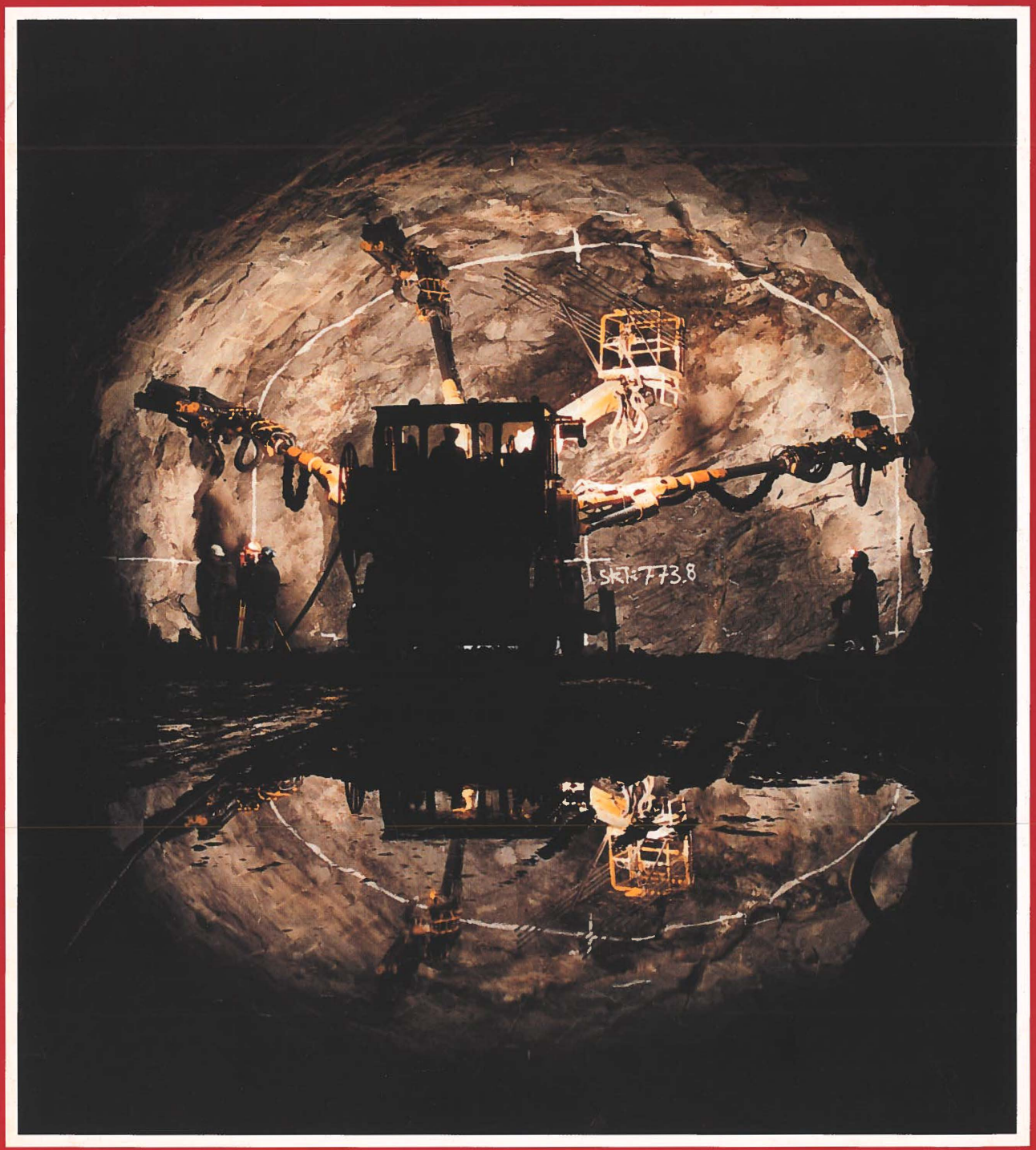
Underground Construction



Sweden in Focus

First Edition

Cover illustration: Excavation of the 2-km long by-pass and twin-tube road tunnel in Gothenburg wich will release the suburb of Lundby from 90% of its traffic. Work started in August 1995 and the tunnel will be open for traffic in October 1997. (Photo: Holger Staffansson)

First edition of

Underground Construction - Sweden in Focus

Published by
BK Swedish Rock Construction Committee and
SveBeFo-Swedish Rock Engineering Research

Managing Editors
Annica Nordmark and Sven Gunnar Bergdahl

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Foreword

Dear Reader,

We have much pleasure in introducing to you the first edition of "Underground Construction - Sweden in Focus".

In April 1988, under the auspices of the Royal Swedish Academy of Engineering Sciences, the book entitled "Going Underground" was published. This was the first Swedish reference work about utilization of subsurface space. A large number of cases and the reasons for choosing underground solutions were presented. The book was very well received and enjoyed international recognition.

The success of "Going Underground" has inspired us to compile the present work. We have chosen seven interesting rock construction projects, and included a presentation of rock-engineering research in Sweden.

The aim of this publication is to present state-of-the-art Swedish rock construction. This time, we have concentrated on projects carried out in our country, but in a planned future edition, Swedish construction activities abroad will be presented. For your convenience, each article gives the name and address of whom to contact for further technical information.

"Underground Construction", is produced by BK Swedish Rock Construction Committee, and SveBeFo Swedish Rock Engineering Research in co-operation. You will find a complete address list of their members on the last pages.

We trust that you will find this publication of value.

Stockholm, November 1996

The Editors

Annica Nordmark Sven-Gunnar Bergdahl

Acknowledgement

This publication is based on contributions from the following companies and organizations (in order of appearence)

Swedish Nuclear Fuel and
Waste Management Company SKB
Siab
Skanska
Nitro Consult
LKAB
NCC
Sydkraft Konsult
SveBeFo

UNDERGROUND CONSTRUCTION
Sweden in Focus

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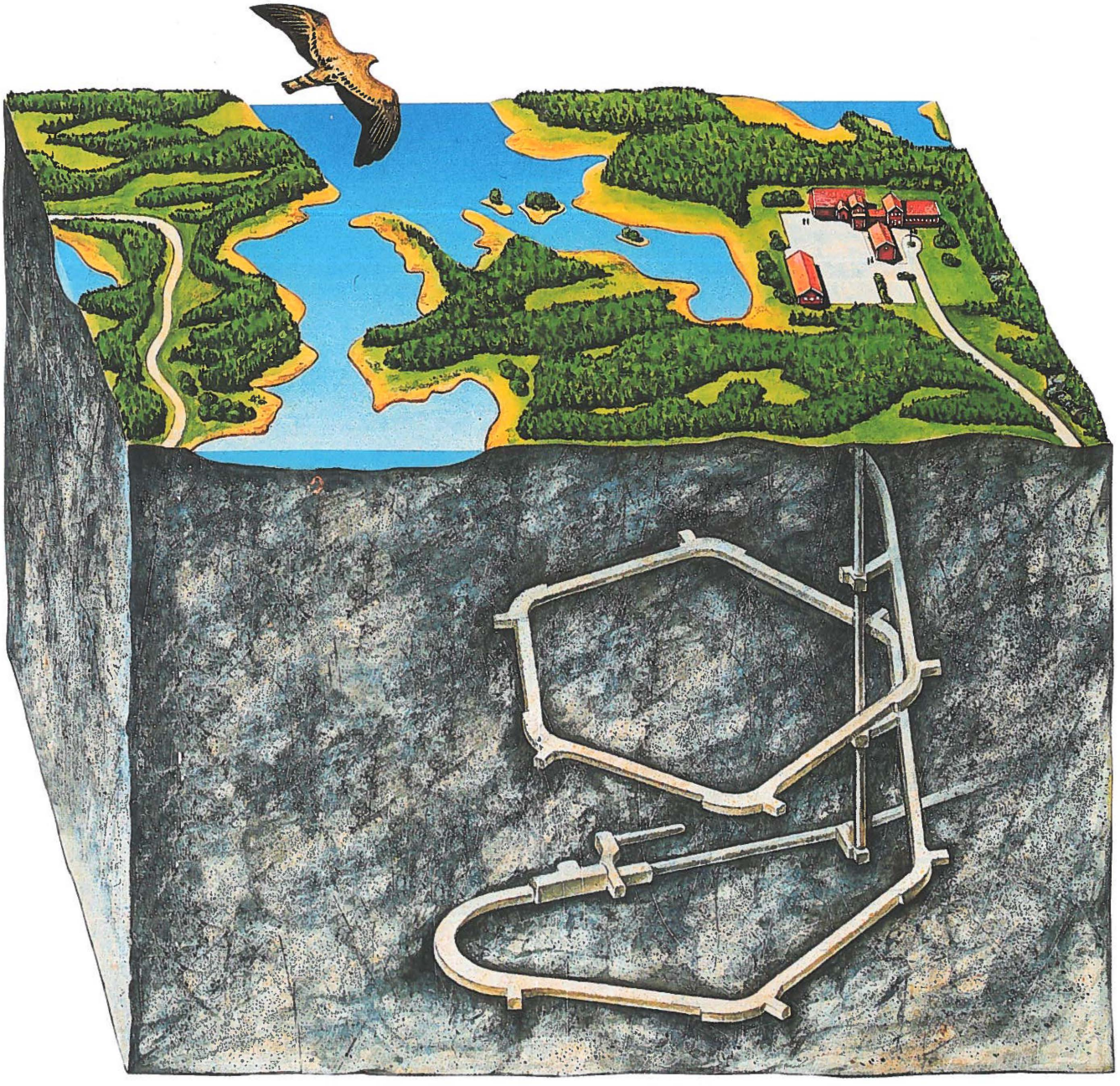
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Acknowledgements *(inside front page)*



The Äspö Hard Rock Laboratory

Facts

Client: Swedish Nuclear Fuel and Waste Management Co (SKB)
Owner: SKB
Contractors: Siab AB, Skanska AB
Consultants: Vattenfall Energisystem AB (engineering)
Construction period: 1990-1995

The management of nuclear waste and spent fuel is a very important issue in society today. It is therefore vital to develop and demonstrate methods for the safe and long-lasting disposal of high-level, long-lived spent fuel. The Äspö Hard Rock Laboratory (HRL) provides an opportunity for research, technical development and demonstration in a realistic setting.

With its varying rock and fracture zone conditions, the Äspö facility offers many opportunities for testing different pre-investigation methods, extensive field studies of the interaction between the engineered barriers and the surrounding rock, as well as investigations of the chemistry and patterns of movement of the groundwater.

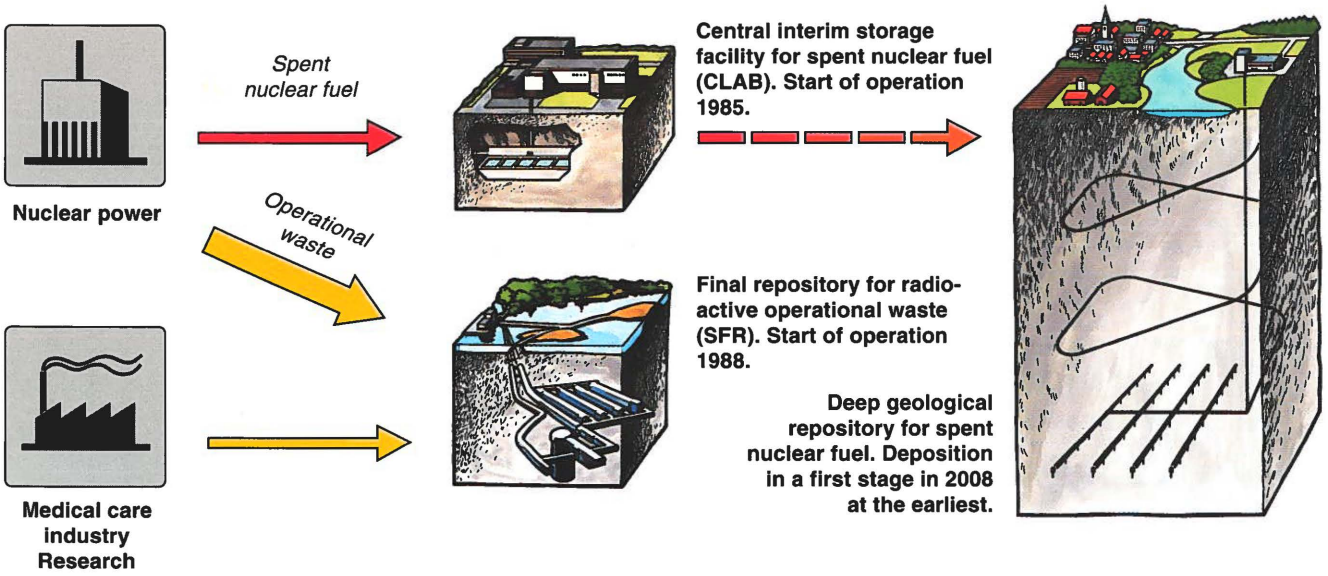
Since the mid '70s, the Swedish Nuclear Fuel and Waste Management Co, SKB, has been conducting research on the final disposal of radioactive waste in collaboration with universities, engineering companies, research institutes and other experts both in Sweden and elsewhere. One major joint project in this respect was the Stripa Mine Project *(described in "Going Underground", 1988).*

Since 1985, SKB has operated a central interim storage facility for spent nuclear fuel - CLAB - and a final repository for radioactive operational waste - SFR - which came into operation in 1988. Both storage facilities are located underground in rock formations on the Swedish east coast.





Äspö island offers excellent opportunities for research in the fields of geology, rock mechanics, ground water flow, ground water chemistry etc.
Photos: Bengt O. Nordin (top) and Jan Collsjöö (below).



Special features and prerequisites for the final repository

2,200 tonnes of spent nuclear fuel are today stored at the CLAB interim facility. In the year 2008, and after pertinent permits have been obtained, SKB plans to move the waste for final disposal 400-800 m underground at an appropriate place somewhere in Sweden.

Extensive investigations of the suitability of some possible locations will be undertaken. Several Acts of Legislation will have to be consulted before the actual construction work can start at the selected site.

The final deep repository facility will comprise

- a tunnel or shaft to a deep repository 400-800 m below ground
- 40,000 m of tunnel
- several connection shafts between the surface and the repository level
- about 4,500 boreholes, 1.8 m in diameter, and 8 m deep, bored from the deposition tunnels. The encapsulated fuel will be surrounded by highly compacted bentonite in the deposition holes
- backfilling of tunnels and shafts.

Äspö HRL

Pre-investigations of the bedrock in the Äspö district were initiated in 1986. The construction work on the research laboratory started in 1990 and was concluded in 1995 at a final depth of 450 m.

Today, the work is concentrated on summarizing the results of both theoretical and practical experiments, and demonstrating the methods for designing and siting a repository for spent nuclear fuel deep down in the bedrock. The repository must be able to meet stringent performance and safety requirements over a long period of time (thousands of decades).

The laboratory tunnel is 3,600 m long and reaches a depth of 450 m. Tunnels have been driven by TBM and drill/blasting techniques to compare mechanical damage created by construction work.





Investigation methods applied at Äspö

Surface investigations

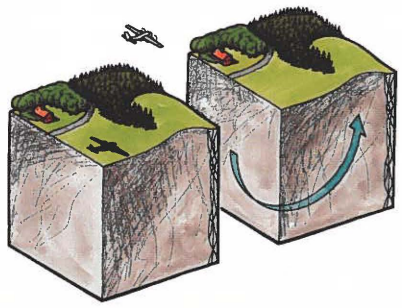
Satellite photos and measurements conducted from aeroplanes provide a rough but adequate picture of rock type variations, and reveal the location of large fracture zones. Measurements performed from the ground give additional and more detailed information. The first simple model will then tell for example where the water flows up out of the bedrock and where it flows in.

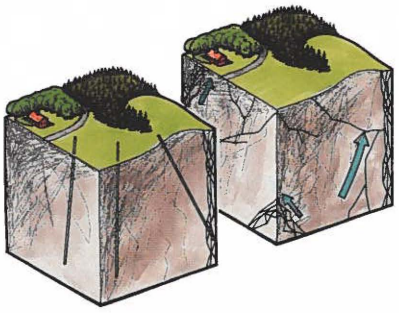
Borehole investigations

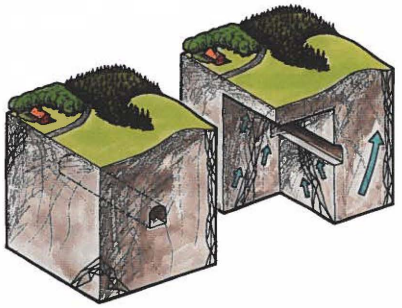
To refine the models, a number of deep boreholes are drilled, up to 1,000 m in length. The drill cores show which rock types occur along the hole as well as fractures and their directions. A small TV camera is lowered into the hole to examine the fracture zones in detail. The boreholes also yield information about the hydraulic conductivity of the rock and the ground water chemistry.

Investigations in the tunnel

The final investigation stage involves "opening" of the rock by building the underground facility. This will reveal whether earlier results have been correctly interpreted, and which methods are best suited for investigating the bedrock. The information obtained from "mapping" the rock is collected in a CAD system for further processing. Previous rock models are updated and developed.







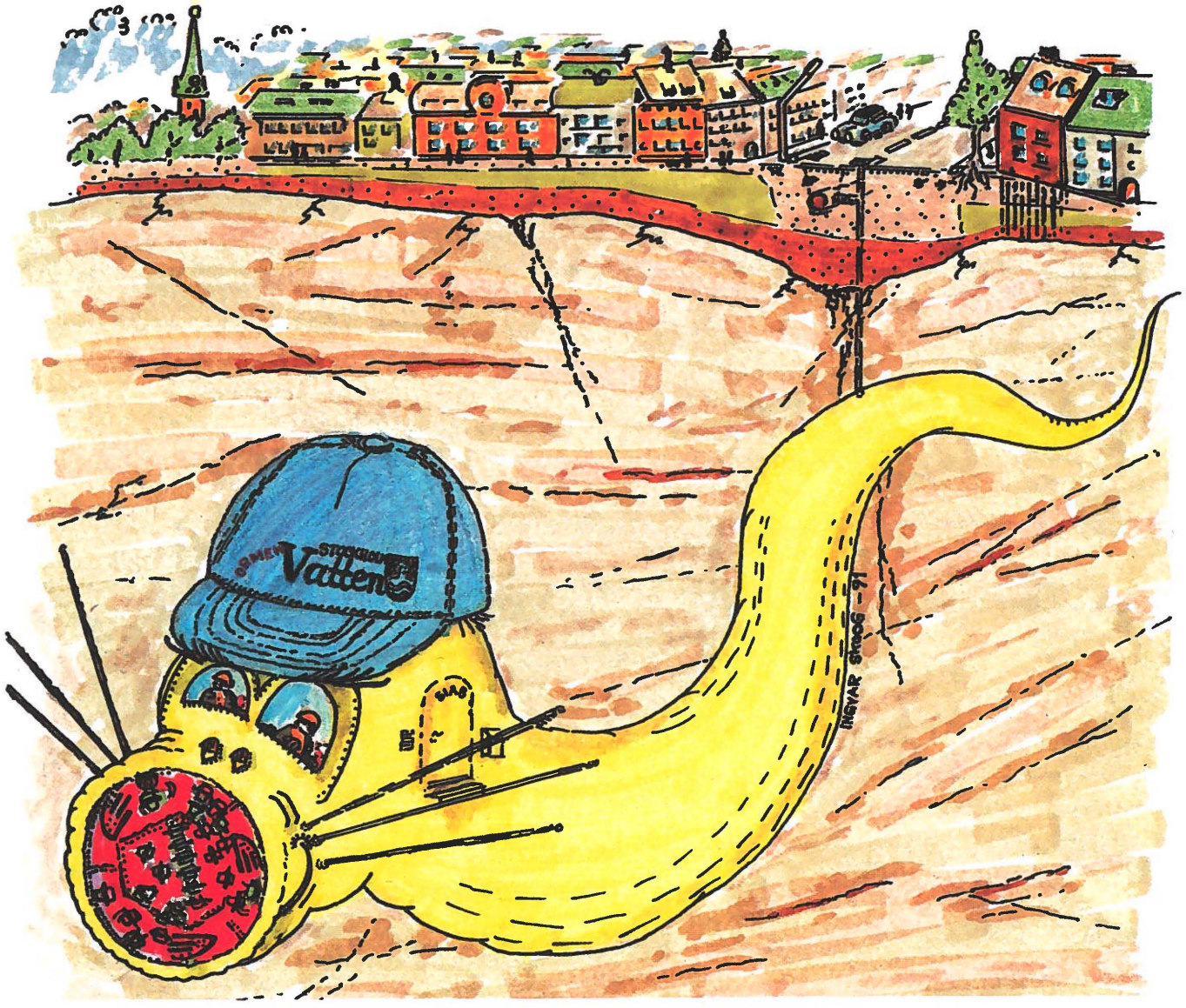
International research and general environmental research

The Äspö project has met with great interest from many countries and the following nations are now involved and contributing to the research work and evaluation of data: Canada, Finland, France, Germany, Japan, Spain, Switzerland and United Kingdom.

Äspö has also been made available for general environmental research through the establishment of the Äspö Environmental Research Foundation.

For further information, please contact:

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Stockholm
Vatten
INGVAR SJÖÖS

The "Snake" Tunnel - a Waste-water Storage

Facts

Client: Stockholm Vatten
Owner: City of Stockholm
Contractor: Siab AB
Consultant: Mineconsult
Construction period: 1990-1993

Rainwater that falls on the city of Stockholm is fed to the waste-water treatment plant at Henriksdal. The water is transported through a network of pipelines where domestic waste-water is mixed with rainwater. At times of flooding, the combined rain- and waste-water is allowed to overflow into the nearest stretch of water. To reduce the adverse effects of this overflow, a tunnel has been built where the "surplus" waste-water is temporarily stored until the load on the pipelines and the treatment works is reduced.

Stockholm is a metropolis where it is possible for people to fish for salmon outside the Royal Palace and House of Parliament from the banks of "Strömmen", the water-course that links Lake Mälaren with the Baltic Sea. A short distance away, against the backdrop of the City Hall, Stockholm's citizens can swim and participate in a number of water-related recreational activities.

This has been made possible by the fact that since the 1950s, the city's waste-water treatment plants have been improved to such an extent that today no untreated effluent is discharged into the surrounding water.



The beautiful waters in the city of Stockholm allow both swimming and fishing.

The city's waste-water network transports approximately 180 million m^3 of waste-water per year. Substantial parts of the network in the inner city were constructed at the beginning of the twentieth century, and constitute a "combi-system" - i.e. surface water is transported to the treatment plants through the same mains system as (domestic) waste-water.

When rains and heavy downpours occur, the mains system cannot cope with the amount of waste-water to be transported, and it is allowed to overflow into Lake Mälaren. It is estimated that approximately 0.8 million m^3 of waste-water overflow into Lake Mälaren every year. A decision was made to reduce this amount radically by providing temporary storage capacity for the waste-water.

The Snake - project planning and method

Instead of building several storage tunnels, it was decided to drive a single full-face bored tunnel under a large area of central Stockholm. Because of its winding course, this tunnel storage got its name "The Snake"!

It was not only the hardness of the rock and its homogeneity that determined the choice of a tunnel boring machine (TBM); the requirement for a watertight tunnel also had to be taken into consideration. Many areas of Stockholm have buildings founded on wooden piles, and any lowering of groundwater levels increases the risk of instability and settlement damage. The maximum acceptable leakage per 100 m of tunnel has been set at two litres per minute. Ground-water levels were checked by means of measurements taken in 110 boreholes along the length of the tunnel.

In planning the route of the tunnel, it was decided to locate it as far away as possible from known stratified zones and fissure systems, and to a depth of 60-70 m below ground level. It is important that water tunnels of this type are located at a depth that allows the upper strata to be used for the public transport system.

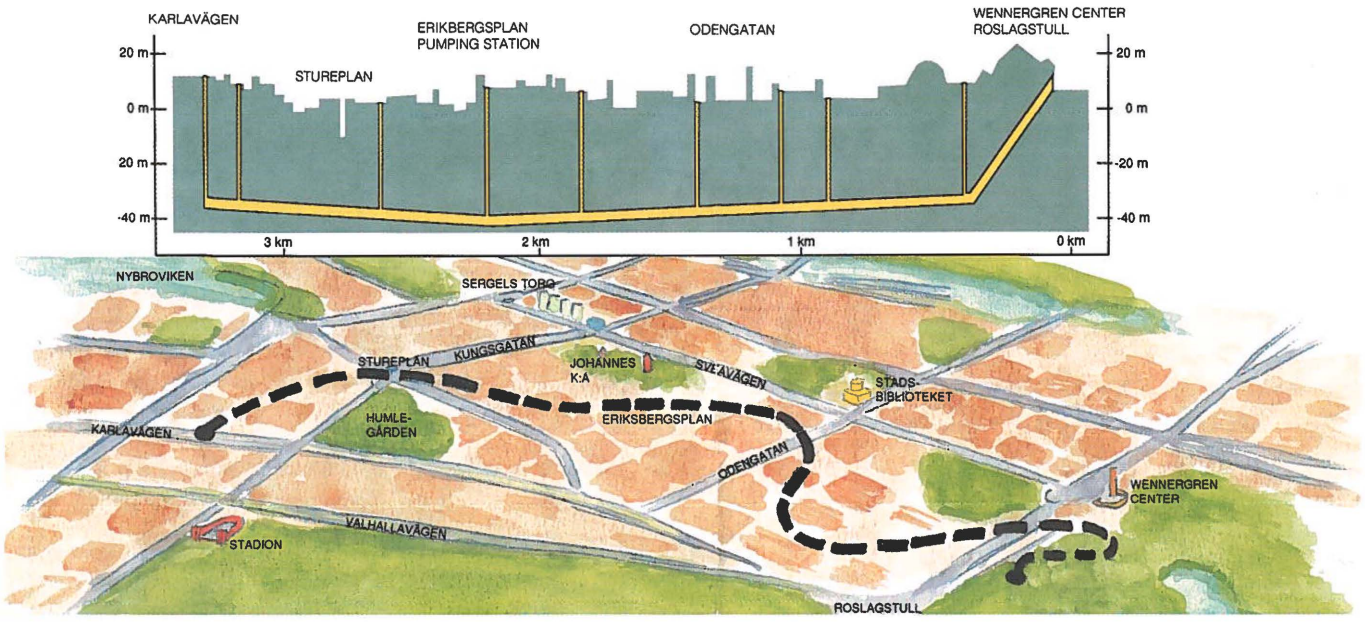
The storage volume created by the tunnel is 35,000 m^3. The existing mains system is connected at eight whirl chamber points, by means of boreholes down into the tunnel. The diameters of the boreholes range between 600 and 1,200 mm. At certain points, the flow through the boreholes can reach up to 3.5 m^3 per second.

When the flow in the mains system decreases, the overflow water is lifted by a pump station situated at the tunnel's lowest point, back up to the mains system for further transportation to the purification plant at Henriksdal.

The pumps have a capacity of 12 m^3 per minute, and the entire storage volume of the tunnel can be emptied in 48 hours.

Parallel ventilation holes were bored in order to lead off the air that is drawn down into the shaft.

The whole operation is automatically regulated by continuously controlling the water level in the mains system and the tunnel by means of computers and motorized sluice gates.



Profile and view of the Stockholm "Snake Tunnel" for waste-water overflow. The tunnel has a capacity of approximately 35,000 m^3.





The transfer station is located at a depth of 40 m. The downward tunnel to the transfer station is 300 m long and is part of the tunnel's overall length, which is 3.7 km. The gradient of the downward tunnel is 1:7.

Geological conditions and technical data

The bedrock in Stockholm is predominantly homogeneous and consists mainly of fine and coarse crystalline granite and gneiss. Certain secondary rock types, e.g. veins of pegmatite and diabase, were encountered in some areas.

Table 1 shows the rock mechanics data for the main rock type. Table 2 shows the technical data and performance of the TBM (Atlas Copco FORO 900 S/3.5).

Table 1.

Rock Mechanics Data	Granite	Gneiss
Axial compression strength (MPa)	150-220	65-180
Point Load (MPa)	5-9	1-7
Fracture toughness (MN/m 1.5)l	2.2-3.0	2.3-3.3
Wear and tear CAl	3.0-5.5	1.9-5.9

Table 2.

Tunnel diameter	3.5 m
Installed cutter head power	675 kW
Travel	1.5 m
Thrust, max.	7000 kN
Disc cutters, diameter	394 & 413 mm resp.
Overall weight (estimated)	130 tonnes
Overall length, mininum	6.2 m
Overall length, maximum	7.7 m
Cutter head speed	12.3 r/minute
Penetration rate (approx.)	4 mm/revolution

Experience gained from operations

Work on the Snake Tunnel was carried out in three shifts, five days per week. Two shifts were responsible for boring operations, while the third was responsible for maintenance and repairs.

Boring required a workforce of five men per shift. Because all of the work involved machinery, it was essential that the workforce have electrical and mechanical expertise. Breakdowns halt the entire construction of the tunnel, therefore availability was essential in order to save both time and money.

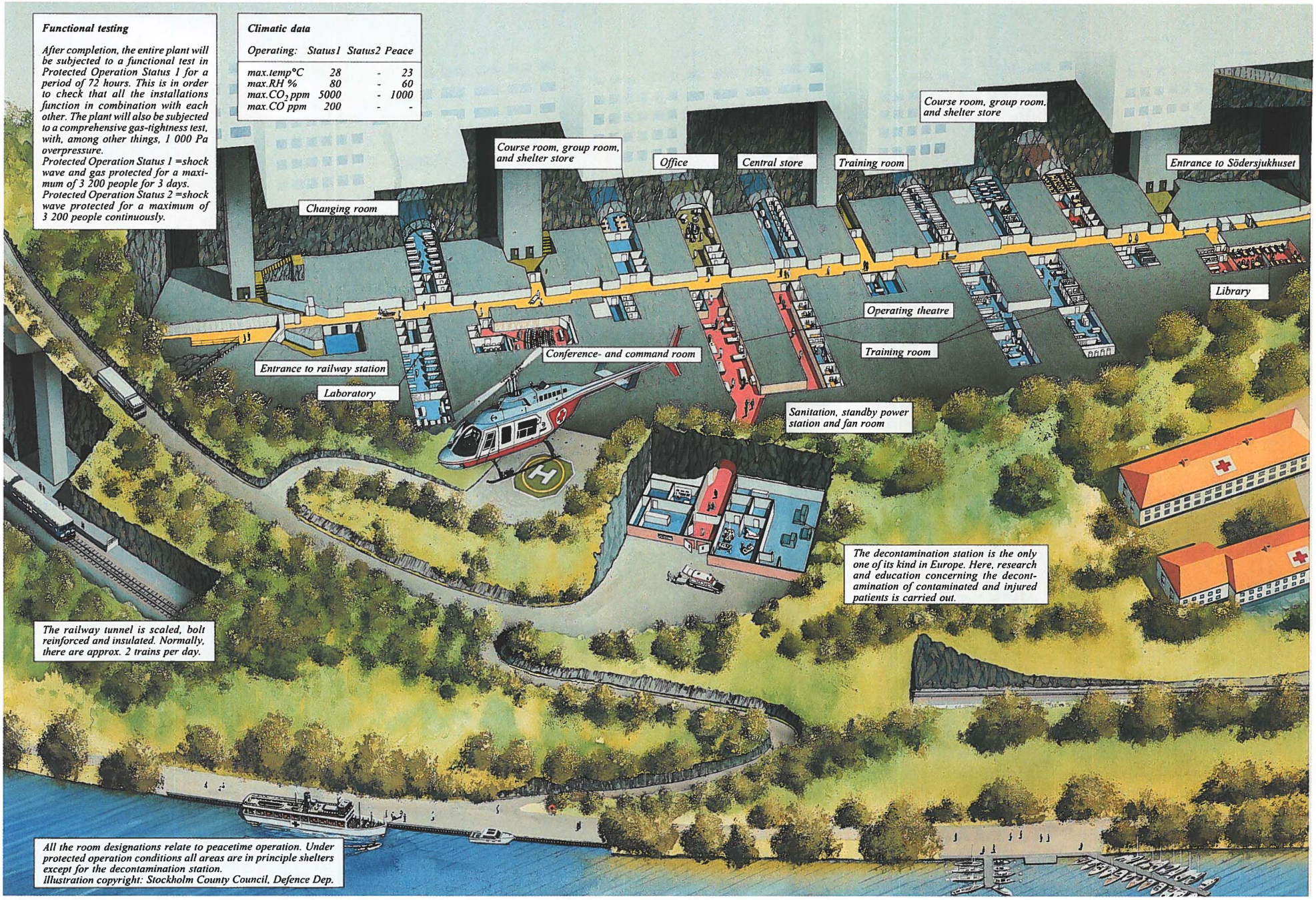
Due to the extensive pre-grouting work, the actual time available for boring was much less than normal. In addition, working hours were limited to avoid disturbing residents from 8 pm to 7 am. Nor was it possible to carry out operations on Saturdays and Sundays.

The work stages can be broken down as follows:

Grouting	30%
Boring	40%
Maintenance & repairs	15%
Miscellaneous work	15%

The machine's net advance in solid hard granite was 2.4 m per hour. Taking these figures into account, the practical average net advance was 80 m per week, which is equivalent to approximately 300 m per month.

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Ph.: +46 8 782 00 00



Ill. Emergency & Disaster Planning Division, Stockholm County Council

Transplanting the Heart of a Hospital

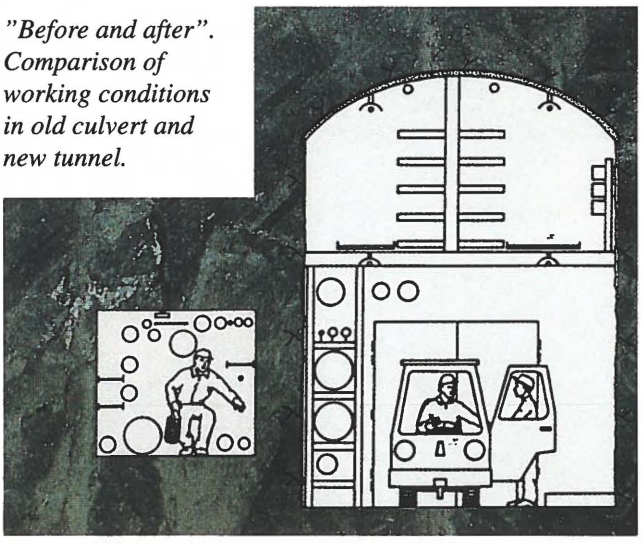
Facts

Clients: Stockholm County Council LOCUM AB
Owner: LOCUM AB
Contractor: Skanska Stockholm AB
Consultant: VBB VIAK AB
Construction period: 1990-94

One of Stockholm's main hospitals, Södersjukhuset, was built in the late 1930s in the southern part of the city. The hospital has about 4,500 employees, and wards and beds for over 700 patients. The technical services systems for water, electricity, gas and sewage mostly date back to the 1940s, with new installations being added in subsequent years. The original service culverts have become cramped, making repairs and maintenance difficult, and restricting plans to expand the capacity of the hospital. In the mid 1980s it was decided to install a completely new system of culverts in tunnels in the rock under the site. In conjunction with this project, rock excavation was carried out to access an air-raid shelter built originally for world war two. This shelter will be converted into a "Disaster and Emergency Medical Centre" which will become a unique facility for international research, education, and realistic training.

It is not very often that tunnels are driven with drilling and blasting less than 10 m under a hospital. Great consideration had to be given to patients and staff in order to minimize disturbances. This was achieved by the free flow of information and close co-operation with the hospital staff, and of course accurate drilling and extremely cautious blasting, carried out by experienced engineers and blasters.

In a hospital, there is a large number of installations such as computers, electronic instruments etc, which are sensitive to vibrations. This equipment had to be isolated from the floor vibrations by means of especially selected shock absorbers before



"Before and after". Comparison of working conditions in old culvert and new tunnel.



(Photo: Staffan Trägårdh)

the tunnelling started. In all, the project comprised excavation of about 50,000 m^3 of rock, including 1,800 m of tunnels with a maximum area of 28 m^2 and 20 raises with areas of 12-25 m^2. Excavation works were finished by the middle of 1990 and installation works were completed in 1993.

The driving technique was conventional with the exception of the extreme requirements for low blasting vibrations, especially when driving the raises, which connect the tunnels with the hospital wards. The wards were functioning all the time, except when the last rounds were blasted. The contractor, Skanska, developed a special drill rig for the raise driving and built it in their own shops.

Risk analysis and vibration control

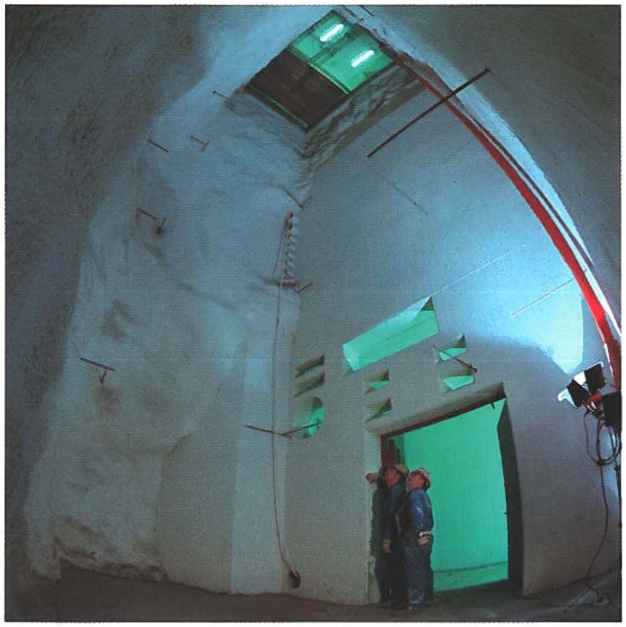
The builder, the Council of Stockholm, commissioned Nitro Consult AB, through the project management firm, VBB-VIAK, to carry out risk analysis and vibration measurement and analysis of all blasting. The risk analysis covered all buildings within the hospital area, sensitive instruments and other equipment, adjacent buildings and a train tunnel from the nearby Hammarby harbour. For most of the buildings, a vibration velocity of 50 mm/s was deemed acceptable, and when blasting within a 5 m distance, 60 mm/s was set as the maximum.

Standing on both feet 10 m above a detonating round, which gives a vibration velocity of 50 mm/s for a period of six seconds is not at all pleasant, but on the other hand, a human being is among the most sensitive of all "instruments". The whole excavation was carried out successfully, thanks to skilled blasters and good communications with hospital staff and "patient patients".

Disaster and Emergency Medical Centre (D&EMC)

In the rock under Södersjukhuset, an air-raid shelter was excavated in the early 1940s. It consists of twelve rooms with a connecting tunnel and has a total area of 3,880 m^2. It will now be modernized and equipped so that qualified medical care can be carried out there, as well as research and training. It will be unique in that

Looking up a raise into a hospital ward.



(Photos: Staffan Trägårdh)

Culverts in operation.



it can be converted from its peacetime function into a wartime hospital within 48 hours. This means that all equipment for research and training must be easy to dismantle, or be arranged so as not to interfere with the wartime functions. The centre will be an international facility for research, education, and realistic training. Since it is adjacent to Södersjukhuset, there is a natural link with the clinical activities. Training will be offered to nursing personnel, politicians and administrators from all over the world. A management and communications centre will be built for training of personnel. It will also be equipped for connecting with SOS-Alarm. When completed, this centre will considerably improve the preparedness against disasters in the Stockholm area.



Operating room in the Disaster and Emergency Medical Center. (Photo: Staffan Trägårdh)

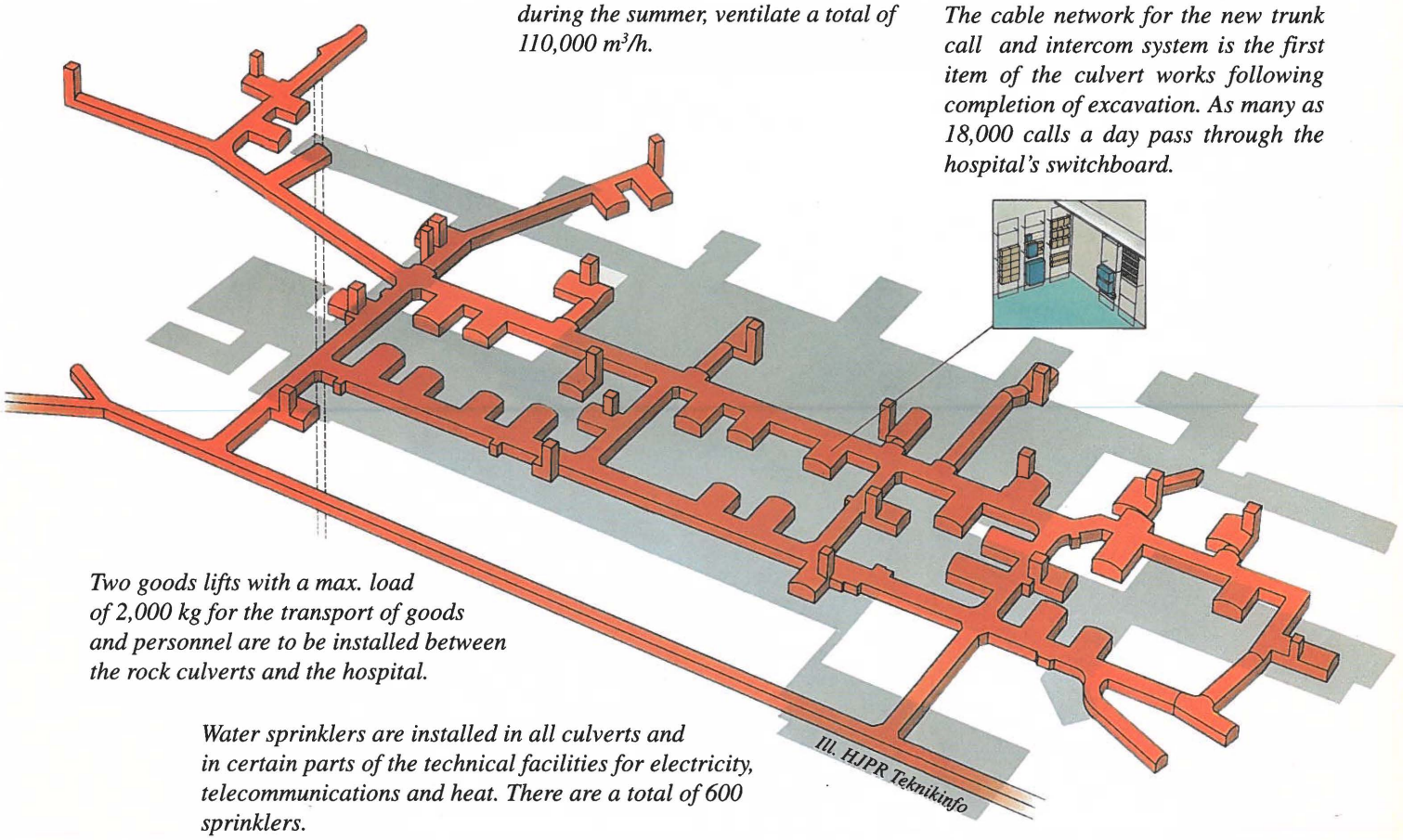
For further information, please contact:

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Two 100 m drillholes lead down to the water table. From here, the hospital can be supplied with water in a crisis situation when the municipal supply is no longer functioning.

The culverts are ventilated by means of 12 fans which, at maximum power during the summer, ventilate a total of 110,000 m³/h.

The cable network for the new trunk call and intercom system is the first item of the culvert works following completion of excavation. As many as 18,000 calls a day pass through the hospital's switchboard.



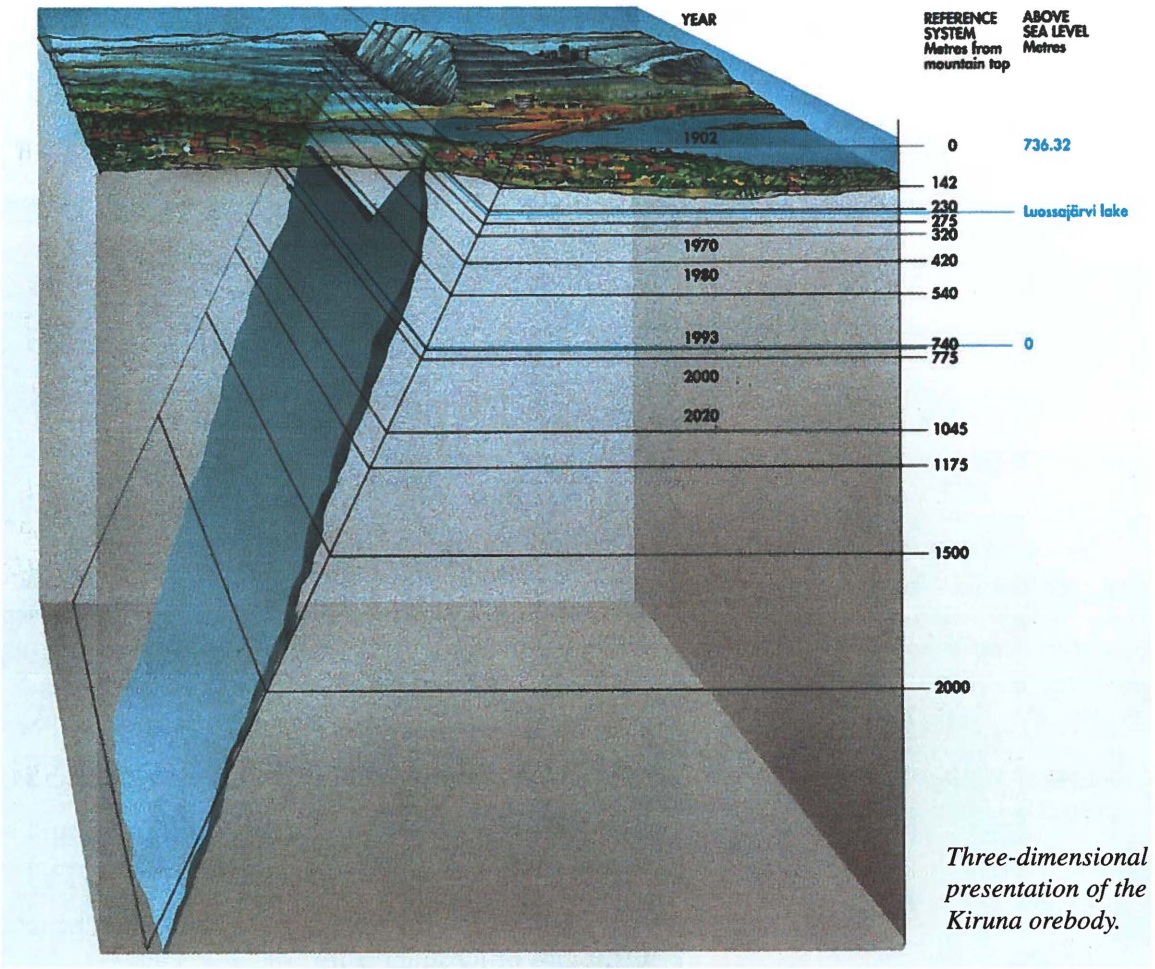
Two goods lifts with a max. load of 2,000 kg for the transport of goods and personnel are to be installed between the rock culverts and the hospital.

Water sprinklers are installed in all culverts and in certain parts of the technical facilities for electricity, telecommunications and heat. There are a total of 600 sprinklers.

The total length is approx. 1.8 km. The main culvert is 4.5 m wide and has a height of about 6 m.



Aerial view of the Kiruna Mine.



Three-dimensional presentation of the Kiruna orebody.

The KUJ 2000 Project in the Kiruna Mine

Facts

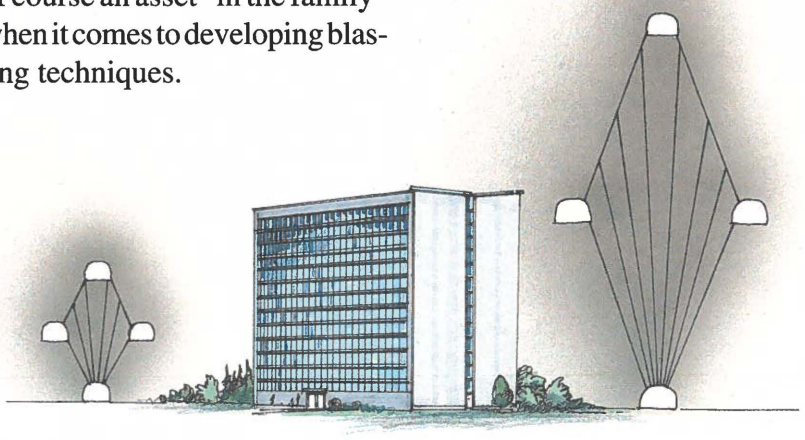
Owner: LKAB
Contractors: Siab Norra, Schakt & Tunnel AB, Skanska Stockholm
Construction period: 1990-1997

LKAB, "Europe's Iron Ore Mine", operates two mines north of the Arctic Circle in Sweden, Kiruna and Malmberget. The company also operates two ports of shipment, one in Narvik, Norway, and one in Luleå, Sweden. Annual production amounts to about 21 million tonnes of iron ore products (pellets, low and high phosphorus ore), 80 % of which are exported. Since both Kiruna and Malmberget are underground mines, they have to be very efficient in order to compete with the big open-pit mines in other countries. At present, an extensive investment programme - the KUJ 2000 project - is being carried out at Kiruna. It includes a new haulage level being installed at 1,045 m level (815 m below surface), which will be operational in 1997 and will provide sufficient operational capacity until the year 2015.

The mining method used at both Kiruna and Malmberget is sublevel caving. Below the present haulage level, 775 m, large scale sublevel caving with sublevel heights up to 30 m will be used. The orebody is over 4 km long and will be divided into eight production blocks. Each block will be "a small mine in the big mine", independent of the other blocks. Continous operation will be possible because the different blocks are independent of each other. Ventilation of one block after blasting does not affect the other blocks, as they are well separated.

New drilling and blasting techniques

Before 1980, a sublevel height of 12 m was standard. Since then, development of drilling accuracy and blasting techniques have made it possible to increase sublevel height to 30 m, thereby increasing productivity considerably. LKAB have a subsidiary, Kimit AB, which develops and manufactures explosives. This is of course an asset "in the family" when it comes to developing blasting techniques.



Sub-levels before 1980 and today, compared with the height of the central office in Kiruna.

Production drilling in the mine will be carried out by remotely controlled one-boom rigs equipped with high-pressure water operated ITH-drills, a new type of drill developed by another LKAB-subsidiary, G-Drill.

Maximum hole depth in the fan-shaped drilling patterns is about 55 m. The use of water as the energy medium is very favourable for the environment. An ITH-hammer makes it possible to drill straight holes with a maximum deviation of 1.5 %.

The rig is highly automated. After starting, it automatically drills a whole fan, 10 holes with a total length of about 300 m. The hole diameter is 115 mm, and one round produces about 10,000 tonnes of ore. According to present plans, one operator will be able to run three drill rigs from a central control room.

Highly mechanized charging of explosives

The development of the mining method has required adaptation of charging and blasting techniques. Charging is highly mechanized. The water-resistant emulsion explosive is pumped into the drill holes by remote-controlled charging units with hydraulic booms. When the charging hose has been inserted into the bottom of the drill hole, charging and retraction of the hose is fully automatic.

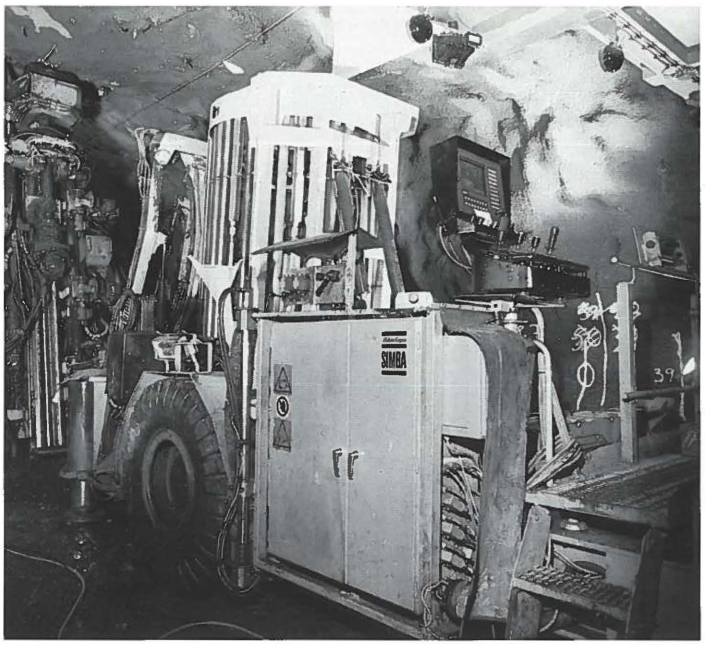
A special technique using water lubrication of the inside of the charging hose makes it possible to pump the explosive with a few bars pressure, in spite of the very high viscosity of the explosive which is required to make it stay in vertical up-holes of 115 mm diameter. The hose is 60 m long.

Transport systems

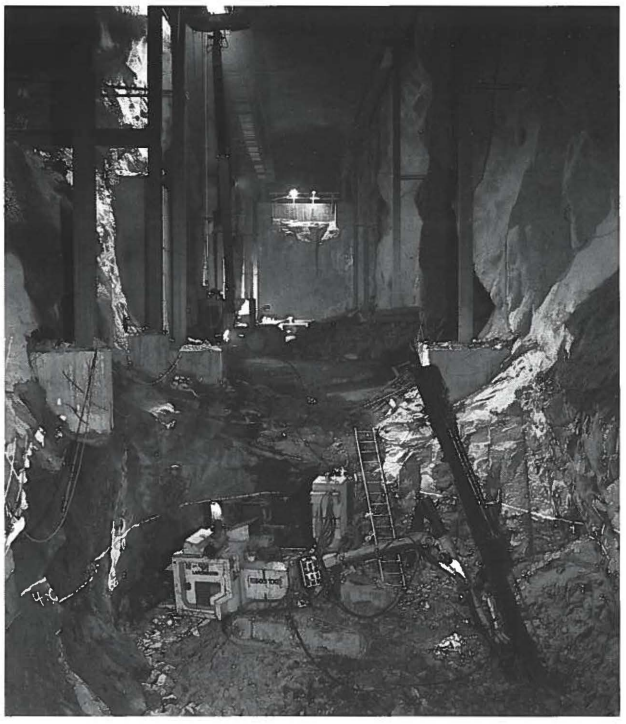
The orebody is about 4 km long, and the transport system at the new main level will comprise horizontal trackbound transport combined with vertical hoisting. Seven automatic, driverless trains, each carrying 500 tonnes will be required for an annual production of 25 million tons of crude ore. The trains will haul ore from eight groups of ore-passes to four crushing plants.

Hoisting will take place in two steps. From the crushing plants, four hoists bring the ore to the present crushing bins at 853 m level, and from there to the surface via the six existing hoisting shafts.

A picture of the new production drill rig during testing in the mine. The operator is positioned on the rig during testing, but when it goes into production, the operator will sit in a control room at the 775 m level.



Four crushing plants will be installed at the 1,076 m level.



Automatic and remotely controlled loading and transport

Within a few years loading and transport from the mining face to the orepasses will be carried out with automatically operated LHD-machines, which will be remotely controlled during the bucket-filling operation. The system has been tested at the 740 m level.

A central control room is planned at the 775 m level, where production planning will be carried out as well as supervision of drilling, loading, transport, and primary crushing. This system should bring about a radical change of the working conditions for many of the miners, with increased opportunities for co-operation and social contacts.

Drainage and ventilation

Drainage and ventilation are of vital importance for an underground mine. A permanent pumping plant with a total capacity of 48 m^3 per minute will be installed at the 1,065 m level.

The ventilation system will be computer controlled in order to optimize distribution of the air. Because the air has to be heated during the winter time, ventilation accounts for a considerable part of operating costs. For the annual production of 25 million tonnes of crude ore, about 40 million tonnes of ventilation air will be distributed throughout the mine.

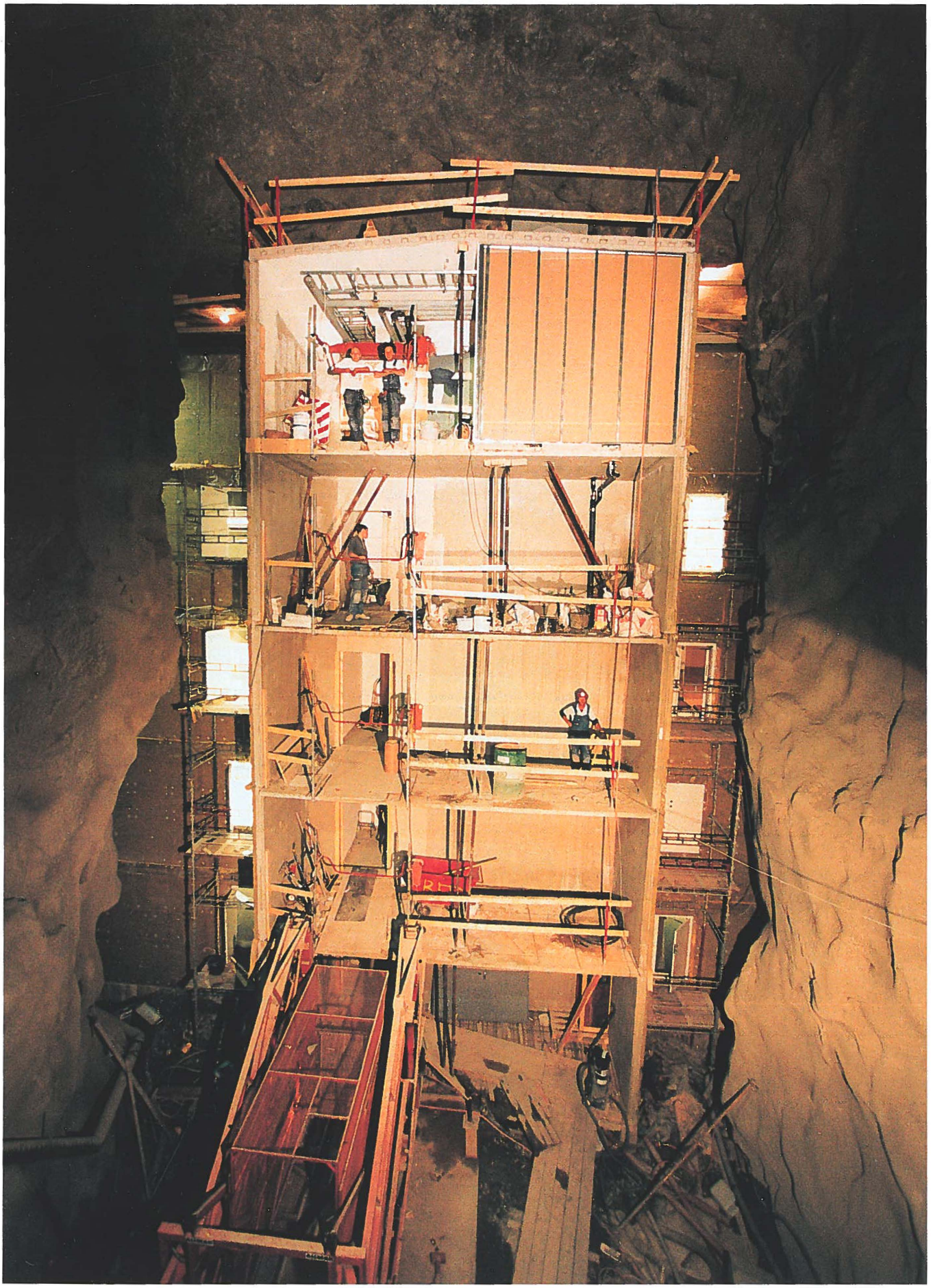
For further information, please contact:
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LHD-machines and trains will be supervised from a central control room at the 775 m level.









Five-storey structure being erected in one of the rock caverns.
(Photo: Fredrik Funck/Pressens Bild)

Underground Expansion of Sweden's Royal Library

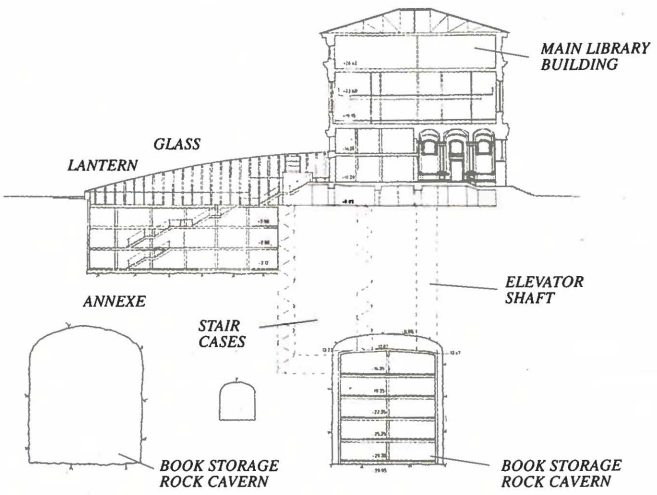
Facts

Client: National Property Board
Owner: National Property Board
Contractor: NCC Anläggning, Region Stockholm
Consultant: Tyréns
Construction period: 1992-93

The Swedish Royal Library is housed in a building constructed in 1878 in one of central Stockholm's beautiful parks, which is surrounded by buildings of high architectural and cultural value. Since 1629, there has been a law in Sweden ordering publishers to deliver one copy of all printed matter to the Royal Library.
The original building was designed for 200,000 volumes and ten employees, a considerable under-estimate of the growth of printing. Today, there are three million volumes in the collection, looked after by 250 employees, and 2,000 m of new shelf-space are required each year.
The only way of maintaining the library in its present location is an underground expansion project, which will be completed in 1996 - with no interruption of the library's operations.



The entrance of the Royal Library and the elements of its expansion.



An extensive renovation project carried out during 1992-1996, includes modernizing the staff working areas, rooms for researchers and public, and expansion of the storage volume in two rock caverns excavated under the library. The caverns - one of which is situated right under the library, only 15 m below the basement floor - are 150 m long, 15 m wide and 19 m high. Total excavated volume is 110,000 m^3. In each cavern, a five-storey concrete structure will house the books. A system of elevators and staircases connects the caverns with the original building.

Before the excavation work was started, a risk analysis of the area was carried out. The local buildings are founded on wooden piles, and consequently groundwater level and vibrations from blast-

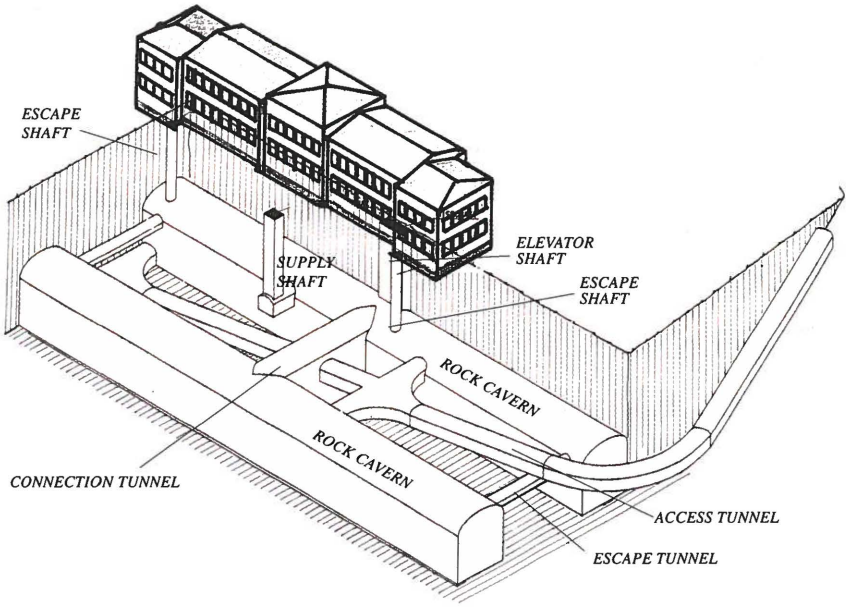
ing were crucial factors. If the groundwater level is lowered, leaving the upper parts of the piles dry, they will rot and cause subsidence of the houses. During excavation, pre-injection of cement grout was carried out in 5 m long drill holes in front of the tunnel face.

The requirements for sealing the caverns were stringent: maximum leakage of 2 litres/minute per 100 m of tunnel. The caverns are situated at 40 m depth and 25 m below the normal groundwater level. The commissioner of the project had given detailed instructions concerning the sealing of the rock. In principle, a 5 m thick concrete shell was to be created around all the tunnels by means of extensive drilling and cement grouting. In total, over 120,000 m of holes were drilled.

The excavation was carried out by conventional methods: ramp down to the gallery level and then excavation of the gallery with pilot tunnel and two horizontal benches. The four raises up to the library building were long-hole drilled. In order to minimize interruption of the library operations, the last 2 m of the raises were blasted at the latest possible moment.

The concrete structures inside the rock caverns also must meet stringent demands:

- No water leakage from the caverns into the library rooms.
- Effective drainage of water from sprinklers installed in case of fire. The whole of the new structures are sprinkler-equipped.
- Constant temperature at 19 +/- 2°C and air moisture at 45 +/- 6 %.



Three-dimensional view of the elements excavated in rock.

Interior of one of the rock caverns with an elevator shaft connecting the cavern with the library annexe. (Photo: Courtesy of the National Property Board)



The project has been carried out successfully. Time-schedule and cost limits have been kept. Water leakage is far below the stipulated level, air moisture meets requirements, and last but not least: the library has been open to the public without interruptions.

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Underground Emergency-centre in Stockholm

Facts

Client: Political Board for Rescue and Fire Services
Owner:
Stockholm Fire Department
Contractor:
Skanska Stockholm AB
Consultant:
Tyréns Byggkonsult (design)
Construction period: 1994-1996

The Johannes fire-station in the centre of Stockholm was built in 1878, and has been the city's main fire-station ever since. Rebuilt and modernised several times, it is the management and administration centre for all the city's fire brigades. Most recently, a new emergency centre for Stockholm province has been constructed in the rock under the fire station. It will house SOS-central, fire-brigade management, and the supervision of energy supplies to the Stockholm area. In wartime, politicians and key administrators from the city and its surrounding communities will be located there. The construction project was very challenging because rock excavation was complicated, and the centre has to provide high-grade office and living conditions even though it is 35 m below the surface.

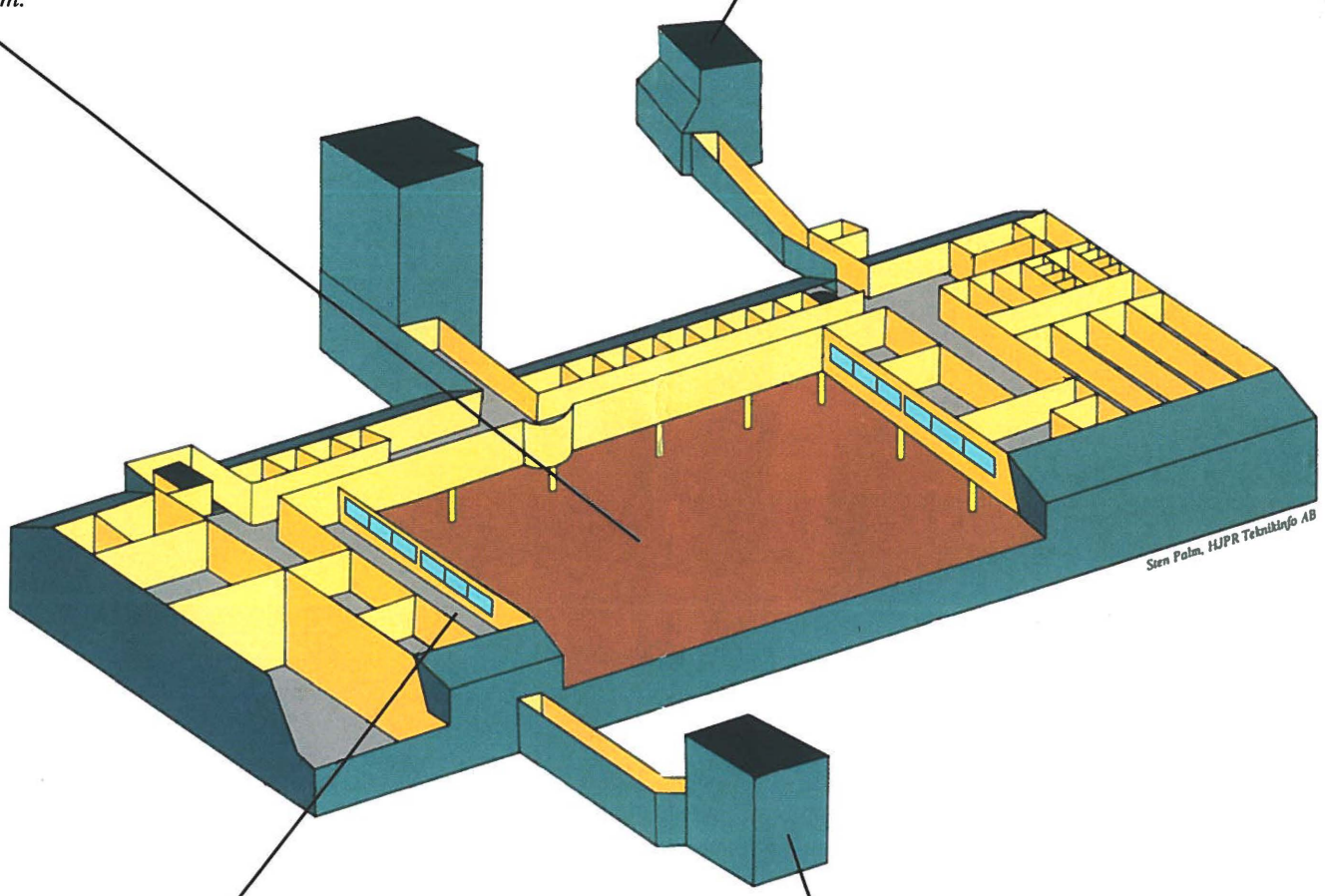
The emergency centre is housed in a two-storey building, erected inside a cavern 25 m under the fire-station. The building has a total floor-surface of 3,000 sq m. In an adjacent smaller cavern, cooling machinery, air purification equipment and an auxiliary power station are installed. In total, about 30,000 m^3 of rock was excavated.



Interior of the communications control room. In the communications control room, the emergency centre and SOS-operators work side by side using a modern, integrated technical system. Work goes on round the clock. (Illustration: Ove Flyckt Arkitektkontor AB and ARC3D)

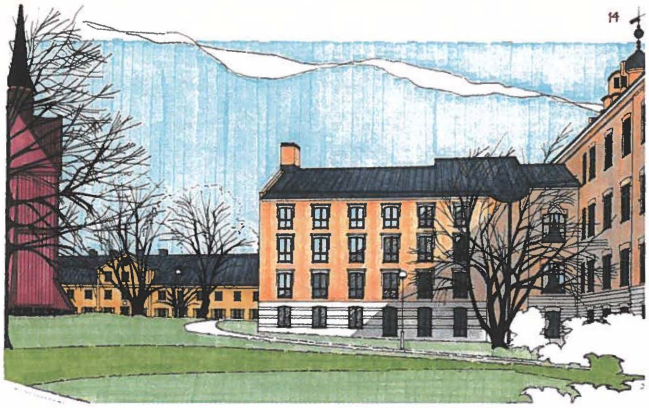
The wartime entrance with elevator and stairway shafts connecting directly to the underground garage.

Three elevator and stairway shafts lead to the emergency centre. One entrance is for visitors and personnel from SOS-Alarm.



In the show room, the supervision of the communications system can be demonstrated to visitors without disturbing work or jeopardizing internal security.

One of the communication shafts is for quick access to the fire-station vehicles.



Extension of the surface building designed to fit into the old surrounding environment. (Illustration: Ove Flyckt Arkitektkontor AB)

The large cavern housing the emergency centre. In total, 30,000 m³ of rock have been excavated, and the whole rock surface has been shotcreted. The picture shows work on the large floor plate. (Photo: Bo Lindh)



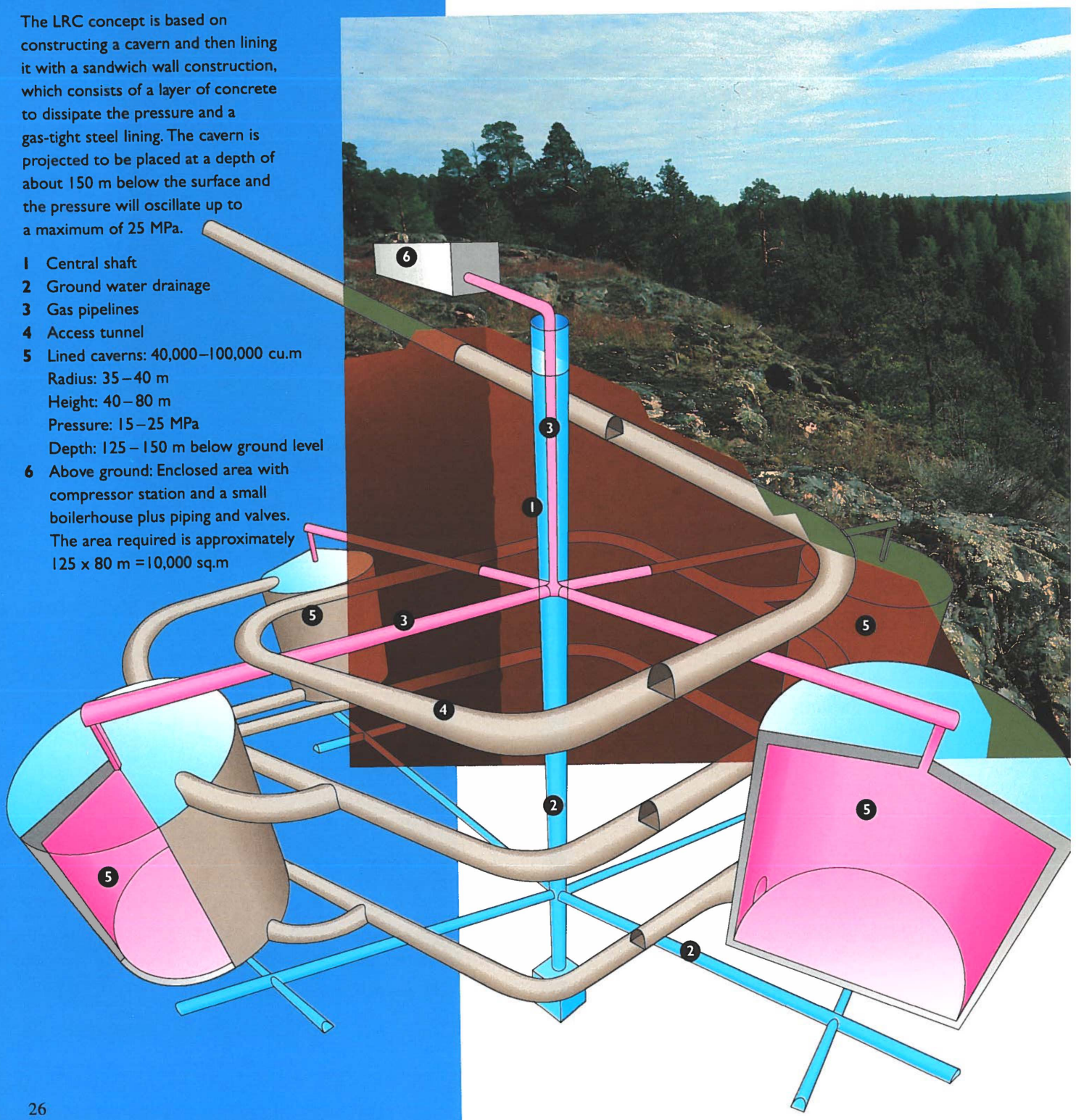
The area around Johannes fire-station is of great historic interest. The first chapel was built late in the 13th century, close to the place where Johannes Church now stands. The ancient history and the beautiful surroundings right in the centre of Stockholm implied very stringent demands on the planning and building of the emergency centre. The blasting operations had to be carried out with close control of noise, vibrations, air shock waves and emission of blasting fumes. Work was limited to 7 am to 6 pm, and vibration measurements were made at numerous points. Special structures were built at tunnel openings in order to reduce noise, and a 32 m high chimney was set up to ventilate all blasting fumes. Skanska's engineers, who were also in charge of tunnelling under the Södersjukhuset Hospital *(also described in this volume)*, consider the blasting operations under Johannes to be even more delicate.

Brunkebergsåsen, the ridge which covers the rock, consists of loose layers of sand which will be compacted by vibration. This required extremely cautious blasting. The bottom of the cavern is about 7 m below the surface of Lake Mälaren, and therefore the whole rock volume around the cavern had to be grouted.

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The LRC concept is based on constructing a cavern and then lining it with a sandwich wall construction, which consists of a layer of concrete to dissipate the pressure and a gas-tight steel lining. The cavern is projected to be placed at a depth of about 150 m below the surface and the pressure will oscillate up to a maximum of 25 MPa.

1 Central shaft
2 Ground water drainage
3 Gas pipelines
4 Access tunnel
5 Lined caverns: 40,000–100,000 cu.m
Radius: 35–40 m
Height: 40–80 m
Pressure: 15–25 MPa
Depth: 125 – 150 m below ground level
6 Above ground: Enclosed area with compressor station and a small boilerhouse plus piping and valves. The area required is approximately 125 x 80 m =10,000 sq.m



Storage of Gas in Lined Rock Caverns

Natural gas demand, particularly in the domestic sector, is dependent on the local climate and varies considerably during different times of the year. Underground gas storage will help to maintain a readily available gas supply throughout the year. During the past ten years, the Lined Rock Cavern (LRC) concept for high-pressure storage of natural gas has been developed in Sweden.

This research and development work has been undertaken because of the fact that Sweden does not have the natural geological formations usually used to store gas under high pressure.

The concept involves the storage of gas in excavated rock caverns furnished with an impermeable lining to prevent gas leakage. The concept is based on the interaction between the following elements:

- An impermeable lining, with no pressure-absorbing function, enclosing the gas in the cavern.
- A concrete layer, serving as a foundation for the lining. The concrete transfers the pressure from the stored gas to the surrounding rock mass, and distributes the deformations, absorbing some of them.
- The surrounding rock mass absorbs the pressure forces and thus acts as the actual pressure vessel.
- A drainage system, taking care of groundwater inflow.

The storage pressure can be high, 15-25 MPa. Each storage cavern has the form of a vertical cylinder with a geometrical volume of 50,000 - 100,000 m^3. This means that each cavern can contain up to 30 million m^3 (NTP) of natural gas.



This tunnel leads to one of the cylindrical test caverns at Grängesberg.

The rock cover needed depends on the storage pressure and on the diameter of the cavern, but is estimated to be in the range of 100-200 m.

The most important part of the development of the LRC concept is the Grängesberg Pilot Plant where the concept was tested and demonstrated between 1988 and 1994.

The pilot plant was constructed in 1988 by a number of Nordic companies, and consists of three rock caverns (scale 1:10) where different types of linings have been tested. Extensive tests of

the behaviour of the concrete and the rock mass have also been performed. A maximum test pressure of 52 MPa has been reached in one of the caverns. Pressure tests were performed with both water and air.

The results from rock mechanics analyses give a good indication for predicting rock behaviour for large-scale gas storage projects with high storage pressure.

Advantages of LRC storage

The LRC concept offers many advantages.

- *Low investment costs*

The initial storage facilities can consist of single modules. As the rock caverns are situated at a shallow depth, the costs of geological surveys and of the access tunnel will be reduced.

A commercial storage plant will probably consist of several units. It is possible to excavate and construct new caverns in order to expand an existing installation. This helps to spread the investment over a longer period of time.

- *Efficient use of entire storage capacity*

Several of the alternative methods of underground storage do not allow the entire gas volume to be withdrawn. However, lined rock caverns can be emptied completely, though normally a certain minimum pressure needs to be maintained.

- *Friendly to the environment*

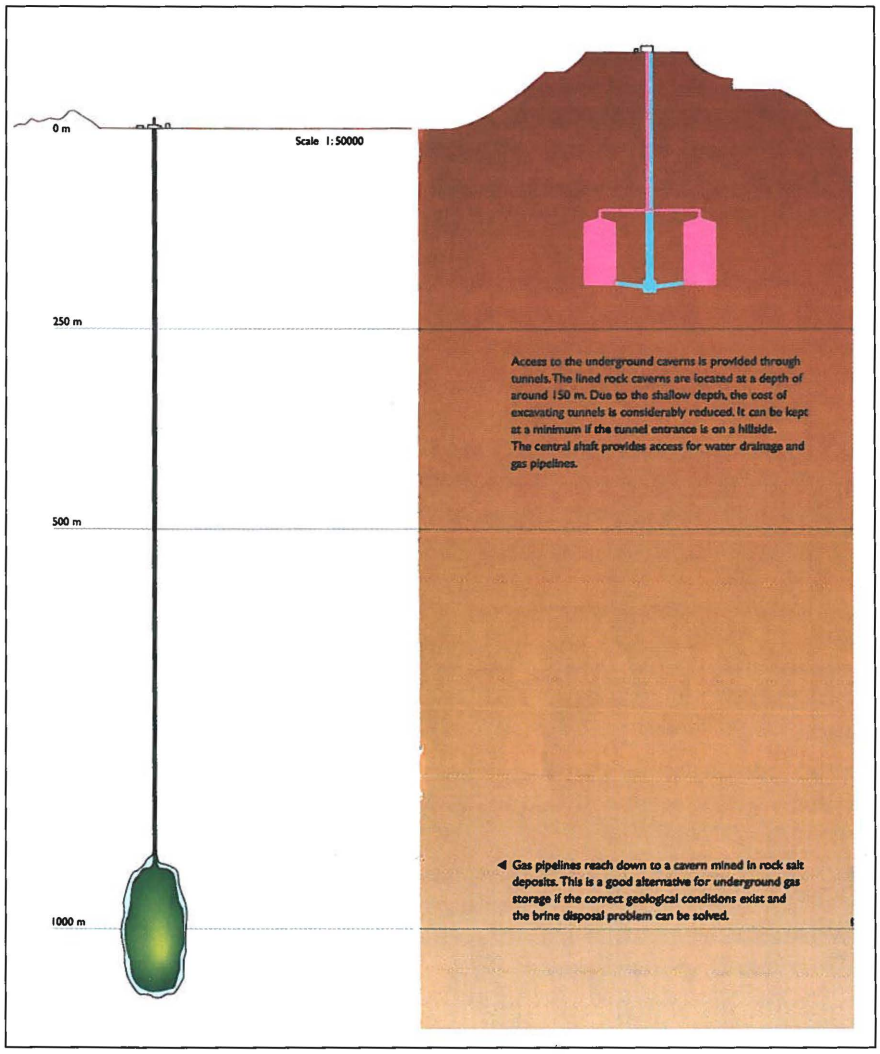
Gas does not leak from a lined rock cavern into the rock mass with the risk of affecting ground water.

- *No gas treatment is needed*

As natural gas never comes into contact with moisture or impurities it never becomes contaminated.

Research and financing

The LRC technology is planned to be realized in an industrial scale when a large demonstrating plant is constructed not far from the Swedish city Halmstad. The main parties involved with financing and others for this project are Gas de France, Sydkraft, Sydgas and Sydkraft Konsult. Other parties involved are Skanska, the Royal Institute of Technology and Chalmers Institute of Technology. However, the demonstration project is still lacking financing and discussions are held with other companies and an application for fundation by the European Union, Thermie program will be made. The basic research has been financed by participating companies in the Grängesberg project as well as through governmental funds (Nutek-Swedish National Board for Industrial and Technical Development).



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Current Research in Rock Engineering and Explosives Technology in Sweden

During the 1990s large infrastructural investments are implemented and planned in Sweden. These include new tunnels in the national rail net, a ring-road tunnel system around Stockholm, underground stations for public transport, and new and extended rock caverns in urban areas for various applications. This programme underlines the importance of continuing the development of techniques for economical and safe underground construction.

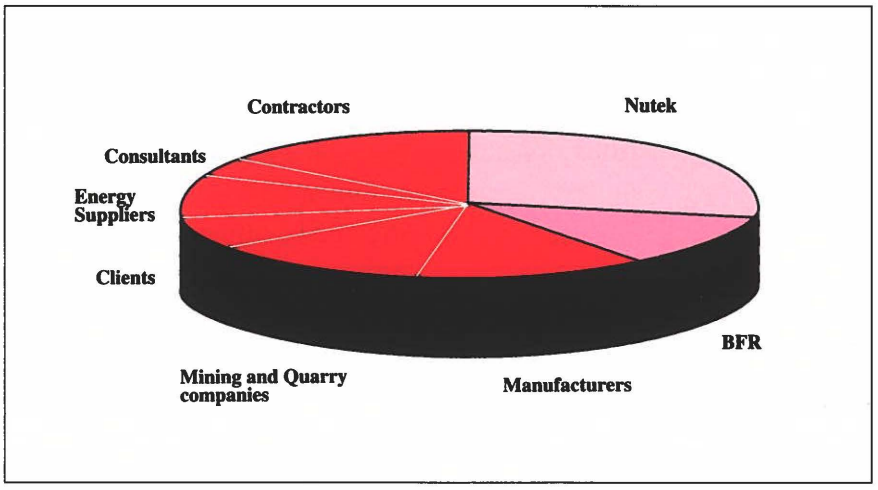
The Swedish construction industry works through SveBeFo - the Swedish Rock Engineering Research Foundation - to carry out technical and scientific research of common interest in the fields of rock construction and explosives technology. The research is financed jointly with government funds.

One of SveBeFo's main objectives is to serve as a forum and catalyst for enhanced collaboration between the industry and university departments. The research programme is therefore to a great extent carried out under the direction of SveBeFo at technical universities, but also within companies and by in-house researchers who specialize in rock blasting and explosives technology.

The main fields of research currently comprise:

- Subsurface planning; legislation and environmental impacts
- Risk and decision analysis in underground design and construction
- Smooth blasting technology
- Rock fragmentation
- Rock reinforcement, function and durability
- Grouting techniques
- Explosives technology

The following research projects are part of SveBeFo's ongoing programme.

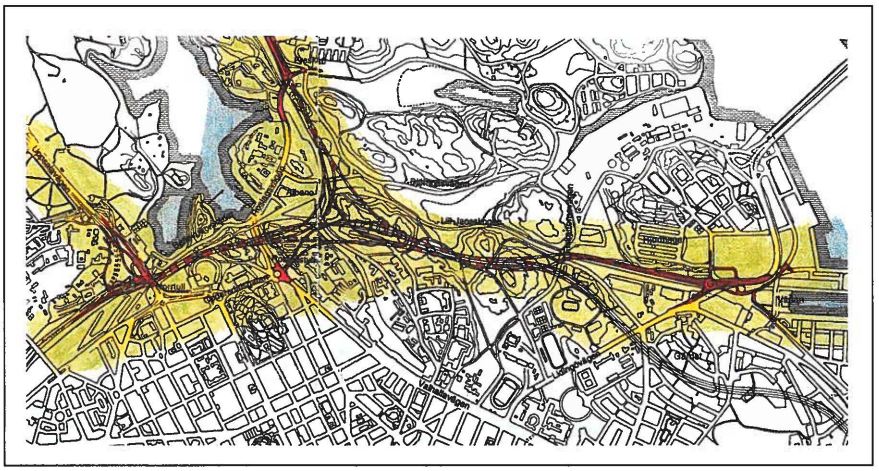


The research programme is jointly financed on a 60/40 basis by SveBeFo's principals and the Swedish government.

Subsurface planning

A growing awareness of environmental values, primarily in Sweden's large cities, has resulted in an increased interest in underground solutions. This, in turn, requires routines for the formal processing of planning matters and building permits for subsurface construction, which are partly governed by new regulations in Sweden. The experience of practising present legislation is as yet, however, relatively limited.

Two projects are currently being carried out, focusing on the co-ordination between existing acts, regulating building permits and impacts on water resources and the road and railway acts, and related to these, the environmental effects in connection with subsurface construction.



The planning of subsurface structures requires special routines, e.g. with respect to buildings directly above the construction and possible effects on the groundwater table. Above is shown the northern part of the planned road tunnel system around Stockholm.

Rock excavation - blasting and full face boring

Fracture development in smooth blasting

Steeper slopes in open cut mines mean moving less waste rock and are thus of great economic importance. They may, however, also cause stability problems, especially if the blasting is not carried out cautiously enough. Blast damage may also cause stability problems in road cuttings and quarries. These are some important motives for continued research into the fracturing process in connection with blasting.

The purpose is to determine what causes the blast damage, and develop methods to minimize it. Controlled full-scale field tests in small diameter blast holes have been carried out. Clear cut differences appear in the fracture patterns caused by different explosives, charge type and velocity of detonation. Results have been reported in two stages: "Crack lengths from explosives in small diameter boreholes", and "Crack propagation in rock from multiple hole blasting". The test series is continuing with the aim of producing recommendations for smooth blasting.



Fracture pattern on a cut rock surface after initiating blast holes simultaneously with electronic detonators. By using these detonators the contour can be made smoother than with ordinary detonators.

Full-face boring

Examples of Tunnel Boring Machine (TBM) projects carried out in hard rock in Sweden are the Saltsjö-tunnel, which is a sewage tunnel 6.5 km long under and across Stockholm; the 3.7 km long storm-water storage under central parts of the city *(see article about "The Snake")* and the 11 km long Klippen hydropower tunnel in Lapland. Because full-face boring in hard rock does not have a very long history, several research projects have been carried out in this context.

One objective of this research has been to make more exact boring rate predictions depending on the rock conditions.



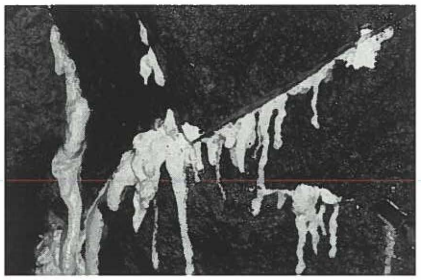
Full-face tunnel boring is today an established alternative to blasting, even for large tunnels in hard rock. The photo shows the 6.5 m diameter equipment used at the Klippen hydropower project.

Another aim is to investigate the disturbed zone during excavation vis-à-vis traditional drilling and blasting. Since the "disturbed zone" may influence both leakage and required sealing measures, as well as the stability and long-term durability of the structure, the matter is of great importance both for rock mechanics evaluations and for production work in practice.

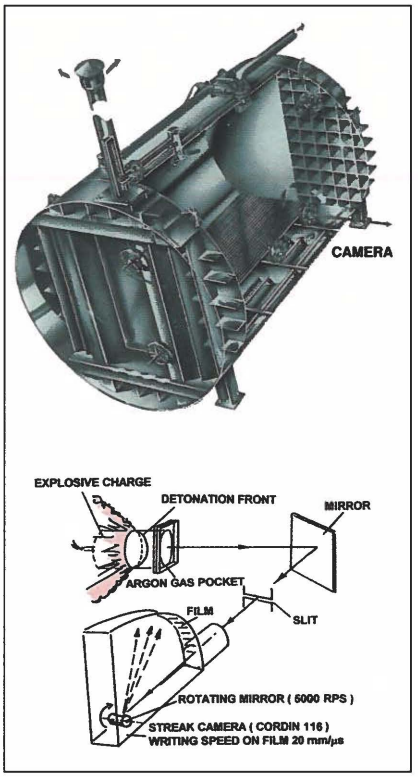
Rock reinforcement and grouting

A better understanding of the interaction between rock and support has always been an important research field for SveBeFo. Theoretical work at doctorate level regarding rock bolts and sprayed concrete (shotcrete) is being carried out, as well as investigations into the sealing effects of cement-grouting materials and "chemical compounds".

The research is carried out in close co-operation with groups within Sweden's national authorities for roads and railways who are engaged in the planning of large tunnel projects. Planning directives for the design of support and sealing measures are presently being drawn up by these authorities. In principle, they are based on functional requirements but must also include more detailed specifications in which it is important to incorporate recent research findings.

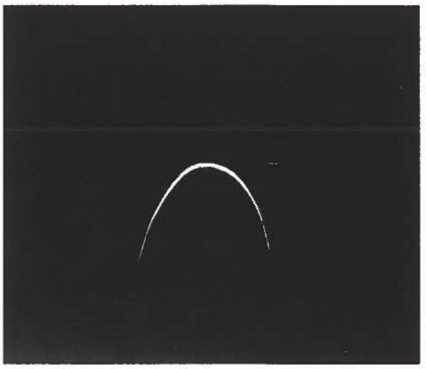


Chemical grouting compounds serve the purpose of sealing fine fractures or early stemming of leakages.



Measurement of the detonation front using high-speed photography, in this case, the curved front in a test charge is swept out over a photographic film at 20,000 m/s by a rotating mirror.

Detonation front in an explosive as registered by the high-speed camera.



Explosives technology

Mining and other construction work in rock is still primarily based on rock fragmentation by blasting. Swedish rock blasting technology is well known internationally for its high quality and efficiency. An important contribution to this is the continued research effort concerning the effects of explosives, which in turn is based on knowledge of the detonation process in various types of explosives.

SveBeFo has its own in-house research staff for explosives technology, and also possesses an advanced high-speed camera and an explosives test chamber where charges up to 5 kg can be detonated. By means of high-speed photography, the detonation process can be studied (see figure).

Examples of current research are:

- A study of the work capacity of bulk explosives.
- Equations of state and burn models for explosives.
- Causes of detonation failures in different types of explosives.
- Crack propagation in rock from multiple hole blasting.

International co-operation

SveBeFo has a wide and well established international contact net comprising many countries. Some of these are to be found within the International Tunnelling Association (ITA), the Society of Rock Mechanics (ISRM) and the European Standardization Committee (CEN).

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Ph.: +46 8 692 22 80

SveBeFo

SWEDISH ROCK ENGINEERING RESEARCH

SveBeFo is promoting and performing research and development in the field of rock engineering, including rock blasting and explosives technology, with application to construction in rock, above and under ground. The research is conducted according to a research programme outlined by SveBeFo´s principals and performed by external research resources at universities as well as in-house staff, specialized in the field of detonics and blasting technology.

Research results are transferred to the industry through direct project involvement, by reports, seminars and conferences. Thus, providing research results in the international forefront as well as high standing competence as a resource for the rock engineering industry are the main objectives of SveBeFo.

SveBeFo´s research programme for 1993-96 is financed by the industry (60%) and the government (40%) and comprises about 25 projects and 32 MSEK over three years.

BK

Swedish Rock Construction Committee

BK BergsprängningsKommittén, the Swedish Rock Construction Committee, is a non-profit association of enterprises working with design, construction and operation of mines and other installations in rock or with production of machines and other equipment for the rock engineering industry.

The main objective of BK is to contribute to the exchange of experiences between principals, thereby promoting research and development in our area. BK also advocates the interests of the principals in information activities directed towards authorities, organizations, the public and media.

BK´s activities are reported to the members at an annual meeting normally attended by over 500 persons. A number of technical papers are also presented, covering interesting works, technical novelties, market development etc. Examples of external information activities are seminars focusing on the use of underground space in modern infrastructure.

Together, the more than 70 members of BK and SveBeFo comprise public and private construction managers, contractors, equipment suppliers, mining companies, consulting firms and institutions, organizations and research foundations representing a major part of Swedish industry and trade.

PRINCIPALS of SveBeFo

The Swedish Construction Federation's Rock Research Group

Skanska AB	S-182 25 DANDERYD
NCC AB	S-171 80 SOLNA
Siab AB	S-115 86 STOCKHOLM
PEAB Entreprenad Väst AB	S-401 80 GÖTEBORG
WP-System AB/Midroc	Box 5785, S-114 87 STOCKHOLM
BESAB	Tagenev. 7, S-422 59 HISINGS BACKA
Stabilator AB	S-182 25 DANDERYD

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Rock Team AB	Box 23030, S-114 35 STOCKHOLM
SCC Bygg & Anläggning AB	Box 4205, S-102 65 STOCKHOLM
Tyréns Infrakonsult AB	S-172 96 SUNDBYBERG
VBB	Box 34044, S-100 26 STOCHOLM
Vattenfall Hydropower AB	Box 533, S-162 16 VÄLLINGBY

Manufacturerers

Atlas Copco	S-105 23 STOCKHOLM
Nitro Nobel AB/Dyno	Gyttorp, S-713 82 NORA
LKAB/Kimit AB	S-981 86 KIRUNA

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Sydkraft AB	S-205 09 MALMÖ
Swedish Nuclear Fuel and Waste Management Co	Box 5864, S-102 40 STOCKHOLM
Swedish Sand, Gravel and Crushed Stone Association	Box 14104, S-161 14 BROMMA

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Stockholm Konsult	Box 8318, S-104 20 STOCKHOLM
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ITASCA Geomekanik AB	Stenbocksgatan 1, S-114 30 STOCKHOLM
AB Jacobson & Widmark	S-181 83 LIDINGÖ
KM Kjessler & Mannerstråle AB	Box 7124, S-171 07 SOLNA
MRM Konsult AB	Box 63, S-951 21 LULEÅ
Nitro Consult AB	Box 32058, S-126 11 STOCKHOLM
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Rock Team AB	Box 23030, S-104 35 STOCKHOLM
SCC Bygg och Anläggning AB	Box 4205, S-102 65 STOCKHOLM
Sydkraft Konsult AB	S-205 09 MALMÖ
Tyréns Infrakonsult AB	S-172 96 SUNDBYBERG
Vattenfall Hydropower AB	Box 800, S-771 28 LUDVIKA
VBB Anläggning AB	Box 34044, S-100 26 STOCKHOLM
Håkan Westerlund AB	Box 70, 191 21 SOLLENTUNA

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PEAB Entreprenad Väst AB	S-401 80 GÖTEBORG
Entreprenad ABV E&G Jönsson	Box 21051, S-200 21 MALMÖ
JM Byggnads AB	Box 27319, S-102 54 STOCKHOLM
NCC Anläggning	S-171 80 SOLNA
Siab AB	S-115 86 STOCKHOLM
Siab AB	Box 39, S-971 28 LULEÅ
Skanska Teknik AB	S-182 25 DANDERYD
Stabilator AB	S-182 25 DANDERYD
WP-System AB	Box 339, S-851 05 SUNDSVALL

(cont.)

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Cementa AB	Box 102, S-620 30 SLITE
Ernström Mineral AB	Björkaverken, S-710 23 GLANSHAMMAR
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LKAB	S-983 81 MALMBERGET
Nordkalk Storugns AB	S-620 34 LÄRBRO
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Allmex AB	Pl 8902, S-653 46 KARLSTAD
Atlas Copco MCT Sverige AB	S-105 23 STOCKHOLM
Boart Longyear AB	Exportg. 33, S-422 46 HISINGS BACKA
Cavotec AB	Box 2024, S-128 21 SKARPNÄCK
De Neef Scandinavia AB	Långvallsg. 15, S-424 57 ANGERED
Dyno Nitrogen AB	Box 56, S-840 10 LJUNGAVERK
G-Drill AB	Hornsg. 79, S-118 49 STOCKHOLM
GIA Industri AB	Box 59, S-772 01 GRÄNGESBERG
Hydro Supra AB, Hydro Kemi	Box 516, S-261 24 LANDSKRONA
Ilmeg International AB	Sjösa, S-611 90 NYKÖPING
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Kimit AB	S-981 86 KIRUNA
Nitro Nobel AB	Gyttorp, S-713 82 NORA
Svets & Maskin Rep. AB	Box 2007, S-981 02 KIRUNA
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