

Äspö Hard Rock Laboratory

Demonstration deposition machine for canisters

Description and experience from design and test operation

W Mützel, E Huth, R Brausam, J Keller

Babcock Noell Nuclear

S Pettersson, R Bäck

Svensk Kärnbränslehantering AB

H Jendenius

Sweco

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Svensk Kärnbränslehantering AB

Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel +46 8 459 84 00
Fax +46 8 661 57 19



**Äspö Hard Rock
Laboratory**

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Author	Date
Mützel, Huth, Keller, Brausam, Pettersson, Bäck, Jendenius	
Checked by	Date
Stig Pettersson	01-10-11
Approved	Date
Christer Svemar	01-10-25

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Sammanfattning

SKB initierade detta projekt för att kunna demonstrera hela systemet med inkapsling av använt kärnbränsle i kopparkapslar, transport av kapslar till djupförvaret och deponering i full skala under realistiska förhållanden. Inkapslingen av använt kärnbränsle studeras och demonstreras i SKB:s kapsellaboratorium i Oskarshamn sedan 1998. SKB anser det också viktigt att utveckla och demonstrera metod och utrustning för hantering i en deponeringstunnel och deponeringshålet.

Denna rapport redovisar erfarenheter från konstruktion och tester av den deponeringsmaskin som byggts av Babcock Noell Nuclear i Tyskland. Deponeringsmaskinen är installerad och testad i en separat demonstrationstunnel på 420 meter nivå i SKB:s berglaboratorium på Äspö.

I december 1996 erhöll Noell uppdraget att utföra en förstudie av en deponeringsmaskinen för utveckling av lämplig utrustning för deponeringsprocessen. Förstudien avslutades våren 1997. Under april 1997 startade nästa steg i utvecklingsarbetet med genomförandet av en preliminär konstruktion av deponeringsmaskinen. Detta arbete avslutades i maj 1998 och ritningsunderlaget och specifikationer utsattes för en ingående granskning av två oberoende företag, SGN i Frankrike och BNFL i England. Relevanta och viktiga kommentarer och synpunkter inarbetades i det efterföljande konstruktionsarbetet.

Arbetet med detaljkonstruktion och tillverkningsritningar inleddes i juli 1997. Under detta arbete måste alla krav och specifikationer samt tillverkningstekniska aspekter inarbetas. Målsättningen var att så långt som möjligt använda sig av standardkomponenter för att erhålla säker funktion i den besvärliga miljö som råder i bergrummen och för att minska risken för felfunktioner under drift. Som exempel kan nämnas att maskinens boggiarrangemang har tillämpats för liknande maskiner som konstruerats och tillverkats av Noell. Andra delar som till exempel lyftverket för kapseln måste dock specialkonstrueras med hänsyn till de speciella krav som föreligger. Kravet är att lyftverket inte får ha större diameter än kapseln eftersom det skall kunna hämta kapseln ur en transportbehållare och placera den i deponeringsmaskinens strålskyddstub.

Tillverkningen av maskinen startade i juni 1998. I början av januari 1999 hade tillverkning och montage kommit så långt att tester av den kompletta deponeringsmaskinen kunde inledas i Kockums verkstäder i Malmö. Efter genomförda och godkända verkstadstester demonterades delar av maskinen i början av juni 1999 för vidare transport till Äspö. Den slutliga hopmonteringen skedde sedan i demonstrationstunneln i Äspölaboratoriet under sommaren och hösten 1999.

Denna rapport ger en översikt av konstruktionsarbetet från den preliminära skedet till detaljkonstruktion och tillverkning. Erfarenheterna av de tester som genomförts med deponeringsmaskinen sammanfattas också i denna rapport.

Generellt är erfarenheterna mycket goda för en så unik maskin som deponeringsmaskinen utgör och med en mycket kort tid för utveckling. De erfarenheter som erhållits kommer att vara mycket värdefulla i det framtida arbetet med att utveckla det slutliga hanteringssystemet för deponering av bentonitbuffert och kapslar i ett framtida djupförvar.

Summary

The Deposition Demonstration Project was initiated in order to demonstrate the entire deposition system with encapsulation of spent fuel in copper canisters, transport of copper canisters to a repository and deposition in full-scale and under realistic conditions. The encapsulation method is being investigated in SKB's canister laboratory since 1998. SKB also considers it important to develop and demonstrate the methods and equipment for canister handling in the deposition phase in the deposition tunnel. This report presents the machine produced by Babcock Noell Nuclear and experience from the design and testing of the machine in the demonstration repository at SKB's Hard Rock Laboratory (HRL) at Äspö.

Late 1996 Babcock Noell Nuclear was awarded a contract of a feasibility study of the deposition machine in order to develop adequate equipment for the deposition process. The feasibility study was completed in the spring of 1997.

In April 1997 next phase started with a conceptual design of the deposition machine. Babcock Noell Nuclear completed the conceptual design in May 1998 and the study was subject to a peer review by two independent companies, SGN in France and BNFL in England. The relevant comments from the peer review were incorporated in the engineering and detailed design.

The detailed design started in July 1997. During the detailed design all requirements had to be implemented and the different manufacturing aspects had to be investigated. The aim was to use standard design of components as much as possible to ensure safe operation in the difficult underground environment and to reduce the risk of failures during operation. For example, the design of the drive bogies has been used for other machines designed and constructed by Babcock Noell Nuclear. However, the grapple unit had to be designed according to very special demands based on the design of the lid of the copper canister. The requirement was that the grapple unit must not exceed the outer diameter of the canister, as the grapple unit has to pass inside the shielded tube during the deposition sequence.

The manufacturing started in June 1998, the testing of the assembled machine at Kockum's workshop in Malmö started in January 1999. The machine was transported to Äspö Hard Rock Laboratory in June 1999 for final assembly and testing in the demonstration tunnel.

An overview is given of the design and design modifications of the demonstration deposition machine from conceptual design to detailed design and manufacturing. The experience of commissioning of the machine is also summarised in this report.

In general the experiences are very good for a machine that is one of its kind and developed under a tight time schedule. The experience gained will be most useful in the coming work for the development of the total system for the handling and deposition of buffer material and canisters in a future repository.

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1 Introduction

Spent fuel from the Swedish nuclear power plants will be encapsulated in copper canisters which will be disposed of in a tunnel system at about 500 m depth in the Swedish bedrock. The copper canister can hold either 12 BWR or 4 PWR fuel assemblies. The weight of the canister, including the fuel, is in the order of 25 tons and the contact dose rate in the order of 300 mSv/h. Before the deep repository for encapsulated spent fuel is commissioned, the methods and equipment for handling of the canister, as well as the buffer and backfill material must be developed and tested. One very important component in the deposition system is the canister deposition machine.

In order to demonstrate the ability of the entire deposition system SKB is accomplishing a Deposition Demonstration Project with transport, handling and deposition in full-scale and under realistic repository conditions. The canister used for the demonstration handling has the correct dimensions and weight but will not contain fuel. The Deposition Demonstration Project is one of the development projects at SKB's Hard Rock Laboratory (HRL) at Äspö just north of the town of Oskarshamn in the south-eastern part of Sweden. The demonstration tunnel at the HRL is located 420 m below sea level. A perspective view can be seen in figure 1.



Figure 1. The Äspö Hard Rock Laboratory

The principles of the deep repository gave the following main design requirements for the deposition machine:

1. The deposition method implies deposition holes drilled in the floor of the deposition tunnel.
2. The bentonite buffer material and the canister shall be handled separately, and not as an assembled package.

3. The canister shall have radiation shielding continuously during handling and transport including the deposition process into the deposition hole.
4. The weight of the canister can be up to 27 metric tons and it has a diameter of 1.05 m and a height of approximately 4.8 m.
5. The canister has to be lifted from the top only and the diameter of the grapple unit must not exceed the diameter of the canister.
6. The deposition hole has a diameter of 1.75 m and a depth of minimum 8 m below floor level.
7. The thickness of the bottom bentonite block is 0.5 m. The outer diameter of the bentonite blocks and rings is 1.65 m and the inner diameter of the rings is 1.07 m. The density of the compacted bentonite is about 2 kg/dm³.
8. The position of the deposition holes can deviate from the centre line of the deposition tunnel. The deviation is estimated to be up to ± 50 mm.
9. The deposition machine shall be rail-bound for good positioning and stability.
10. The deposition machine must have good positioning capability before lowering the canister into the stack of bentonite rings. The nominal radial clearance between the canister and the bentonite is only 10 mm.
11. The size of the deposition machine shall be minimised to give reasonable dimensions of the deposition tunnel cross section in order to limit the total tunnel volume. The total tunnel length will be in the order of 30 to 40 km so any change in the cross section dimensions will have a considerable influence on the volume to be excavated.
12. It shall be possible to use the deposition machine for emplacement of compacted bentonite blocks and rings into the deposition holes.
13. The deposition machine shall be remotely operated.
14. Repair and interventions shall be possible if a malfunction should occur.
15. It was assumed that the transfer of the canister from the transport cask to a shielded tube will be done in a reloading station at repository level. The shielded tube is adapted to suit the deposition machine.
16. It was also assumed that the transport of the shielded tube between the reloading station and the deposition machine in the deposition tunnel will be done with a big handling truck.
17. It shall be possible to license the deposition machine for operation in both Sweden and Germany.
18. The handling equipment is affected by the following environmental conditions:
 - Air temperature: $T_A =$ approximately. 5 - 15°C
 - Humidity: 100%
 - Dripping saltwater: approximately. 1 – 1.5% salt, dominated by Na-Ca-chloride

- Water temperature: $T_w =$ approximately. 12 – 17°C

The following factors were of importance for the selection of the deposition equipment:

- the ALARA principle for personnel radiation dose rates;
- safe operation, reliability and risk minimisation;
- ability to return to a safe stage in case of malfunction;
- minimisation of deposition tunnel dimensions;
- reverse canister transfer to a safe position;
- cost.

Based on the feasibility study and the conceptual design, worked out by Babcock Noell Nuclear as well, the engineering and detailed design that started in July 1997. Parts of manufacturing, which started in June 1998 were awarded to Kockums in Sweden and Voest Alpine in Austria. The mechanical assembly of the machine on the test bed at Kockums was completed in February 1999. The workshop testing was performed in the spring of 1999 and the deposition machine was transported to Äspö in the beginning of June 1999. Babcock Noell Nuclear completed the installation of the machine at the site in September 1999. The final testing and training of SKB personnel continued until the spring and on March 9, 2000 the inauguration of the demonstration area took place.

The main features of the deposition machine for the Deposition Demonstration Project, shown in figure 2, are:

- a transfer platform, used for the transfer of the shielded tube from the truck to the deposition machine in the deposition tunnel
- a remotely operated and railbound deposition machine in the deposition tunnel
- radiation shielding, extended or simulated to illustrate the design necessary later on in the future repository. It is simulated by:
 - a split shielded tube with intended size and weight with two main parts:
 - upper part with grapple unit
 - bottom part with bolted bottom plug
 - a circular shielding house, called gamma-gate, designed as full-scale model
 - an additional hoist for placing the bentonite top block (shielding plug) on top of the canister in the deposition hole
 - several additional shielding systems between the moving and fixed parts, designed as full-scale models

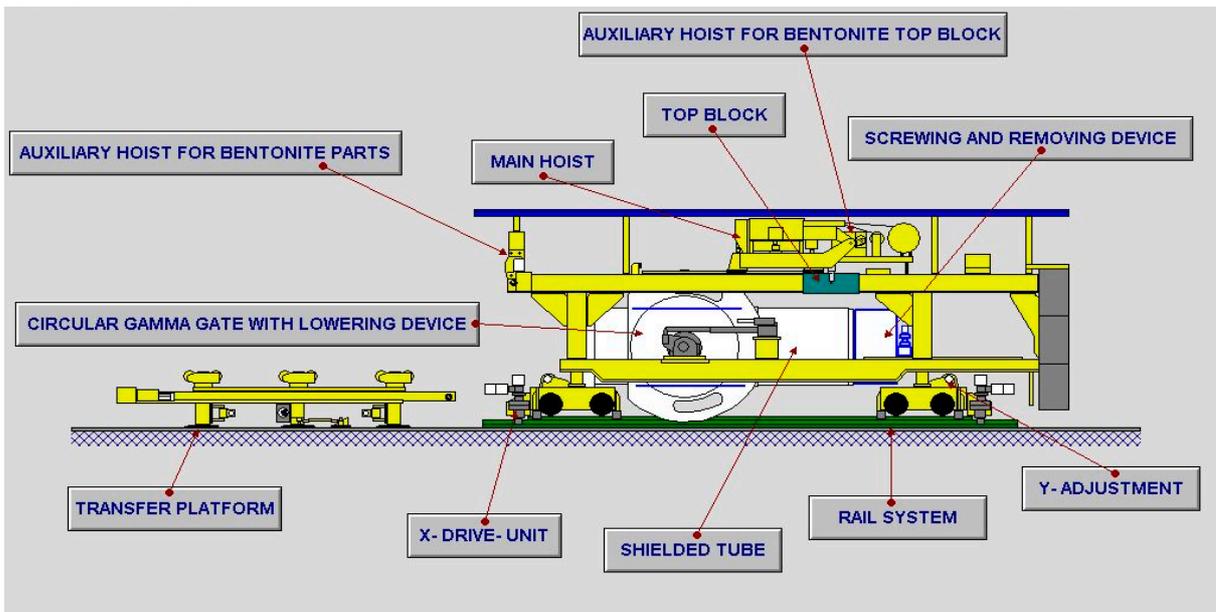
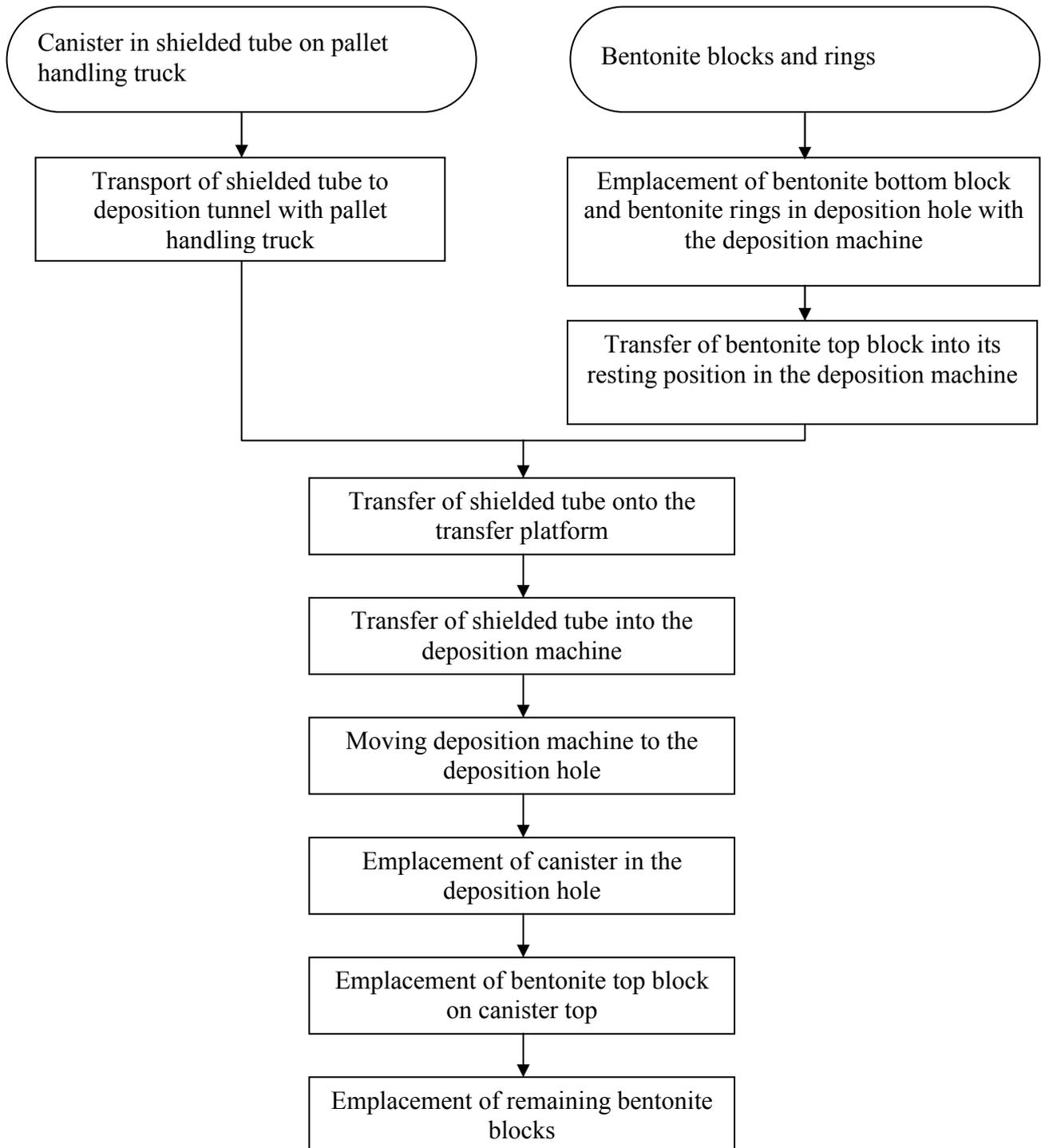


Figure 2. Overview of deposition machine with names of main components

2 Main handling steps for the deposition process

Flow sheet of the main handling steps for the deposition of canisters in the demonstration tunnel:



The following descriptions show the main handling steps for the deposition process. More details are given in the descriptions of the separate units in chapter 3.

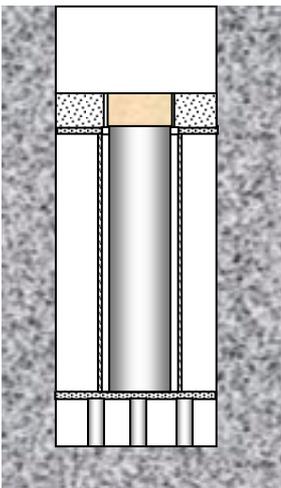
2.1 Handling truck for shielded tube

No special handling truck has been used in the present project phase for the transport of the shielded tube with canister to the deposition tunnel. Therefore, the shielded tube is either located on the transfer platform or within the deposition machine for the actual demonstration project.

2.2 Deposition tunnel

2.2.1 Emplacement of bentonite blocks and rings

The deposition machine is equipped with two auxiliary hoists, one of which can be used for the transport of bentonite parts and for miscellaneous service tasks, the other one for the bentonite top block. For the demonstration process the upper ring and the top block is made of concrete. The relevant height is achieved by a steel tube, mounted on a platform in the deposition hole.



The arrangement can be seen in this figure.

The bottom bentonite block is represented by the platform, consisting of a plate on legs. The bentonite rings are replaced by a steel tube with a top plate on which the concrete block is placed.

Figure 3. Arrangement of the deposition hole for demonstration

2.2.2 Transfer of bentonite top block into its resting position in the depository machine

Handling steps:

- a transfer pallet is placed on the transfer platform
- the bentonite top block is placed on the transfer pallet
- the deposition machine is moved to the transfer platform at the entrance of the deposition tunnel
- the transfer pallet is pushed into the shielding house of the deposition machine with the insertion device of the transfer platform

- the bentonite top block is picked up by the grab of the auxiliary hoist and is lifted into its resting position in the deposition machine
- the transfer pallet is pulled out of the shielding house and is removed from the transfer platform

2.2.3 Deposition of canisters

The deposition process takes place in automatically executed sequences and can be partially monitored via TV cameras.

Handling steps at the entrance of the deposition tunnel:

- the insertion device of the transfer platform is moved into the base position
- the shielded tube is placed on the transfer platform
- the transfer platform is positioned to its reference position with spindle drives
- the deposition machine is moved to the transfer position in front of the transfer platform
- the shielded tube is transferred into the deposition machine with the insertion device of the transfer platform and is fixed by the locking devices.
- the deposition machine is moved to the front of the deposition hole by means of programming the exact X-coordinates. (X = direction along the rails).

Handling steps at the deposition hole:

- the screwing and removing device is connected to the bottom part of the shielded tube
- loosening of the screws at the bottom part of the shielded tube with the screwing device
- removing of the bottom part of the shielded tube with the removing device
- positioning in front of the deposition hole by means of programming the exact Y-coordinates, (Y = direction across the rails).
- tilting of the canister into the borehole centre (vertical position) by combining the X movement of the deposition machine and the rotation of the circular gamma-gate
- lowering of the canister 780 mm by means of the lowering device.
- moving of the main hoist trolley with implemented docking device from the parking position to the working position above the shielded tube

- lowering of the docking device to the grapple unit which is installed at the top of the shielded tube
- locking of the docking device with the grapple unit and transfer payload to the main hoist
- unlocking of the bayonet ring of the canister grapple to release the grapple unit with the copper canister from the shielded tube
- lowering of the canister by the main hoist in the final position
- unlocking of the grapple hooks from the canister
- lifting of the empty grapple unit by the main hoist and locking at the top of the shielded tube
- lifting of the docking device into its upper position
- moving of the main hoist trolley to its parking position.

The bentonite top block is then placed at the top of the copper canister, which requires:

- lifting of the lowering device to the upper position
- turning of the circular gamma-gate with tilting device into the horizontal position
- positioning of the deposition machine by means of programming the exact X-coordinates so that the auxiliary hoist for the bentonite top block is above the centre of the deposition hole
- lowering of the bentonite top block and positioning on the top of the canister
- unlocking of the grab
- lifting of the empty grab to the upper position.

The shielded tube parts are then re-connected in the opposite sequence.

After the deposition machine is positioned in front of the transfer platform, the shielded tube can be pulled back by means of the insertion device of the transfer platform.

3 Handling equipment in the demonstration tunnel

3.1 General

The following components are installed in the demonstration tunnel for the deposition machine operation:

- power supply and distribution and signal and data transmission
- operator station, control systems and TV cameras
- rail system
- transfer platform with insertion device
- shielded tube
- deposition machine with
 - steel structure with X drive unit and Y adjustment
 - shielding house with circular gamma-gate and tilting drive (shielding simulated)
 - lowering device
 - screwing and removing device
 - trolley with main hoist and docking device
 - auxiliary hoist with grapple for the bentonite top block
 - auxiliary hoist for handling of bentonite parts
 - cabinets

3.2 Rail system

The rail system consists of steel plates with bolted-on rails. The steel plates are anchored in the grout concrete.

The rack for the X drive unit is bolted to the rail on the guiding roller side of the rail system.

Technical data:

Length: 28.7 m

Width of track: 3.0 m (Distance between centrelines of the tracks)

Capacity: 140 t

3.3 Transfer platform with insertion device

The transfer platform with the insertion device is located at the demonstration tunnel entrance and is articulately fixed to the anchored support plates. It is used to transfer the shielded tube into the deposition machine.

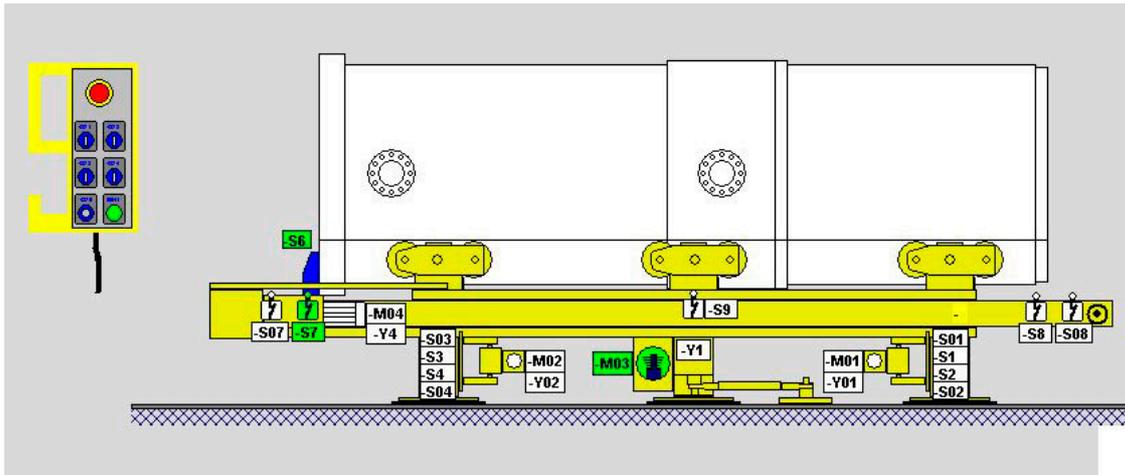


Figure 4. Transfer platform with shielded tube

The transfer platform consists of:

- machine frame with base, equipped with sliding Teflon plates
- six roller pairs designed as bogies
- electrically-driven insertion device, which pushes the shielded tube in and pulls it out of the deposition machine, consisting of a roller chain drive and a follower sledge
- the positioning system for adjustment of the transfer platform in Y direction (across the rail) and β angle (centreline angle in the horizontal plane).

The machine frame is placed on support plates on its base, which are equipped with Teflon plates. In this way, the complete transfer platform can be shifted around the articulately fixed point in Y direction and in β angle by two spindle units. This is necessary for compensating the tolerances of the parking position of the transport truck during transfer of the shielded tube.

At the overtaking position, the shielded tube will be placed onto the roller pairs of the transfer platform.

The transfer platform is then returned to its reference position with the positioning system. The deposition machine is then moved to the transfer position in front of the transfer platform.

The shielded tube is pushed into the deposition machine with the insertion device by actuating on a cam at shielded tube.

Technical data:

- Insertion speed: $v \approx 2 \text{ m/min}$
- Positioning range in Y direction: $S_Y \approx \pm 150 \text{ mm}$ (limited to approximately. $\pm 50 \text{ mm}$)
- Positioning range for β -angle: $\beta \approx \pm 5^\circ$ (limited to approximately. $\pm 2^\circ$)

Electrical data:

- motor insertion device: 3 Phases 230V/400V AC; 1.5 kW; IP 55
- spindle drive motors: 3 Phases 230V/400V AC; 1.1 kW; IP 55
- limit / cam gear switches: NO/NC; IP 56
- travel measurement: Encoder; 24 bit; IP 65
- proximity switch: Ultrasonic type; IP 55

Experience.

The differences between the Basic Design and the As-built Design are listed below:

Designation:	Basic Design:	As-built Design:
Insertion device	Roller chain drive	Second cup spring for the friction coupling necessary
Travel limit switches	Standard limit switches	Cam gear switch for the travel limit in front position due to position tolerances caused by the drive chain and shielded tube condition (with/without canister)
Positioning switch	Not designed	Ultrasonic proximity switch necessary due to different positions with and without copper canister in shielded tube

 *Some problems occurred during the commissioning of the transfer platform and they were solved as follows.*

- *Due to an unsuitable manufacture of the foundation (steel beams and plates) and the frame of the transfer platform as well as the arrangement of the bogies during workshop assembly and commissioning, it was almost impossible to push the shielded tube into the deposition machine. To solve the problem, the gap between the running surfaces of the upper and bottom part of the shielded tube had to be filled with shims.*
- *Adjustments and alignment activities (roller line of transfer platform to roller line deposition machine) were difficult and time consuming due to the above mentioned problem and the different load conditions (shielded tub with or without canister inside) during movement and insertion of the load (shielded tube).*
- *The additional installation of the cam gear switch and the proximity limit switch were necessary due to different positions of the shielded tube, depending on whether the copper canister is in the shielded tube or not (see also remarks "transfer platform" and "lowering device").*

3.4 Transfer pallet for bentonite top block

The transfer pallet is a steel structure used for transporting the bentonite top block into the deposition machine.

The transfer pallet is equipped with two roller tracks which travel on the rollers of the transfer platform and the deposition machine. The transfer pallet is inserted into the shielding house of the deposition machine using the insertion device of the transfer platform.

Experience.

- ↳ *The experience is limited as the transfer pallet has been in use only at two occasions (in workshop and on-site). After the additional stiffening of the cam for shifting the pallet, no problem occurred.*

3.5 Shielded tube

The shielded tube is used as a transport cask for transporting the copper canister from the reloading station to the deposition hole.

The cast-iron part of the shielded tube has the required dimensions and weights (130 mm thick cast iron walls (GGG40)). For demonstration purposes there is no need for neutron shielding, therefore the shielded tube is equipped with guiding and supporting blocks and shim-plates to reduce the diametrical clearance between shielded tube and canister.

The shielded tube consists of:

- The upper part with the grapple unit (see chapter 3.6.11).

- The bottom part, which is bolted to the upper part. The connection is designed with bolts, which can be manipulated by a remote-controlled screwing device, and six threaded inserts into the upper part.

For the various handling steps, the shielded tube is equipped with:

- trunnions, located on the upper part
- two roller tracks, installed along the entire length of both parts

Technical data:

Dimensions: Ø 1850 x 5400 mm

Divisions: 2 (upper part L = 3400 mm, bottom part L = 2000 mm)

Weight: 30 t

Numbers of screws: 6

Experience.

The differences between the Basic Design and the As-built Design are listed below:

Designation:	Basic Design:	As-built Design:
Upper part	Threads direct in the cast iron	Inserts
Distance between the two roller tracks	≈ 1520 mm	1450 mm
Space between the two roller tracks (longitudinal)	400 mm	Space closed with a screwed plate (roller track profile)

↳ *One of the screws that hold the shielded tube together was jammed in its inner position. All screws were removed whereby the jammed one was drilled out. All threads (M36 x 4) were drilled out and replaced with insert threads.*

3.6 Deposition machine



Main data for the machine:

Height	4.6 m
Width	3.7 m
Length	11.8 m
Weight, empty	90 tons
Weight, with shielded tube and canister	140 tons
Speed	10 m/min
Power supply	Cable
Capacity, main hoist	30 tons
Capacity, auxiliary hoist	5 tons
Capacity, hoist for bentonite top block inside machine	1 ton

Figure 5. Deposition machine installed at Äspö Hard Rock Laboratory

3.6.1 General

The deposition machine is composed of the following structural components:

- steel structure
- X drive units
- Y adjustment
- shielding house
- circular gamma-gate with tilting drive
- lowering device
- screwing and removing device
- trolley with main hoist and docking device
- auxiliary hoist for bentonite top block
- auxiliary hoist for bentonite parts
- cabinets and junction boxes
- electromechanical parts for driving and positioning (motors, encoders and limit switches etc.)
- Video camera with pan and tilt heads

- power and signal cabling
- roof

Experience.

The general differences between the Basic Design and the As-built Design are listed below:

Designation:	Basic Design:	As-built Design:
Height of the deposition machine	≈ 4.4 m	≈ 4.6 m
Roof	A roof covers the whole deposition machine against leaking water	Redesign after installation
Depth of the deposition hole (Lifting height)	≈ 8.2 m	≈ 8.9 m

3.6.2 Electrotechnical Equipment Stages

The power distribution and power electronic devices on the deposition machine are incorporated in nine cabinets (3 x 3). These cabinets and also the peripheral components have in most cases a protection grade of IP 55 and the cabinet for power control purposes is equipped with an air conditioning system.

3.6.3 Steel structure

The steel structure of the deposition machine consists of:

- two welded main girders:
The main girders connect the X drive units and support the circular gamma-gate, the screwing and removing device, the frame for the hoists and the lower part of the shielding house. The rollers and roller pairs inside and behind the shielding house are connected to the main girders.
- the welded frame for the hoists:
The frame for the hoists supports the main hoist, the auxiliary hoists for the bentonite top block and the bentonite parts, the upper part of the shielding house, the cabinets and the roof
- the frame for the auxiliary hoist for the bentonite top block
- beams for the connection of the two main girders at the front and rear side of the deposition machine.

The shifting of forces which occurs during the loading and unloading processes are taken into consideration for the design of the steel structure.

Experience.

There were no differences between the Basic Design and the As-built Design.

3.6.4 X drive unit

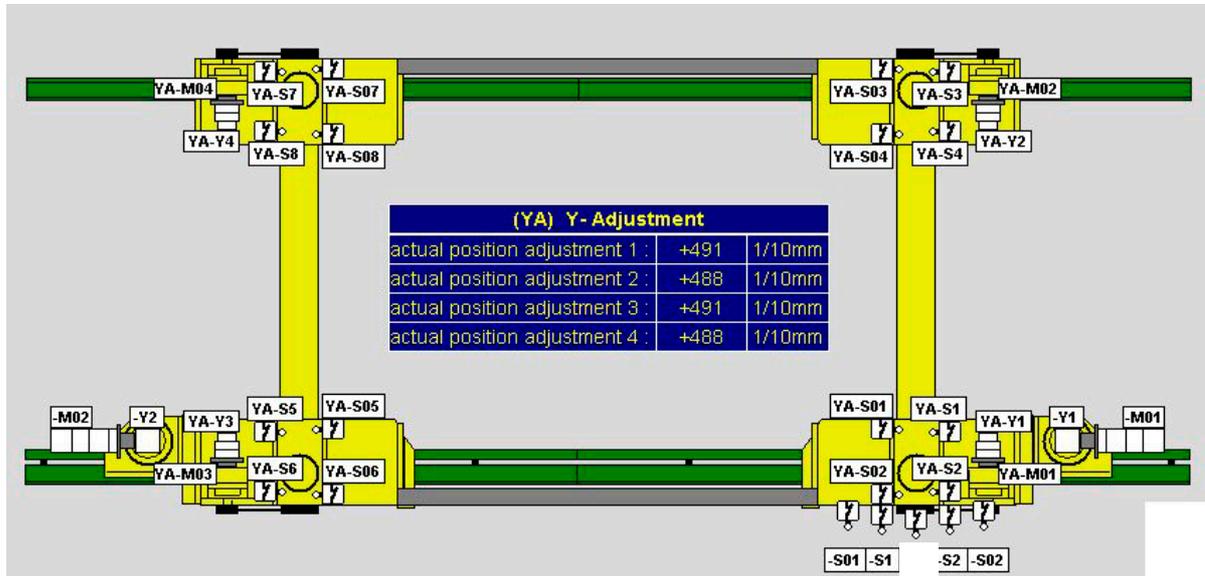


Figure 6. Top view on X drive unit and Y adjustment

The deposition machine is equipped with four bogies. Each bogie is equipped with two ball-bearing travel rollers and the Y adjustment. On the guiding side of the rail system the bogies are equipped with four guiding rollers and a rack-and-pinion drive unit.

A pair of asynchronous motors with brakes, driven by a frequency converter for velocity control is used for the X drive unit. An accurate and co-ordinated operation down to almost zero speed is a requisite for the path movement during common „Driving and Tilting“ mode.

One of the bogies is equipped with an encoder for absolute travel measuring which is used for position detection and measurement.

Additional to the encoder four limit switches limit the travel path of the unit in the tunnel.

Technical data:

Travelling speed in X direction: $v = 0 - 10 \text{ m/min}$

Electrical data:

- motors: 3 Phases: 230V/400V AC; 11 kW; IP 55
- limit switches: NO/NC; IP 56

- travel measuring: Encoder; 24 bit; IP 65

Experience.

The limit switch S3 “borehole reached” was canceled.

3.6.5 Y adjustment

For alignment purposes in Y direction, the steel structure (deposition machine frame) can be adjusted by shifting ± 50 mm above the bogies. The Y axis adjustment unit is executed by linear guiding tracks, driven by four electrically controlled motors.

The positions of the Y axis adjustment unit are measured by encoders for absolute travel measuring.

Two limit switches and two emergency limit switches for each drive are used for travel limit detection.

Technical data:

- motors: 3 Phases: 230V/400V AC; 0.75 kW; IP 55
- limit switches: NO/NC; IP 56
- travel measuring: Encoder; 24 bit; IP 65

Experience.

There are no differences between the Basic Design and the As-built Design.

3.6.6 Shielding house

The copper canister with fuel assembly is protected by the shielded tube. Since the bottom part of the shielded tube must be removed for the canister deposition process, the deposition machine has to take over the shielding function.

The shielding house and the circular gamma-gate are provided for this purpose. A part of the shielding function continues to be performed by the bottom part of the shielded tube. Space is provided in the shielding house for the bentonite top block, which must also be placed under radiation protection conditions.

Roller pairs are also located in the shielding house for the movement of the shielded tube.

For the demonstration at Äspö the shielding walls of the shielding house and the circular gamma-gate (see chapter 3.6.7) are simulated by thin plates.

The shielding house consists of:

- the back wall, with an opening for removal of the bottom part of the shielded tube
- the lower front wall
- two lower parts of the side walls, which are connected to the main girders
- one upper part of the side walls, which is connected to the frame for the hoists: the second upper part of the side walls is replaced by transparent plastic in order to enable visibility to the handling steps for demonstration purpose
- the roof wall with the chamber for the bentonite top block
- two manual lowerable sliding shielding plates at the front wall and at the back wall of the shielding house, simulated as hollow double plate sections

Experience.

The are no differences between the Basic Design and the As-built Design.

3.6.7 Circular gamma-gate with tilting drive

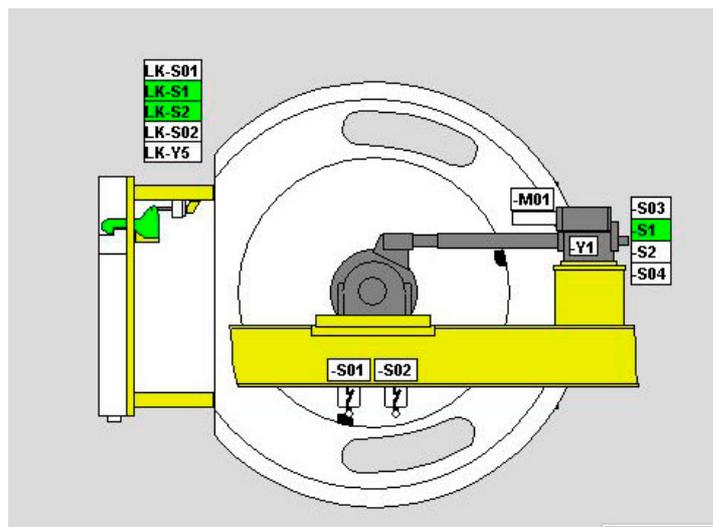


Figure 7. Circular gamma-gate with tilting drive

One encoder measures directly the absolute angle of rotation of the gamma-gate and two additional encoders are used to measure the spindle stroke to detect unnormal deviations during The circular gamma-gate is located within the deposition machine and forms a part of the shielding house. The roller pairs for transport and guiding of the shielded tube are connected to the side shields of the circular gamma-gate. The lowering device (see chapter 3.6.8) is located inside the circular gamma-gate.

The gamma-gate is supported on both sides by axles. The axle bearings are supported on the main girders.

Each of the two tilting drives is designed as electrical driven linear actuators with a servo driven brake motor, supplied via frequency converter for velocity control mode and angle-synchronisation of the two spindle drives.

One encoder measures directly the absolute angle of rotation of the gamma-gate and two additional encoders are used to measure the spindle stroke to detect abnormal deviations during movements.

In addition, two load measuring bolts are installed in the spindle eyes to monitor the load distribution of the two driven sides of the gamma-gate.

Technical data:

Diameter circular gamma-gate: $d = 3.2 \text{ m}$

Tilting speed: $n \approx 0.1 \text{ rpm}$ (depends on path movement requirements)

Electrical data:

- motors: 3 Phases: 230V/400V AC; 1.5 kW; IP 55
- limit switches: NO/NC; IP 56
- rotation measuring: Encoder; 24 bit; IP65
- stroke measurements: Encoder; 24 bit; IP65
- proximity measurement: Linear Potentiometer; IP55
- load measurement: Bolts; 200kN each; IP65

Experience.

The differences between the Basic Design and the As-built Design are listed below:

Designation:	Basic Design:	As-built Design:
Tilting drive	One tilting drive for demonstration purposes; redundancy can be reached easily by adding another drive on the other side	Second tilting drive necessary and uniball bearing enlarged, loadcell installed, balance weight mounted, spindle drive journal replaced



The circular gamma-gate arrangement was the main system, which had to be modified due to malfunctions as follows:

- *After turning the upper part of the shielded tube with implemented empty grapple unit into horizontal direction for the first time, the spindle eye of the one spindle unit broke and the load dropped to horizontal position and was blocked by two steel supports only. This damage was caused by a mistake in*

the calculation during the design phase, which has not considered, that the worst load case appears when the copper canister does not act as counterweight.

- *A second spindle unit needed to be installed to cover the maximum force of approximately. 340 kN. Due to some free play in the heavy load ball bearings (one on each side), an electrical angle-synchronisation had to be installed additionally.*
- *The modifications led to an almost complete redesign of the electrical and electronical equipment. Main consideration beside the functionality was to monitor almost all important parameters (angular position, forces and spindle stroke synchronisation)*
- *For the future it is necessary to design the tilting drive units with 2 x 100% power, to ensure that the tilting could be finished in the case of failure of one drive unit. At the actual deposition machine this could not be reached because there was not enough space to add larger drive units than the designed ones.*
- *After installation of the second spindle unit and after a couple of test movements, the journals of the spindle casings bent off due to improper weld seams. The journals in the support plates were rewelded and reinstalled. Test operations and force measurements were performed to demonstrate compliance with the design parameters.*

3.6.8 Lowering and locking device

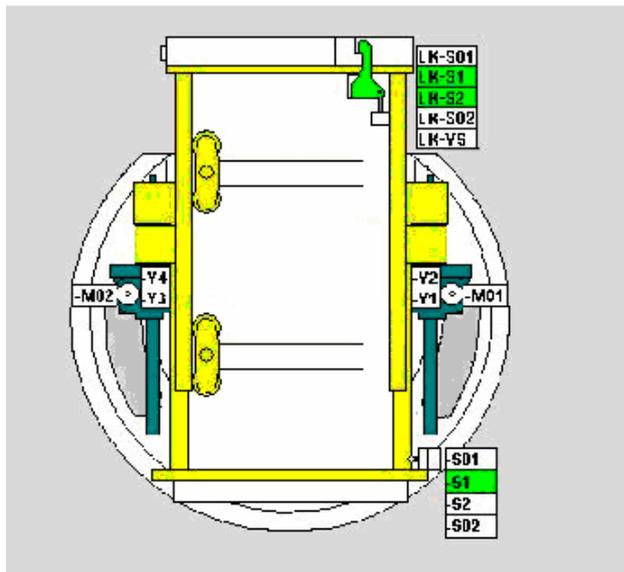


Figure 8. Sectional view on locking and lowering device

After pushing the shielded tube into the deposition machine with the insertion device of the transfer platform, the shielded tube is locked to the steel structure of the lowering device with the locking devices. Two hooks will be used to lock the shielded tube in the deposition machine. For unlocking pneumatic cylinders move the hooks.

The lowering device is located in the circular gamma-gate. Spindle drives between the lowering device and the gamma-gate allow to lower the entire unit with canister and upper part of shielded tube by 780 mm, with the arrangement in vertical position. Two motors with brakes are used to drive the four spindle lifting units which are mechanically synchronised. The movement of the lowering device is controlled by four limit switches.

Access to the four spindle units and the two drives is possible via openings in the side walls of the circular gamma-gate. An additional intervention possibility is given by lifting the spindles which can be reached from above.

Technical data:

Lowering speed: $v \approx 0.18 \text{ m/min}$

Lowering stroke: $s = 780 \text{ mm}$

Electrical data:

- motors: 3 Phases: 230V/400V AC; 4 kW; IP 55
- limit switches: NO/NC; IP 56
- solenoid valves: 24 V DC; IP 56

Experience.

The differences between the Basic Design and the As-built Design are listed below:

Designation:	Basic Design:	As-built Design:
Jacks	Spindle with pulling forces; spindle nut is rotating	Installation of stops to avoid the axial displacement of the spindles, counter-nuts to fasten the top plate of the spindles

↪ *The arrangement of the lowering device caused problems during commissioning and tests and had to be changed as follows:*

- *The necessary flexibility within the system (performed by rubber plates in the spindle kinematics) led to positioning problems, depending on the different load cases in horizontal position. Due to the negative inclination in horizontal position (approximately. $-1,1^\circ$), the rubber-plates expanded differently and therefore, the position of the lowering device with or without the payload of the copper canister was different. Additional measurement systems was to be installed in order to solve the problem (see also remarks "transfer platform").*
- *During the tilting of the shielded tube there was a collision with the cable bridge of the cables of the lowering device. The cable bridge was moved to a new place.*

3.6.9 Screwing and removing device

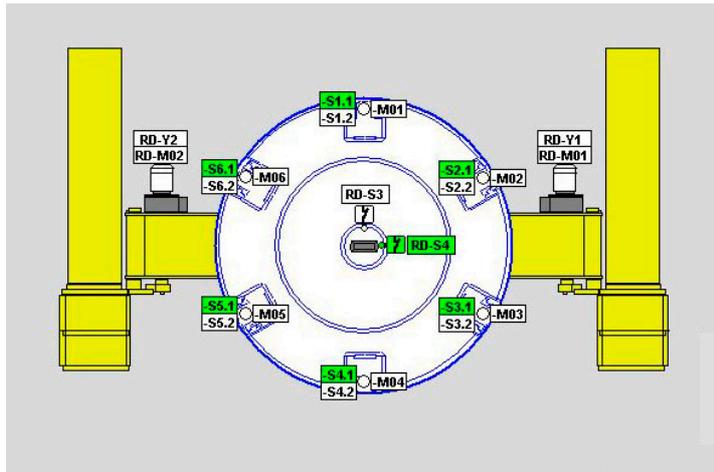


Figure 9. Screwing device. Top view seen from the shielding house.

The screwing and removing device system is located behind the shielding house. It is locked to the bottom part of the shielded tube with a twist lock pin.

The screwing device consists of six motors with friction clutch for loosening/tightening of the screwing connection between shielded tube upper part and bottom part. Each motor will loose one screw. Six limit switches detect if the screws are released.

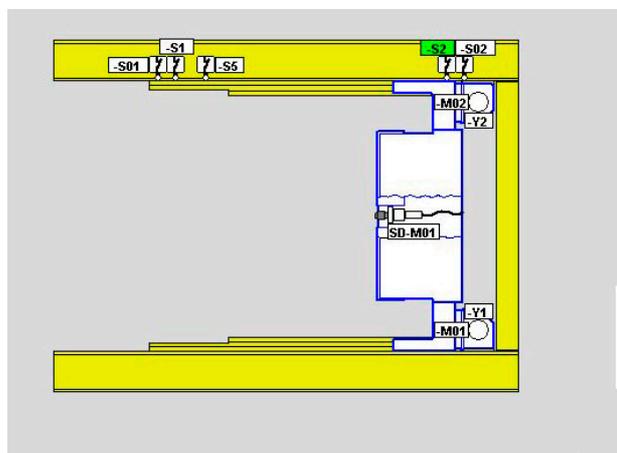


Figure 10. Top view on removing device seen from the roof

The removing device is a pinion / rack drive unit, equipped with two motors with brake and friction clutch, for moving the bottom part of shielded tube between open and closed position. The shielded tube bottom part is guided on single rollers which form the extension of the roller pairs installed inside the circular gamma-gate and the shielding house.

Four limit switches are used for travel limit detection to control the horizontal movement.

Technical data:

Torque of screwing units: $T =$ approximately. 500 - 1200 Nm

Speed of removing device: $v \approx 2.0$ m/min

Electrical data for screwing device:

- motors: 1 Phase; 230 V AC; 0.5 kW; IP 55
- limit switches: NO/NC; IP 56

Electrical data for removing device:

- motor: 3 Phases; 230V/400V AC; 0.75kW; IP 55
- limit switches: NO/NC; IP 56

Experience.

The are no differences between the Basic Design and the As-built Design.



The arrangement of the screwing and removing device caused also some problems during commissioning and tests and had to be changed as follows:

- *A fifth limit switch has been installed to detect the position of the shielded tube without the copper canister. In addition, a proximity switch has been installed to detect the precise position of the bottom edge of the shielded tube to remove the bottom part, independent of the situation whether the shielded tube is loaded with the canister or not. These modifications were necessary for accurate and repeatable positioning due to the arrangement of the lowering device (flexibility by rubber plates / see also remarks "lowering device").*
- *As the screwing motors are only manually adjustable to a tightening torque, tolerances occurred which led to time consuming adjustments for the run-down times of the screwing process.*

3.6.10 Main hoist and trolley

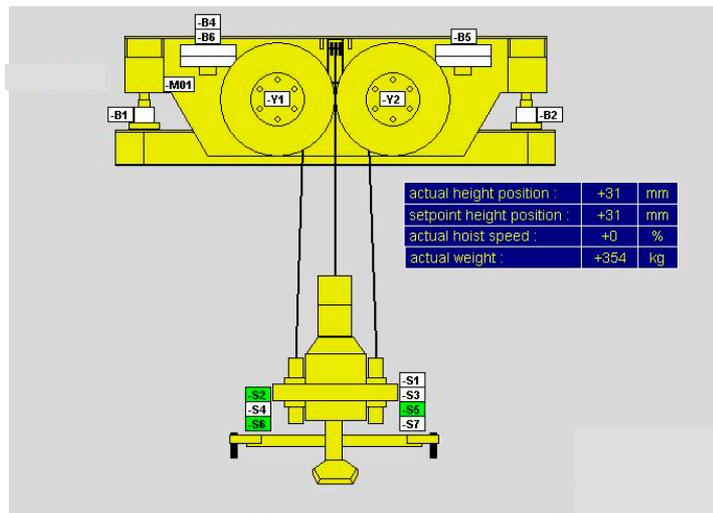


Figure 11. Main hoist with docking device

The main hoist is mounted on a trolley, which is belt driven sliding on Teflon on the upper girders of the frame. The movement of the trolley is only possible when the canister, together with the upper part of the shielded tube, has been lowered by the lowering device. The trolley with the main hoist can then be positioned above the centre of the shielded tube for docking and lifting/lowering functions. The function of the docking device which is part of the main hoist is described in chapter 3.6.11, "Grapple unit and docking device".

The hoisting equipment is driven by one velocity controlled motor with an operational brake, acting on the wire drum. An additional, emergency brake is installed for safety purpose, activated in case of hoisting drive failures. The lifting height of the hoist is measured by three cable operated encoders. A cam-operated switch controls the upper and lower limit positions of the hoist.

For the trolley movement, a pole-changing motor with brake is installed. Four limit switches are installed to control the travel limits of the trolley.

Main features of the main hoist and trolley:

- The hoist is equipped with four cables on two cable drums.
- The two cable drums are coupled with gear wheels which provide load stability in case of single kinematic chain failure.
- Planetary gears are placed inside the cable drums.
- The hoist is equipped with two brakes; one brake can carry the whole load.
- The hoist is equipped with a load measurement device, used for fail-safe overload protection and slack-cable detection, and a lifting measuring system.

- The hoist is supported on two hydraulic cylinders. This hydraulic balance system is part of the safety devices of the docking device, especially when taking over the load.
- The hoist trolley can be moved from parking position to working position and back with a belt drive unit and fixed stops.

Technical data:

Lifting load:	$F = 300 \text{ kN}$
Lifting speed:	$v = 0 - 1.2 \text{ m/min}$
Lifting height:	$s \approx 5.5 \text{ m}$

Electrical data hoist:

- motor: 3 Phases: 230V/400V AC; 15 kW; IP 55
- limit switches: NO/NC; IP 56
- travel measuring: cabl-operated encoder; 24 bit; IP65
- load measuring bolts: Strain gauge type

Electrical data trolley:

- motor: 3 Phases: 230V/400V AC; 0.75 kW; IP 55
- limit switches: NO/NC; IP 56

Experience.

There are no differences between the Basic Design and the As-built Design.

3.6.11 Grapple unit and docking device

The grapple unit is part of the shielded tube (see chapter 3.5) and the docking device is part of the main hoist (see chapter 3.6.10). The cross section of the grapple unit is shown in figure 12.

The grapple unit is an all mechanical unit. It consists of:

- lower shielding plate, which can be connected to the canister via grapple hooks
- upper shielding plate, which can be connected to the shielded tube via a bayonet ring
- three articulated rods as connection rods between the lower and the upper shielding plate. There are three of them in order to avoid bending forces on the grapple hooks during transport of the shielded tube.

The lower shielding plate is equipped with:

- 12 grapple hooks
- a large diameter bearing with internally toothed outer ring with arched switch outer contour for activating the grapple hooks
- a drive shaft with pinion for activating the turning ring and the grapple hooks; the drive shaft is equipped with a mechanical locking system.

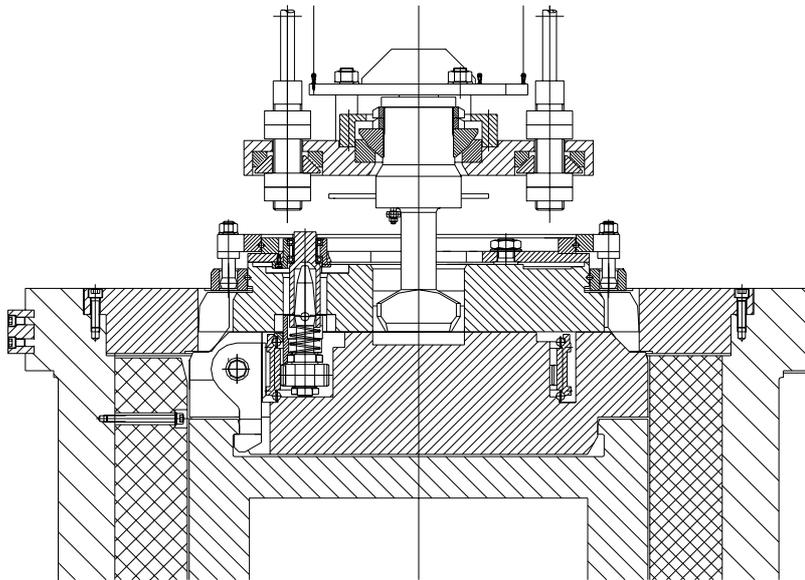


Figure 12. *The cross section of the grapple unit and the top part of the shielded tube*

The upper shielding plate is equipped with:

- a centring and positioning contour on the outer edge
- a large diameter bearing with a bayonet ring as an outer ring
- a mechanical locking system for the bayonet ring and the turning ring for activating the grapple hooks
- the bayonet-type boring for supporting the load with the twist lock pin of the docking device

The docking device consists of:

- a support plate with an articulated cable suspension system for the four cables
- a turning twist lock pin with a pyramid-shaped centring block for centring at the main hoist; the twist lock pin is suspended articulated at the support plate
- a docking plate with a large-diameter bearing with two followers located on the outer ring for the bayonet ring of the grapple unit
- a hollow shaft as a follower for the drive shaft for the grapple hooks
- centring parts for centring to the grapple unit which are connected to the docking plate

- four spacing bars between the centring block of the twist lock pin and the docking plate, which hold the docking plate spring-loaded in a horizontal position up to the placement on the grapple unit
- three pneumatic drives for activating the twist lock pin, the bayonet ring and the grapple hooks. Six solenoid valves for the pneumatic cylinders at the docking device. Two of them control the bayonet ring, two valves lock and unlock the twist lock and two valves are used for the grapple
- a motorised cable reel for the power supply to the docking device
- control devices with load cells and measurement system
- seven limit switches for status detection and control of the docking device functions.
- three wire encoders detect the position and the horizontality of the docking plate.

The main features of the mechanical interlocking system are:

- the bayonet ring of the grapple unit is locked, if the twist lock pin is not under load
- the turning ring for activating the grapple hooks is locked mechanically, when the twist lock pin is under load
- the drive shaft for the grapple hooks is locked when the docking device is removed.

This means:

- during transport of the shielded tube the bayonet ring and the grapple hooks are locked mechanically
- during lifting or lowering the canister with the main hoist the grapple hooks are locked mechanically.

Technical data:

- limit switches: NO/NC; IP 56
- solenoid valves: 24 VDC; IP 56

Experience.

The differences between the Basic Design and the As-built Design are listed below:

Designation:	Basic Design:	As-built Design:
Steel construction of the grapple unit	Two shielding plates connected with articulated rods to avoid bending forces on the grapple hooks during transport of the shielded tube	Distance between the shielding plates: 3 mm; the rods are replaced by rods with a larger thread and locking nut (M45)

↶ The arrangement of the docking device and the grapple unit caused no specific problems during commissioning and tests.

However, one extraordinary problem occurred - causing a load crash of the copper canister and the lower part of the grapple unit. Due to a manufacturing problem, the rods which carry the lower part of the grapple unit and the load were machined as M40-threads instead of M45 and in addition, improper washer-plates were used. This led to a loosened connection between the upper and lower part of the grapple unit after a few operations with load.

3.6.12 Auxiliary hoist for handling of the bentonite top block

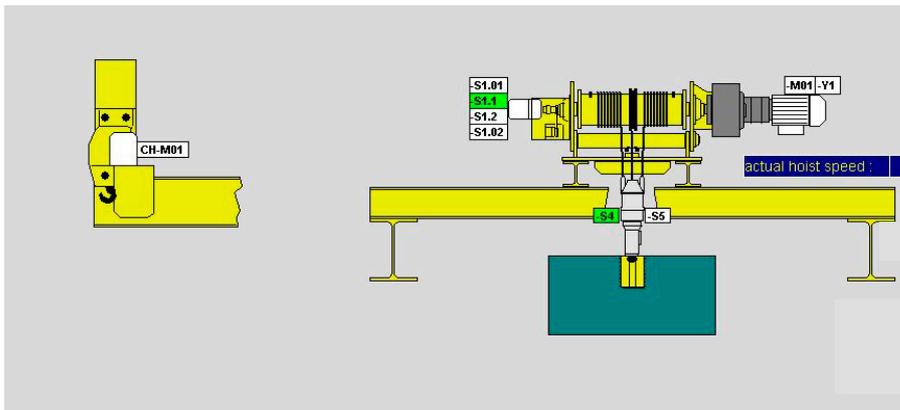


Figure 13. Auxiliary hoists

The chamber for the bentonite top block is located in the shielding house above the area for the shielded tube. The top block is inserted before loading the shielded tube.

The metal part for picking up the block with the grab is fixed in the block.

A grab and a hoist are provided for handling the bentonite top block.

The grab is equipped with a mechanical lock and an electrical unlocking mechanism. The grab of the hoist is actuated by a solenoid stroke actuator. Two proximity switches detect the state of the grab.

The hoist is driven by a servo motor with a brake. The hoist is constructed as a 2-cable winch and is equipped with a lift measuring system and a guide roller for the cables. A load measuring cell is installed. A spring-type cable reel is used for the power supply of the solenoid valve and limit switches in the grapple. A cam-operated switch detects the limit positions of the hoist.

The hoist is positioned by moving the deposition machine in the X-direction.

Technical data:

Lifting load: $F \approx 10 \text{ kN}$

Lifting speed: $v \approx 2.0 \text{ m/min}$

Stroke: $s \approx 5.2 \text{ m}$

Electrical data:

- motor: 3 Phases: 230V/400V AC; 2.2 kW; IP 55
- limit switches: NO/NC; IP 56
- lifting height measurement: cable operated encoder; 24 bit; IP 65
- load measuring cell: Strain gauge type
- grab actuator: 24VDC; IP 56

Experience.

The differences between the Basic Design and the As-built Design are listed below:

Designation:	Basic Design:	As-built Design:
cables	--	Guiding roller mounted

3.6.13 Auxiliary hoist for bentonite parts

For installation of the borehole liner and the concrete ring as well as for miscellaneous service tasks, a bracket with an auxiliary hoist is provided on the back side of the deposition machine.

The auxiliary hoist for the bentonite parts is a conventional hoist with a hook, designed as a 2-chain winch. It is driven by a motor with a brake and temperature control. For overload protection, a friction clutch is implemented in this standard equipment.

Technical data:

- Lifting load: $F \approx 50 \text{ kN}$
- Lifting speed: $v \approx 2.7/0.7 \text{ m/min}$
- Stroke: $s \approx 12.0 \text{ m}$

Electrical data:

- motor: 3 Phases: 230V/400V AC; 2.6 kW; IP 55

Experience.

There are no differences between the Basic Design and the As-built Design.

3.7 General description of electrotechnical equipment

This description covers the general design for the electrical and electronic equipment for the deposition machine.

The electrotechnical details of separate components are presented in the sections describing the components and devices for the deposition project.

3.7.1 Basic configuration

The complete system consists of several subsystems and components.

The electrical equipment comprises four main subsystems. The systems are:

- the energy supply and signal/data transfer to/from the deposition machine and the transfer platform,
- the stationary operator control panel and a hand-held unit for local manual mode,
- the power and control equipment at the deposition machine,
- and the power and control equipment at the transfer platform.

3.7.2 Energy supply from the site

The site supply has been made available at the main cabinet, located at the front of the tunnel. The main cabinet is equipped with the main circuit switch, the power distribution stage and converting devices to generate the necessary control voltage levels.

Technical data of the power supply:

- | | |
|------------------|----------------------|
| - System | TN-S / L1-L2-L3-N-PE |
| - Voltage | 400/230 Volts |
| - Frequency | 50 Hertz |
| - Required power | approximately. 45 kW |

3.7.3 Energy supply to the deposition machine

The energy to the deposition machine is supplied via one cable, which is installed in a plastic energy chain (together with signal and data cables).

The runway of the deposition machine is only 28.7 m and the energy chain has guiding elements. No technical problems have occurred with this rather limited extension.

3.8 Control & monitoring equipment

3.8.1 Configuration of control equipment

The following configuration and equipment perform the control applications:

- Stationary control cabinet
The stationary control cabinet is equipped with a Programmable Logic Controller (PLC type SIEMENS S7-400), serving as the control system for the transfer platform.
- Stationary operator panel
The stationary operator panel is equipped with a Personal Computer (PC type HP Vectra), which links the operator orders with the control functions of the deposition machine and the transfer platform.
A monitor with keyboard and mouse is used as Men-Machine-Interface (MMI).
- Deposition machine control system
For the control of all deposition machine tasks, a second PLC (S7-400) is implemented. This controller performs and controls all movements of the deposition machine subsystems.
For local manual setting-up operation, a text display unit with reduced keyboard functionality is plugable.
- Communication lines
The communication and data transfer between the PLC systems is performed via a serial data bus, which is of the PROFIBUS DP specification with a data rate of 1.5 Mbaud.

Experience

Due to interlocks in conventional relay control, which exist parallel and additional to the program of the PLC, there are based on the complexity of the machine additional informations on the operator control system necessary.

For the problems we will give two examples with proposals for a solution:

- Auxiliary hoist for bentonite top block:
The limit switch “AH in upper position” is not activated. All other movements of the machine were blocked. This could be seen on the relevant picture on the screen, but it would be better, if the operator gets a message e.g. a message in a separate window, why no other function is selectable.
- Lowering device:
To deposit the canister, the lowering device must be in lowest position, so that the trolley with the main hoist can drive above the canister. After depositing the canister, replacing the grapple unit in the upper part of the shielded tube and moving the main hoist in upper position, the limit switch ”LD in lowest position” was lost because the rubbers buffers, where the shielded tube is fixed on, are not so strong compressed then with load. The result is that the trolley can not move away because the lowering device is not in the lowest position. You can see this also on the relevant picture, but for the operator it is difficult to find out the reason.

3.8.2 Monitoring equipment

For observation and information there is a video equipment with several colour CCD cameras installed to see the actions of the storage process on a monitor in the control room.

Depending on the actual action the PLC switches automatically via a video switcher to the corresponding camera. All the necessary lightning will be switched automatically by the PLC.

One camera in the middle lateral area of the machine shows the inner of the shielded house and when the shielded tube is loaded the correct working of the screw drivers and the opening/closing of the shielded tube.

In the lower part of each borhole there is mounted one camera that shows the tilting of the canister into the borehole and the lowering of the lowering device.

Additional it is possible to watch the coupling of the docking device with the grapple unit, the opening of the bayonet and the start of lowering of the canister into the borehole with a camera mounted on the rear upper girder. To see further sequences the PLC switches back to the camera in the lower part of the borehole.

Another camera in the upper part of each borehole shows the moving canister, when the docking device has passed it. Lowering of the canister, decoupling the grapple unit and lifting the main hoist with docking device and grapple unit could be seen.

4 Experience and conclusion

4.1 General

Summarised from today's perspective, some modifications and improvements could be observed and considered for future applications. General redesigns - self-propelled - equipment for example - and additional retrievability and safety requirements have not been taken into consideration hereafter.

During the previous project time reasonably small deposition tunnel dimensions were achieved by the following means:

- removal of the bottom part of the shielded tube before tilting the canister
- tilting the canister by simultaneously movements of the X-drive and the tilting device
- lowering the canister into the deposition hole in vertical position before connecting the canister grapple to the docking device of the main hoist.

On the basis of the environmental conditions in the tunnel it seems necessary to apply a slope in deposition tunnels. This causes some of the problems, described hereafter, for the handling of the deposition machine. For future applications it is advisable to reduce the slope to a minimum and to compensate the slope during loading and unloading of the shielded tube.

Besides the already mentioned time consuming problems for alignments, the slope leads to additional stresses for the complete kinematics:

- Driving power for the transfer platform's insertion has to be overdimensioned; this leads to additional dynamic forces while pushing the shielded tube against the lowering device frame.
- The number of bogies at the transfer platform and in the gamma-gate might be modified for an improved load distribution. This may lead to an advantageous design of the shielded tube (keeping the gap at the shielded tube roller running tracks simplifies the borehole geometry).
- Shifting the payload horizontally might also allow for an improved stabilisation of the bogey/roller arrangement.

A horizontal (0°) shifting of the payload and a horizontal load alignment will also have extreme advantages regarding, reliability and repeatability. As repeatedly mentioned in the report, the different load situations (shielded tube with or without copper canister and/or shielded tube open or closed) mainly resulted in electrical adaptations for detection of the positions (range of approximately. 1 cm). These different inclination forces will not apply in 0° -position.

Another problem that has to be solved in the future was the selection of the materials. Because of the environmental conditions - dripping salt water - many of the materials rust. One of the causes is that due to reducing the costs for the prototype machine, only part of the non-painted materials are made of stainless steel.

During the further handling also radiation has to be taken into account for the selection of the used materials

4.2 Object oriented experiences

Rail System

No specific problems occurred during erection and commissioning tasks with the rail system design and arrangement.

In the future the rail-bedding for the deposition machine has to be considered. On one hand installation and alignment of the rails are very time consuming. On the other hand the rails have an advantage for the precise positioning of the machine at the boreholes.

Transfer Platform

Basically, the transfer platform functioned quite well. The modifications as aforementioned in this document are derived from the different load situations.

Nevertheless, commissioning experience leads to additional ideas for improvement:

- The electrical and pneumatical supply to the insertion device should be carried out by cable/hose reel to avoid complications with routing.
- An independent air-supply by a distribution pipe in the tunnels will be better than the compressor on the transfer platform

Tilting Drive

Although the actual arrangement functions quite well, a different design of the drive for the gamma-gate seems to have more back-up possibilities and be more reliable:

- The gamma-gate can be designed as a so-called direct drive; that means, that the gamma-gate is equipped with a circular rack and the motor(s) carry the pinion to actuate the turning movement.
- This allows for a more-motor arrangement and therefore a higher safety factor, and an advanced force and load distribution by using an improved lever ratio and the possibility to design retrievability devices.
- The tilting drive should be designed as a redundant system, to enable putting the canister in a safe position in case of failure of one tilting device.

Screwing and Removing Device

The screwing device itself caused some adjustment problems. These were mainly derived from the insufficient (only manual) possibility to adjust the screwing torque exactly.

For further applications, electronically torque controlled screwdrivers might be of advantage for repeatability and also quality documentation, if necessary. An other solution is to install travel measurement devices for controlling the movement of the screws.

Commissioning of the removing device was also time consuming due to the different positions (caused by the load situations) of the shielded tube. This fact will also be negligible with a horizontal load arrangement.

If there is no possibility to achieve a horizontal load arrangement due to the slope, it should to be considered if the used limit switches can be replaced by another measuring system.

Main Hoist

The design of the main hoist caused no specific problems during commissioning and tests only a few minor things should be considered for future main hoist arrangement.

As the hoist is almost completely covered, working holes and reasonable accessibility are necessary to allow space for adjustments and exchange of devices and cables etc.

Another aspect, which should be regarded for future applications, is the technical design of the main hoist in regard to the arrangement of taking over the load. Although the function – together with the hydraulic balancing unit – works reliable, stress is introduced during the lifting of the grapple unit against the body of the shielded tube which affects mainly the lowering device.

The belt drive for the trolley causes improper time for maintenance to ensure the function under the given environmental conditions.

To reduce the height of the main hoist possible advantages with a chain-lifting system should be checked.

Locking Device

As the tolerance between the hooks of the locking devices and the locking frames mounted at the shielded tube, has to be minimised in order to avoid movements of the shielded tube during operation, applicable pushing forces have to be increased to lock or release the hooks. This caused few problems during commissioning.

It might be of advantage for future applications to think about a positionable and moveable locking device to decrease forces and stresses to the kinematics.

Grapple Unit and Docking Device

The design of the grapple unit proved good and reliable. The concept and design should be kept basically.

The arrangement of the docking device, however, can be improved with regard to adjustment and reliability. Especially tolerances of the pneumatically actuated movements should be minimised to reduce stress induced to mechanics, hoses, cables and limit switches.

Auxiliary hoist for bentonite top block

The design of the auxiliary hoist caused no specific problems during commissioning and tests.

Auxiliary hoist for bentonite rings

In the future and outside of the demonstration project, the emplacement of the bentonite blocks and rings into the borehole should be carried out with a separate machine, specifically designed for the bentonite handling. Another solution is to install the auxiliary hoist with a lateral movement.

Electrotechnical Equipment

As aforementioned repeatedly, an extravagant expenditure based on the slope within the different load cases and the tolerances within the complete kinematic load-chain occurred during the commissioning phase.

One of the main improvements with regard to reliability and precision therefore should be the use of direct measuring systems, which detect the relevant positions of the payload (shielded tube) direct or at least minimises the measured value tolerances.