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Avancerad borrutrustning för KBS-3V deponeringshål

"Pre-study of down-reaming equipment"

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Introduction

The Swedish Nuclear Fuel and Waste Management Company, SKB, is preparing for the construction of a final repository for spent nuclear fuel. The deposition method is based on KBS-3V, implying deposition of spent nuclear fuel encapsulated in copper canisters. The canisters are inserted in vertical holes in drifts in crystalline bed rock on a depth of about 500 m. SKB has previously tested and evaluated several methods for the excavation of vertical deposition holes. The repository will be planned for 6 000 deposition holes.

Each deposition hole has the diameter of 1.75 m and a preliminary depth of 8.2 m. Robust equipment and working procedures are to be developed and tested to prove the feasibility of the chosen technology.

SKB has asked Sandvik Mining and Construction Sverige AB to make a pre-study design on equipment for "down-reaming" to be used for the deposition holes. This pre-study should be considered as a first step to the design of a complete unit for down-reaming using standard components within TRB Raise Borers Ltd and the SANDVIK group. This pre-study will focus on standard techniques and on well-known products used in the raise boring industry for several years. The report investigates the possibilities to build a complete unit for down-reaming with the use of such standard components.

The purpose of this pre-study is to investigate if boring and reaming equipment based on Sandvik standard components can produce deposition holes that meet the SKB requirements.

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Prerequisite for the pre-study

Arrangement of deposition drift and deposition holes

The planned arrangement of the deposition drifts with holes for canisters can be seen in figure 2-1. The length of the deposition drift will be up to 300 m and the distance between deposition drifts will be up to 40 m.

Figure 2-1 shows a centred position of the deposition hole in the drift. However, the row of holes shall be put about 30 cm aside from the centre. The reason is that the deposition machine shall leave a suitable passage for personnel on one side, when it is placed over the hole. The distance between deposition holes will be about 6 m but is dependent on site conditions.

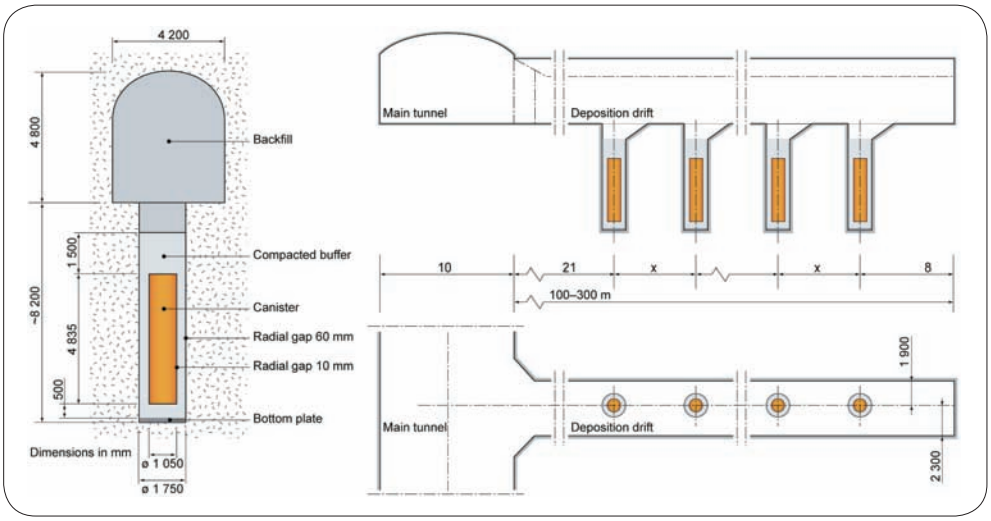

Figure 2-1. Geometrical sketch of the deposition drift and the deposition hole. Diameter and depth of the deposition hole

General

The diameter and depths of the deposition hole is mainly determined by the dimension of the copper canister with spent fuel and the dimension of the buffer material as shown below but also on a number of conditions of importance for the long term safety of the repository.

The canister have the following main data:

- Length: 4 835 mm
- Outer diameter: 1 050 mm
- Weight – BWR-canister 24.6 tons
- Weight – PWR-canister 27.6 tons

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Based on long term safety studies and requirements for installation of buffer and canister the diameter of the deposition holes should be 1 750 ± 5 mm and the depth of the deposition hole should be about 8 200 + 300/-0 mm.

The deposition hole would be in the range of 1 745–1 755 mm. It is assumed that the gap is wide enough, about 60 mm if the buffer is absolutely vertical, so that a temporary sealing by plastic sheets can be put down into the hole to hamper water inflow into the bentonite blocks during the deposition work. On the other hand the gap should be less than a certain value so that the buffer density would be > 1 900 kg/m^3 after swelling. In case the canister and buffer is not centred it might be assumed that the swelling pressure and density after saturation is evened out.

Stray materials

There will be strict restriction on stray materials in the deposition hole and the general strive is cleanliness. In case of oil spillage etc, the deposition hole could of course be cleaned before deposition, but this should be an exceptional situation. Therefore the equipment should be designed to prevent spillage of oil and other substances.

Robustness

The work should be conducted in strict observance of all statutory and regulatory requirements and such those vital principles in ongoing activities and the design of new facilities are effective in safety, environmental awareness, quality and costs. Robustness is defined as repeated good performance to fulfil the geometrical and other requirements without destroying hole positions.

Energy efficiency and low consumption of wear parts

The preliminary functional requirements of energy efficiency and low consumption of wear parts are important from a sustainability point of view and should be captured as cost factors.

Productivity

The dimensioning capacity of excavating deposition holes corresponds to the dimensioning rate of deposition, one canister deposition per day. In order to meet this production rate it is assumed that the work will be made with two shifts per day.

Rock conditions

It is assumed that the rock conditions are similar to conditions at the SKB potential repository sites. The rock conditions for Äspö HRL are given in the table 2-1. The rock conditions must be updated based on data from the selected site before start of detailed design of the equipment.

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Table 2-1: Rock conditions at different SKB sites

Parameter	Äspö HRL	Laxemar	Forsmark
	Value	*Value*	*Value*
Uniaxial compressive strength	214 MPa	167–280 MPa	214–373 MPa
Tensile strength	14.8 MPa	13–19 MPa	11.5–14.8 MPa
Youngs modulus	73 GPa	71–80 GPa	74–82 GPa
Poissons ratio	0.27	0.25–0.33	0.23–0.30
Cohesion	31 MPa	24–33 MPa	24–33 MPa
Friction angle	49 degrees	53–60 degrees	56–60 degrees
Major horizontal stress	28 MPa	30 MPa	41 MPa
Minor horizontal stress	14 MPa	14 MPa	23 Mpa

Specific requirements for the down reaming machine

The developed equipment shall comply with the functional requirements that can be summarized in short:

- The down reaming machine shall be self-propelled using a diesel engine but the drilling shall be done using electrical power.
- The adding and removal of drill rods shall not need action from the operator.
- All parameters from drilling the pilot hole and reaming operations shall be recorded.
- The removal of cuttings is assumed to be done using water and not a vacuum system.
- The deposition hole shall fulfil the specifications on geometry and surface requirement.
- Emission of oil and grease and other stray materials in the deposition hole shall be kept to a minimum.
- The equipment has to be robust in the sense that the finished deposition holes fulfil the specifications and that breakdown time and need for maintenance is minimised.
- The excavation shall be energy-efficient and with reasonable usage of wear parts.
- The productivity has to be high. The time for excavation of one deposition hole including set-up, drilling of the pilot hole, reaming to full diameter, confirmation of geometry etc. and demobilization should be such that two machines are enough to excavate the rate one hole per two-shift day.

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Table 2-2: Summary of data and requirements for the down reaming equipment

Component	Parameter	Value	Tolerance
Deposition drift	Length	300 m	±100 m
	Height	4,8 m	± 0,1 m (The tolerances will be decided later)
	Width	4,2 m	+ 0,3 m (The tolerances will be decided later)
	Gradient		1:100
Deposition hole	c/c distance	6 m	+ 1,5 m (dependent on rock conditions and selected distance between deposition drifts)
	Diameter	1 750 mm	± 5 mm (The tolerances will be decided later)
	Depths	8 200 mm	+ 0,3 m (Final depths will be depending on final design of canister/buffer support)
	Starting point		25 mm parallel with deposition drift
	Starting point		25 mm perpendicular to deposition drift
	Straightness		A measured centre point at any depth shall not divert more than 5 mm from a theoretical line between the starting point and ending point.
	Maximum deviation from centre line at the bottom of the hole		≤ 5 mm
	Surface roughness		± 5 mm
	Penetration rate during reaming	1 m per hour	
	Time for adding or removing drill pipes	5 minutes	
	Drilling of a pilot hole	Drilling of pilot hole 1–1.5 m/h, total time about 8 hours	
	Capacity	Completion of one deposition hole per two-shift day is the goal	

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The top part of the deposition hole will have a chamfering on one side of the top. The reason for the slot is to save height of the deposition drift. The radiation shielding tube with the canister can now be tilted 90° degrees, from horizontal to vertical position without moving the deposition machine. The radiation shielding tube is now rotated at its centre point and the slot is about 1.6 m in length at the drift floor and has a depth of about 1.25 m. Figure 2-3 shows the principle for rotation of the shielded tube and emplacement of the canister in the deposition hole.

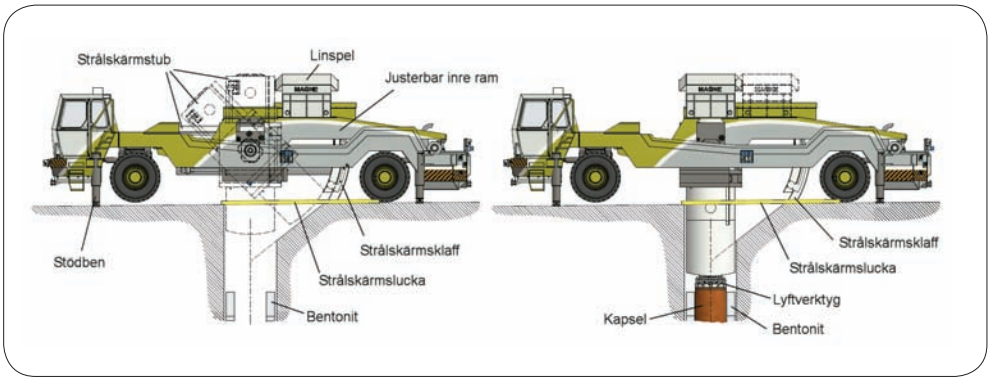

Figure 2-3. Principal for the rotation of the shielded tube and emplacement of the canister.

Excavation equipment for down reaming

Principle for down reaming

Down reaming begins by drilling a conventional pilot hole, diameter 300-400 mm, in the same way as for doing raise boring. However, during raise boring the reaming head is pulled from below up to the floor level where the raise bore machine is standing. In raise boring the cuttings simply falls down at the lower lever from which the reaming started. In down reaming the reaming head is pushed downwards and the pilot hole mainly serves as a guide for the reamer head. During reaming a blind hole as the deposition hole, the cuttings must be removed from the underside of the reamer head by using water.

Cratering is the term used to describe the crushing action in the rock directly beneath the contact area of the cutter edge. This action is referred to as triaxial crushing and occurs when the load is transmitted through the contact area of the cutter edge overcomes the strength of the rock.

As the penetration of the cutter edge into the rock increases due to increases in cutter edge load, the compressed powder transmits imposed stresses into the adjacent rock mass. Some of these cracks eventually find their way back to the free surface of the rock some distance from the sides off the cutter edge. As the penetration of the cutter edge into the rock continues to increase, the cracks expand and eventually chips from around the cutter edge are ejected explosively.

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Down reaming machine

The down reaming machine is based on a standard raise boring machine but some part must be modified as the reamer head is pushed instead of pulled during the reaming operation. The handling of the cuttings also needs additional equipment.

The main parts of the down reaming machine can be seen in figure 3.2. The machine is self-propelled and consists of a carrier (bottom platform) moving on crawler tracks. The carrier bears three main parts, one central main frame which holds and surrounds the drilling machinery, one part to the right in the figure with a cabinet with the power supply unit and the manipulator for the drill rods, rod handler, and one on the left side with space for the operator's cabin and the reamer head.

The carrier has four hydraulic jacks, which are lowered to the floor during the drilling and reaming operation. The top of the main frame has two hydraulic jacks, which are pushed up against the ceiling, thereby providing a stable position for the machine.

To the right, between the main frame and the power cabinet, the storage with drill rods can be seen. The manipulator holds a rod, shown close to the main frame on the picture. To the left of the main frame the reamer is seen.

The reamer, which can be put into operation in the main frame when the pilot hole has been drilled.

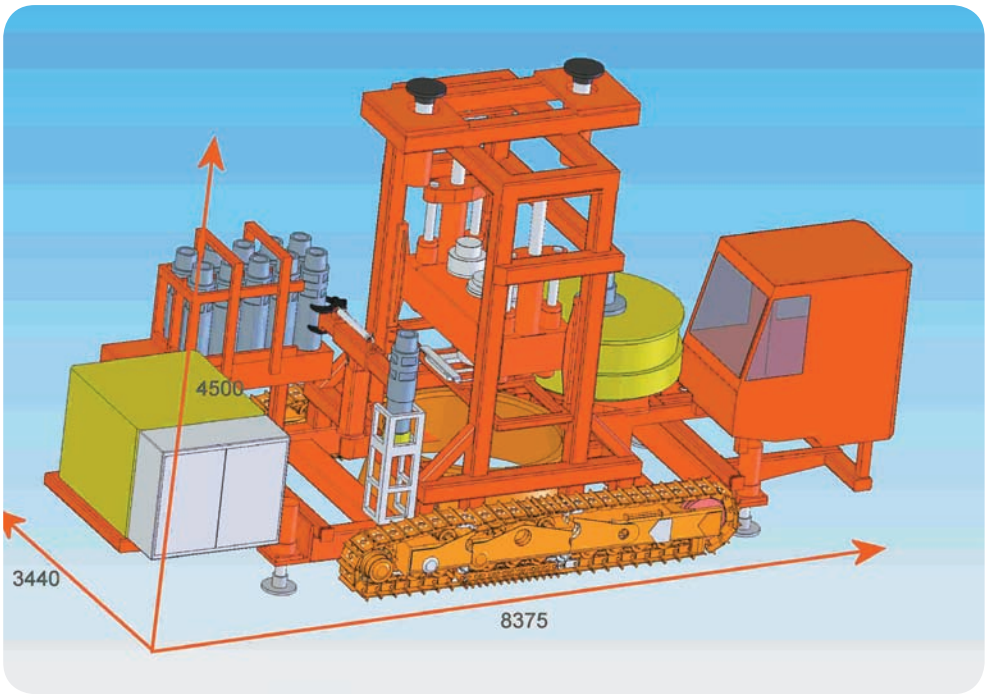

Figure 3-2. Down reaming machine.

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The main components such as gearbox, thrust cylinders, rod handler and parts of the hydraulic and electrical system will use the same equipment as TRB:s standard raise boring machine Rhino 400.

This will ensure a good performance and reliability. Many parts in this design have been taken directly from other products within the SANDVIK group such as:

- Crawler Tracks
- Diesel engine
- Parts of the operator's panel
- Cutters and saddles
- Pilot Bits

This is important for future supply of spare parts and technical information.

Structure/Frame

The total weight of the complete unit with reamer is estimated to 32 500 kg. A supporting system with adjustable beams and hydraulic cylinders will keep the machine in place during drilling as shown in figure 3-3. The main components listed

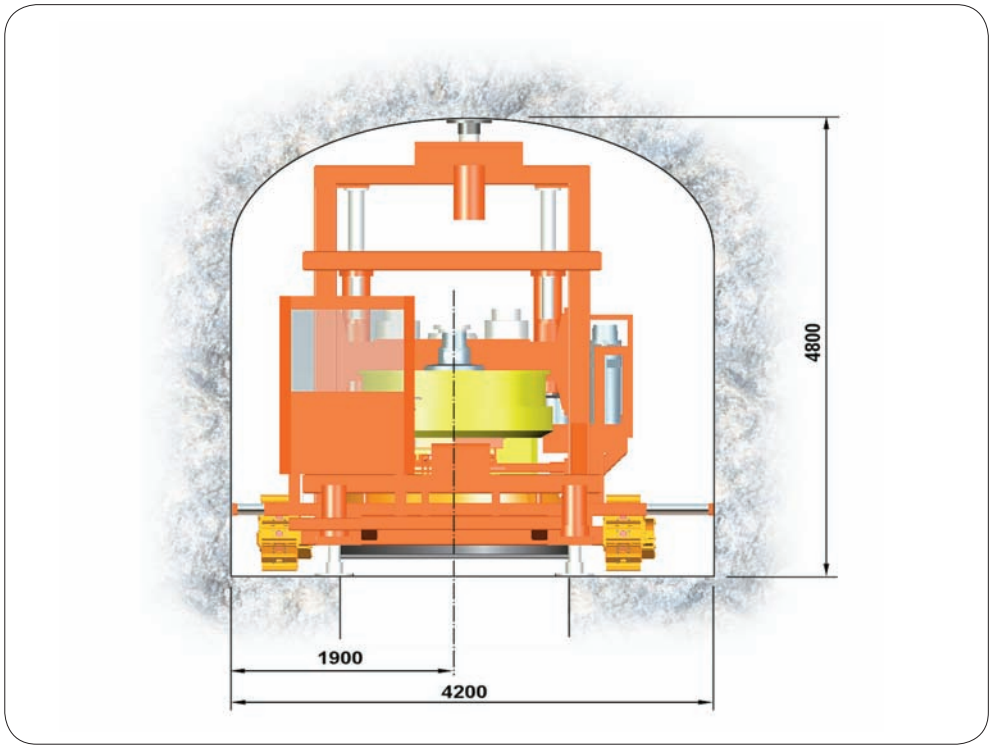

Figure 3-3. Supporting system with adjustable beams and hydraulic cylinders. The machine is levelled in the illustration and the collar is still not lowered to the floor.

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below supplies the rotational and thrust forces necessary for rotating the pilot bit and the reamer as well as for raising and lowering the drill string. The components of this system are:

- Main frame
- Columns
- Head frame (Top base plate, keeping the columns together)
- Hydraulic cylinders
- Drive train assembly “gearbox”

The columns provide torque transfer from the drive train assembly into the main frame. The hydraulic cylinders supply the thrust required for raising and lowering the drill string. The cylinders supply the thrust necessary for both pilot hole drilling and for the down reaming.

Rod handler

The rod handler is used for placing and removing drill rods during pilot drilling as well as reaming. The hydraulic rod handler arm lifts and moves the rod into position under the gearbox. It’s operated from the operator’s cabin and can place the rods safely and with precision in the storage area when they are not drilling. Figure 3-5 and 3-6 show the handling of the rod with the drill bit for the pilot hole but all handling of the rods are identical.

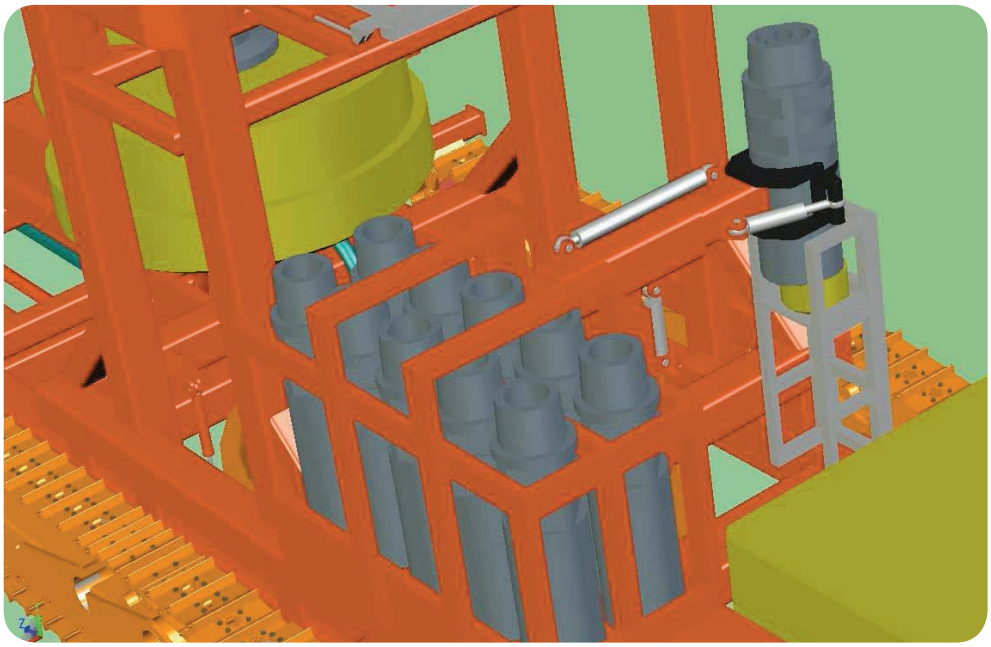

Figure 3-5. Rod handler grabbing rod with pilot bit.

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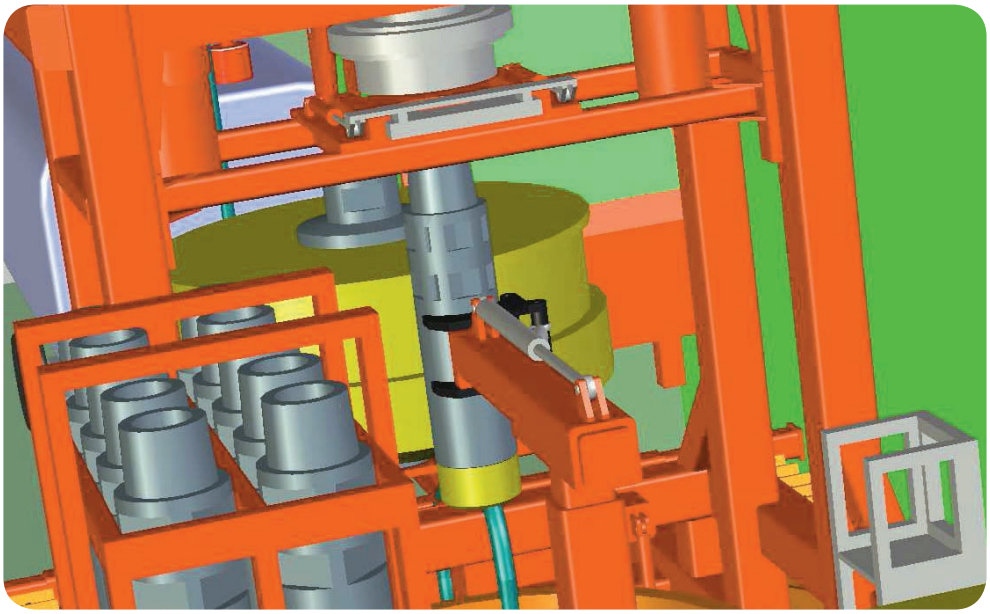

Figure 3-6. Drill rod with the pilot bit in position under the gearbox.

Collar for collecting water and cuttings

A collar is placed in the centre of the machine and serves as a tank for water and cuttings. The collar has a sealing ring that can be pressed down on the drift floor to make a tight water tank. During pilot drilling the collar will be a part of the storage for cuttings and a suction hose from the vacuum pump will be placed inside the collar. The collar is pushed against the floor to prevent water from leaking out in the drift.

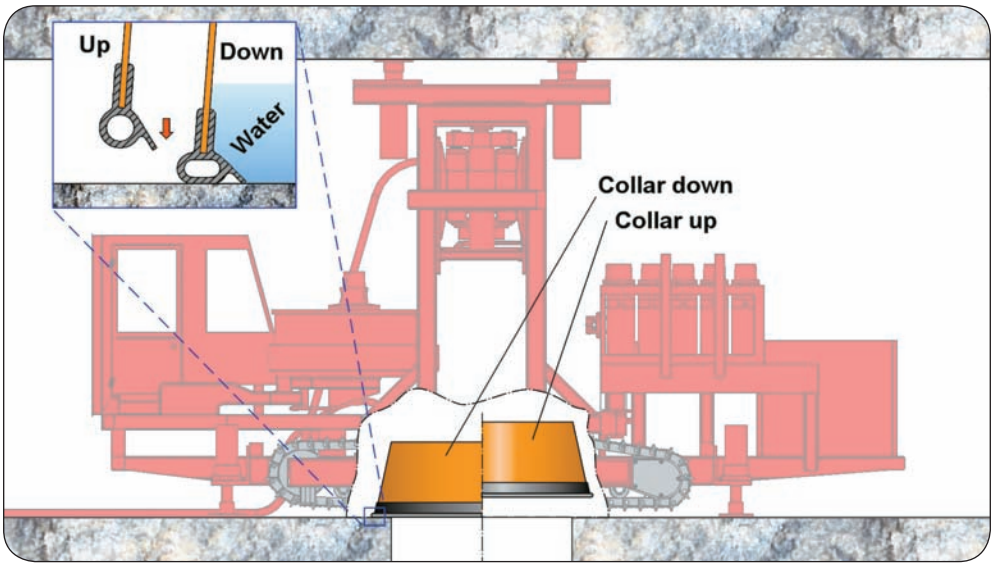

Figure 3-8. Hydraulic collar in upper and lower position for sealing.

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Electrical

The main data for the electrical system are as follows:

- Power Consumption 110 kW (95 A) 1 000 V
- Cable reel 140 m but can be extended to 300 m if needed
- Cable cross section 4 x 50 mm^2 diameter 42 mm
- Lubrication motor in gear box 2.2 kW

The levelling system will also monitor and adjust the machine so it will be horizontal at the set-up and under the pilot/reaming operation.

Tools

Pilot bit design

The Sandvik pilot bit programme covers all the standard pilot hole diameters used in the raise boring industry. It ranges from Ø 229 mm (9”) to 381 mm (15”) with the option to tailor design / manufacture other diameters if required. There are a number of different button design / carbide grade options to choose from in order to use the optimum bit for the project. Figure 4-1 shows some of the pilot bits in the Sandvik programme.

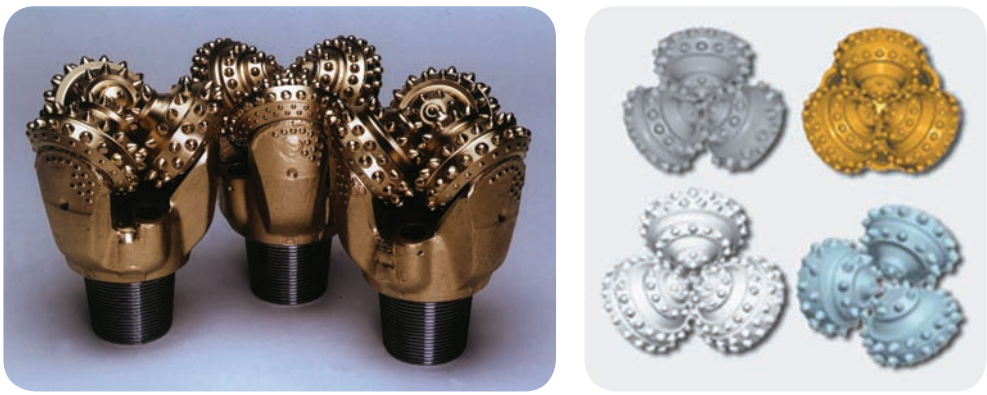

Figure 4-1. Sandvik standard pilot bits.

One special feature is an asymmetric gauge button design for improved gauge service life. Its special design allows a larger area of the button = more cemented carbide in contact with the rock to improve the wear resistance.

A standard 15” or 17” drill bit will be used to drill the pilot hole. The offset on a pilot drilled hole of 8 meters will be expected to be more or less zero. The average penetration rate with this type of bit is approx. 1.0 m/hr.

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Drill rods or drill string

The drill string is the mechanical connection between the cutting components and the down boring machine. The drill string is composed of several steel components of cylindrical shape with hollow centres. The hollow centres are for the bailing fluid (water) to be routed from the machine to the pilot bit for cooling and removal of the cuttings during pilot hole drilling and for suction of cuttings mixed with water during down reaming. In this case, where the holes are very short, the rods will be of a "stabilizer" type throughout the total length of the hole. The rod size would be Ø $12^{7/8}$ inch depending on which type of reamer that will be used. The maximum force that will be applied on the rods will be 240 tones (20 tones/cutter). The final design of the reamer will also affect the rod size and the rest of the machine.

Maximum load on drill string (pushing free standing rod string for raise boring):
$12^{7/8}$ inch rod 250 tone load max rod length 9.43 m

Example of drill rod.

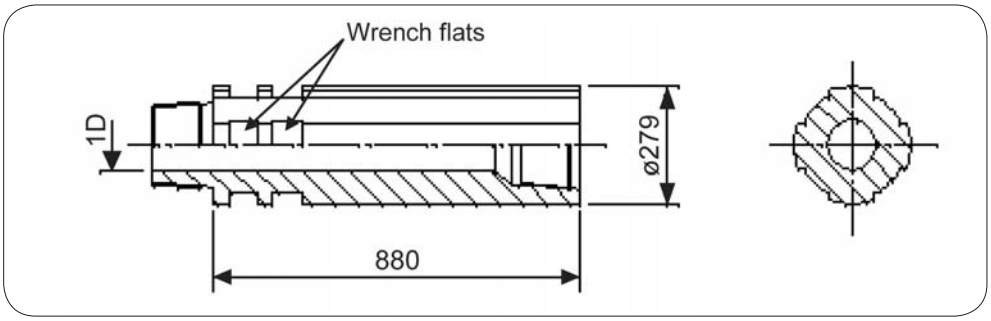

Figure 4-3. The stabilizer with complete ribs.

The rib stabilizer is designed with extreme stiffness and minimal clearance between its guiding ribs and the wall of the pilot hole. This design helps minimize directional deviation during pilot hole drilling without limiting upward flow of bailing fluid and cuttings.

Factors to be observed for design of the flushing system:

- Volume of flushing water
- Speed of flushing water

Accuracy of pilot hole:

- The major factors, which are affecting the accuracy of the pilot hole:
- Set-up and alignment of drilling machine
- Drilling speed
- Construction of gear box and machine frame guidance
- Condition of pilot bit and stabilizers

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Reaming head

Based on SKB's boring parameter request, the SMC project group can offer a possible reaming head system as follows:

Main features for the down reaming system:

- "Bull nose" design to follow a predrilled pilot hole and leave a pot with max depth of 300 mm.
- Ø 1 750 ± 5 mm.
- Cutting removal through a water suction system.
- Wall straightness with maximum 5 mm curvature.
- Wall surface finish with maximum 5 mm irregularities.
- Operating rate of penetration 1 m/hr.

The pre-study has resulted in four different reaming head design options:

- Design option 1) Standard Sandvik reaming head design with "bull nose"
- Design option 2) V-shaped Sandvik reaming head design with "bull nose"
- Design option 3) Standard Sandvik reaming head design without "bull nose"
- Design option 4) Special Sandvik reaming head design without "bull nose"

Design option 1: Standard Sandvik reaming head

This design is proven and used on basically all Sandvik reaming heads around the world with good and reliable performance. A design with a "bull nose" will reduce the risk of deviation through the support of the "bull nose" in the predrilled pilot hole. The standard reaming heads according to design option 1 are shown in Figure 4-6.

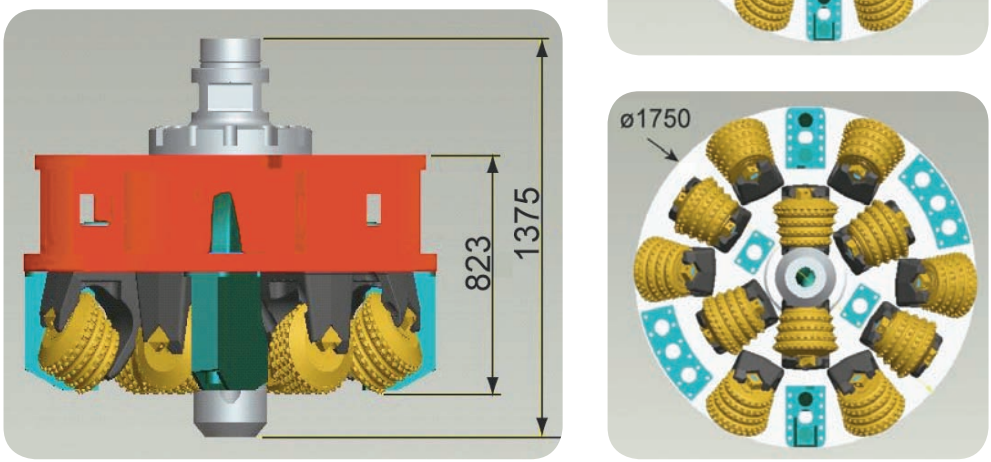

Figure 4-6. Standard Sandvik reaming head with bull nose and with four or six gauge cutters.

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The design with standard raise boring cutters will cut a relatively flat bottom profile with a chamfer towards the raise wall and leave a “centre pot” at the bottom of the deposition hole. Figure 4-7 is an illustration of the bottom profile using design option 1.

The design for “down boring” will have a suction pipeline system added including some inlets spread out between the cutters. The inlets should be located near the bottom of the hole and also through the bull nose for efficient suction and cutting removal.

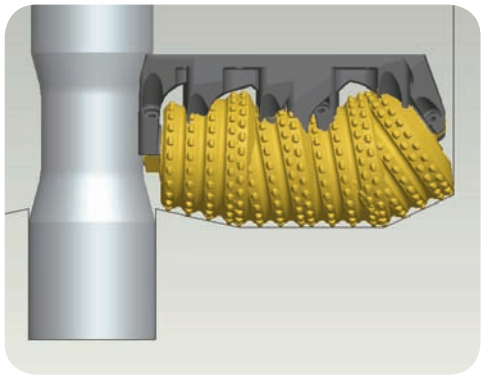

Figure 4-7. Bottom profile using design option 1.

Design option 2: V-shaped Sandvik reaming head design

The advantage with the V-shaped design is to concentrate the suction through one (1) inlet in the centre of the bull nose / stem only and up through the drill string which should improve the efficiency of the cutting removal. A V-shaped design with a “bull nose” will reduce the risk of deviation through the support of the “bull nose” in the predrilled pilot hole but will generate a V-shaped profile and also leave a “centre pot” at the bottom of the deposition hole.

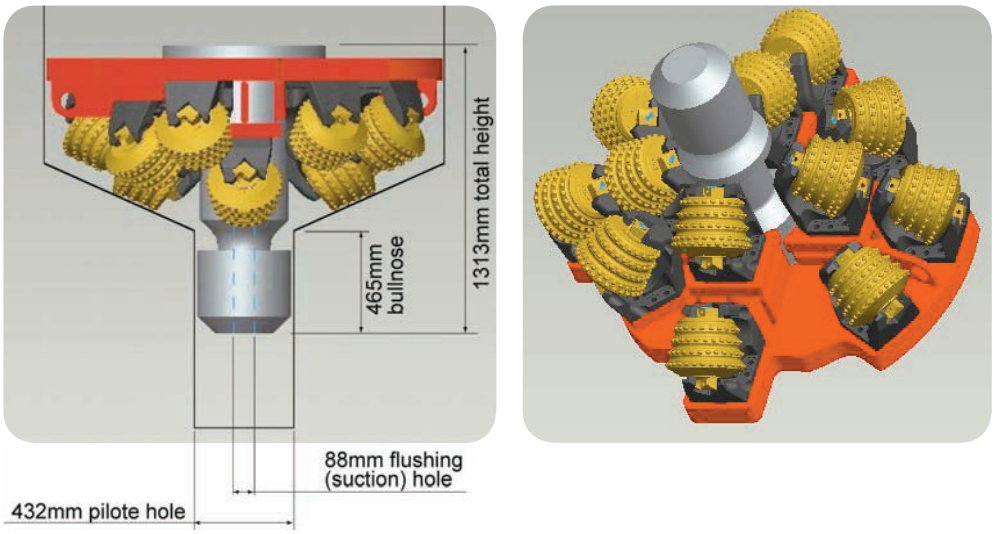

Figure 4-8. V-shaped reaming head with bull nose six gauge cutters.

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Design option 3: Standard Sandvik reaming head design without "bull nose"

This design without a bull nose, figure 4-10, is proven on Sandvik box hole borer and uses the same cutters as design option 1 and a pilot bit to cut the centre of the hole.

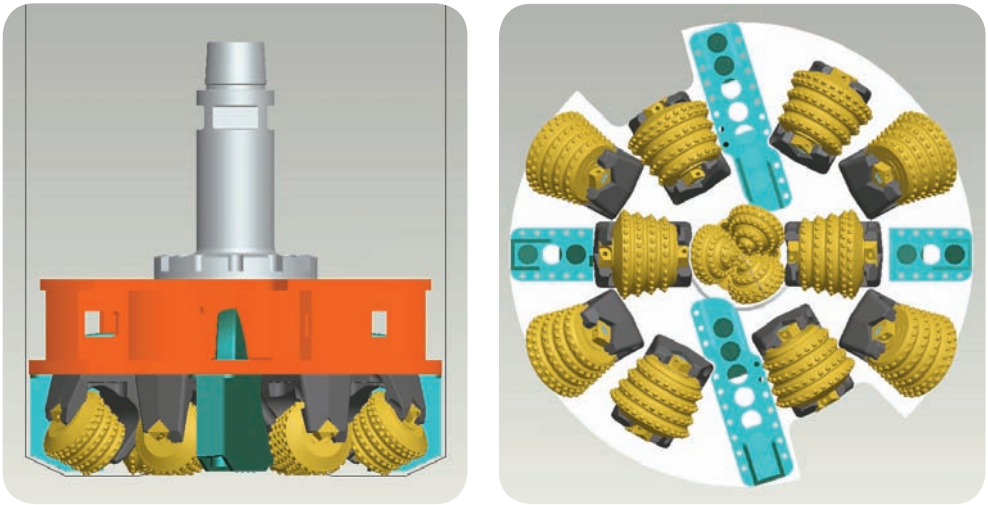

Figure 4-10. Standard reaming head without bull nose and with four gauge cutters (it is also possible to have six gauge cutters for this type of reaming head.

The disadvantage is the collaring process with limited support for the Ø 1,8 m reaming head and the increased risk of deviation at the final depth as there is no "bull nose" support. The suction from the centre is also causing some concern as the size of the pilot bit nozzles is limited which will affect the efficiency of the suction in the centre. The bottom profile for such a reamer is shown in figure 4-11.

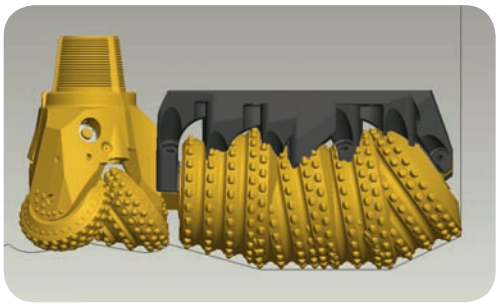

Figure 4-11. Bottom profile using design option 3.

Design option 4: Special Sandvik reaming head design without "bull nose"

This design, shown in figure 4.12, uses a mix of standard raise boring cutters and roller bit cone / leg assemblies and this design is unproven. The advantage with this design is that it will cut a relatively flat bottom profile and without a "centre pot" at the bottom of the deposition hole. The disadvantage is the collaring process with

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limited support for the Ø1,8 m reaming head and the increased risk of deviation. The advantage with this design is that it will cut a relatively flat bottom profile and without a “centre pot” at the bottom of the deposition hole.

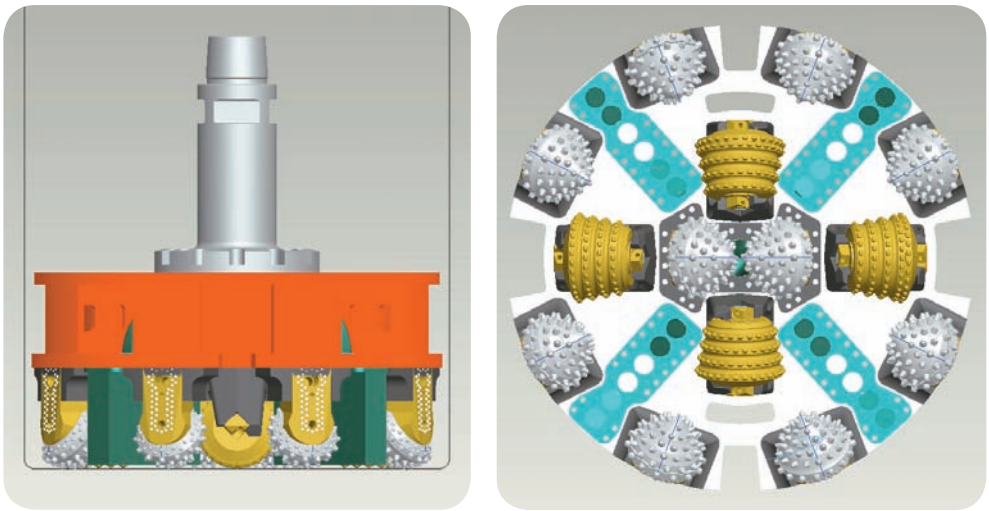

Figure 4-12. Special reaming head without bull nose and a mix with cutters and roller bit cones.

Furthermore, the performance of drilling Ø1,8 m holes using a combination of raise boring cutters and roller bit cone / leg assemblies is unknown. The skidding in hard rock increases the wear of the cemented carbide buttons and the torque requirement to turn the Ø1,8 m reaming head. The bottom profile using design option 4 is shown in figure 4-13.

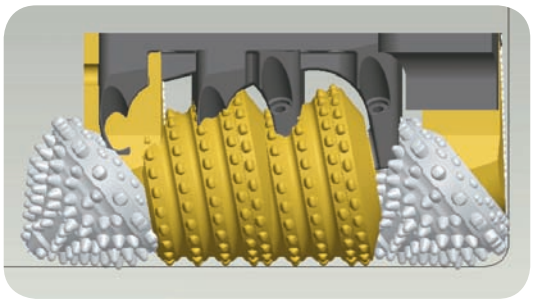

Figure 4-13. Bottom profile using design option 4.

Cutter design

The Sandvik raise boring cutters are used around the world in many different projects/applications. The key performance features are durability and productivity. The durability comes with a tailor designed bearing system to cope with high loads together with a heavy duty seal system to protect the bearing system from any cuttings penetrating in to the system.

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Productivity comes with the optimum button shape in combination with optimum spacing between the button rows. There are a number of different standard button row spacing options to choose from together with buttons in different carbide grades.

It is also possible to tailor make a new design/ carbide grade to optimize the performance in the SKB project.

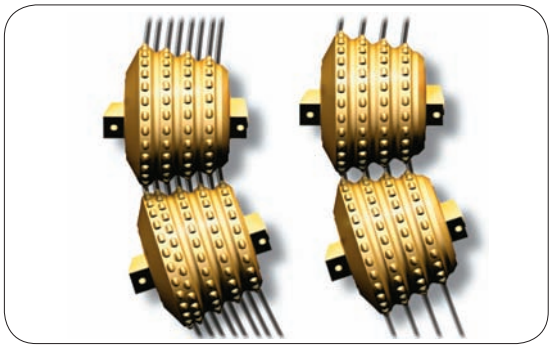

Figure 4-14. Options with different button row spacing using standard cutters, 25.5 mm or 51 mm

Material transport

It is assumed that the removal of the cuttings will be done with water and not vacuum in spite of the fact that vacuum was used both by Posiva in Finland and SKB at Äpsö HRL. The main reason is that use of water would be more energy efficient and erosion in the pipe system would be less severe.

Conclusion

The pre-study done by SANDVIK Mining & Construction and TRB Raise Borers Ltd shows that a down reamer machine for SKB:s conditions can be designed and constructed. SANDVIK Mining & Construction and TRB Raise Borers Ltd also have the resources and knowledge to design and construct a down reaming unit with parts and technologies known within these two companies based on a standard raise boring machine.

However, some areas must be investigated in more detail before starting a basic/ detailed design of the down reaming machine. These areas are mainly:

- The capacity of the handling system for the cuttings will determine the productivity of the reaming. It is therefore recommended that studies should be performed in order to get a better understanding of the design parameters and design requirements for the handling system for the cuttings.
- The design of the reamer head is also very important. In the pre-study four different design options are presented.
- The requirements for the deposition hole, surface roughness, requirement and acceptance criteria for the bottom of the hole.
- Required production capacity for the pilot drilling and the down reaming operation.