light reinforcing mat is placed at the inside of the concrete lining. This reinforcing mat will avoid spalling of large chunks of the concrete when the expected high stress and strains occur during later mining activity.

The concrete is poured in 4.2 m lifts. The lifts are separated from each other by a continuous 0.30 m wide joint which is only closed on the side exposed to the rock by a 0.07 m thick concrete curtain. Apart from this, the joints which are used during shaft sinking for the support of the sinking stage will remain open. The separation of the lining into single concrete rings will allow a certain amount of yield in the vertical direction. This lining system will minimize damage, due to high compressive and tensile strains in the surrounding rock, brought about by mining activity. Furthermore, any future repair work can be more easily executed.

A 4.2 m high steel formwork will be used following sequentially the sinking operation. The formwork is placed on a curb ring. The curb ring is suspended from hanging rods, 13.5 m long, which are fixed to anchor plates placed on the already cured concrete above.

A 4-deck stage is used for the installation of the lining. Once the stage is in position and fixed, one complete ring can be poured without changing its position.



Rotating concrete delivery chute

# 4. Sinking schedule

In November 1978 the shaft sinking contract for Haltern No 1 shaft was awarded to the consortium, consisting of Deilmann-Haniel and its fully owned subsidiary Gebhardt & Koenig.

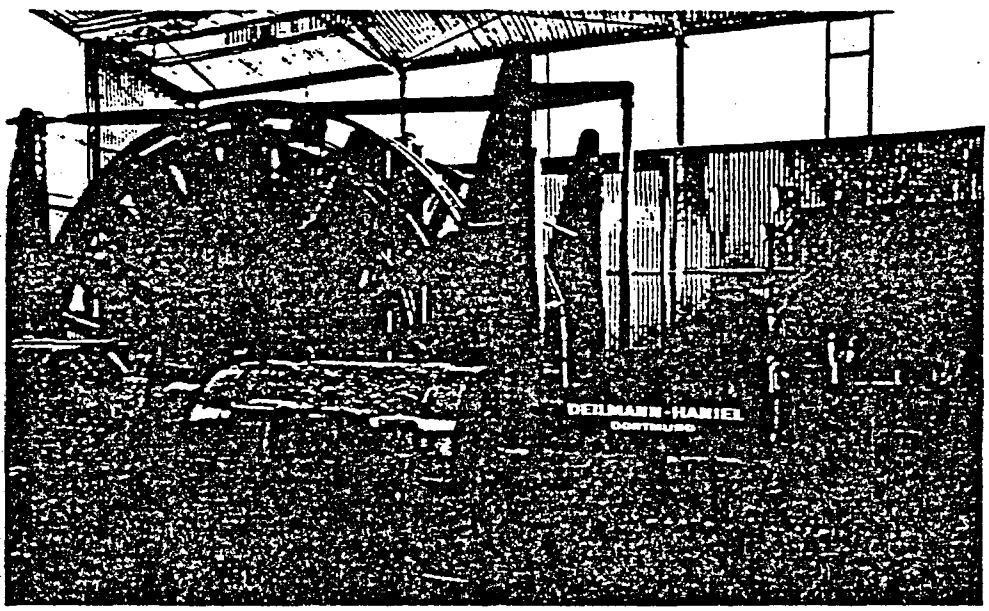
After completion of an access road and preparation on the shaft site, actual work in the field started with the construction of the freeze cellar, shaft collar to a depth of 9 m and various surface facilities required for the sinking of the shaft. The refrigeration pipe holes were drilled in 3 months. After completion of the foreshaft to a depth of 38 m and installation of machinery and equipment required for shaft sinking, excavation was resumed in February 1980.

Meanwhile the consortium, Deilmann-Haniel and Gebhardt & Koenig, was also awarded the contract to sink the Haltern No 2 shaft. This contract was awarded as a follow up to the An der Haard No 1 shaft contract. Upon completion of this shaft in the summer of 1981, the personnel, machinery and sinking equipment has been moved to the Haltern No 2 shaft site.

The first bucket at the Haltern No 1 shaft and the turning of the first sod at Haltern No 2 was celebrated with a ceremony on February 25, 1981.

It is scheduled to hand over the completed Haltern No 1 shaft to the owners, Berbau AG Lippe, in mid 1983 and Haltern No 2 shaft in spring of 1984.






Double bobbin hoist for sinking

Hoist control room

# Technical data on machinery and equipment used for sinking one shaft

## Shaft sinking installations

**Hoist**
2-drum Bobin with 2 x 800 kW driving output (5 kV)
rated load (capacity): 5-$m^3$ buckets

**Headframe**
light tubular steel construction
height: 36 m
base: 18 x 14 m
weight: 95 to
total of max. load: appr. 200 to

**Muck tipping frame**
base: 8 m x 6.5 m
height: 15 m
automatic bucket tipping device

**Sinking stage**
4-deck stage, weight 40 to
stage ropes = guide ropes for hoisting

**Stage winches**
4 drum winches, lifting capacity 35 to each,
max. rope storage on each drum: 3,500 m with 40 mm rope dia

**Compressed air**
3 compressors
with a total output of 75 $m^3$/min.

**Shaft drill jumbo**
Deilmann-Haniel System
centre column with 4 booms

**Mucker**
0.8-$m^3$ cactus grab on fully rotational frame

**Concrete forms**
collapsible steel form
height: 4.20 m
curb ring suspended on 8 steel rods
total weight: appr. 25 to

**Concrete batch plant**
pan mixer, 1,500 l capacity
proportioning system for cement and aggregates 3 size grains, 0-2, 8-16, 16-32 mm
transportation of concrete into shaft width drop bottom buckets, 2.5 $m^3$ capacity

## Ground freezing installations

**Refrigeration plants**
2 screw-compressors with a capacity of 1.7 mio. kJ/h ea. at −25°C brine temperature, installed power 2 x 355 kW

1 screw-compressor with a capacity of 1.3 mio. kJ/h at −25°C brine temperature, installed power 250 kW

**Coolant**
calcium chloride brine with a concentration of 30° Be.
brine freezing point appr. −40°C
circulating brine volume appr. 120 $m^3$

**Brine pumps**
4 centrifugal pumps with a pump capacity of 2 $m^3$/min. each at a pressure of 4 bar
total pumping capacity: approx. 480 $m^3$/h

**Refrigeration pipes**
seamless steel pipes St 52
127 x 6.43 mm with Omega-connections

**Down-pipes**
polyethylene pipes 75 x 4.3 mm

**Ground freezing monitoring devices**
45 permanent temperature sensors in the brine supply- and return lines. continuously recording

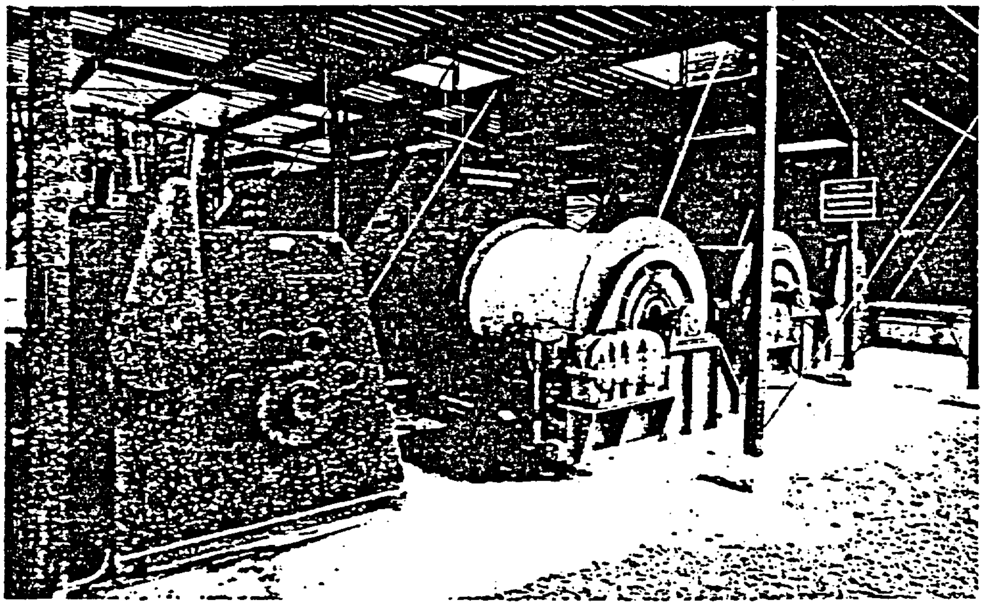
2 mobile single temperature sensors to check ground temperatures anywhere in the ground temperature monitoring holes

3 permanently installed temperature-sensors string to check ground temperatures in the ground temperature monitoring holes at critical strata locations

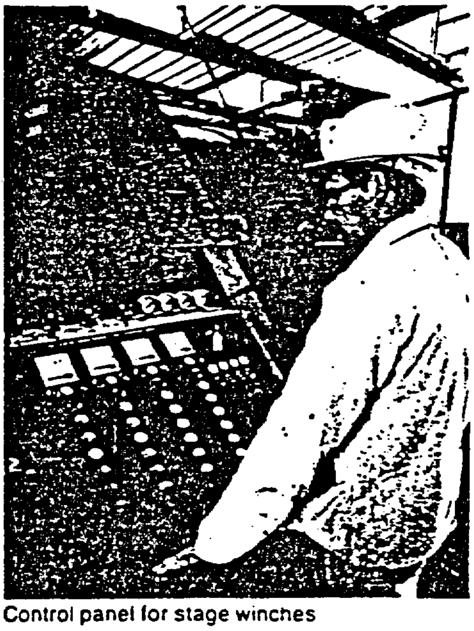
1 flow meter in the brine supply line

device to measure the brine flow in the return line of each refrigeration pipe

Various installations are common to both shafts



Winches for the sinking stage



Control panel for stage winches

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