R-08-43

KBS-3H

Horizontal emplacement technique of supercontainer and distance blocks

Test evaluation report

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December 2008

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Box 250, SE-101 24 Stockholm
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ISSN 1402-3091
SKB Rapport R-08-43

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Summary

KBS-3H is an alternative method to the Swedish and Finnish reference design KBS-3V for the deposition of spent nuclear fuel. The KBS-3H project is a joint project between SKB and Posiva. The aim of the project phase 2004–2007 was to investigate if the KBS-3H method is a feasible concept or not. This report describes the full scale deposition equipment, which was developed and manufactured during 2005 and 2006 and the result and experiences from the full-scale demonstration with the equipment that was carried out on the KBS-3H deposition technique at Äspö HRL during 2007. The manufacturing and the demonstrations of the deposition equipment is also included in the new Integrated Projects within the European Commission 6th R&D program. This Integrated Project is called ESDRED ("Engineering Studies and Demonstration of Repository Designs"). The demonstrations/tests with the Deposition Equipment were successful. The tests performed have shown that the emplacement equipment tested is operating effectively for the transport & deposition of Supercontainers with a weight of 45 tons in horizontal drifts excavated in hard rock. Further tests are however required to verify the availability and the reliability of the equipment for a longer period of time. The tests have also disclosed a number of weaknesses that needs to be improved in the future. The report proposes a number of potential solutions for this. The tests have also shown that the integrity of the Supercontainer is not jeopardised during the handling/transport. In the performed tests, have however concrete been used as buffer. One uncertainty is how a bentonite buffer will withstand the handling/transportation. Further tests are also required for the transportation of Distance Blocks and also the demonstration that the machine is capable of placing the Distance Blocks in direct contact to the Supercontainer and protect the bentonite buffer from water.

Sammanfattning

KBS-3H är en alternativ metod till den Svenska och Finska referensmetoden KBS-3V för deponering av det använda kärnbränslet. KBS-3H är ett samarbetsprojekt mellan SKB och Posiva. Målet för projektfasen 2004–2007 var att utreda om KBS-3H-metoden är lämplig för deponering av det använda bränslet.

Denna rapport beskriver deponeringsutrustningen som utvecklades och tillverkades under 2005 och 2006 samt resultatet och erfarenheter från de fullskaletester/demonstrationer som genomfördes med deponeringsutrustningen i Äspölaboratoriet under 2007. Tillverkningen samt de demonstrationer som genomförts med deponeringsutrustningen ingår i de nya integrationsprojekten inom europakommissionens sjätte forsknings- och utvecklingsprogram. Detta integrationsprojekt kallas ESDRED (”Engineering Studies and Demonstration of Repository Designs”). Demonstrationerna och testerna genomförda med deponeringsutrustningen har genomförts med framgång. Testerna har visat att deponeringsutrustningen fungerar effektivt för transport och deponering av supercontainrar med en vikt av 45 ton i horisontellt borrade deponeringstunnlar. Ytterligare tester erfordras dock för att verifiera deponeringsutrustningens tillgänglighet och tillförlitlighet i ett längre tidsperspektiv. Testerna har också blottat ett antal svagheter som måste åtgärdas i framtiden. Åtgärdsförslag på dessa svagheter redovisas i rapporten.

Testerna har också visat att supercontainerns integritet inte äventyras under hanteringen. I testerna har dock betong använts som buffer i supercontainrarna istället för bentonit. En osäkerhet är hur en bentonitbuffer kommer att klara hanteringen.

Ytterligare tester erfordras för transport av distansblock samt verifiering att deponeringsmaskinen kan placera distansblock i kontakt mot supercontainern och skydda bentonitbufferten från vatten under hanteringen.

Contents

1 Introduction

KBS-3H is an alternative design to the Swedish and Finnish reference design KBS-3V for the deposition of spent nuclear fuel. The KBS-3H project is a joint project between SKB and Posiva. The aim of the project phase 2004–2007 is to investigate if the KBS-3H design is a feasible concept or not.

One part in the project is to demonstrate that the emplacement technique for Supercontainers and Distance Blocks. This part is also included in the new Integrated Projects within the European Commission 6th R&D program. This Integrated Project is called ESDRED ("Engineering Studies and Demonstration of Repository Designs"). It is conducted with the purpose to building industrial scale demonstrators for the following four technical areas.

ESDRED contains four technical modules as follows:

- Module 1: "Buffer construction technology"
- Module 2: "Waste canister transfer and emplacement technology"
- Module 3: "Heavy load emplacement technology"
- Module 4: "Temporary sealing technology"

The KBS-3H deposition design is one of the three different heavy load emplacement concepts included in the Module 3 of the ESDRED programme.

Partly financed by the European Commission, SKB and Posiva have for this purpose purchased and developed a deposition machine, ancillary equipment, Supercontainers and Distance Blocks.

2 Purpose

The purpose with this report is to describe the developed equipment and to summaries the result and experiences from the full-scale tests and demonstrations that was carried out on the KBS-3H deposition technique at Äspö during 2007. Recommendations regarding additional tests, improvement of the equipment and other critical issues are also included in the report.

3 Description of the KBS-3H design

3.1 General

The KBS-3H design is based on horizontal emplacement of several spent fuel canisters in a drift whereas the KBS-3V design calls for vertical emplacement of the canisters in individual deposition holes, see Figure 3-1.

3.2 Deposition drift

A typical layout of a KBS-3H deposition drift is illustrated in Figure 3-2 in which the so-called Supercontainers and Distance Blocks will be emplaced.

- Length of the deposition drifts is assumed to be up to 300 m.
- The diameter of the deposition drift is 1.85 m.
- The inclination of the deposition drift is 2° ± 1° (upwards).

The drift can, depending on site-specific conditions, accommodate up to 30 Supercontainers. The space between the Supercontainers will be filled with Distance Blocks.

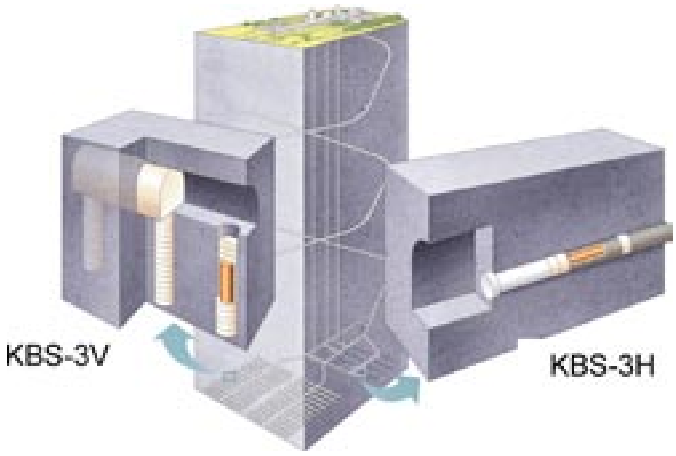


Figure 3-1. *Artist impression of the KBS-3 concept showing both the vertical deposition (KBS-3V) and the horizontal deposition (KBS-3H).*

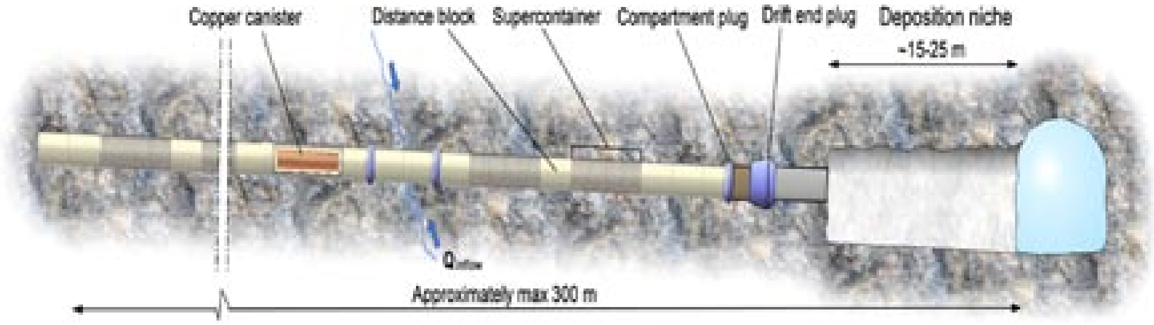


Figure 3-2. *Typical layout of the KBS-3H deposition drift.*

3.3 Supercontainer and Distance Blocks

Figure 3-3 shows an illustration of the Supercontainer, which contains the copper canister with encapsulated Spent nuclear Fuel (SF), the compacted buffer material and the perforated steel shell. The Supercontainer is provided with feet to allow the container to be transported with the deposition machine.

The Supercontainer has following dimensions and weight:

- Shell diameter 1,765 mm ± 5 mm
- Shell length 5,550 mm ± 5 mm
- Height of feet 45 mm[1]
- Weight approximately 45 tons

The SF canister exists in two variants for BWR respectively PWR fuel assemblies.

The BWR canister has space for twelve fuel assemblies and the PWR canister has space for four fuel assemblies see Figure 3-4.

For the tests were one Supercontainer with a BWR canister containing 12 fuel dummies and one Supercontainer with a PWR canister containing 3 fuel dummies (one fuel position free) manufactured. The free fuel position in the PWR canister was to simulate a scenario regarding the requirement of the maximum allowed residual heat effect of 1,700 W of the fuel, put in one canister. Free fuel positions in the canister create an unbalance, which was set as a functional requirement that the deposition machine should be able to handle.

Figure 3-5 shows an illustration of the Distance Block according to the DAWE and STC alternatives see ref. /1/. The Distance Blocks are circular blocks made of compacted bentonite without any supporting shell. Feet necessary for the transport are fixed directly to the bentonite block with expander screws.

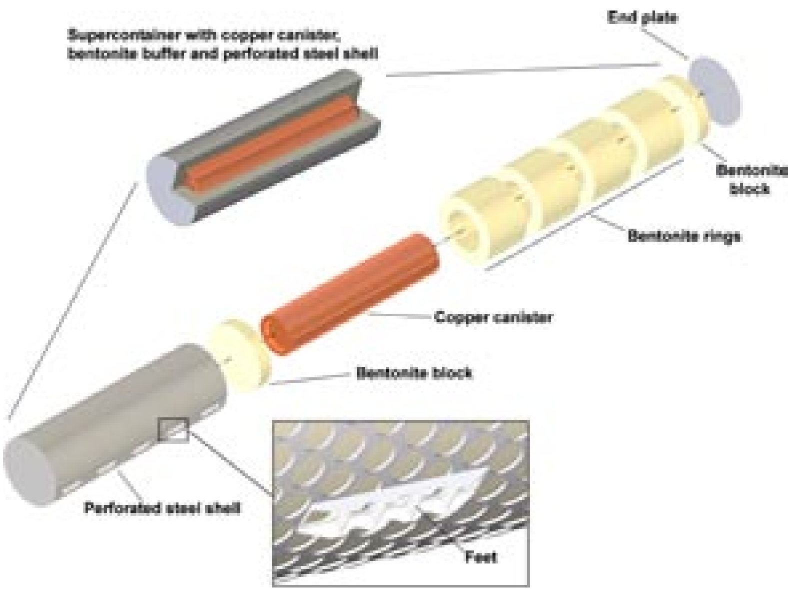


Figure 3-3. Supercontainer.

[1] Due to some introduced changes of the pallet has the feet height for the tests been changed to 50 mm.

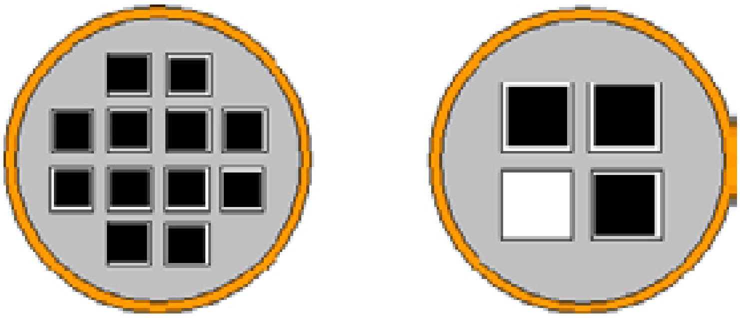


Figure 3-4. Cross section of the BWR canister (left) and the PWR canister (right).

Figure 3-5. Distance Block.

Depending on the final repository layout and site specific conditions can the total length of distance blocks between two Supercontainers vary. A length of approximately 1.7 meter is assumed for the SKB Forsmark site and a length of approximately 5.5 meter is assumed for the Posiva Olkiluoto site.

The Distance Blocks manufactured for the test have the following dimensions and weight:

- Diameter 1,765 mm ± 5 mm
- Length 900 mm
- Height of feet 45 mm
- Weight approximately 4.6 tons

For test purposes were the Supercontainers and Distance Blocks manufactured for the tests mock-ups with concrete instead of bentonite as buffer material. The mock-ups have however the real payloads and correct physical dimensions.

4 Deposition equipment

4.1 General

The equipment developed and manufactured during 2005 by CNIM, France, for the emplacement of Supercontainers/Distance Blocks consists of the following main components.

- Deposition Machine
- Start Tube for Deposition Machine with Transport Support
- Transport Tube for Supercontainer with Transport Support
- Control Room

Figure 4-1 shows a 3-D illustration of the set-up of the equipment manufactured for the tests that have been carried out at Äspö HRL level –220 during 2007 to verify in full-scale that the KBS-3H transport concept with water cushion technology is technical feasible for emplacement of Supercontainers and Distance Blocks.

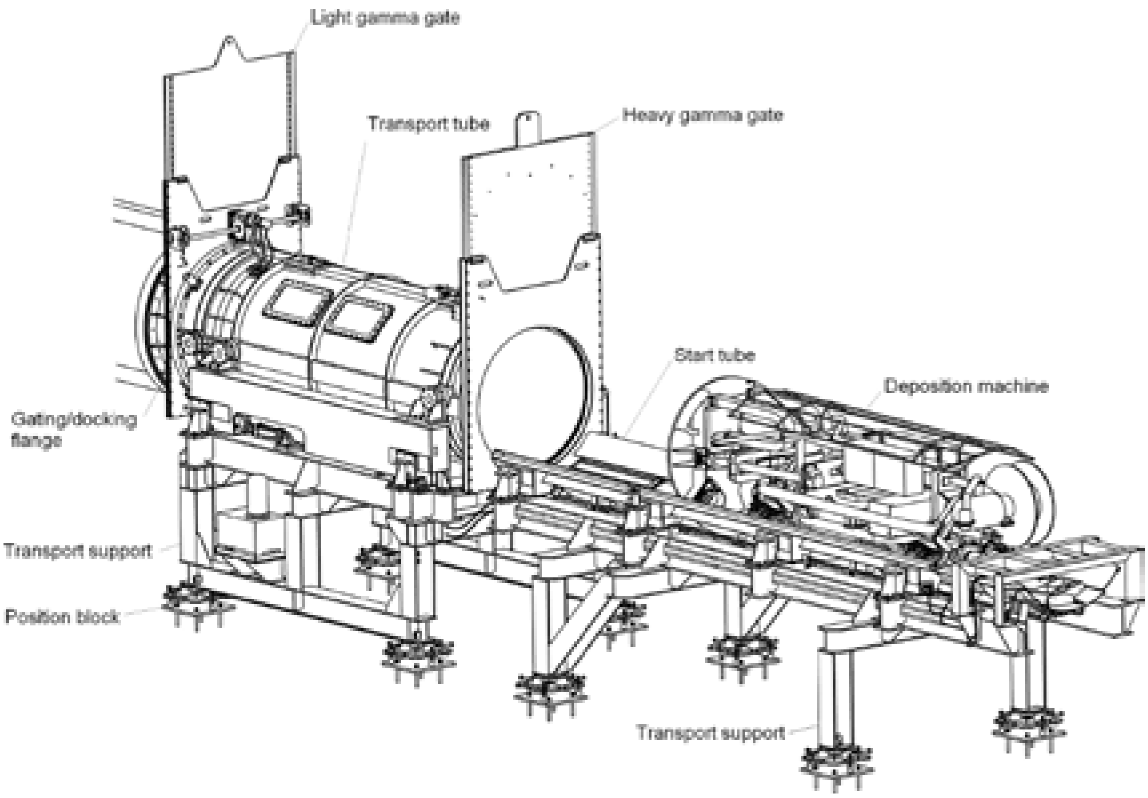


Figure 4-1. *3-D Lay-out of Deposition Equipment.*

For demonstration purposes has the following simplifications been made to the equipment:

- The deposition machine has been designed without consideration to radiation shielding. The machine is however provided with a 40 mm thick radiation shield and the radiation levels on the surface of the Supercontainer are considered to be relatively low. Performed calculations have indicated that the surface dose rate on the Supercontainer end plate is in the range of 0.5 mSv.
- The transport tube and the gamma gates are designed without consideration to radiation shielding.
- The start tube is just a "half" tube, in order to better observe the Deposition Machine during the demonstration. When handling real Supercontainers with SF canister the start tube will be closed for radiation shielding.
- The deposition drift has not been provided with a gammagate.
- Supercontainers and Distance Blocks are mock-ups with concrete instead of bentonite as buffer material. The mock-ups have however the real payloads and correct physical dimensions. The reason to use concrete instead of real buffer at this stage was that the main purpose to test the technology in large and secondly that manufacturing of the buffer would have required substantial investments in new manufacturing capability that was thought to be premature in consideration of the early design phase. The concrete buffer used for the integrity tests of the supercontainer and the distance blocks were a special unreinforced concrete mixture with mechanical properties close to bentonite.

4.2 Transport principle

The deposition equipment design is based on a transport principle where the Supercontainer is moved stepwise inside the drift. The process is repeated continuously until the Supercontainer is in the correct position in the deposition drift.

The Supercontainer, which is provided with feet, as described in section 3.3, is moved with help of a lifting cushion pallet, see Figure 4-11, and a slide plate placed in the space between the feet underneath the Supercontainer. The transport principle is described in Figure 4-2. The transport principle is chosen to reduce required forces needed to move the Supercontainer, which will minimize the risk for damage of the surrounding steel shell and the bentonite buffer. The same transportation principle is used for transport of Distance Blocks according to the DAWE and STC, ref. /1/.

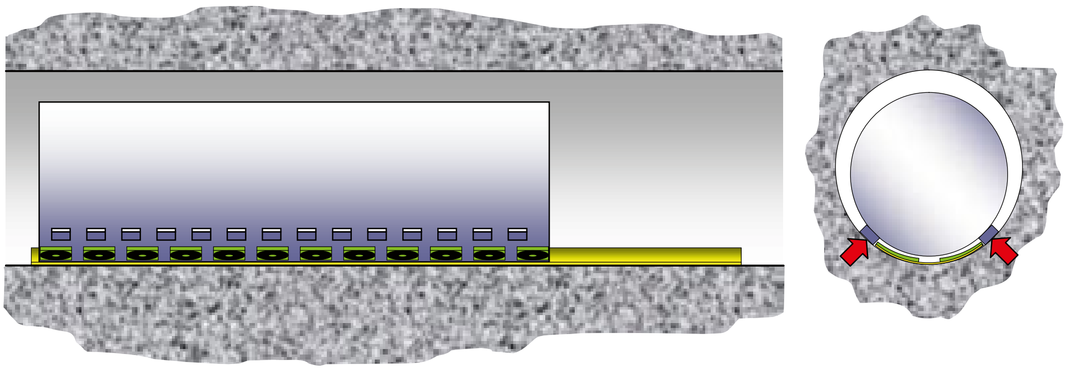
The used lift cushions are standard air cushions for heavy load handling that have been adapted to run on a cylindrical surface with water as pressure medium the function of the lifting cushion is show in Figure 4-3. Water as the pressure medium, instead of air was chosen after performed mock-up tests, which shown that water is more energy efficient than air.

4.3 Performance requirement

The performance requirement for the Deposition Machine is that the equipment should be able to deposit, as a minimum, one Supercontainer and required number of Distance Blocks per one day. The Deposition Machine is therefore designed to meet the operating performances listed in Table 4-1.

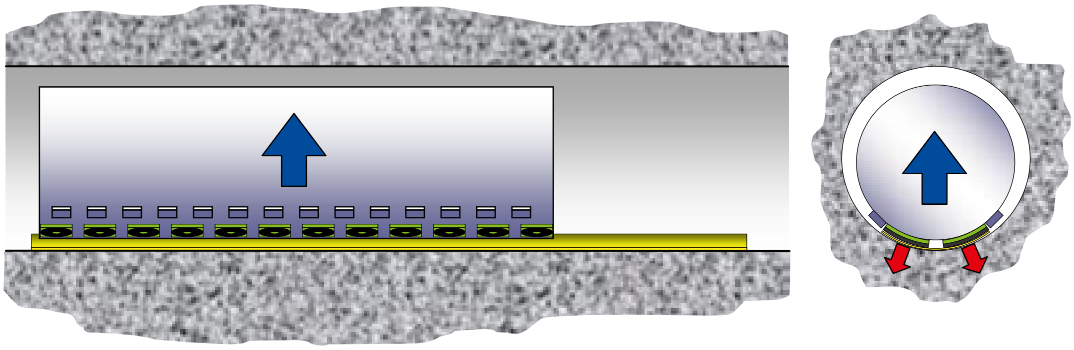
Table 4-1. Performance requirements.

Average Transport Speed with Supercontainer	Min 20 mm/s
Average Transport Speed with Distance Blocks	Min 30 mm/s
Transport Speed (only machine)	Min 100 mm/s



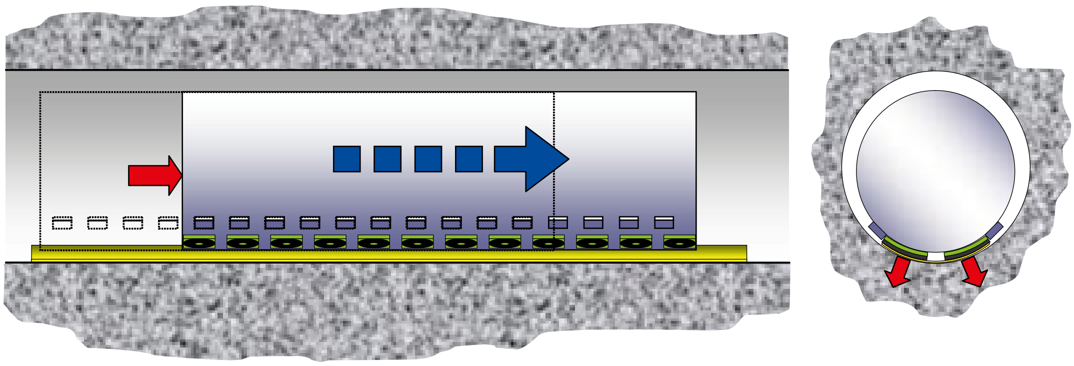
Step1

The Supercontainer is resting on its support feet (indicated with red arrows). The lifting pallet/slide plate located between the Supercontainer feet is inactivated.



Step 2

When the lifting cushions on the pallet are activated (indicated with red arrows) the Supercontainer is lifted. The Supercontainer floats on a thin film of water.



Step 3

Floating on the water film the Supercontainer is moved forward one stroke (1.5 meters) on the slide plate. After fulfilled stroke the lifting cushions are inactivated and the Supercontainer is lowered for support on the feet and the slide plate is moved forward to prepare for the next cycle.

Figure 4-2. *Schematic of the chosen transport principle.*

Step 1
Prior to inflation, the load is solidly supported on landing pads. These pads protect the lifting cushion from being crushed when the load is at rest.

Step 2
When water supply is applied to the lifting cushion, the cushion inflates, creating a seal against the slide plate surface and raising the load approximately 10 mm.

Step 3
When the pressure within the cushion is sufficient to offset the load's weight, water slowly and evenly escapes between the flexible cushion and the slide plate. The load is literally floated on a thin, nearly frictionless film of water.

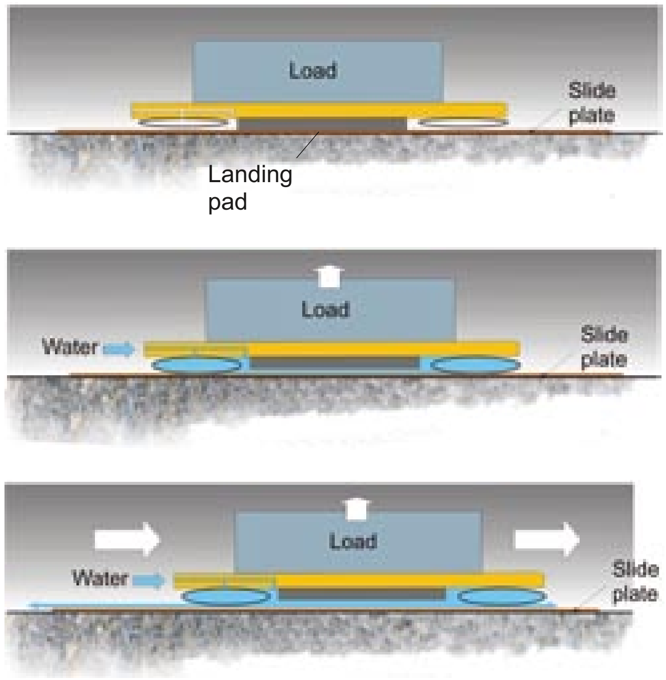


Figure 4-3. *Schematic illustration of the lifting cushion principle.*

The Deposition Machine is also designed to meet the following functional requirements that shall be verified during the tests (Input data and functional requirements are also listed in ref. /2/):

- The machine shall be able to position Supercontainers and Distance Blocks in contact with each other.
- Prevent that water comes in contact with the buffer.
- To handle an unbalanced Supercontainer.

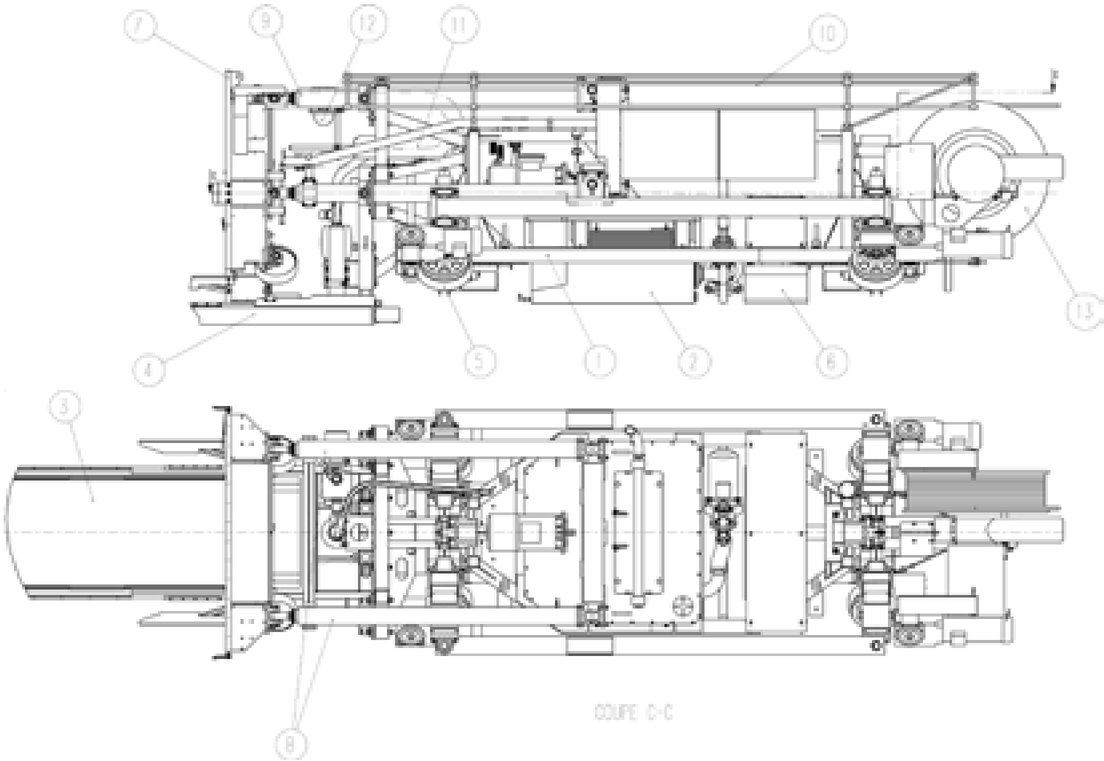
4.4 Deposition Machine

The main assembly drawing for the Deposition Machine is shown in Attachment 1.

The deposition machine Figure 4-4, Figure 4-5 and Figure 4-6 forms a complete unit with the sliding plate and the lift (water cushion) pallet. The main frame of the deposition machine consists of steel beams with rectangular cross sections. The machine is wheel driven with electrical gear motors on all wheels.

The wheel arrangements are mounted to the main frame with spherical bearings allowing for rotation between the main frame and the wheel arrangements. The wheel arrangement allows for active steering of the wheels. The position of the wheels is controlled by inclinometers on the wheel support.

The slide plate, on which the lift pallet is sliding on, is made of stainless steel and is attached to the main frame. The slide plate is in the front provided with two cameras with lighting facing forward and backwards, see Figure 4-9. The slide plate is also provided with sensors (forward and backward) for detection of obstacles in front of the machine and for positioning of the Supercontainer.



1 Main frame
2 Water system, tank, main pump
3 Lifting pallet
4 Slide plate
5 Drive wheels for the machine
6 Ballast
7 Radiation shield
8 Actuators
9 Actuators
10 Electrical cabinet
11 Fire extinguishing system
12 Video camera
14 Cable reel

Figure 4-4. *Deposition Machine main components.*

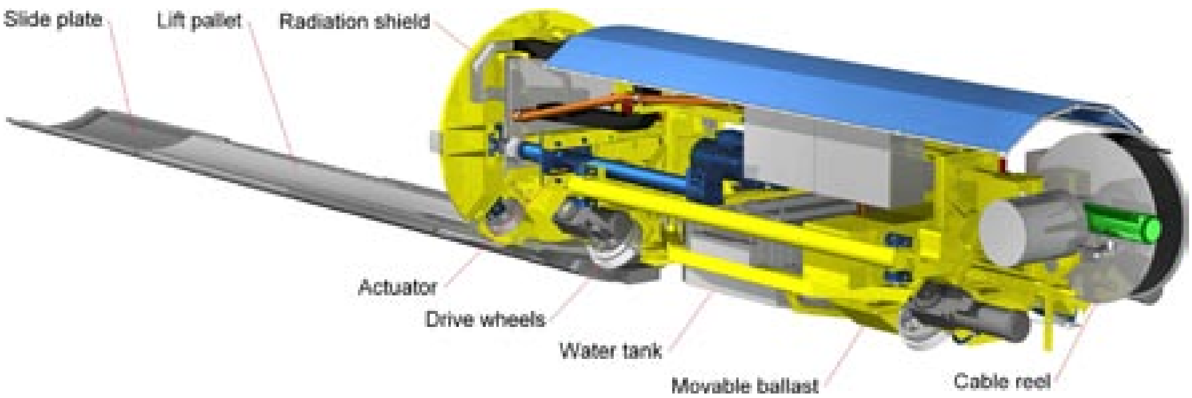


Figure 4-5. *3-D Illustration of the Deposition machine, view from back left side.*

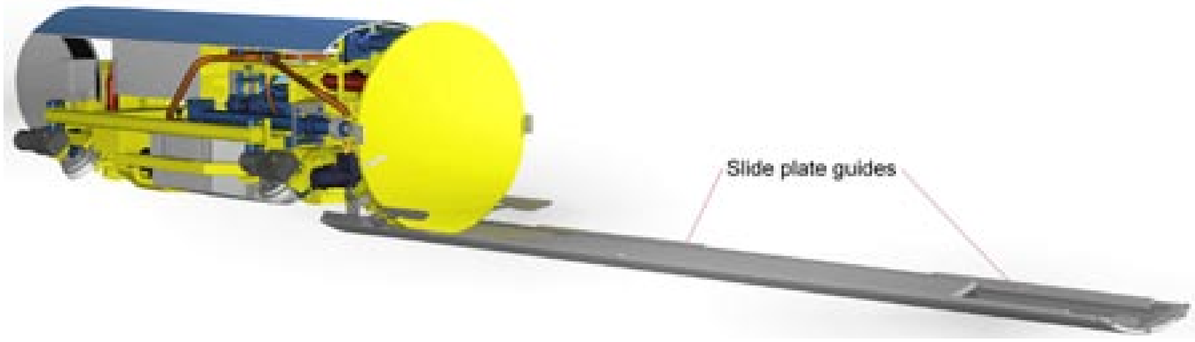


Figure 4-6. *Deposition Machine, view from front right side.*

The lift pallet is attached to the radiation shield, which is connected to the machine frame via three synchronized actuators allowing for the stepwise movement. The stroke of the actuators is 1,500 mm.

The lift pallet is guided on the slide plate to prevent rotation of the Supercontainer during transportation, see Figure 4-7. The position/orientation of the machine and the Supercontainer is continuously monitored and adjusted by means of an inclinometer on the radiation shield and the movable ballast on the machine.

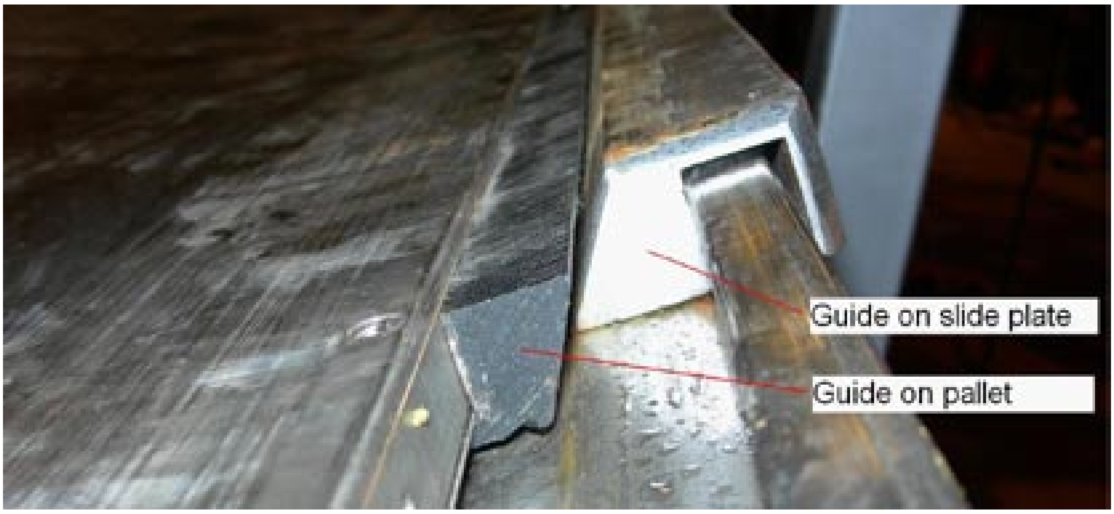


Figure 4-7. *Guides between the pallet and the slide plate.*

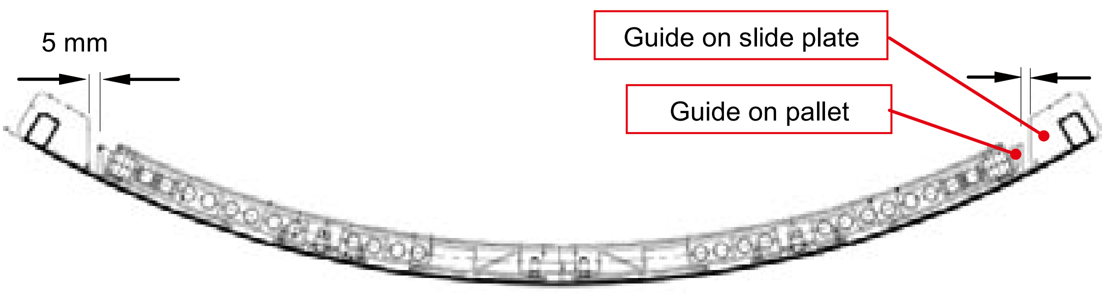


Figure 4-8. *Cross section of the pallet and slide plate showing the gap between the guides.*

Figure 4-9. *Front of slide plate.*

For centring of the slide plate/pallet between the Supercontainer feet is the radiation shield provided with “forks”, see Figure 4-10. The feet also ensure that the Supercontainer not can rotate relatively the radiation shield.

On the machine used for the tests at Äspö is the slide plate and the pallet made demountable to allow them to be retracted underneath the machine to minimize the overall length during transport.

The lift pallet, which is provided with 24 water cushions in two longitudinal rows left/right, is shown in Figure 4-11.

The water cushions are inter-connected in pairs along each side, except for cushions in rows 1, 4, 7 and 10, which are cross connected between the left and the right side to allow for cushion selection, in case of transport of Distance Blocks (whose weight is lower than that of the Supercontainer), see Figure 4-12. The cross connected cushions in rows 4 and 10 are normally closed during transport of the Supercontainer, which means there are only 20 out of 24 cushions active at a time. This set-up has been chosen with regards to the cushion pressure/load behaviour. It appeared in the previous cushion tests that the cushion lifting height is sensitive to load and/or pressure changes. The sensitivity is however less at higher pressure. The set pressure is 2.7 bars with 20 cushions.

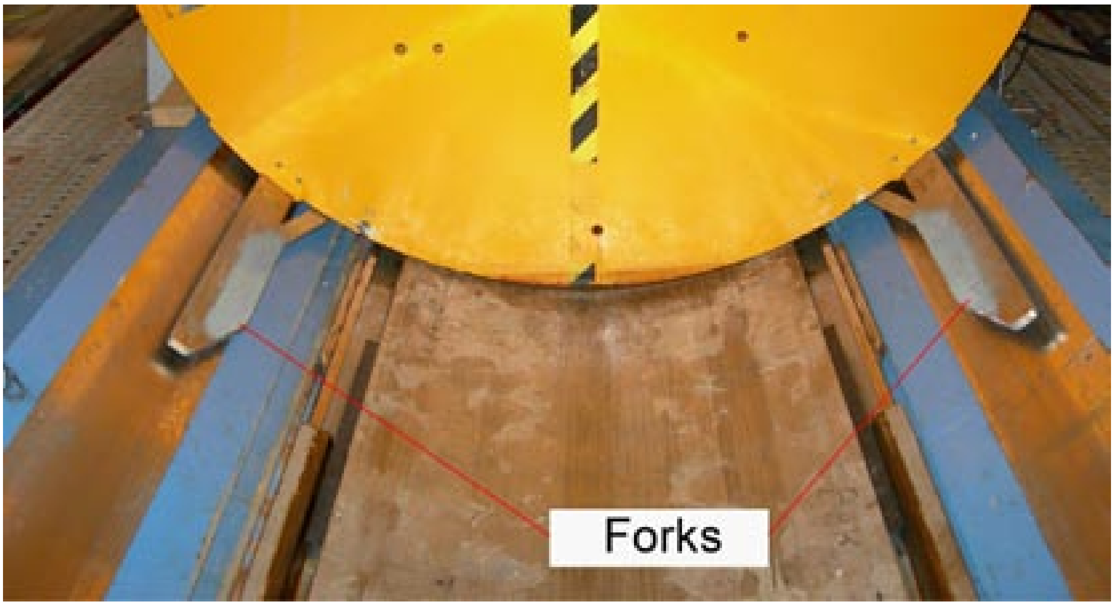


Figure 4-10. *Forks mounted on the radiation shield for centring of the container.*

__Figure 4-11.__ View of underside of the lift pallet during installation of water cushions.

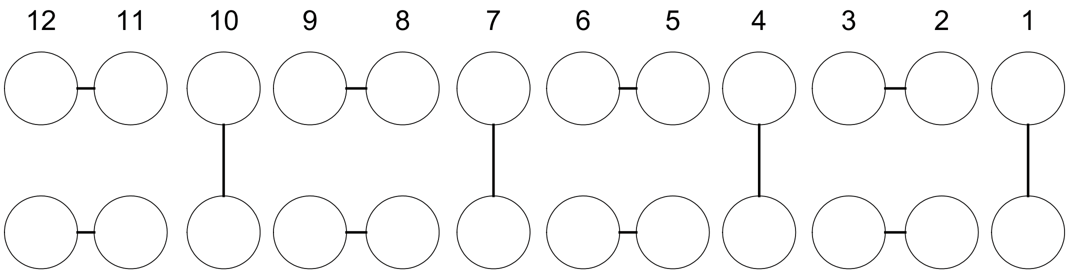


__Figure 4-12.__ Configuration of water cushions, all cushions are pair wise connected. Cushions in row 4 and 10 are normally closed during transport of the Supercontainer.

The pallet is also provided with four (4) lift sensors for indication of the lifting height, see Figure 4-13. The sensors are located between the cushions in row 4/5 and 11/12. The lift sensor is a simple toggle-arm fixed to the pallet and by gravity resting against the slide plate. The sensor has 5 fixed indication levels. The pallet is normally lifted 20–25 mm, which results in a lift of the Supercontainer of approximately 10 mm (space measured between the feet bottom part and the rock surface).

The water cushions are feed with water from a pump, which takes the water from a tank located at the middle of the machine. The water pumped out from the cushions is pumped back to the tank via a recovery pump located in a sump at the aft of the slide plate.

The pallet is designed to prevent water from coming in contact with the Supercontainer.

All electric power and communication is done via a cable with integrated optical fibres winded on a motor driven cable reel located in the aft of the machine.

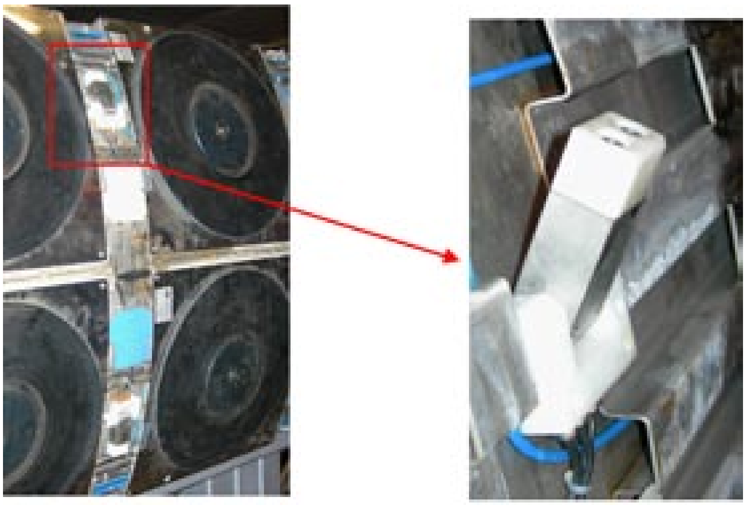


Figure 4-13. *Lift sensors.*

4.4.1 Safety features

The deposition machine is provided with several emergency/functional stops in case of danger.

In positions where there is a risk for personnel injuries by crushing between machine components the equipment is provided with visual warnings or protections.

The deposition machine can at any time, in case of failure, be pulled out back to the niche with a steel cable that is connected to the machine in the aft, see Figure 4-14.

The machine is provided with an automatic fire fighting system consisting of a powder system (9 kg) for machine components and a CO_2 system (2 kg) for electrical cabinets in case of fire.

Figure 4-14. *Winch for retraction of the machine.*

Figure 4-15. Fire extinguishers for electrical cabinet (left) and motors (right).

4.4.2 Performed improvements

The equipment described in the sections above is the result of changes found necessary after the pre tests performed at Äspö during 2006 before the commence of the SAT. The major introduced changes are:

- Installation of guides between the slide plate and the water cushion pallet.
- Lift sensors for the pallet to be able to verify the actual lifting height.
- Installation of new water cushions.
- Installation of a third actuator for movement of the radiation shield /water cushion pallet.
- Frequency converter for the water pump to allow for optimisation of the water flow to the cushions.

Guides

Originally was one requirement that the deposition machine should be able to handle Supercontainers with SF canisters with free fuel positions due to the requirement regarding the maximum allowed residual heat effect of the fuel, put in one canister as described in section 3.3. Free spaces in the canister can when placed in the Supercontainer create an unbalance. It was however shown during the pre tests concluded that it is impossible to handle Supercontainers that are unbalanced. **Therefore have all tests been performed with balanced Supercontainers.**

The problem was revealed when the water pallet got stuck between the side beam on the slid plate and the Supercontainer see Figure 4-16.

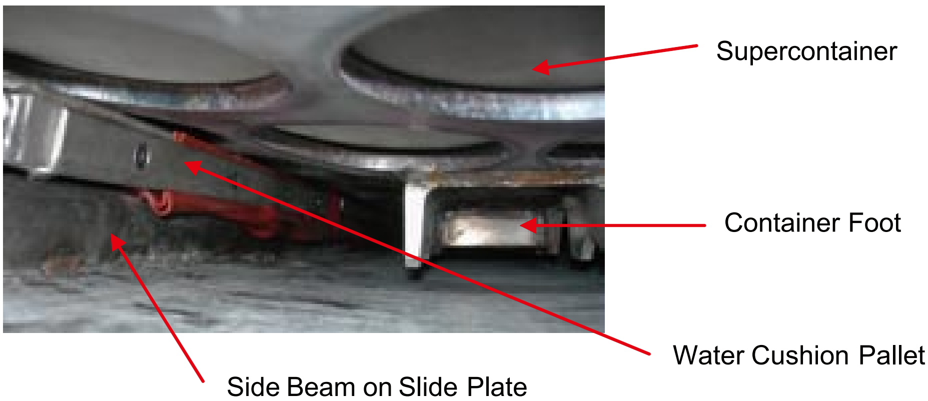


Figure 4-16. Pallet stuck between the container and the slide plate side beam.

It was concluded that the ballast (balancing system) on the machine could not prevent or control the rotation of the container. This led to a number of different proposals that were evaluated and tested. One of the first steps taken to evaluate the behaviour of the system was to make the container well balanced. This showed that the ballast system on the machine was only capable to balance the container in a static situation and not when moving the container forward/backward. As soon as the container was moved it started to rotate left or right. The rotation of the container happened very quickly and could therefore not be corrected / controlled with the balancing system on the machine. Some of the attempts to make the system more stable included the following actions: reconfiguration of the water cushions, and a rising of the rotation centre above the container centre of gravity. All attempts however had only marginal effect and it was therefore concluded that the only way to keep the container from turning during transport was to guide the pallet against the slide plate edge (by installing a guide system) to prevent rotation. The guides are shown in Figure 4-17.

When the guides were introduced resulted this in that the present splashguard had to be removed due to space limitations. All tests have therefore been performed without any splashguard.

Lift sensors

Lift sensors was installed for verification that the pallet is not lifted more than what is allowed for a proper function of the guides on the pallet and the slide plate.

New water cushions

Another problem that was observed is that the lifting height is very sensitive to pressure or load changes. One crucial point with the installed guiding system is the need to accurately control the lifting height and not lift too high; it was therefore decided to perform additional tests on the cushions to verify the actual lifting height in a workshop test. This test was carried out at CNIM's subcontractor ECA's workshop in Toulon, France.

The test bench used for the tests is shown in Figure 4-18. The test bench only allowed for static testing of the cushions. The cushion force was measured for different water pressures and for different fixed heights. The test bench also allowed for tilting of the cushion and measurements of vertical forces due to the tilting.

The main result is shown in Figure 4-19 and it can be seen that the original cushions (manufactured by Bertin), which are marked in blue in the diagram, are very sensitive to small variations in pressure. The cushions are also lifting very high and the lifting height is in practice almost impossible to control.

A different type of cushion from another manufacturer, Solving (Finland), was also tested. The result is marked in red in the diagram, Figure 4-19.

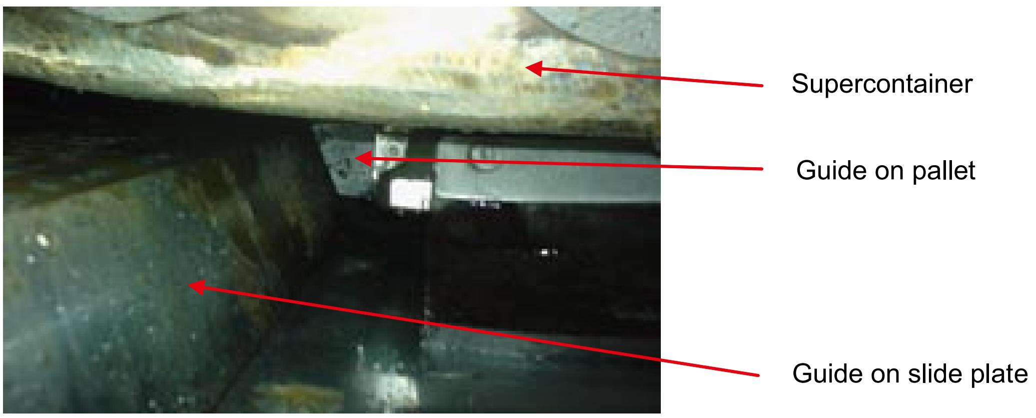


Figure 4-17. *Guiding devices between pallet and slide plate.*

Figure 4-18. *Test bench for cushions at ECA's premises.*

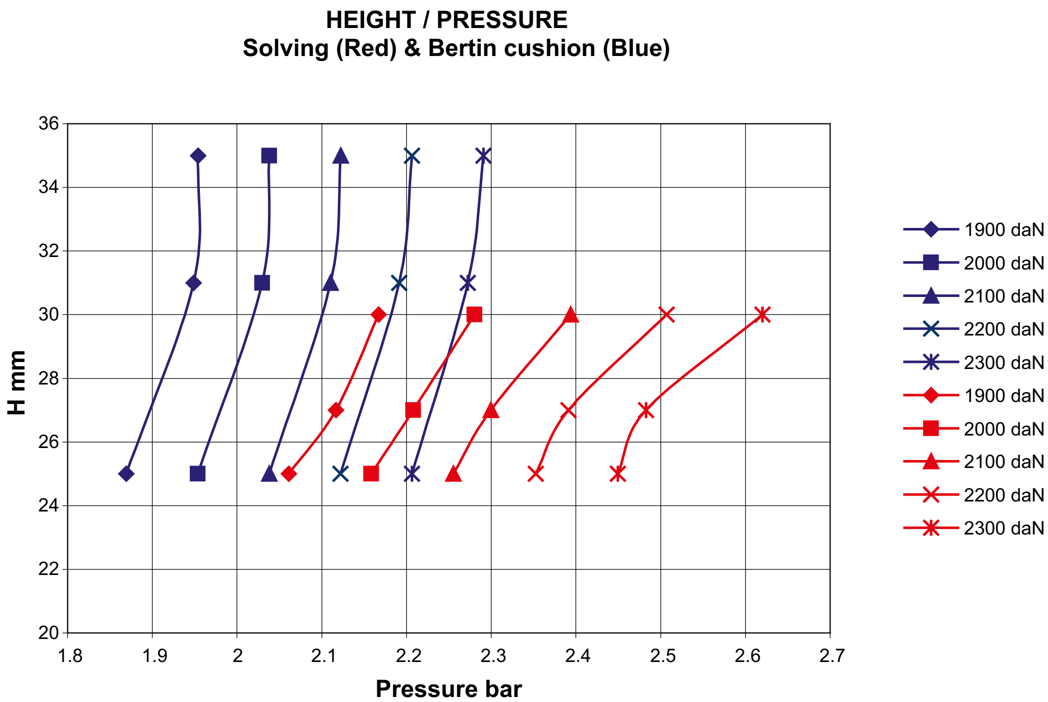


Figure 4-19. *Results from cushions tests (Solving in red, Bertin in blue).*

A comparison between the tests shows that the cushion from Solving has less maximum lifting height and is also less sensitive to pressure and load variations.

It was therefore decided to change existing cushions from Bertin to cushions from Solving: it was considered more likely to obtain a positive result with the Solving cushions than with the original cushions manufactured by Bertin, because of the lower lifting height and because the cushions are less sensitive to pressure and/or load changes.

Water flow control

From the beginning was the idea to have separate control of the water flow to each cushion. The flow should with simple manual valves be controlled individually to each cushion. This control was however not possible due to the sensitivity of the cushions as described above.

Instead of the valves was a frequency converter installed to the pressure pump and the water flow is distributed to all cushions without any additional control. The pressure can be set via the control interface.

Third actuator

A third actuator was installed to minimise the flexion between the radiation shield and the pallet, which can lead to fatigue of the pallet. The third actuator will also ensure the correct position of the radiation shield. See illustration Figure 4-20.

4.5 Control system

The general architecture for control and electrical power for the equipment is shown in Figure 4-21 below.

The control system is in detail described in the "User Manual".

The Human Machine Interface (HMI) is built with the WinCC software, which allows the operator to watch the moving of the deposition machine and the Supercontainer or Distance Blocks in real time.

Operator's supervision monitors and controls in the control room are shown in Figure 4-22. The operator has one monitor for the HMI, one monitor for the movable camera on the machine and on monitor for the cameras on the slide plate.

The illustrations below are example of the presentation of what the HMI-system can present to the operator.

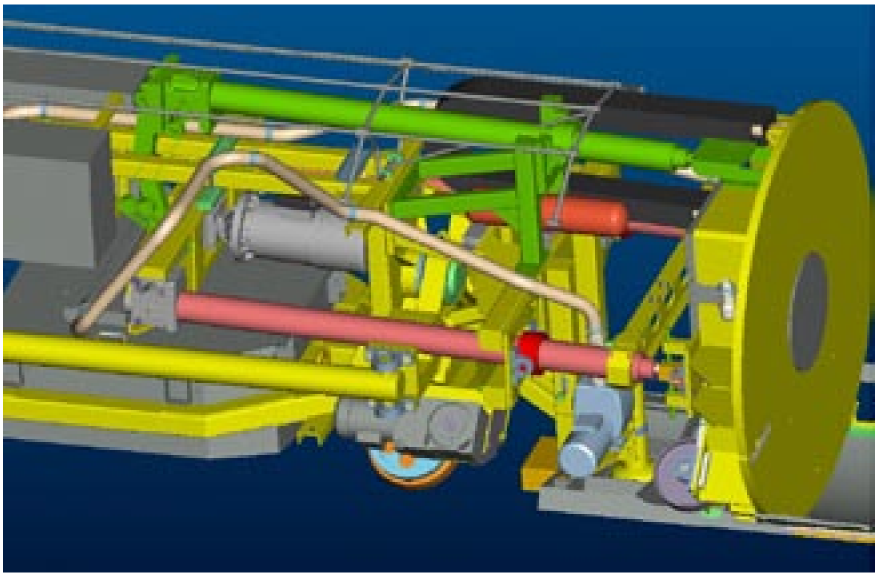


Figure 4-20. *The third actuator is viewed in green.*

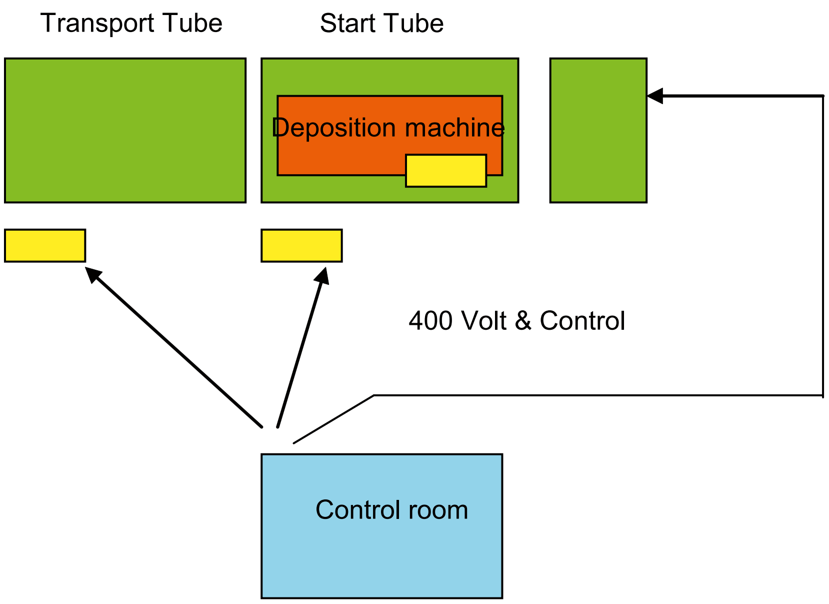


Figure 4-21. *General Architecture.*

Figure 4-22. *Equipment in the Control Room, (monitor for movable camera on the machine, right – monitor for HMI, middle – monitor for cameras on the slide plate, left).*

The operator can choose between the following screens on the HMI:

- Overview
- Deposition Machine
- Niche Arrangement
- Reverse Equipment
- Fault Messages
- Maintenance
- Flow Diagram
- Trends
- Reports
- Wheel Control

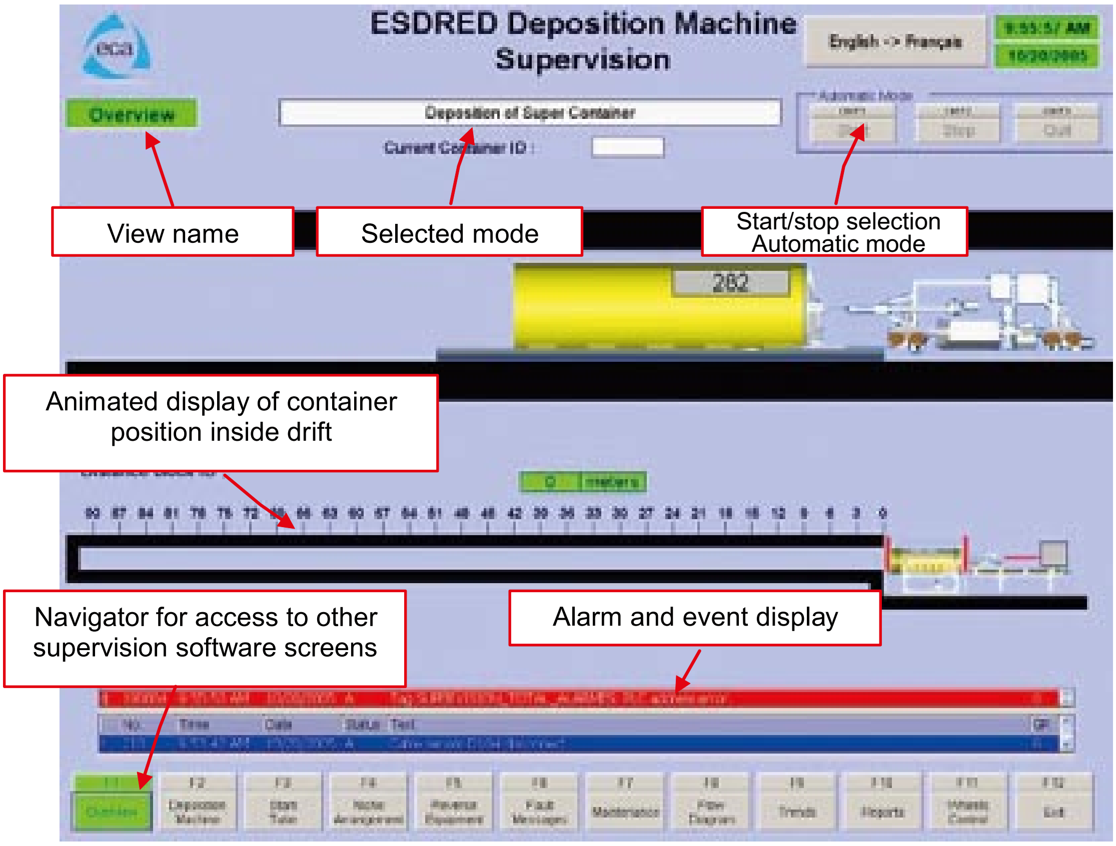


Figure 4-23. *Overview Screen Transportation of Supercontainers.*

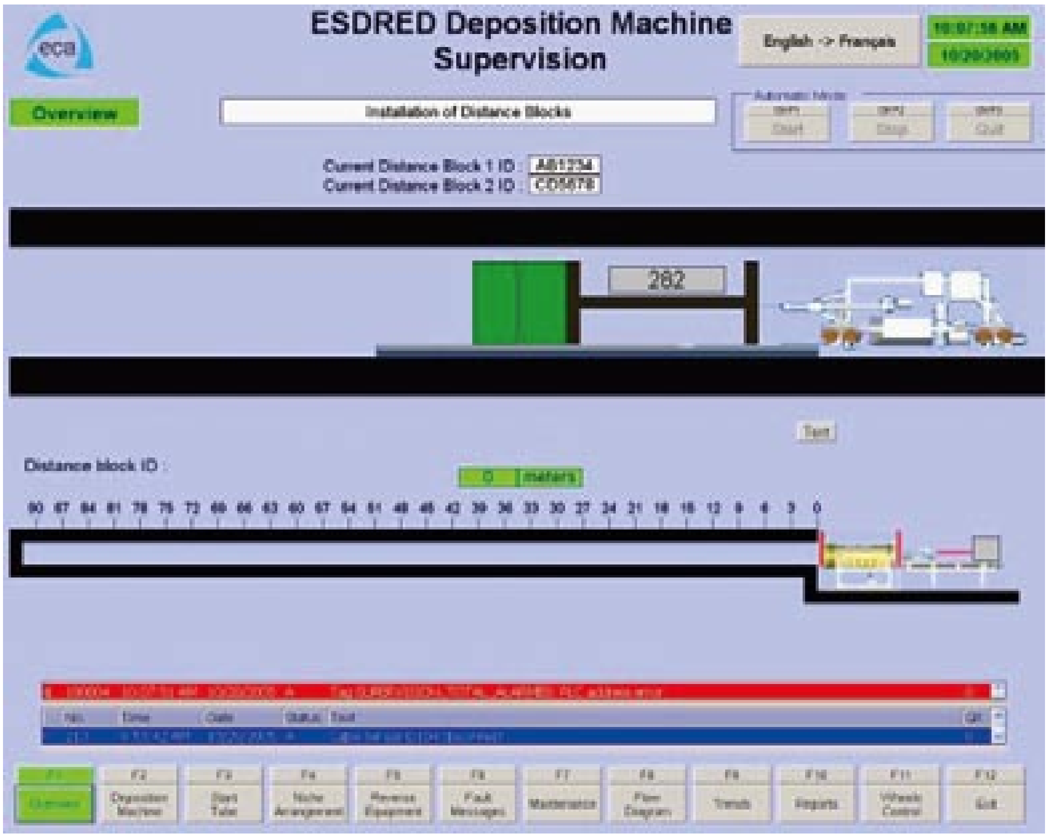


Figure 4-24. *Overview Screen Transportation of Distance Blocks.*

In the “Deposition Machine” screen, see Figure 4-25 and Figure 4-26 the operator can select the following various operating modes:

- "Manual mode"
- "Preparation for deposition/installation of Container/Blocks "
- "Deposition of Supercontainer "
- "Installation of Distance Blocks"
- "Retrieval of Supercontainer"
- "Retrieval of Distance Blocks"
- "Return of machine after deposition/installation of Container/Blocks"
- "Preparation for retrieval of Container/Blocks"
- "Pendant"

In this screen the operator can see all operating parameters.

Depending of mode selected the operator get access to different controls. In the mode “Manual” the operator get access to operate all functions manually.

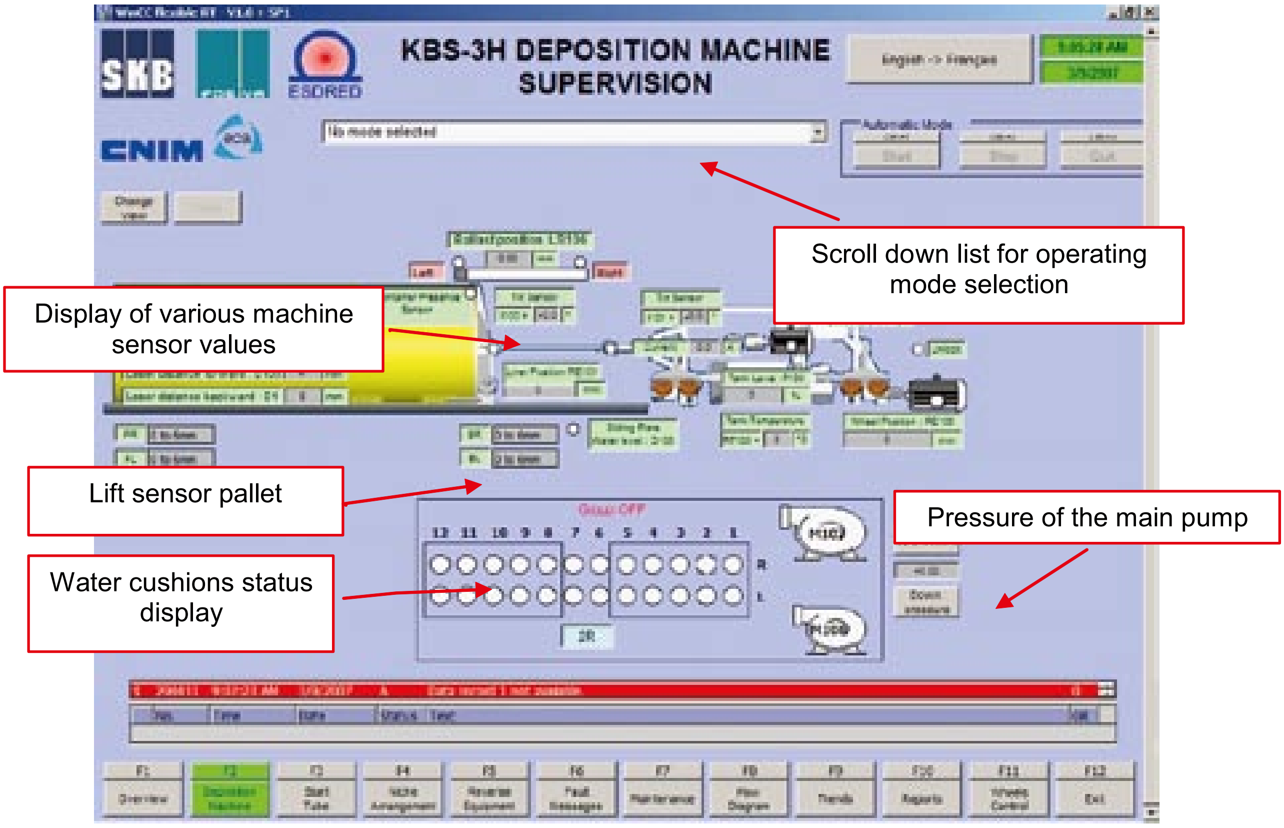


Figure 4-25. *Deposition Machine Screen (Supercontainer).*

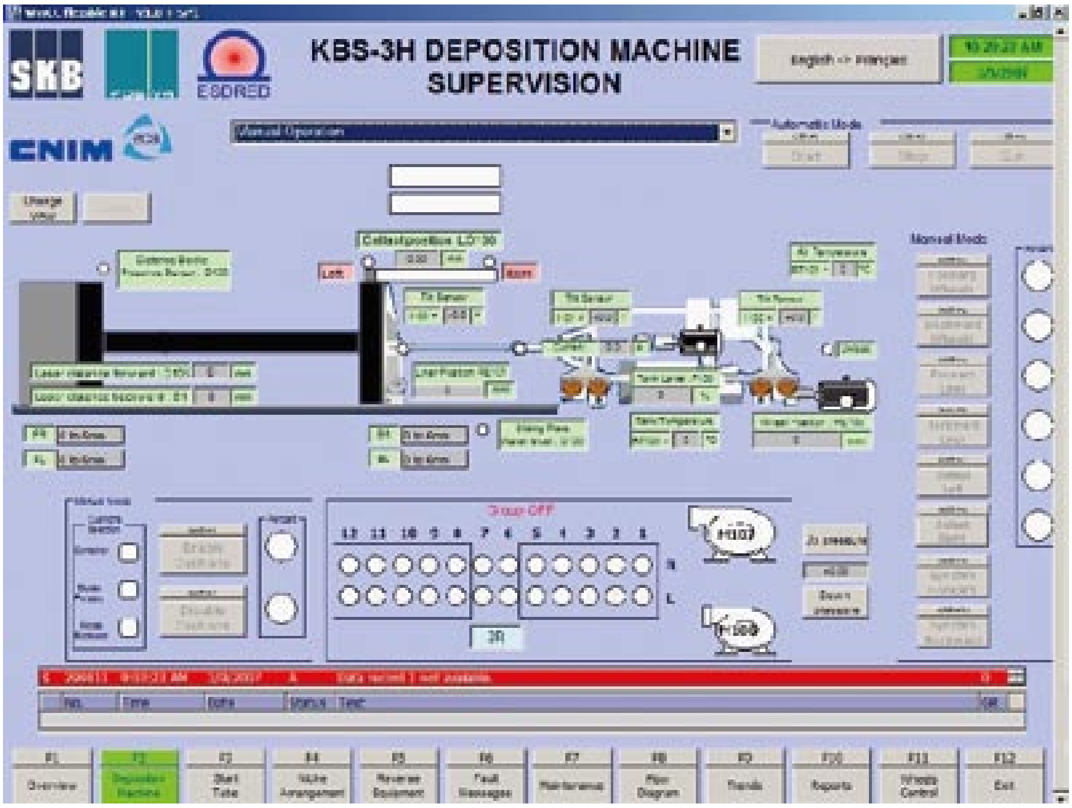


Figure 4-26. *Deposition Machine Screen (Distance Blocks).*

4.6 Start Tube and Transport Support

The main assembly drawing for the Start Tube and the Transport Support is shown in Attachment 2.

The transport support for the deposition machine is designed to allow for transport with SKB's existing transport vehicles.

The Transport Support is provided with a, in longitudinal direction, movable cradle "start tube", on which the Deposition Machine is parked, allowing the "start tube" for docking to the Transport Tube. The start tube is manoeuvred with help of two hydraulic actuators.

To minimise the overall length of the start tube is the slide plate and pallet during transport retracted underneath the deposition machine. The slide plate and the pallet can after docking to the transport tube be slide into position with help of a feeder on the start tube.

For demonstration at Äspö HRL is the start tube just a "half" tube, in order to better observe the Deposition Machine during the demonstration. When handling real Supercontainers with SF canister the start tube will be closed for radiation shielding.

The transport support is provided with a winch allowing for retraction of the deposition machine from the drift in emergency situations. The winch wire is attached to the deposition machine at the aft.

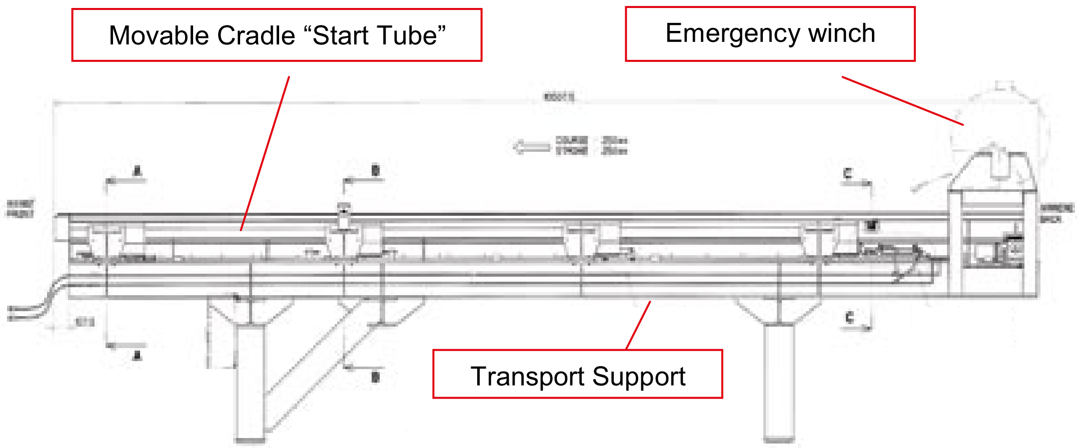


__Figure 4-27.__ Side view of the "Start Tube/Transport Support".

4.7 Transport Tube and Transport Support

The main assembly drawing for the Transport Tube and the Transport Support is shown in Attachment 3.

The Transport Tube is designed to allow for handling of the Supercontainers in both vertical and horizontal positions to allow for a radiation-shielded transportation of the Supercontainer between the assembly hall and the deposition drift. The Transport Tube is provided with trunions allowing the transport tube to be lifted with a special lifting beam. The Supercontainer, which is assembled in a vertical position, is lifted inside the Transport Tube and tilted to a horizontal position on the transport support with help of a overhead crane, see Figure 4-28.

The transport tube is provided with detachable radiation shielding gates named light gamma gate and heavy gamma gate. The heavy gamma gate is designed for the Supercontainer load when the transport tube is in a vertical position. The light gamma gate is not designed for any external loads and is only a mock-up. The gates are of the type "sliding" gates are provided with a hydraulic operated rack and pinion drive.

The transport tube is provided with two inspection windows to allow for view inside the tube, as this equipment will be used for demonstration for the public. The transport support is on the inside provided with necessary guides supporting and locking for the Supercontainer during handling/transport from the reloading station to the chamber with the deposition equipment. Supporting of the Supercontainer inside the transport tube, when tilted, is achieved by inflatable air bladder in the top of the transport tube.

__Figure 4-28.__ Tilting of the transport tube. Only the heavy gamma gate is mounted to the transport tube.

The transport tube and gamma gates for the tests are designed without any consideration to radiation shielding.

The transport support for the present test equipment is designed to allow for transportation with SKB's existing transport vehicles.

The Transport Tube is resting on a movable cradle to allow for docking of the transport tube to the drift entrance. The movable cradle is supported on the transport support and manoeuvred with help of two hydraulic actuators.

The transport support is designed to allow for transportation with SKB's existing transport vehicles.

The transport tube with gamma gates resting on the transport support is show in Figure 4-29.

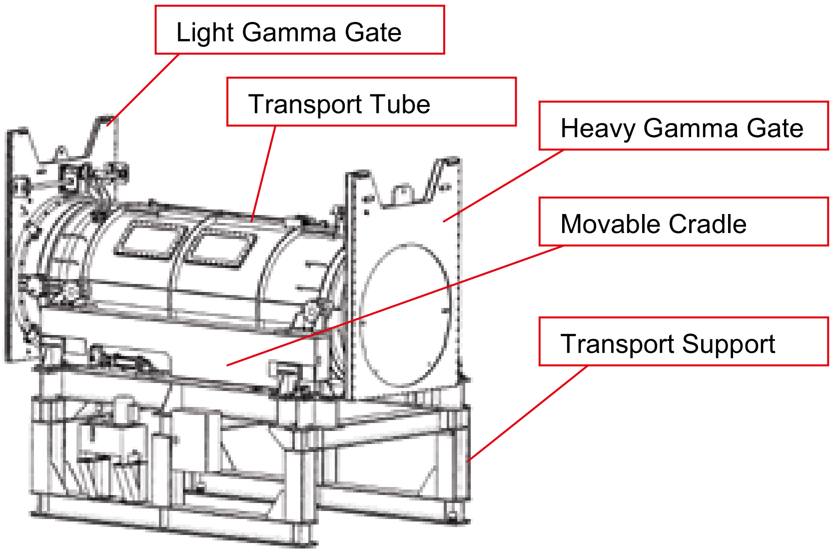


Figure 4-29. *3-D illustration of transport tube with gamma gates resting on the transport support.*

5 Performed tests

5.1 General

Following demonstrations and test was performed during the period March to October 2007:

- SAT (Site Acceptance Test) of the Deposition Equipment.
- Initial transportation tests with Supercontainer.
- Endurance tests with Supercontainer.
- Distance Blocks transportation tests.
- Supercontainer integrity test.

5.2 Test objectives

The main objectives for the tests were:

- In full-scale verify that the KBS-3H design with water cushion technology is technical feasible for emplacement of Supercontainers and Distance Blocks in a horizontal disposal drift with small tolerances.
- To test the reliability and availability, in a longer perspective, of the developed machine and ancillary equipment.
- To demonstrate the integrity of the Supercontainer and Distance Blocks during the deposition process. The Supercontainer and the Distance Blocks are not a part of the scope in the ESDRED project Module 3.

5.3 Test site

The tests on the KBS-3H Deposition Equipment that were performed at Äspö HRL started in March 2007. The tests was performed in the niche at level –220 m, see Figure 5-1, where a 95-meter long drift have been excavated.

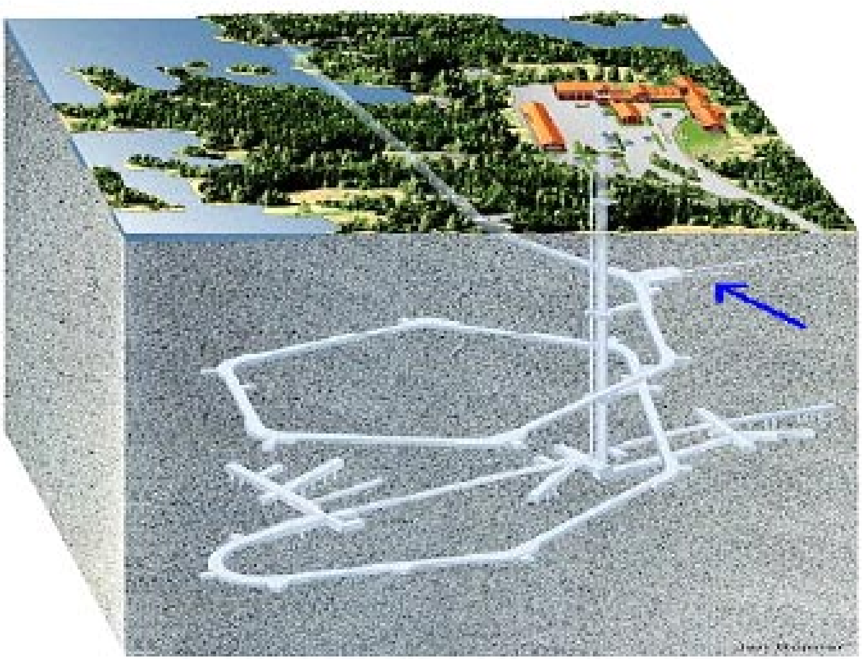


Figure 5-1. *The arrow is pointing on the niche at level –220 m at Äspö HRL.*

Figure 5-2. Set-up of equipment at the test site at Äspö HRL, level –220 m. The Supercontainer is inside the transport tube with the shielding gamma gates open. The control room is on the left side on this photo.

Figure 5-2 shows the set-up of equipment and the control room at the test site.

For positioning of the equipment in the niche has adjustable position blocks been embedded in the niche floor and the drift entrance has been provided with a flange allowing for docking of the transport tube to drift.

Even though that positioning blocks had been installed in the niche floor for positioning of the equipment was a lot of time spent with the work to set-up the equipment due to manufacturing tolerances of the equipment. It is especially the tolerances of the start tube that have caused problems. Adjustments had to been done several times before it could be considered sufficient but still not really good.

For access around the equipment are scaffolding platforms erected on each side of the machine.

5.4 SAT (Site Acceptance Tests)

The purpose of the SAT is to verify the function of the equipment and consist of:

- Pre-operational tests of all mechanical and electrical systems to assure proper operation before and after transport to the Test Site.
- Verification that the deposition machine is functionally complete and capable of emplacement of Supercontainers and Distance Blocks.
- Verification that the deposition machine fulfils the requirements listed in the "Functional Requirements".

All tests from the **SAT** have been recorded and documented in the test sheets. What follows is only an overview of the main observations and results made during the tests.

The first tests with the machine showed, that there is a high risk that the rotation about the long axis of the container could increase cumulatively each time the container is moved due to the gap between the guides on the pallet and the slide plate. The gap is 5 mm, which allows the container to rotate approximately +/– 0.2–0.3 degrees every 1.5 m step.

Tests showed however that this could be controlled with the ballast if the correction is done, as soon as an inclination deviation is indicated / observed. Therefore, the ballast system has been made active in automatic mode to compensate for the rotation that can occur within the remaining gaps between the guides.

An other observation made is that if the container together with the pallet and the slide plate is rotated more than 3.5–4 degrees, then this movement can create problems for the good functioning of the water cushions (due to the uneven load distribution which will result from such a configuration). As described in section 4.4.2 are the water cushions sensitive to load variations. The problem that occur with a too important rotation is that the cushions, which get more loaded than normal are not able to lift the container. It is therefore considered not possible to properly handle an unbalanced Supercontainer with the present water cushion system.

It was also observed during the tests that the system is sensitive to alignment between the emplacement equipment and the drift. It is also of importance to have the best possible initial alignment between the deposition machine and the Supercontainer (which means that the initial position of the Supercontainer in the transport tube is very important too).

Besides the change of the requirement that the machine should be able to handle unbalanced containers, all the other requirements have been fulfilled.

After completion of the first check tests, the Supercontainer was transported approximately 20 meters into the drift, see Figure 5-3. Both manual mode and automatic modes were tested.

The average deposition speed reached during the **SAT** when running in automatic mode was measured to be approximately 15 mm/s, which is lower than the performance requirement of 20 mm/s and the speed reached during the **FAT** (19.8 mm/s). It was however at the time considered possible to reach the pre-determined requirements if the cycle times for lifting and lowering were further optimised.

The cycle times those were measured for the transport and deposition of the Supercontainer is listed in the Table 5-1.

Due to time restraints, the deposition and recovery of Distance Blocks was not tested. This transportation is however considered to be easier than the transportation of the Supercontainer and it was decided that this could be tested later during the SAT.

Table 5-1. Achieved/measured cycle times and average transportation speed during the SAT.

Lifting of container	35 s
Container transport	19 s
Lowering of container	35 s
Machine transport	11 s
Total Cycle Time	**100 s**
Travel Distance	1,487 mm
Average Transport Speed	**14.9 mm/s**

Figure 5-3. *The deposition machine has entered the deposition drift – The Supercontainer is placed approximately 20 meters into the deposition drift (right.)*

The emergency retraction system was also tested during SAT. The machine was parked inside the drift approximately 20 meters from the entrance and pulled out to the start tube without problems. However the winch is not provided with any wire guide, which causes problems with the distribution of the wire on the wire drum, see Figure 5-4.

5.5 Initial transportation tests with Supercontainer

The initial tests performed directly after the SAT was associated with number of problems mainly related to the water control valves and sensor allowing the machine to operate in automatic mode.

The performance requirement for the average deposition speed of 20 mm/s was however finally reached after correction/adjustment of the water cushion control valves. The cycle times that were measured for the transport and deposition of the Supercontainer are listed in the Table 5-2.

5.5.1 Disturbances/interruptions

The causes for disturbances/interruption are described below:

Automatic mode

During the initial test period was it in the beginning not possible to operate the machine in automatic mode due to sensor failure. The slide plate is in the very front provided with an ultrasonic sensor for detection of obstacles in front of the slide plate. If the sensor is broken the control system interpret this as an obstacle is in front of the slide plate and blocks automatic operation.

Table 5-2. Achieved/measured cycle times and average transportation speed during the initial transportation test period.

Lifting of container	28 s
Container transport	19 s
Lowering of container	16 s
Machine transport	11 s
Total Cycle Time	**74 s**
Travel Distance	1,487 mm
Average Transport Speed	**20.1 mm/s**

Figure 5-4. *Emergency retraction winch.*

Water control valves

The water cushion control valves is however a permanent problem, since they have a tendency to jam after a period of operation. The problems are related to the function of the actual valve used. The valves are of the diaphragm type with the medium on both sides of the diaphragm, medium on the upper side of the diaphragm is also in contact with the core. Particles in the medium can cause the core to jam in the core tube. The problem is also related to the orientation of the valve and it has been observed that valves that are mounted up side down are affected more often. In our case are some of the inlet valves mounted up side down. The problem is corrected by manual cleaning of the valves. Figure 5-5 shows a section view of the valve and the arrangement of valves in the cabinet. As can by seen in Figure 5-5 is the space in the cabinet very limited, which make the cleaning of the valves difficult and time consuming.

The jamming of the valves causes the following problems:

- Uneven lifting (inlet valves)
- Uneven lowering (relief valves)
- Extreme cushion pressure (relief valves)
- Cycle times can not be kept (relief valves)
- Flooding.

The uneven lifting and lowering can cause rotation of the Supercontainer if one of the sides of the pallet is lifted/lowered slower than the other side due to the gap between the guides on the pallet and the slide plate. As described earlier, in section 5.4, will the rotation increase cumulatively for each step the container is moved, and the ballast can in this case not correct the rotation of the Supercontainer.

Jamming of the relief valves when they shall open can also cause extreme pressure in the cushion that can damage the cushions. This is the direct cause why two cushions had been changed quite early in the test period, see Figure 5-6.

The jamming of the valves will also affect the cycle times. The time for lifting and lowering will have a direct resulting on the transportation speed.

The jamming of the valves can also cause flooding of water on the slide plate due to the capacity of the recovery pump.

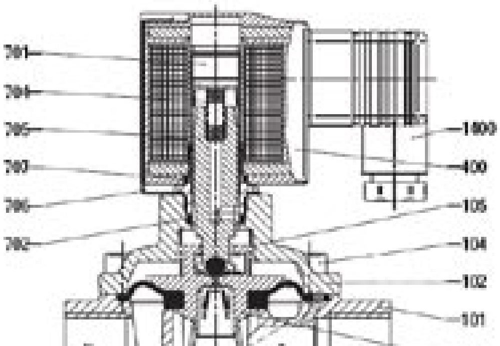


Figure 5-5. *Section view of water control valves and a picture of the valve cabinet.*

Figure 5-6. *Broken cushion due to high pressures.*

Pallet adjustment

There is no problem for the machine to control the rotation of the Supercontainer as long as the pallet is well aligned/adjusted, however the alignment/adjustment of the pallet is very sensitive and impossible to perform when the Supercontainer is parked in the transport tube. The whole pallet must be visible to perform the alignment/adjustment. Se also section 5.6.2.

5.6 Endurance tests with Supercontainer

According to the endurance test programme was the goal to make as a minimum one deposition and subsequent recovery of the Supercontainer per day (8 hour).

The tests were performed during the period 2007-04-01 to 2007-09-19. The test period was only interrupted by the transport tests with Distance Blocks in June and for the summer vacation period in July. Performed tests were recorded daily in a logbook.

Statistics from the tests shows that the average deposition distance during the test period was 141 meter, but distances up to 340 meters were achieved during the period. Statistics from the tests is shown in the Table 5-3 below. Performed transports are shown in Figure 5-7 and Figure 5-8.

Figure 5-7 shows the total transport distance per day and Figure 5-8 shows the transports divided in forward respectively reverse operation.

5.6.1 Disturbances/interruptions

According to the statistics were approximately half of the performed transports interrupted by different causes. Most of the disturbances/interruptions are related to control system and were corrected without any major efforts and loss of time. The most frequent causes for interruption are described below.

Table 5-3. Statistics from the test period 2007-04-01 to 2007-09-19.

Total available Operating days (working days)	70 days
Downtime without operation due to repair	9 days
Number of operating days with disturbances	33 days
Total cumulative transport distance	7,964 meters[1]
Average distance per operating day	141 meters
Maximum transport distance performed in one day	338 meters

[1] The total transportation distance including the periods before the endurance test period is approximately 12 km.

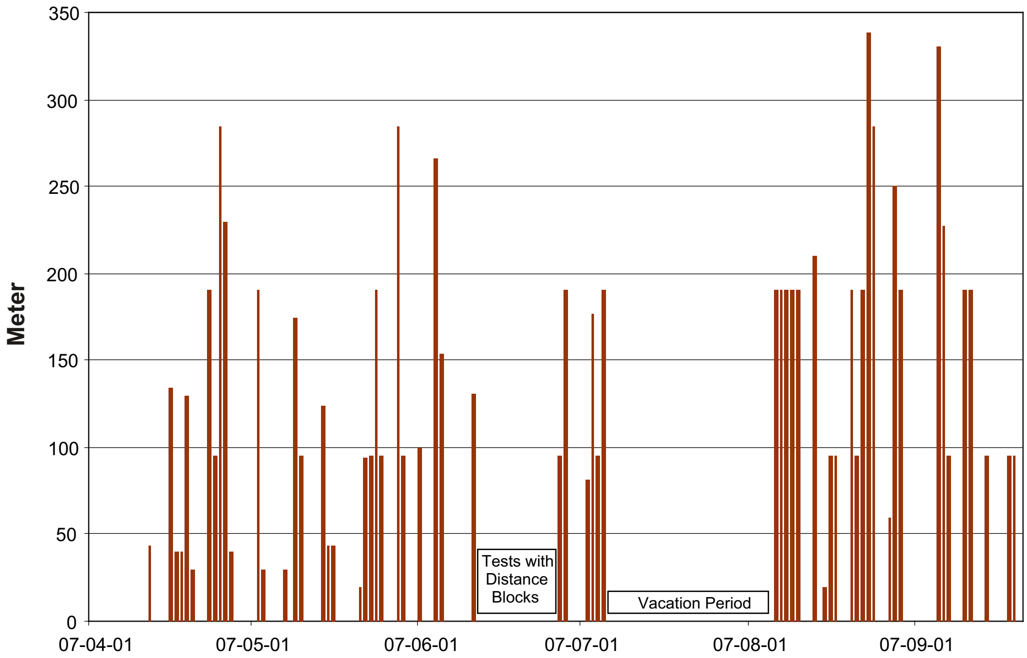


Figure 5-7. Diagram showing the total transport distance performed per day.

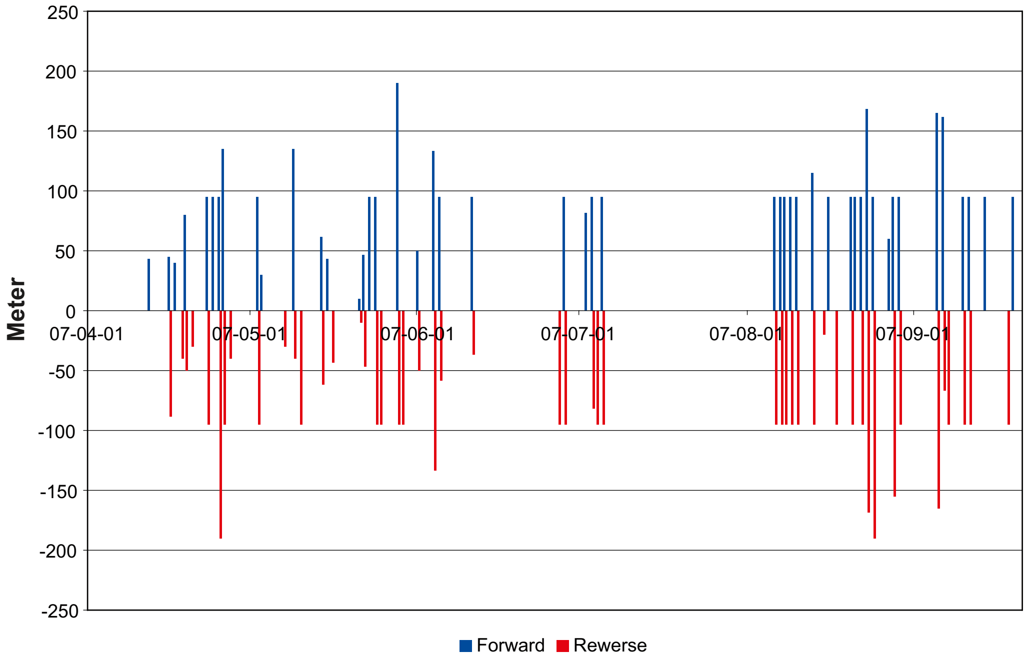


Figure 5-8. Diagram showing performed transport divided in forward resp. reverse operation.

Tank water level

The present system has the set parameters minimum water level 70% and maximum water level 100%. If min or max levels are reached the automatic operating cycle is stopped. This has caused a number of interruptions.

The maximum level can be reached if the leak water from the tunnel is flooded over the front of the slide plate and entering the water system on the machine.

The minimum level can be reached if water is flooding on the slide plate due to insufficient capacity of the recovery pump. The capacity of the pump is some times limited due to a too small distance between the suction nozzle and the slide plate. The problem is mainly in the start position due to misalignment in the set-up and the fact that the slide plate is bended. The back end of the slide plate where the nozzle is located can due to the misalignment move vertically up and down, see Figure 5-9.

Water control valves

Valves are jammed as described in section 5.5. The situation got somewhat better when a finer filter was installed in the tank, screening away sand transported from the drift.

Ballast

The ballast stops to operate, seams to be randomly, probably due to faults/bugs in the PLC program. The only way to rectify this is to reset the system. If the ballast stops to operate this affects the rotation of the container, this situation must be observed by the operator otherwise the system continuous to run until maximum tilt is reached.

Actuator drive

The belt for the third actuator some times "jump" due belt tensioning device. This has also caused break of the belt due to the wear when the belt jumps. The belt-tensioning device must be more rigid. See Figure 5-10.

Water cushions

As described in section 5.5.1 have some of the cushions broken because of too high water pressure due to the incorrect functioning of the water control valves.

Tilt sensors

Tilt sensors, on the wheel supports, reach the set limits. The automatic cycle is stopped if the set limit is reached. The wheels are straightened up if the machine is manually moved forward/backward.

Figure 5-9. *Water recovery pump and suction nozzle.*

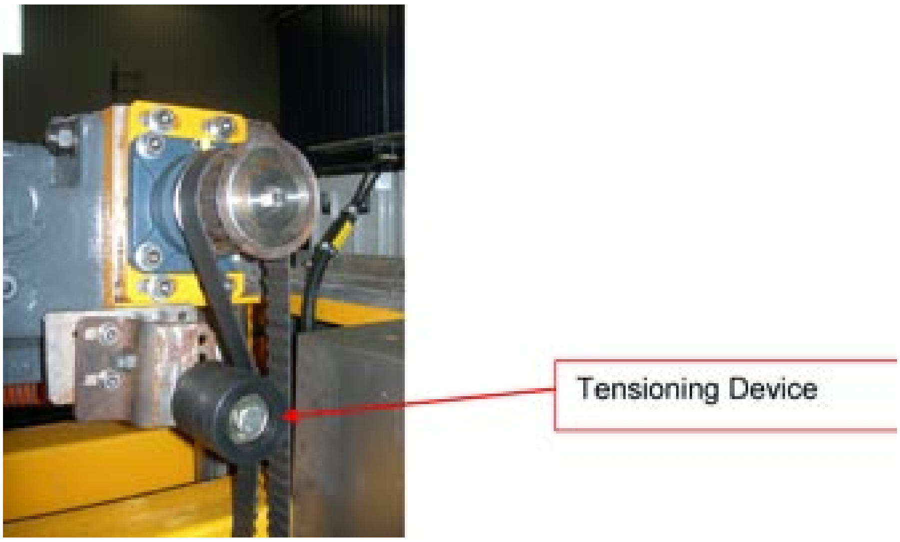


Figure 5-10. Belt drive for the third actuator.

5.6.2 Other observations noted during the period

Water cushions

The connection between the water pipes on the pallet and the connection block on the water cushion fixing plate is not reliable. The connection leaks if not correctly installed.

Lift sensors

The reliability and the accuracy of the lift sensors are not sufficient. It is believed that the sensors are affected by the water flow underneath the pallet, which can result in that incorrect lift values are shown on the control panel.

Water cushion platte

When mounting the pallet to the radiation shield, it is very difficult to see if the pallet is perpendicular to the radiation shield and if the pallet is located in zero position compared with the inclinometer on the radiation shield. See Figure 5-11.

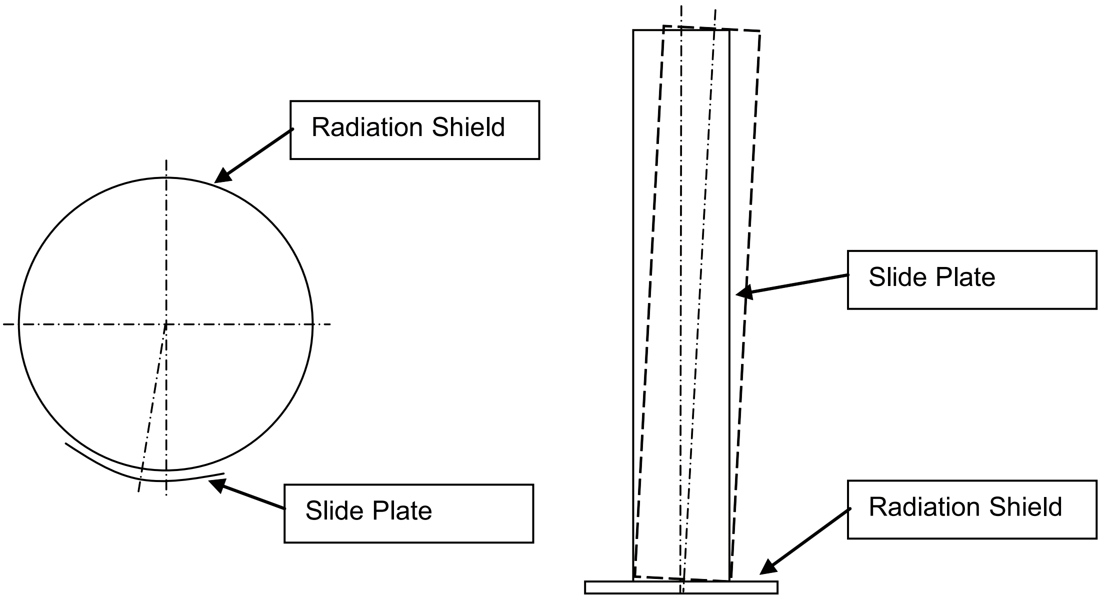


Figure 5-11. Possible causes for misalignment between the radiation shield and the pallet.

Splashguard

As mentioned in section 4.4.2 has the tests been performed without any splashguard. As can be seen in Figure 5-12 has water entered the side plate and the concrete buffer has come in contact with water during the transportation. It has been difficult to see and verify where and when the water is spraying. To protect the buffer from water is a critical issue that should be tested further, however development of a new splashguard is a design issue that should not be critical to solve.

Control system

A number of bugs have been found during the period, which has been forwarded to the manufacturer.

It has not either been possible to access the information from the trend and report generator.

The identification number requested by the control system to start a deposition must be improved.

5.6.3 Wear and tear

Slide plate

The wear of the slide plate against the rock surface has been concluded to be negligible during the test period.

Guides

The wear of the guides between the slide plate and the pallet has been concluded to be negligible during the test period.

Water cushions

The wear of the water cushions are concluded to be negligible during the test period. However some cushions have shown cut damages probably due to sharp shaped debris on the slide plate. A number of cushions have also burst due to high pressures due to jammed relief valves.

Other component

A clamp free hose system has been used for the water supply between the water control valves and the connection on the pallet. It has been shown that this is not a reliable system why clamps have been mounted on all connections.

Figure 5-12. *The picture shows that water has entered the slide plate and that the buffer has come in contact with water.*

5.6.4 Material qualities and surface protection

Below are some observations listed regarding material and the surface protection of equipment that lacks in quality. Some of the areas now showing problems were discussed with the manufacturer during the design phase. Most of the observations can be handled as warranty issues towards the manufacturer. During the negotiations for the final payment of the equipment was an agreement made with the manufacturer regarding the surface protection.

All parts made of aluminium are after this quite limited test period affected of corrosion. Figure 5-13 shows the connection block for the water supply lines to the pallet, which is made of aluminium.

It has been observed that water has entered some of the electrical connectors due to insufficient tightness classes of the electrical connectors.

The Surface protection of the equipment varies from good to poor see Figure 5-14. It is mainly the supports for the equipment that shows a poor quality of the surface protection. The machine and the transport tube are of much better quality. The conclusion from the inspection is that support should be blasted and repainted to reach acceptable quality.

Figure 5-13. *Connection block for water supply lines on the pallet.*

Figure 5-14. *Example of the quality of the surface protection on the transport support for the deposition machine.*

5.7 Distance Blocks transportation tests

The present machine is designed for transport of both Supercontainers and Distance Blocks. To allow for a tight fit to the Supercontainer or Distance Blocks already placed in the drift the Distance Blocks must be placed in the very front of the pallet for the transportation. A distance frame is therefore needed between the radiation shield and the Distance Blocks to compensate for the difference in length compared with the Supercontainer, see Figure 5-15.

The transportation cycle starts with that the blocks are placed, with a mobile crane, in front of the radiation shield on the start tube. After placement are the blocks lifted and moved to make space for the distance frame. The distance frame is with screws fixed to the radiation shield. It is important that there is a straight angel between the radiation shield and the pallet when the distance frame is mounted.

During the performed transportation test, which were performed in June 2007, was the distance frame installation considered as quite time consuming and is not recommended for the real repository.

Due to some problems with the sensor that indicate if a distance block is present or not was it not possible to test the automatic mode for deposition of Distance Blocks, it was however possible to perform the transportation in automatic mode for deposition of Supercontainer. The only difference between the modes is the deposition speed, which is set to 20 mm/s for transportation of Supercontainers and 30 mm/s for transportation of Distance Blocks due to the lower weight. The performance requirement for deposition speed could therefore not be tested.

There were also some problems to set the optimum number of cushions and pressure required for transport of the Distance Blocks. Cushion row 8, 9, 11 and 12 were finally selected for the transport, this must however be tested further.

During the tests was the Distance Blocks transported in and out two times (total 360 m). It was at the last transportation outwards observed that the feet on the un-reinforced block had fallen of from the block. See Figure 5-16 and it was concluded that the fixation of the feet to the blocks must be improved.

Two different possible causes was identified, the lifting height not enough or the fixation of the feet is not sufficient.

***Figure 5-15.** Distance frame for transportation of Distance Blocks.*

Figure 5-16. *The feet have come loose from the Distance Block.*

If the lifting height is not enough the feet will drag against the rock and can get stuck against edges in rock surface.

The second cause discussed is that the screw expander, selected for the fixation is not suitable for the actual installation. The expander may loose its grip after repeated loading and unloading when lifting and lowering the blocks during the transportation.

The first proposal was to investigate if more suitable expanders are available, in that case is no redesigning of the block feet needed.

Some additional tests were performed after improvement of the fixation (change of screw expanders) of the feet with a positive result. Further tests are however required for verification.

If the improved fixation after further tests is seem to be not reliable a proposal could be to have the feet attached to a cradle, on which the blocks are resting. This will minimise the load variation for the expander screws, see Figure 5-17.

The result from these initial transportation tests with Distance Blocks indicates that the fixation of the feet to the block must be improved and that further tests are required to verify this. Further test are also required to verify that the machine is able to place the blocks in direct contact with the Supercontainers.

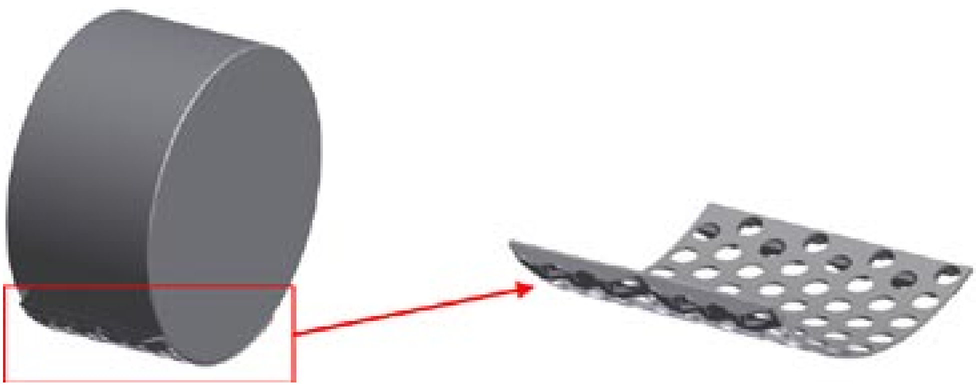


Figure 5-17. *Proposal, fixation of feet to the distance block.*

5.8 Supercontainer integrity tests

The purpose with the test is to demonstrate the integrity of the Supercontainer during the deposition process. The test was carried out with the Supercontainer made of a carbon steel shell and with un-reinforced concrete buffer as similar as possible to bentonite. The copper canister used was of the type BWR fully filled with fuel dummies. The test was performed 5 – 6 November 2007.

For this test was the Supercontainer transported in and out trough the deposition drift two times, total transport distance approximately 360 meters.

The Supercontainer was after performed transportation test taken to the workshop for examination of potential deformations and/or cracks.

To allow for examination of all components was the Supercontainer totally dismantled in the workshop, see Figure 5-18.

The examination consisted of the following:

- Visual examination of the steel shell with regards to deformations.
- Penetrating liquid examination of welds around feet with regards to cracks.
- Visual examination of concrete blocks with regards to cracks and fall outs.

The examination was performed without any remarks that can jeopardise the integrity of the Supercontainer. Only some minor fallout of pieces was found from sharp edges on the concrete blocks. All examinations are recorded and documented in the Activity Plan.

Figure 5-18. *Dismantling of the Supercontainer.*

Figure 5-19. Examination of the concrete rings.

5.9 Remaining critical issues

To meet the main objectives for the KBS-3H design the following issues remains to be verified:

- Additional transportation tests with Supercontainer are required to verify the reliability and the availability of the equipment.
- Additional transportation tests with Distance Blocks are required to verify that the fixation of the feet is reliable.
- Additional to verify that the machine is capable of placing the Distance Blocks in direct contact to the Supercontainer.
- How will a bentonite buffer withstand the handling/transportation.
- Development and testing of a new splashguard to protect the bentonite buffer from water.

6 Equipment improvements

In general has the equipment functioned well. Several improvements have however been identified. The following is a summary of recommended improvements of the equipment that have been found during the test period.

6.1 Deposition machine

6.1.1 Water cushion pallet

The mounting of the pallet to the radiation shield should be improved to allow for a faster installation and easier alignment. It is however not advised for the real repository to have the pallet and the slide plate retractable underneath the machine to allow for transportation of the machine. The tests have shown that the system is very sensitive for a correct installation and alignment of the pallet and it is therefore advised to transport the machine in its full length. This will minimise the risk for installation errors and it will also minimise the preparation time needed for the setup of the equipment.

6.1.2 Lift sensor

The lift sensors on the pallet should be improved with regards to the accuracy of the measured values. The present design seams to be affected by the water flow underneath the pallet. A solution is maybe to have the present toggle arm spring loaded to prevent it to be lifted by the water stream. It is also advised to investigate if other systems/sensor are available on the market for such conditions. If the measured values can be improved can the height be included as one control parameter to allow the machine to start "moving" presently is this only controlled by timers.

6.1.3 Splashguard

Due to the introduction of the guides between the slide plate and the pallet was the splashguard removed. The tests have shown that there is a need of a splashguard and it is advised to investigate different solutions to sure that water are prevented to come in contact with the bentonite buffer.

6.1.4 Slide plate

The slide plate should be provided with a channel along the plate to allow leak water from the rock to run underneath the slide plate instead of running over the front of the slide plate and entering the water system on the machine. This will prevent the salty leak water to enter the system and it will probably also minimise the amount of silt from the tunnel to enter the system. This change will also affect the profile of the pallet, which must be adapted to the new shape of the pallet.

It is advised to have the guides for the pallet incorporated in the side beams of the slide plate and that the guides should run along the whole length of the slide plate.

The total height of the slide plate should be reduced with 5 mm. The present system requires that the feet are 50 mm instead of the 45 mm, which is the original design.

The fixation of the slide plate to the machine should be reviewed with possibilities to alignment between the machine and the slide plate.

6.1.5 Water system

The arrangement of the water control valves should be improved for easier access.

All electrical components should be separated from the water control valves and water pressure sensors.

The tank should be provided with a better filter and/or sedimentation pockets inside the tank.

6.1.6 Ballast system

It is advised to increase the ballast weight and also increase the speed of the motion of the ballast for a faster reaction when compensation for an unbalance. The control loop for the motion of the ballast should also be further optimised to avoid if possible unnecessary the full stroke of ballast actuator.

6.1.7 Actuators

The drive arrangement for the third linear actuator needs to be improved. It is advised to change the belt drive to a chain drive, which is considered to be more reliable for this type of application.

6.2 Start Tube

It is for the real repository advised to have the start tube provided with features that allows for adjustment of the position of the start tube after the placing in front of the transport tube. The system with position blocks is not reliable due to the narrow tolerances required for the alignment of the equipment and the transport tube. The transport support should allow the start tube to be adjusted in all directions *x, y* and *z* in relation to the support.

It is as described in section 6.1.1 advised to transport the deposition machine in its full length, this means that the length of the start tube will be increased to approximately 15 meters. The increased length will make it very difficult to transport the start tube within the repository with the present SKB vehicles. It is therefore advised to make the transport support for the start tube self propelling.

The winch system for the emergency retraction should be provided with a wire guide for an even distribution of the wire on the wire drum.

6.3 Transport Tube

Due to the attempt for the real repository to minimise the needed cross section in the niches and the transport tunnels should the height of the gamma gates be lowered with approximately 500 mm.

It is for the real repository advised to have the transport support provided with features that allows for adjustment of the position of the Transport Tube after the placing in front of the deposition drift, the system with position blocks is not reliable due to narrow tolerances required for the alignment of the equipment and the deposition drift. The transport support should allow the Transport Tube to be adjusted in all directions *x, y* and *z* in relation to the support.

7 Operating performance

This section is a reasoning based on the experiences from the performed tests about the operating performance that can be expected at the real repository.

With the present deposition machine will the transportation speed be reduced if the Distance Blocks are longer than approximately 2 meters. For transportation of Distance Blocks that are up to 5 meters, which is the case for the Oilkiluoto site, must the transportation speed be reduced to the same speed as for the supercontainers (20 mm/s).

The rates above are achieved when running with automatic cycles, the rates are limited if the equipment is operated manually. The minimum requirement is that the equipment should be able to deposit one supercontainer and one required number of Distance Blocks per one day.

It is however assumed that the operation of the drift is based on deposit supercontainers and Distance Blocks in campaigns. All emplacements in one compartment will be carried out in one campaign in continuous operating shifts.

For calculation of the total operation time for deposit of Supercontainers and Distance Blocks has the operation sequences been divided in the following chronological steps including preparatory and supporting works and assumed times, see Table 7-1. Installation work for the compartment plug has not been included in this calculation and it is also assumed that all preparational work for the compartment plug has been done before the deposition start.

The times for installation of distance blocks are based on the DAWE alternative, in case of the STC alternative the installation time must be increased, since the STC design is not yet fixed this will be calculated later.

The total transport time depends of course on the length of the deposition unit, which depends on the chosen length of Distance Blocks and the drift length.

In a 260-meter long deposition drift, which is assumed to be the average drift length at the Forsmark site is the expected longest emplacement time for the first distance block 293 minutes (4.88 hours) and for the first supercontainer 363 minutes (6.05 hours), including preparation and supporting works.

Table 7-1. Assumed times for the different operating sequences.

Pos	Work step	Time (min)
1	Positioning and docking of transport tube to the deposition drift	30
2	Positioning and docking of start tube to the transport tube	30
3	Preparation of machine for emplacement of supercontainer	15
4	Transport of supercontainer	25–215[1)]
5	Retrieval of machine	5–43[1)]
6	Transfer of start tube/deposition machine	15
7	Transfer of transport tube to reloading station	15
8	Positioning and docking of Distance Blocks to the deposition drift	30
9	Positioning and docking of start tube to the Distance Blocks	30
10	Preparation of machine for emplacement of Distance Blocks	15
11	Transport Distance Blocks	17–144[1)]
12	Retrieval of machine	5–43[1)]
13	Removal of start tube/deposition machine	15
14	Removal of transport support for Distance Blocks	15

[1)] Depends on transportation distance.

It is for the Forsmark site assumed that totally 28 supercontainers can be deposited in a 260-meter long drift devided into two compartments. The time to fill the first compartment with assumed 14 supercontainers will take about 134.3 hours (5.6 days) if the operation is based on three shifts utilizing 24 hours a day operation and about 80 hours (3.3 days) to fill the second compartment, see Figure 7-1.

The calculation is based on a 7.2 meter spacing between the supercontainers and that the drift contains a 35 meter long compartment plug containing the unusable part located in the middle of the drift and a 25 meter long drift end plug.

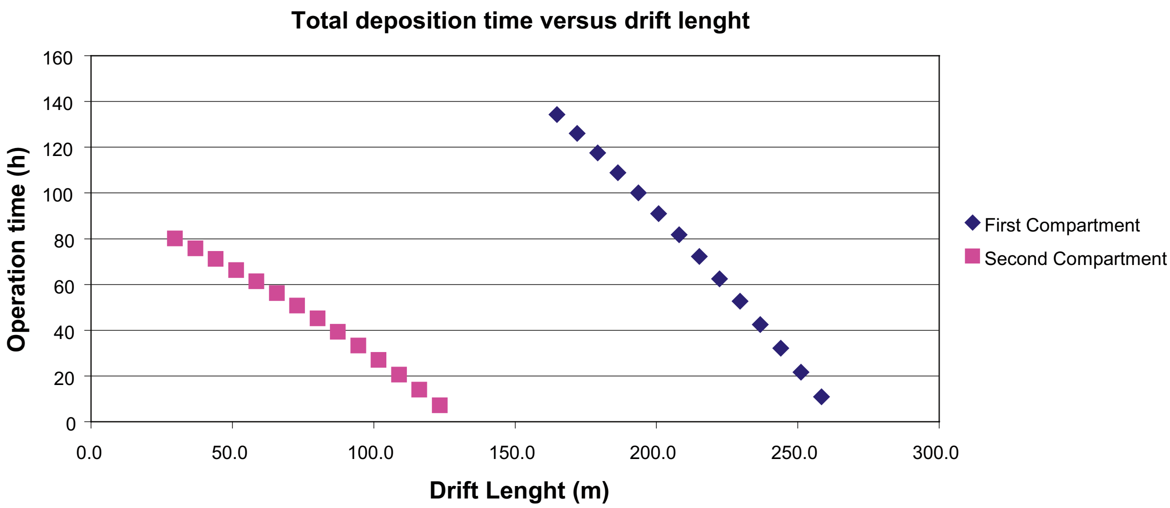


__Figure 7-1.__ Accumulated operational time versus drift length for filling of the first and second compartment with 14 supercontainers and distance blocks respectively.

8 Summary and conclusions from tests

The tests with the Deposition Equipment have in general been successful. The total transportation distance with Supercontainers during the period March to October 2007 is approximately 12 km. The tests performed have shown that the emplacement equipment tested is operating effectively for the transport & deposition of Supercontainers with a weight of 45 tons in horizontal drifts excavated in hard rock.

Further tests are however required to verify the availability and the reliability of the equipment for a longer period of time.

Further tests are also required for the transportation of Distance Blocks and also the demonstration that the machine is capable of placing the Distance Blocks in direct contact to the Supercontainer.

It has however also been concluded that the water cushion technique, which is used, is sensitive to load variations. This means that the Supercontainers to be transported must be well balanced. This is a deviation from the main functional requirements that was established for the deposition machine. **This new requirement implies that all fuel positions in the SF canisters must be filled with fuel elements or fuel dummies.**

The system/technique is also sensitive to the alignment in the set-up between the transport tube for the Supercontainer, the deposition drift and the start tube for the deposition machine.

A number of issues regarding the PLC program have been observed, which needs to be improved before further testing.

The tests have also disclosed a number of weaknesses that needs to be improved in the future. The report proposes a number of potential solutions for this.

The tests have also shown that the integrity of the Supercontainer is not jeopardised during the handling/transport. In the performed tests, have however concrete been used as buffer. One uncertainty is how a bentonite buffer will withstand the handling/transportation.

The "splashguard" to protect the bentonite buffer from water, which was established as one of the main functional requirements for the deposition machine, must be improved. The present system is not sufficient.

9 References

/1/ KBS-3H Design Description 2007.

/2/ ESDRED, Deliverable Module 3 – WP3 – D1, “Input Data and Functional Requirements”.

/3/ ESDRED, Deliverable Module 3 – WP3 – D6, “Evaluation and Final Report”.