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WP5: KBS-3V Emplacement tests in ONKALO (EMP)

DELIVERABLE D5:05
Quality Assurance and Problem Handling during buffer emplacement

Author(s): Jari Talka Insinööritoimisto Comatec Oy
Keijo Haapala, Posiva Oy

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QUALITY ASSURANCE AND PROBLEM HANDLING DURING BUFFER EMPLACEMENT

Contents

Quality Assurance and Problem Handling During Buffer Emplacement

1. General

The quality of bentonite buffer block installation and handling of problems during the installation on buffer blocks are areas in need of study. The quality of installation is a key aspect in making sure that the multi-barrier system functions as designed. Technical or operational problems during the installation of clay components may cause delays in installation schedules and could possibly jeopardize the disposal system's function.

There are three components to the development of buffer installation: LOT1: methodology; LOT2: assuring the quality of the installation; and LOT3: how to handle any problems encountered during its installation. This document discusses LOT2 and LOT3 components.

2. LOT2: Quality Assurance of the Bentonite Buffer Installation Process Accomplished by BIM.

2.1. The Scope of the LOT2

The scope of the LOT2 defined for LUCOEX is to develop sensor systems to deliver the data needed to achieve the quality assurance targets (QA), as defined in the original LOT2 quotation request for the KBS-3V disposal geometry. In practice this means choosing the most suitable sensor technologies, designing the needed Buffer Installation Machine (BIM) / transfer device mounted support mechanics and electronics and provide the data produced from these activities for use in QA-related software. Developing the automated analysis tools associated with the buffer installation process is a vast software engineering task and is beyond the scope of LOT2. 3rd party, off-the-shelf analysis programs may be used in the initial assessment process but they might not allow for conduct of a fully automated QA process.

2.2. The Scope of quality assurance

This document identifies and describes alternative sensor technologies and approaches that could achieve the QA targets described in the LOT2 project description for the KBS-3V installation geometry. Technologies and methods are analysed and compared in respect to the general requirements and parameters (such as reliability, costs, complexity, time usage, suitability for underground environment etc.) and in respect of the requirements of each individual QA target. As a result a recommended approach is given for each QA target.

The motivation for and the accuracy targets of each QA item are described based on the discussions with and the guidelines provided by the LUCOEX project team.

This study is limited in that it is based on communication with the instrument supplier candidates, interviews, web researches and experiences of the author but not on tests accomplished in real application environment with real materials and full scale dimensions.

This means that some final technology decisions are delayed until actual full scale application environment is available.

A primary guideline for the development of the QA process is avoiding slowing down the buffer installation process lowering any instrumentation down to the deposit hole with a separate winch should be avoided. Additionally, development of support systems such as databases and automated analysing tools are beyond the scope ofLOT2 and so they are not handled in this document.

2.3. LOT2 QA targets

The QA targets defined in document LOT2: consultancy services for development of quality control equipment are as follows:

- a) The integrity of the buffer blocks during the process
- b) The final position of the buffer structure
- c) The accurate position of individual block in the final buffer assembly
- d) The compactness of the joint between the blocks and between the pellets and the host rock
- e) The width of the gap between assembled block and the host rock
- f) The inclination of the assembled buffer and each block

Based on the discussions at the initiation of this work, targets b), c) and f) were combined into one target. This new target covers the whole installation accuracy of the bentonite buffer and the blocks it consists of. In addition, the compactness of the joint between the blocks (originally part of the target d) also falls within this new target. This new target is called "The quality of the position of the assembled buffer and the bentonite blocks the buffer consists of" (It is referred to as target QA_2).

For revised listing of QA targets are as follows:

- QA1: The integrity of the buffer blocks during the process.
- QA2: The quality of the position of the assembled buffer and the bentonite blocks the buffer consists of.
- QA3: The width of the gap between assembled block and the host rock.
- QA4: The compactness of the joint between the pellets and the host rock.

These targets (QA1 – QA4) and possible approaches to reach them are studied in the following chapters.

2.3.1. QA1: The integrity of the Buffer Blocks during the Process

Background and motivation

The goal of this QA target is to ensure that a bentonite block will end up as one piece in its target position in the deposition hole. A fracture in a bentonite block may decrease the strength of the block so that it breaks into pieces under its own weight or because of the movements undertaken as part of normal BIM handling of the block.

According to studies undertaken on large buffer blocks, fractures capable of endangering a block will be visible on the outer surface of the block. Because of this it is enough to inspect only the outer, side surface of the block as shown in the Fig. 1. The minimum crack width that needs to be found during inspection is 0.2 to 0.4 mm. Measurements have to be done without physical contact and without any alteration to the surface of the block (such as powders or moisturized air) as these could compromise the blocks integrity. Surface area to be inspected varies between 4.98 m^2 and 2.1 m^2 depending on the block type being inspected. The circumference of the blocks is 5183mm and so scanners must be able to examine this length of surface.

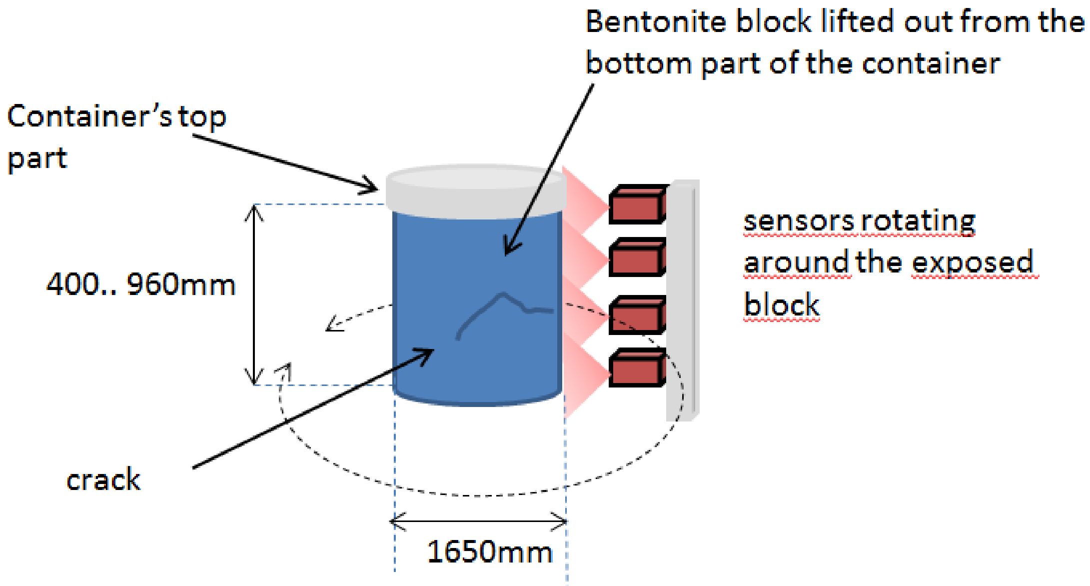

Fig. 1. Method proposed for crack inspection of buffer block

Challenges

The accuracy target for identification of a 0.2 mm defect is quite high. Collecting and analysing the data should be preferably accomplished in a minute or two at maximum.

Studied Approaches

There are three technologies that have been identified as having possible applicability for surface inspection of buffer blocks. These are:

1. Close range laser scanner. The laser is used to scan the surface from distance of 50-100 mm. Scanning area from one position is approximately 100 x 100 mm and one partial scan takes about one second. Scanner produces a 3D point cloud which can be processed further to a surface model. The surface model produced can then be compared against the CAD design and the measurement data that was gathered at the factory as part of the manufacturing QA to identify possible deviations on block's surface.

2. White light technology involves the measuring device projecting a light pattern on the surface under inspection. The pattern is then photographed and used to produce a point

cloud based on the acquired data. One measurement covers an area of approximately 500 x 500 mm, taking less than a second to complete. Depth of the measurement field is 270mm. Measurement distance is 700 to 800 mm.

3. Machine vision is based on taking ordinary or high resolution photographs and analysing and processing them then with a computer or by human inspection. Various illumination technics such as structured laser illumination, side lighting etc. can be used to tune the technology to various measurement tasks.

The key features and parameters associated with each of these methods is presented in Table 1 and then their cost and technological applicability are summarised in Table 2.

Table 1. QA1: Sensor technologies studied

	Short distance laser scanner	White light	Machine vision (5M camera)[1]
Parameter			
Suitability for application environment (0-5 with 0 unsuitable and 5 ideal)	3	4	4
Field of View	100 x 100 mm	500 x 500 mm	200 x 200
Approx. required “shots” with 5% overlap horizontal 5442mm vertical 1008mm Total	 55 11 605	 11 2 22	 28 5 140
Measuring Distance	75mm	700mm	300-400mm
Accuracy class	100-300um	220um -> cracks of 0.3-0.5mm would be visible	Resolutions: 5Mpix:0.1mm 30Mpix: 0.0X mm accuracy up to tests
Depth of the field of view	25mm	270mm	depends on lens used and resolution required. Requires testing
Shooting time / shot	1s	1s	0.1s
Processing time for go/not to go decision	20-30s per shoot	1 s / shoot	1-2s /pear each shoot
Estimated total scanning time for 960x1650 mm (height x diameter) bentonite block. Assumes 200 mm/sec movement speed for the sensor actuator and one sensor	analysing time dominates 605 * (20)s 12120 to 18150s	shooting + movement time dominates 22*(5+2.5)=165s	analysing time dominates 2 *140 = 280s

([1]): More resolution and bigger image area without loss of accuracy might be achieved by using a higher resolution camera. This would result in an increased cost (30MP -> 15k€) and longer measuring and analysing time.

Table 2. QA1: Design alternatives and costs of the studied sensors

Parameter	Short-distance Laser Scanner	White light	Machine vision
Cost of one measurement sensor	20-40k€	70-100k€	5k€ (5Mpix) + 1 analysing computer per each camera (2-3k€) 15€ (30Mpix)
Number of sensors needed (to be able to reach target accuracy and time frame of 120 sec/inspection).	8-10	1	3 (200mm vertical view area / shoot), requires moving the sensors once vertically
Total sensor cost	excessive (160-400k€)	70-100k€	35k€ - 40k€
Complexity of required software engineering (1-5)[1]	3	3	2
Complexity of required support electronics and mechanics (1-5)[1]	4 a lot of cabling and data processing units needed	3	2
Price estimate for the required support automation Hardware (motors, actuators, sensors, controller)	7.5 -10 k€	6.5 -9 k€	7.5 -10 k€
Required design effort in man hours, excluding analysing software	200-300	80-150	100-200
Price estimate for developing automated analysing software	10-20k€	10-20k€	5-15k€
Probability of success (required accuracy in given measuring time) with this technology	60-70%	90-95%	95-100%

[1] In this rating system 1 is a simple task and 5 is extremely complicated.

Analysis of options

Each of the technologies described above in Table 1 and Table 2 requires similar mechanics to move the sensor or sensors around an exposed bentonite block. Mechanics is not very complex and it doesn’t have to be designed by the sensor supplier.

- Close range laser scanner,
    - Produces a 3D model,
    - Smallish scanning area (size of hand) -> many sensors or more scanning time due increased amount of sensor movements -> very high cost,
    - Block's position in container can be measured at the same time,
    - Real time analysing is as-yet undetermined but most probably it's too slow, and
    - Cost is too high compared to benefits and the same benefits can even be achieved with white light technology
- Machine vision
    - Lowest cost,
    - Most accurate,
    - Depth of focus is as-yet uncertain,
    - Easy and fast analysing of images,
    - Will not allow for production of a 3D model, and
    - Block's position in container can be measured at the same time
- White light technology
    - 0.5 * 0.5 m measurement area -> one sensor is enough,
    - Produces a 3D model,
    - The resolution (of the point cloud) of 0.22 mm will provide crack detection capability of 0.3 to 0.5 mm which might not be good enough,
    - Block's position in container can be measured at the same time, and
    - Instrument can also be used separately to measure drilled holes.

Preferably the sensor assembly and required control electronics will be installed on the BTD (Bentonite Transportation Device). This would ease the design effort of the mechanics by providing more room and less complexity compared to an installation on the BIM.

In addition to the conduct of the fracture scan described above, some additional QA actions can be performed to increase the certainty that the block wasn't harmed during transportation or BIM handling. Although transportation monitoring doesn't belong to the scope of LOT2 deliverables it is a logical to bring it up as part of the discussion of this deliverable. Transportation from the factory down to the point when the BIM is used to open the transport container can be monitored with a battery powered data logger mounted on the top part of the container. This logger would be able to monitor things like the accelerations that the container has experienced humidity, temperature and vacuum pressure levels. Data can be extracted from the logger either when BIM attaches to the container or when the BTD delivers the block to the BIM. Data inspection while the transport container is still on the BTD would be the preferred approach as it wouldn't increase the total buffer installation time. The same data logger could also be used to log the accelerations and gripper pressure levels experienced by the buffer block while the BIM handles the load.

Recommended approach to monitoring of buffer block integrity

Both machine vision and white laser technology are good candidates. They are accurate and fast enough to do within the allowed time for inspection and the required engineering effort to apply them is not overwhelming. Use of a close range laser scanner is not feasible due to the small shooting area and especially due to the long data analysing time that cannot be easily overcome by increasing the number of sensors used because of the relatively high sensor cost. Machine vision would probably provide the lowest cost and smallest engineering effort and so is currently the most attractive approach. A White-light laser scanner would also accomplish the inspection task and it could be used to measure the drilled holes, but it won't provide any remarkable benefits compared to machine vision and is a more costly option.

However, some additional investigations and especially bench-top and field tests are still needed to be able to finalize the technology selection for fracture detection in buffer blocks. The conduct of additional testing and evaluation is not a risk to the schedule for technological application as all the presented sensor technologies require similar supporting mechanical and electronic equipment.

2.3.2. QA2: The quality of the position of the assembled buffer and the bentonite blocks the buffer consists of.

Background and motivation

Two things motivate the requirement to track the positioning quality of the buffer assembly in a deposition hole:

1. There is a need to guarantee that the spent fuel canister can be installed in the buffer-lined deposition hole. The radial clearance between the inner surface of the ring shaped bentonite buffer blocks and the spent fuel canister is defined as being 10 mm.

2. The second geometric requirement is that the gap between the host rock and the outer surface of the buffer blocks has to be properly aligned in order to allow for proper pellet filling. The radial width of the host rock to block gap has to exceed 25 mm to allow proper filling of this space with bentonite pellets.

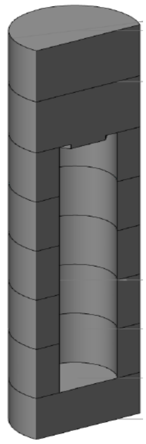

Figure 2: Sketch showing arrangement of the buffer segments without the presence of a canister

Alignment of the individual blocks in respect other blocks and the verticality of the whole buffer structure are critical parameters for ensuring the canister clearance requirements are met. This is the motivation for tracking, preferably preventing the possible tilting of the assembly and measuring how close to the target XY-coordinate each block is installed. Because there is practically no vertical asymmetry in a bentonite block (the height of one block is the same no matter where it's measured) the only source for tilting is a foreign object on the surface to which the next block will be lowered (touch point for now on), or an initially non-level foundation. This is the reasoning for checking that the touch point between the blocks is clean.

It should also be noted that even if all the individual blocks are aligned precisely with respect one-another but the whole buffer assembly is not correctly positioned in the XY-plane, the gap between the host rock and the block can deviate unacceptably from the installation specifications. This may create problems during filling the gap with premeasured amounts of pellets.

The sub-targets of the QA2 therefore are:

- To ensure that the buffer and blocks are vertically aligned with an accuracy of ±0.01 degrees,

  from which two sub tasks can be derived:

  - To ensure that every block sits precisely on top of the block below it (and the first block on the bottom of the hole.
  - To ensure that block's upper touch point is clean enough that the structure won't start tilting after the next block is lowered.

- To ensure that the whole buffer and each block are placed within ±1mm tolerance to the planned XY-coordinate.

2.3.1.1. Ensuring that the buffer and blocks are aligned vertically

Two tasks can be identified as part of the need to ensure that individual blocks and the overall verticality of the buffer is achieved. The first task is to track the horizontal alignment of the assembled blocks and the second one is to check that the touch point surface on the previously lowered block / bottom of the deposition hole is clean before the next block is lowered into the hole.

2.3.1.2. Measuring the pitch and roll angles of assembled bentonite block

Studied Approaches

Measuring the horizontal angle of the installed bentonite block is quite straight forwarded. The following three methods were studied:

1. Using the laser tracker which already measures the 3D coordinates of the container during the block lowering The angle of the block can be measured indirectly with the BIM mounted laser tracker. Tracker’s main purpose is to track the 3D-coordinates of three reflectors mounted on the top of the container (which carries the block) while BIM handles the container/ block compo. The tilt angles (pitch and roll as per the drawing below) can be calculated from the 3D-coordinate data. The worst case 3D coordinate accuracy between two points (having max 1 meter difference in distance to the laser tracker) measured by the Leica AT901 laser tracker is 36 µm (-15µm –(15 µm +6 µm)). To achieve the target angle measurement accuracy of 0.01 degrees the distance between tracked reference points has to be at least 210mm which can be arranged easily.

2. Using a precise dual axis inclinometer mounted to the container or gripper, A two axis inclinometer measures the pitch and roll angles as presented in Figure 3 : Pitch and roll angles. The needed accuracy of 0.01 degrees is at the high end on what’s achievable with inclinometers in general and achievable only with special technologies such as servo inclinometers. The inclinometer could be mounted either in the gripper (which grips to the container) or in the container (which carries the bentonite block). The container mount would provide more accurate measurements in theory because the possible misalignment between the gripper and container won’t add then a constant error (constant per every individual container to gripper attachment) to the measurement. Although it’s possible to correct the gripping error with the measurement data received from the laser tracker but in that case it comes harder to reason why the laser tracker data couldn’t be used directly to provide buffer’s installation angle. Of course having two independent (if gripping is neglected) measurement increases the reliability of the angle measurement.

3. Using laser distance meters mounted to BIM’s frame to measure the distance from the BIM to the lowered bentonite block. In this method a laser distance meter mounted to the BIM to measure direct distance to the upper surface of the bentonite block. Sensor or sensors could be arranged to several different setups. 3-4 sensors mounted to fixed position in the BIM’s frame or 1-2 sensors mounted on the rotating fixture. Rotation

allows following the upper surface of the bentonite block. The distance would be measured at 0, 90, 180 and 270 degrees rotation angles. This method would eliminate the effect of possible deviation in distance sensor's verticality and remove also sensor's absolute accuracy from the equation. 0.25mm repeatability in distance measurement would provide 0.009 degrees accuracy in angle measurement. A second sensor would increase the reliability of the measurement and decrease the overall measurement time by 25-40%.

Table 2 describes the most important parameters of the three approaches described above.

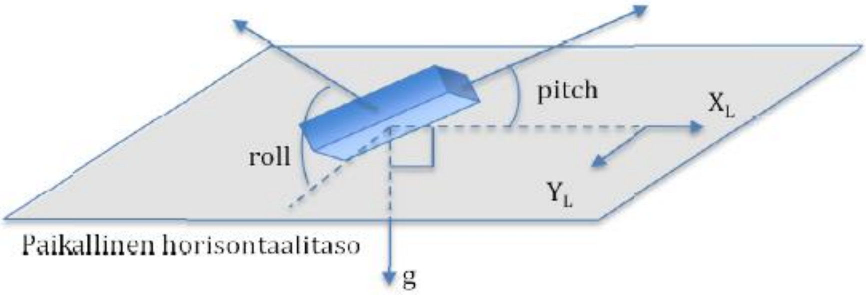

Figure 3 : Pitch and roll angles

Beyond the misalignment that could occur during block installation, the presence of improper location of the bentonite block within the container carrying the block is a potential error source in any approach where block's angle is measured indirectly by measuring container's or gripper's angle. The block is pre-aligned in the container at the factory and the result of this installation is also measured. The later remeasurement of the position allows for compensating of factory-originated misalignment during the buffer installation if both sets of data are available. Transportation originated misalignment will be most probably be observed when block's position in the container is measured as part of block's integrity check (Chapter 2.3.1 : QA1: The integrity of the Buffer Blocks during the Process).

Table 3: QA2: Summary of studied sensor technologies

Parameter	Laser tracker	Inclinometer	Laser distance meters in rotating fixture
Achieved angle accuracy	0.003 to 0.01 degrees depending on the distance between the reflectors	0.01 degrees with a high end product	0,01 degrees with a sensor providing 0.25mm repeatability
Direct measurement	NO	NO	YES
Reliability (1-5)	4 (indirect)	4(indirect)	5
Measurement time	1s	0.5s	1s/ per measurement point, 3-5 secs. to rotate the fixture 90 degrees ->4* (4+1) = 20sec.

Design effort of support electronics(1-5)	0	0	2
Design effort of required support mechanics(1-5)	0	1	3
Design effort of the software (1-5)	1	1	3
Sensor cost	No additional cost, already used in other tasks	8-13k€ to upgrade to high end	3-8k€
Cost of support electronics	0	0	1-2k€ (rotating fixture excluded)
Probability of success	98-99%	90-95%	95-99%

Recommended approach for determining horizontal alignment

Because the laser tracker will probably be used as BIM's 3D-coordinate measuring instrument, using it also to provide horizontal angle information for the lowered block comes almost at zero additional cost and effort. The disadvantage to this method is that the measurement is not direct but assumes that block's angle can be derived from transport container's angle.

Using a state of the art inclinometer doesn't provide any advantages compared to the laser tracker. Inclinometer also does not measure a block's angle directly and it doesn't provide better accuracy than other approaches.

A laser-based distance measurement unit mounted on the rotating fixture on BIM's frame produces accurate and directly measured angle information. It requires some additional mechanics and support electronics but those will probably be needed anyways for the QA_3 and QA_4.

The recommended approach is to combine the data that the existing laser tracker already provides with the direct measurement with one laser distance meter mounted on the rotating fixture.

2.3.1.3. Ensuring that block's touch point is clean enough to prevent the tilting

Motivation and Background

The buffer structure should be vertically aligned to allow successful canister installation and pellet filling as described in Chapter 4 (2.3.2. QA2: The quality of the position of the assembled buffer and the bentonite blocks the buffer consists of. Checking that the touch point surface (the upper surface of the previously assembled block or the bottom of the hole) is free of foreign items is r

elevant because they are the most probable reason for tilting. This is true due to the tight manufacturing tolerances of the bentonite blocks. Although it's possible that a bentonite block could develop a slight height asymmetry during the transportation/storage phase (not observed thus far in development process).

The most probable cause for loss of horizontal alignment is a bentonite pellet from the gap fill between the host rock and buffer blocks accidently falling onto the installed block. This sets the minimum particle size to be observed on the buffer block's surface to 5mm x 10mm (diameter x length) as shown in Fig. 4.

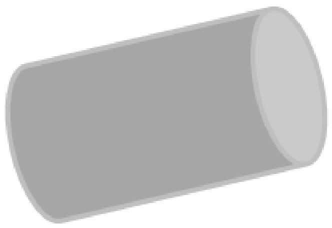

Figure 4: A cylindrical bentonite pellet

The maximum observation distance from monitoring sensor to surface is 12 meters (when installing the first bentonite block).

The maximum area to be inspected (shown in blue in Fig. 5) is 2.55m2

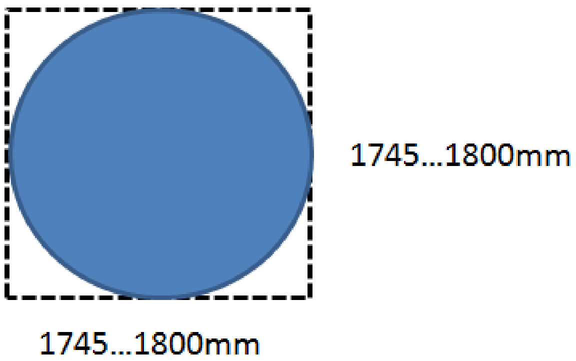

Figure 5: Top view of the area to inspected.

Studied approaches to inspect touch-point surface

The following table (Table 4) describes the two candidate technologies studied for this task, machine vision and laser scanning.

Table 4: Summary of the sensors studied for use in ensuring the horizontal surfaces in a deposition hole are clean

Parameter	Machine vision	Laser scanner
Pixel resolution at maximum measuring distance of 12 meters	5Mpix:0.80mm , 30Mpix: 0.33mm (requires motor zooming) accuracy up to tests	2mm (3D –coordinate accuracy)
Measurement time	1-2s	1-2min
Analysis and data transfer time	5-10s	4-6 min
Design effort of support electronics(1-5) 1: very small, 5: very high	2 (excluding possible structural illumination)	1
Design effort of required support mechanics (1-5)	2 (excluding possible structural illumination)	1
Design effort of the software (1-5)	2 (excluding possible structural illumination)	2-3
Sensor cost	5k€ (5Mpix) 15€ (30Mpix) + analysing computer per each camera (2-3k€) + motorised zoom object 2-4k€ 9-22k€	35-60k€, depends on the model
Cost of support electronics	0.5 -1k€ (excluding possible structural illumination and automation of the rotating fixture)	0
Price estimate for the required rotating fixture automation HW (motors, actuators, sensors, controller). This is can be shared with laser distance meters	7,5 -12 k€	
Cost of support mechanics	< 500€	< 500€
Probability of success	95–99%	95-99% But if max measurement time of 60 secs is to be maintained, the probability is less than 10%

Recommended approach to inspect touch-point surface

It is quite clear that machine vision is the most viable of the two approaches considered unless the inspection time is relaxed to 4-6 minutes per block. To be able to operate at varying measuring distances without losing resolution, a motorised zoom lens is required. Particle observation accuracy can probably be boosted by adding a structured laser illumination to highlight the deviations in surface. The same machine vision system could be possibly used also for other QA tasks such as the gap measurement (between the host rock and buffer) and analysing the pellet formation created in gap filling.

2.3.1.4. Ensuring that the whole buffer and each block are placed within ±1mm tolerance to the planned XY coordinate.

The motivation and background to defining a need to measure the XY- coordinates of individual bentonite block and the whole buffer were explained in the beginning of Chapter 4.

Studied approaches to ensuring X-Y placement tolerance is met
There are three basic approaches available to accomplish measurement of the X-Y placement tolerance:

1. Laser tracker. This device is already used during the installation process and so its use in X-Y tolerance determination would be advantageous.

2. Machine vision: This could be undertaken as described for pitch and roll angles (Section 2.3.1.2) and touch point inspection (2.3.1.3).

3. Laser scanner: This could be undertaken as described for pitch and roll angles (Section 2.3.1.2) and touch point inspection (2.3.1.3).

Table 5 presents a brief summary of the degree of resolution that is possible using the three techniques listed above. It should be noted that the target accuracy in block placement of ±1mm can only be reached by the laser tracker. Other methods such as machine vision may be used as a support measurement but none of them is able to give information other than that the installation is totally out of the desired position.

Table 5 : comparing the accuracy of LT, Machine vision and LT

Parameter	Laser tracker	Machine vision	Laser scanner
Achieved accuracy	100-400 µm	3-5mm	2-3mm
Type of block position measurement	Indirect (via container)	Direct	Direct

While the laser tracking technique is capable of achieving the desired positional measurement accuracy, there are some limitations to its use in this application. The main limitation is that the laser tracker is that it is also used to guide the block to the correct XY coordinate during the lowering process. Hence a QA measurement of the positioning is made with the same device as used in the initial positioning, which is not an entirely desirable situation. However, by tracking an external, known 3D-coordinate and comparison of the positioning results to premeasured data provides an independent check of position.

There are two different ways to accomplish an external positioning check.

1. A reference reflector can be mounted on BIM's crane at known 3D coordinates (in BIM's local coordinate system). Then by measuring the position of the reference reflector the accuracy of the laser tracker in positioning the blocks can be accomplished. The only restriction to use of this technique is that there cannot be any moving parts between the reference reflector and the laser tracker or the reliability of this procedure is compromised.

2. The second method is to compare the factory measured, 3D location of each container-mounted reflector within the container's local coordinate system to the measurements from the laser tracker. Depending on the desired reliability level, a separate reference reflector to the crane may or may not be added.

The other issue with respect to use of using the laser tracker is that it is not measuring block's XY- coordinate directly, but via container mounted reflectors. This approach assumes that we know exactly how the block is positioned in the container. Position is measured at the factory but there is a risk that the block is dislocated during transportation to the BIM. To be able to detect and compensate for such movements, the position of the block in the container can be measured just before BIM lowers the block in to the deposit hole. This measurement can be accomplished as a part of the block's integrity test either with machine vision or by using 2 laser distance meters.

Therefore, by using a reference reflector and block's positioning measurement devices, the error sources associated with block location can be reduced to:

1. The untracked movement of the bentonite block in the container. This would occur while BIM handles the block. This is judged to be unlikely because the container holds the block firmly in place with a vacuum-type device on the block's upper surface.

2. When the block is released from the container at the end of the lowering process. It is possible that the block moves when it is released from the container at the end of the lowering. The risk of undesired movement can be reduced by utilising two tactics. The first one is that the block is lowered to the touch point very evenly so that block's pitch and roll angles are within 0.01 degrees of the angles of the previously lowered block. The second tactic is that the block will not be released until it is fully supported by the bottom of the hole or the previously lowered block. This can be detected with the force sensors mounted to each of the ropes which holds the gripper (which holds container which carries the block).

Recommended Approach to ensure XY co-ordinate positioning

The recommended approach is to rely on the accuracy of the laser tracker, monitor its accuracy and minimize the risk of block movement within the container. Machine vision can be used as a supportive method as it is able to identify major changes to block location.

2.3.2. QA3: The width of the gap between assembled block and the host rock.

Background and Motivation

The accuracy target for the gap width measurement between the assembled blocks and the host rock is 5mm. It should be noted that the surface of the host rock is not smooth while it might have horizontal roughness of 10mm as the result of the diamond drilling process. This will make accurate placement of the blocks a challenge since radially measured distances will vary with depth in the deposition hole.

The buffer installation including the gap filling is planned prior to the actual buffer installation. Planning is done is completed in an office location external to the deposition location to ensure undisturbed analysis can be completed. Analysis of the material needs, positioning targets and activity sequencing is based on the 3D model of the deposition hole, provided at the time of its excavation. By measuring the gap between the host rock and just assembled block during the buffer installation process and then comparing this to the pre-installation measurements, it is possible to ensure that the installation process is going as planned.

Studied Approaches

The width of the gap between the buffer and the surrounding rock can be measured either at the gripper level before releasing the bentonite block from the container or it can be measured from the top of the hole with sensors mounted to BIM’s frame.

For sensors mounted on the gripper, one downward looking sensor is mounted on each of the three pads of the gripper. The main purpose of the pads is to take support from the walls of the hole during the block’s final positioning and lowering phase (Final lowering phase starts 15-25mm above the planned touch point). Placing the sensors onto the gripper would provide close range measurements but the bentonite block is not visible. This is because the outer diameter of the container is 16mm bigger than the outer diameter of the bentonite block. The container’s OD is bigger than the block’s OD because of the sealing requirements of the vacuum based lifting device. Also a gripper mounted, but different type of, sensor could be used to measure the horizontal distance from its mounting point to the host rock to provide the gap width. However this is an indirect measurement and would require a wide sensor beam to compensate the surface roughness of the hole.

An alternative sensor location would involve placing the gap width sensor or sensors on the BIM’s frame or crane instead of to the gripper. This enables a direct measurement and compensation for the roughness of the hole. Measurement from frame/crane level can be done only after the gripper has been lifted from the hole.

Two possible sensor types were studied for their potential in measuring the gap dimension. First using a laser scanner or secondly use of machine vision. Properties of both technologies were discussed previously in Section 2.3.1.3. Both technologies would achieve the accuracy target needed in the gap width measurement. However the use of a laser scanner for positioning and measurement still has the same disadvantage as noted previously in that the acquiring, data transfer and analysing takes several minutes.

Machine vision provides a fast method to resolve the dimensions in this particular case. The bentonite block installed to the hole and having very tight manufacturing tolerances can be used as measuring stick to resolve the gap width from the picture. This is possible while we are interested to know the gap between the rock and top surface of the block.

The cost of using machine vision to accomplish gap measurement is the same as presented in Section 2.3.1.3. Both tasks could share the same hardware (camera+ support electronics etc.).

Recommended Approach
Machine vision is the most promising candidate for tackling the gap measurement challenge.

2.3.3. QA4: The compactness of the joint between the pellets and the host rock.

Background and motivation
The surface created when the gap between the host rock and bentonite block is filled with bentonite pellets needs to be measured to ensure that the minimum density of the bentonite buffer is reached. As with the block location activities within the deposition hole, the pellet filling activity is planned prior to the actual buffer installation using the actual 3D model of the hole generated at the time of its excavation. This allows use of premeasured amounts of pellets which can be dosed into the compartments of the above the container holding the buffer block so that the variation in the gap width (due to hole drilling tolerances) can be compensated for. Pellets are released after each block has been lowered to correct XY-coordinate but prior to the block's release (or before the container has been moved from the release position).

The main concern associated with pellet placement is that pellets may form bridges in the annular gap, which causes empty spaces in the filling and decreases the density achieved. In addition to decrease in overall buffer density, it is possible that the bridging is so severe that the pellets won't fit into the available gap. In this case pellets may end up to the touch point surface, disrupting subsequent block placements.

Studied approaches
The target in terms of evaluating the volume of and consistency of pellet fill within the annular gap is to reach the elevation measurement accuracy of approximately one pellet thickness in formation inspection.

The advantage of gripper mounted sensors is that the measurements could be done in prior releasing the block which might allow for positioning corrections (which are undefined) to be completed. The fact that the top part of the container (which carries the block) is wider than a bentonite block is a serious limitation in this QA task. Measuring the surface's elevation uniformity and location with a gripper-mounted sensor before releasing the block has some difficulties. The sensors which are mounted on gripper's pads allow for only 20-30 % of the filling surface to be scanned with these 3 sensors. The amount and position of these sensors are defined by the support pads (3 pieces, spaced evenly (120 degrees between each). There would also be small blind sectors adjacent to each gripper. The width of each blind sector would be approximately 8mm.

In contrast to the use of gripper-mounted sensors, when measuring from the level of BIM's frame or crane there won't be any blind sectors caused by the container. The drawback to this approach is that because the block has already been released it may be even harder to take any actions to correct the situation.

There are two candidates for use in achieving the desired measurements, laser scanning and machine vision. Both have been presented earlier in this document in respect of accuracy, measurement times, costs etc. The measurement distance is also the same as in QA3: The width of the gap between assembled block and the host rock., but the measurements become harder to make as each block is installed since the outer edge of a block shadows the gap to an increasing degree the closer the block is to the sensor. In practise this means that the sensor should move to a viewpoint above the gap so that there is always line of sight to the gap. The same mechanics that can be used in direct pitch and roll measurement of the assembled block with a laser distance meter (2.3.1.2), could also be used to provide exact distance information for the pellet fill.

Recommended Approach
A laser scanner is an excellent option for use in measuring 3D formations. The only disadvantage to its use is that measuring, data transfer and analysing consumes several minutes is problematic in applications that require response time(s) of a few minutes at maximum. Because of this, the Machine vision (photogrammetry) method is also recommended for consideration in accomplishing this QA task. It is not the ideal solution for 3D mapping but is accurate enough and the same instrument could also be used to other QA tasks such as gap width measurement and touch point cleaning – inspection (Section 2.3.1.3).

2.4. Summary of LOT2

Based on the studies outlined above, all QA targets QA1-4 are feasible and the probability of successful implementation is high. As a result of these evaluations and considerations, the estimated sensor cost of the BIM has been decreased by using less expensive sensor technologies and using the same sensor in more one QA task. The probability of meeting the development schedule for the BIM and its operation was also improved by choosing technologies that will require only moderate engineering effort to complete. Table 6 provides a brief summary of the costs associated with each approach.

The QA targets and their briefs are listed below:

- QA1: The integrity of the buffer blocks during the process.

The motivation behind the target is to get the buffer blocks into place in the deposition hole safely. To be able to do this, each block has to be inspected in prior of moving it above the deposition hole.

> According the results from estimations, video inspection is sufficient to accomplish this task. The block will be inspected by cameras when it has been lifted out from transportation container, before lowering to the deposition hole.

- QA2: The quality of the position of the assembled buffer and the bentonite blocks the buffer consists of.

  The motivation for the QA2 is to ensure that there is enough clearance for the canister's installation and also for the filling of the gap between the buffer and host rock. This means that each bentonite block and the whole buffer construction have to be installed at the planned XY-coordinates and maintain levelness. The following subtasks can be derived from the target:

  - Measuring the tilt angles (pitch and roll) of each installed block,
  - Reducing the risk of tilting by inspecting that the surface where the block is lowered is free from particles, and
  - Measuring the XY position of each installed block

Use of a Laser tracker and inclinometers are suitable for precise installation. According to the estimations made, camera inspection is sufficient to check that installation area is free from particles.

- QA3: The width of the gap between assembled block and the host rock.

  The width of the gap between the host rock and block is an important dimension because the gap will be filled with premeasured amount of pellets. Filling is done in stages, one filling increment per each lowered block. The bentonite pellets are dosed based on the 3D model of the hole. By measuring the gap between the host rock and just assembled block during the buffer installation process we can increase the certainty that the gap filling with pellets goes as planned.

To ensure gap width, inspection using the machine vision cameras is the recommended solution.

- QA4: The compactness of the joint between the pellets and the host rock.

  The gap between the host rock and the bentonite blocks is filled with bentonite pellets as described in QA3. The density of the filling has to reach the minimum level to guarantee that the buffer works as planned. This is the reasoning to measure the surface formation created in the filling.

The use of a camera viewing method is the recommended solution for this task.

Table 6 Summary of recommended sensor technologies for use in QA activities.

Method / instrument	Crack detection QA1	Buffer position and tilt QA2	Gap width QA3	Pellet formation QA4
Machine vision/ photogrammetry Mounted to the block transfer Device (BTD) or camera	M 41-50k€ 3k€	S		
Laser tracker		M 2k€ (additional prism.)		
Laser distance meter mounted to rotating fixture in BIM's frame		S 4-10k€ *		S
Machine vision mounted to rotating fixture in BIM's frame or Camera		S	M 10-23k€ + 7,5-12k€ for the fixture * automation 17,5 -35k€ 3 k€	M
Electronics approximation per each QA (sensors+required automation + actuators). Cost is given only once if same sensor is used for several tasks	3 k€	2 - 12k€	3 k€	

M: Main instrument

S: Support instrument

*: Laser distance meter and machine vision to look down to the deposit hole share the same rotating fixture.

Achieved QA data is visualised but developing automated analysing tools is out of the scope of the LOT2.

3. LOT3: Bentonite buffer installation problem handling and error handling

As part of the bentonite buffer installation process the blocks are transported from the factory in single block containers to the central tunnel in ONKALO where they are loaded into the container on the transportation machine before being moved into the deposition tunnel. In the deposition tunnel, the installation machine, equipped with a vacuum lifter takes the bentonite block out of the container on transport machine and moves the block over the deposition hole and then lowers the block into place. Bentonite blocks are fragile objects which cannot tolerate physical impacts without risk of cracking or breaking.

In WP5 LOT3 (how to handle any problems encountered during buffer installation) will be developed methods and equipment for bentonite buffer emplacement problem handling.

3.1. Problem handling scope

Error handling in buffer installation can involve a wide range of situations. They could include such things as dealing with a water filled deposition hole, to a hole and buffer contaminated by oil leaking from deposition tunnel backfilling machinery, through to mechanical failure of the buffer during or post-placement in the deposition hole. As a result, some limitations to project scope were identified in the LUCOEX WP5 LOT3 work description and further limitations to LOT3 were identified while completing the work in LOT2 (buffer quality assurance) and LOT1 (buffer emplacement).

As noted the scope of LOT3 needed to be revised and narrowed and this occurred the feasibility assessment phase of problem handling methods and equipment. Some problem descriptions and subsequent technical demands led to very complex remediation/recovery handling equipment of high cost and high technological risk associated with them. In evaluation of the options for remedial activities, these demands and situations were re-assessed with the intent to achieve realistic, practical and technically robust design(s) that could perform the task of dealing with installation upset situations while ensuring both worker and long term safety in deposition tunnels.

3.2. Problem situation descriptions

In the likely range of situations that could be encountered in the process of installation of the buffer there are several situations that could be expected to occur. Below is a listing of the types of items/materials that the installation/remediation equipment should be able to remove from the deposition hole:

- Irregularly shaped bentonite clods
- Gravel like small bentonite pieces
- Bentonite pellets
- Bentonite dust

- Slurry from bentonite/bentonite water mixing
- Small rocks
- Rubber moisture protection shield and pieces of it
- Complete bentonite blocks
- Broken bentonite blocks
- Machine parts, nuts, bolts, pins
- Chemically (not radiologically) contaminated blocks
- Water

3.3. Problem handling: Scope limitations

Defining Scope:
The Scope for remote controlled problem handling associated with buffer installation was limited by the LUCOEX WP5 machine design project steering group's direction. It was also decided to assume that scratching or other damage to the used fuel canister could be caused when using problem handling equipment. As a result, on recovery the canister will be taken back on ground and spent fuel will be installed into a new fuel canister. Furthermore it was decided that all deposition holes whose deposition action has failed so that canister is removed will be discarded and filled with leftover bentonite. These limitations reduce the physical reach needed for remote controlled equipment (as maximum reach is from tunnel floor to canister top), and provides more space to operate as bentonite between base rock and fuel canister doesn't need to be removed.

Based on these limitations and guidelines, it was also determined that no research would be made regarding removing a spent fuel canister from a deposition hole with bentonite that has had interaction with moisture (e.g. swelled into contact with rock or canister). This goal is also feasible as canister removal from completely swollen bentonite buffer is probably very demanding task which will greatly complicate dismantling actions. Therefore, assuming that the fuel canister can be removed leads to a clearly scoped and defined approach to development of remote controlled problem handling equipment and methods. Work in this project will therefore be focused on bentonite buffer removal above the canister to enable canister removal from a deposition hole and for more or less human operated actions if recovery is to occur before canister is installed (or after canister is removed if it is decided to do so). As a result of the clearly defined scope and restrictions listed above, this project is intended to focus on two activities; first, how to enable canister removal with remote controlled equipment if problems during the buffer installation occurs after canister installation, and second how to handle problems before canister installation with human interaction (no radiation field). Scope limitations have also affect what materials and objects can be removed, with the main goal of the study being to suggest remote controlled equipment for as-built bentonite block and pellet materials and foreign particles.

Radiological Considerations:

As a spent fuel canister could be installed in the deposition hole before problem handling equipment is needed, there is a need for remote controlled operations to safely handle the error situations. As part of this study, a simulation of radiation field associated with an installed spent fuel canister installed in the deposition hole has been made and is shown in Fig. 6. According to these simulations a minimum 4 meters distance (measured from deposition hole centre point), is needed for a deposition hole with a spent fuel canister installed in it. This will provide sufficient distance to be beyond the influence of the radiological field present (before any bentonite is installed on top of canister). This simulation result establishes that it will be possible to use short distance remote control technologies for problem handling cases. It should be noted that the radiological field simulation results shown in Fig. 6 was only made available rather late in this study and so long distance remote controlled systems were also studied and are presented below.

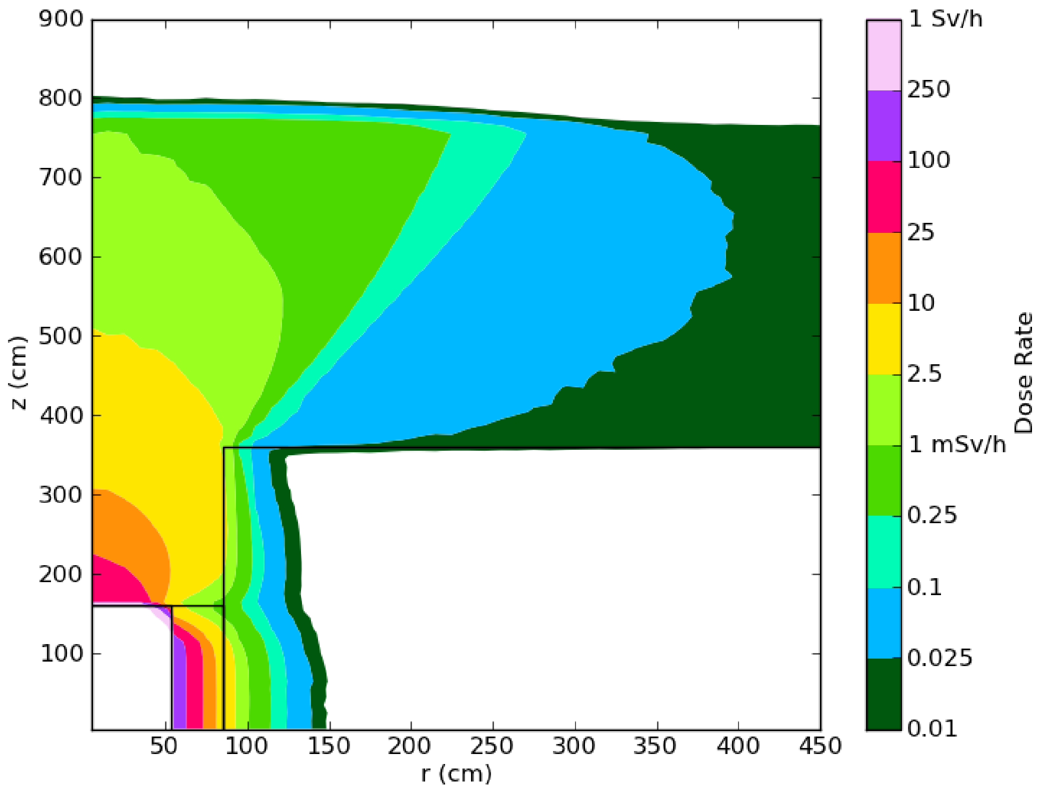

Figure 6. Dose rate in disposal tunnel as a function of radial and horizontal distance from spent fuel canister/1/

3.4. Remotely controlled problem handling equipment and method concepts

The design of remotely-controlled handling equipment is driven by the reach required of it and the distance required between it and the human controller. The maximum vertical distance from tunnel floor to canister top is 2.5m (400mm, 800mm, 800mm and 500mm bentonite blocks above canister) and this is also maximum operational vertical reach needed for problem handling equipment that would be tasked to clean the canister top prior to its removal. Reach is also needed across the whole diameter of deposition hole. From these basic geometric bounds recovery and problem-handling equipment can be developed.

Concept development of the problem handling equipment and methods have been discussed, developed and assessed during the design of LOT1 and LOT2 work. Concepts range from BIM attachments to complete autonomous devices and combinations of these. Several options identified in those studies have been further developed and assessed as part of LOT3 and are presented below together with discussion of their ability to remove objects and materials described in Chapter 2.1.

3.5. Long distance, remote-controlled concepts

Most of the long distance, remotely-controlled concepts were developed before the radiological field simulations provided in Fig. 6 were available and some of the scope restrictions presented in chapter 2.1 were established. In all the concepts considered, only tools to be used in a deposition hole were developed, and all will require use of suction cleaning machinery and waste transportation machinery in the tunnel to carry away the waste taken from the deposition hole. All concepts described below will use the BIM to provide up-down movement and some cases provide suction and pneumatics to problem handling equipment.

In all long distance, remotely-controlled concepts, sophisticated control and video systems are needed. Using of equipment can still be rather demanding as situations to be handled vary greatly and user interaction will be needed through video imagers.

Sections 3.5.1 through 3.5.5 briefly present and discuss some of the technologies considered as potentially viable for use in removal of problematic buffer materials.

3.5.1. Screw lifter

Screw lifter is a mechanical lifter attached to the BIM, with multiple self-tapping coarse threads attached to its underside. The Lifter would be lowered into contact with the top of a broken bentonite block and the screws would be turned to penetrate and grip the bentonite block pieces. This method could allow bigger broken bentonite pieces to be lifted from deposition hole with one lift (see Fig. 7). A Screw lifter would be able to handle full bentonite blocks, broken bentonite blocks and possibly bigger bentonite clods, but not any other materials, smaller bentonite pieces or slurry. For smaller parts and pellets, suction cleaner etc. would be needed.

Concept pros:

- Relatively reliable when correct thread type and hole size has been found
- If screws can be lowered individually, lifted bentonite blocks can be highly damaged as screws can grip bentonite clods better than vacuum lifter
- Method is robust; no need to worry about dust in pumps etc.
- Blocks and big block parts can be removed without risk of damaging block or canister below

Concept cons

- Hard to control, visibility under screw set is very limited, instrumentation for screws penetration to bentonite hard to engineer. These cause unreliable operation.
- Extremely complex mechanics is needed if an operational advantage over vacuum gripper is wanted.
- Needs possibly long test and re-engineering phase for screws and control to achieve reliable operation.
- Lifting reliability highly dependent on screw penetration and mass, bentonite fragments with small top surface area and high mass may not be possible to lift
- Risk of unintentional release and fragments impacting surface exposed in the deposition hole (other buffer segments or canister).

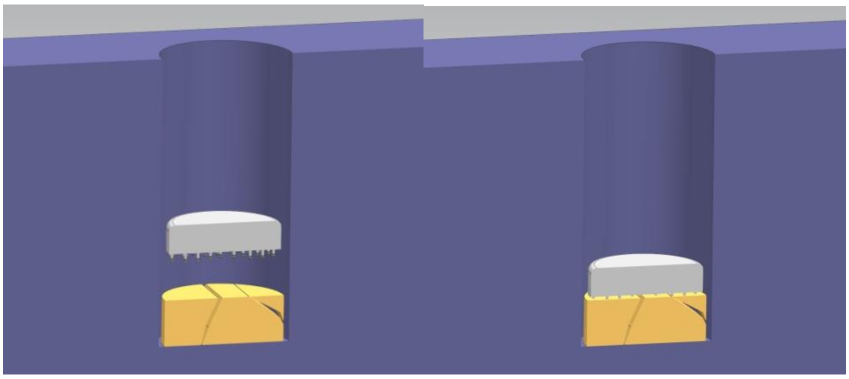

Figure 7 Screw lifter in deposition hole with broken bentonite block. Lifter approaching (left) and attached to broken block (right).

3.5.2. Surface conforming vacuum lifter

Surface conforming vacuum lifter is attached to the BIM with a container top type of vacuum lifter which can move out of horizontal alignment and also laterally within the deposition hole. All vacuum lifter pads would be instrumented with suction sensors and should vacuum be lost each pad could be individually closed using magnetic valves. In this way a surface conforming vacuum lifter could be used with full blocks and broken/cracked bentonite blocks, without the need to switch lifter components. A suction cleaner and possibly some other tool for breaking bigger clods is also needed for use with this tool so as to allow handling of pieces that cannot be handled by the main lifter.

Concept pros:

- Relatively easy remote operations, lifter has a grip if several suction pads can maintain a grip
- BIM can provide power and pressure/vacuum to the equipment
- Blocks and big block parts with undamaged block top can be removed without risk of damaging block or canister below

Concept cons:

- Blocks and canister still have a risk of damage as clods can’t be removed and maybe some breaking equipment needs to be used.
- Added complexity because of surface conforming function compared to normal vacuum lifter
- Horizontal forces on suction pads if lifter has to conform angles before lifting
- High amount of instrumentation and valves
- Danger of dust from broken bentonite in ejectors and pipes causing blocking
- Only relative large and cleanly broken bentonite pieces can be lifted
- Risk of loss of grip and subsequent release and impact on material below the block being handled (blocks, pellets or canister)

3.5.3. Bentonite grinder and suction cleaner

Bentonite grinder is a machine that grinds damaged bentonite block into small, gravel-like pieces or dust and contains an integrated suction cleaner that takes away the bentonite fragments. A Grinder and suction cleaner combination can be used for all kinds of objects to need to be removed, but its ability to remove water and slurry depends on suction head design. There is a risk of damaging bentonite blocks and spent fuel canister below the fragmented material, but risk can be minimized with depth measurements and machine reach cut-offs.

Concept pros:

- Suitable for all objects to be removed
- Robust method
- Easy operation, sequence is always similar
- Can be integrated to work with BIM
- Can be operated remotely with minimal interfacing equipment

Concept cons:

- Very high amount of dust (depending on the nature of the grinder teeth and speed of movement)
- Dust can cause problems with measuring equipment
- Risk of harming bentonite blocks and canister below grinder

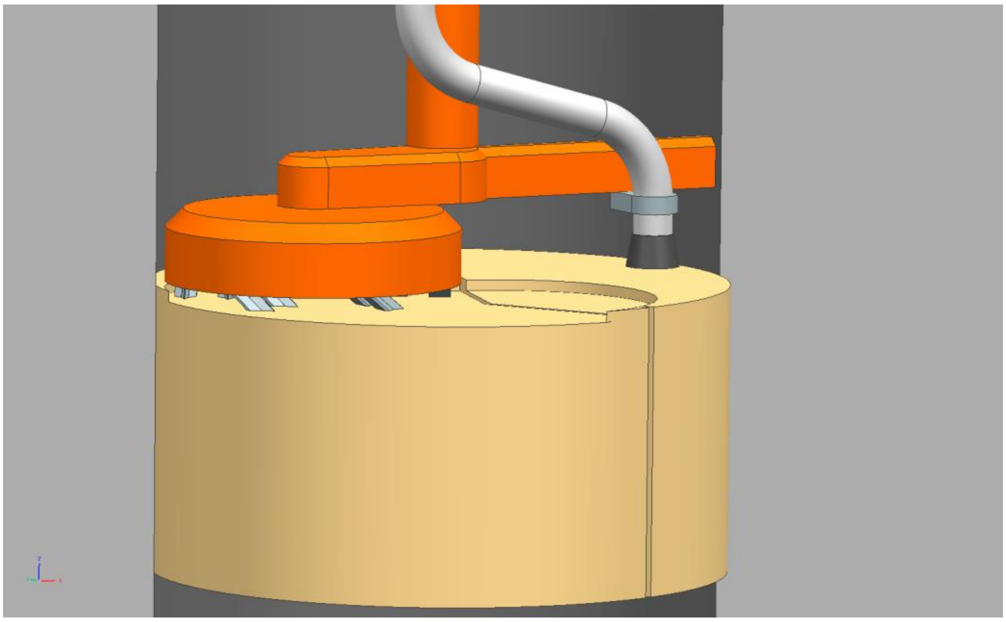

Figure 8. Grinder suction cleaner combination, grinding broken bentonite block in deposition hole.

3.5.4. Robot with various tools

In order to provide a universal cleaning tool for removing different kinds of blocks and foreign objects from deposition hole, downwards oriented robots were also studied (Fig. 9). The robot would be attached to BIM gripper and lowered to deposition hole with the gripper. Gripper pads would be used to avoid gripper and robot swinging. The robot would be equipped with various interchangeable tools that could be used for breaking bigger bentonite parts, grinding vacuum lifter lifting surfaces and using vacuum lifter and mechanical gripper to lift objects from hole. Additionally, some sort of collecting bin and tool changer cabinet would be needed within the deposition hole. Robot size is very limited and full bentonite block lifting with a robot-type device is not possible. Tasks to be done using such a device will be unique in all cases where it is used and so no useful automated robot handling system can be engineered with reasonable effort. As a result, only human operation of robotic manipulators is a possible option. Linear controls would need to be developed in order to allow for its remote operation.

Concept pros:

- Universal tool especially for picking up small objects in deposition tunnel
- Can be used for various tasks for buffer emplacement, for example helping pellet blocking problems
- An experienced operator should be able to avoid harm to blocks and canister below the affected segment(s)

Concept cons

- o Highly complex design and operation, engineering amount versus product capabilities not in reasonable relation
- o Limited capacity, approx. 200kg is maximum handled load
- o Limited capacity causes need of breaking larger pieces which makes task every time different and requires well trained personnel
- o Limited space for robots, needs engineering to avoid harmful collisions with deposition hole wall

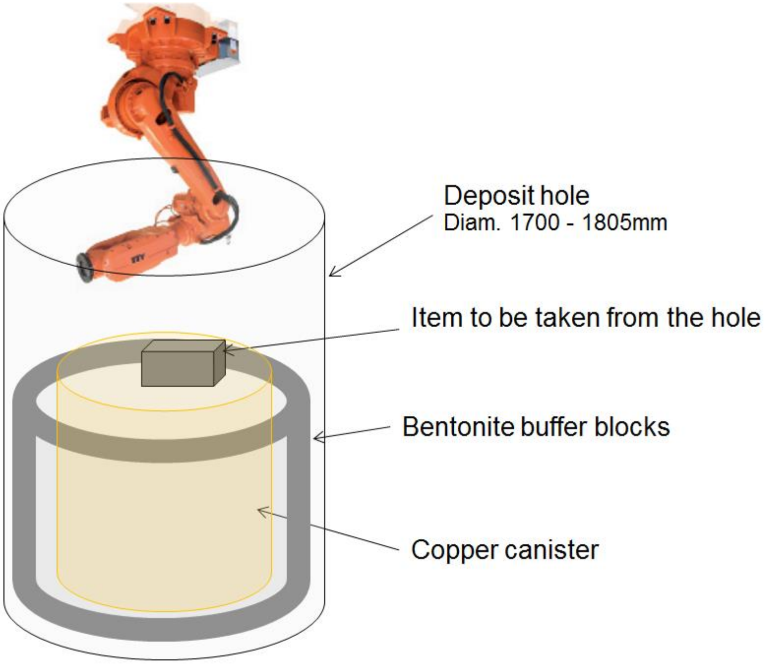

Figure 9. ABB IRB6620 industrial robot operating into deposition hole

3.6. Short distance, remote controlled concepts

Short distance remote controlled concepts are equipment and method concepts that are used from relatively near a deposition hole. As a human user is in effective visual range of the equipment, it allows greater operator feedback into equipment operation. Both of the short distance remote controlled concepts described below require the BIM to be taken away from the deposition hole.

3.6.1. Radiation shield and robot arm

Radiation shield and robot arm concept is some suitable, robot-like manipulator installed in a transparent radiation shield that would allow direct line-of-sight operation into a deposition hole containing a problematic object. As very limited space for objects to be removed is a major problem in this concept this concept was not further studied or modelled. Major handling problems would occur if this approach were attempted after the uppermost blocks were installed in the deposition hole.

3.6.2. Remote controlled demolition machine

Remote controlled demolition machine is typically a tracked vehicle with excavator boom and diesel or electric motor. It is typically used mainly for demolishing buildings and for operation in hazardous and dangerous spaces. Demolition machines are also used for remote controlled operations in nuclear applications. In buffer installation problem handling, a couple of tools would be needed: a gripper scabbler and suction cleaner, both of which would be equipped with video monitoring capability.

An example of this type of equipment is Brokk™, who manufactures demolition machines with a big enough reach to clean a deposition hole down to a canister's top surface (Fig. 10). BROKK machines would fit between the frame of BIM, so light operations can be done even with BIM positioned above deposition hole, short distance remote controlling enables good line of sight to possible collisions between BIM and demolition machine.

Concept pros

- Commercially available, contractors available for testing purposes
- Compact design, suitable for tunnel operations
- Operator can see machine and boom quite near, good understanding of movements
- Large assortment of tools available, normal excavator tools can be also fitted
- Using suction cleaner or mechanical grabble, small and medium sized pieces can be removed and totally disturbed big bentonite blocks can be grinded to gravel like and removed with suction cleaner

Concept cons

- Limited visibility to deposition hole with manual operation still needs trained operator
- Risk of harming bentonite blocks and canister below when using scabbler

Figure 10. A BROKK 330 demolition machine with scabbler breaking concrete structure

3.7. Problem handling methods before canister installation

If installation of buffer blocks fails before a canister has been installed, there is no radiation source in the deposition hole. In this case the fastest, most accurate and fail safe solution is to use human operators in the hole for cleaning. Some equipment will be needed to break the bentonite blocks and to lift block pieces and pellets from the deposition hole. These tools are simply heavy hammer drill, vacuum cleaner (industrial cleaning truck) and screw lifter or chemical anchor for bentonite clods that needs to be developed to gain maximum grip from bentonite blocks. If the item to be remediated is as simple as a metallic fragment (e.g. bolt, nut, small rod), the problem remediation could be as simple as using a magnet on a line, lowered into the deposition hole, to recover the item(s). A similar approach could be used in a deposition hole containing a canister excepting that the line and magnet would need to be controlled from a greater distance and could be monitored using existing machine vision equipment mounted on the BIM.

Human workers can clean the broken bentonite block away such that the lifting surface of the first complete bentonite block remains unharmed. This enables subsequent complete buffer dismantling with a vacuum lifter in minimum time in a situation where a complete ring block has fallen on top of previously installed blocks.

As humans are operating in the deposition hole, on top of the normal safety regulations the following points need attention before starting the dismantling work:

- Safety of the human workers (safety harness, helmet etc.)
- Safety regulations on lifting weights
- Safety regulations on lifting orders when lifting bentonite using screw attachment
- Safety regulations on working depths (cm level below bentonite top level)
- Safety regulations on tunnel operations during the cleaning work
- Safety when working in a confined area (air flow, air quality, overhead protection)

3.8. Project group suggestions regarding equipment suitability

Based on the information provided above the LOT3 Project group suggested that two different equipment types were most suitable for handling of the various tasks necessary to deal with a need to remove materials already in a deposition hole. Firstly, for complete and cracked bentonite block removal, a vacuum lifter with controllable suction pads should be used. Then for cleaning and odd shaped object removal a demolishing-type machine would be used. This same machine will then be used for bentonite pellet and small object removal with its vacuum cleaner attachment.

3.8.1. Vacuum lifter

As described in Section 3.5.2, a vacuum lifter can be used for lifting complete and cracked bentonite blocks from the deposition hole. The BIM will be used as lifting machine, but BIM gripper ejectors will not be used for generating suction within the removal lifter in order to prevent bentonite dust from getting into the BIM gripper lines and ejectors.

Suitable configuration for testing purposes can be achieved by fitting Posiva’s old test vacuum lifter to the BIM gripper (Fig. 11). The available test lifter also has manual valves for each suction pad, so cracks in the bentonite do not cause complete loss of vacuum. Electrical power to run the gripper may need to be brought to the BIM on a separate line if the BIM electrical supply at the gripper is not sufficient to run the vacuum lifter. The existing test vacuum lifter developed by Posiva can be used to remove 800mm high bentonite blocks from a deposition hole when installed using an adapter plate to the BIM gripper (Fig. 12). Ring segment removal will probably not be possible using the standard lifting and moving procedure as space between the BIM legs and gripper is limited.

With a vacuum lifter the following items can be removed from the deposition hole in error situations:

- Complete bentonite blocks
- Broken bentonite blocks
- Contaminated blocks

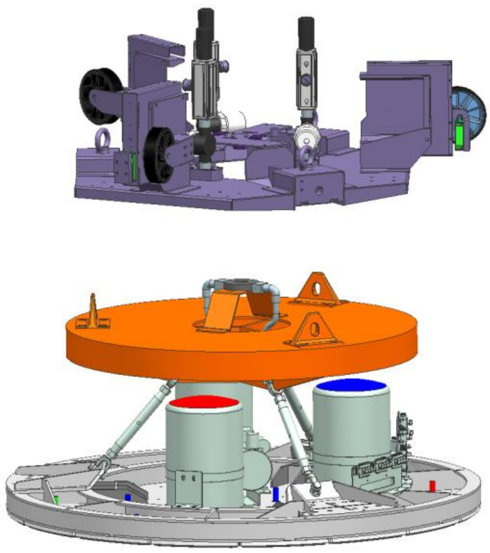

Figure 11. Posiva's test vacuum lifter with BIM adapter plate

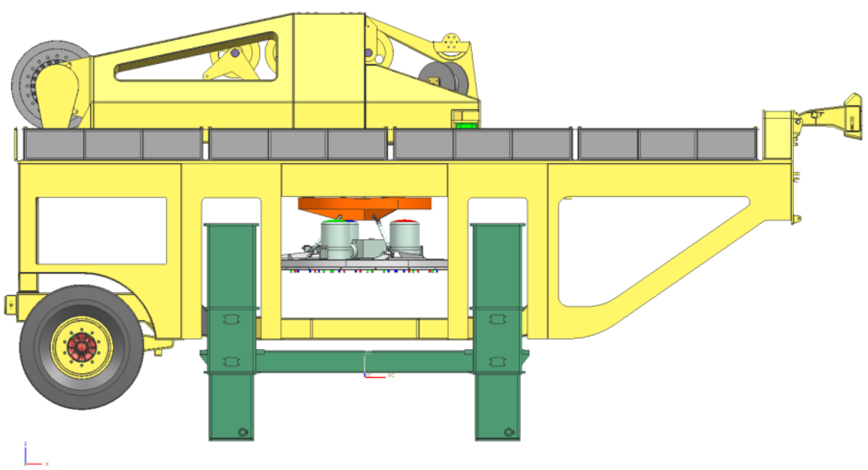

Figure 12. Posiva's test vacuum lifter in BIM gripper

3.8.2. Demolition machine with scabbler, bucket and suction cleaner

A demolition machine (Brokk 330 etc.) can be used for suction cleaning when the BIM is positioned over the deposition hole to remove pellets, machine parts and other small foreign objects from deposition hole. This debris removal is done simply by attaching a suction truck hose to a demolition machines boom and using the boom to guide the hose within the deposition hole. Cameras from BIM and demolition machine boom will be used for remote controlling.
When more robust work needs to be done, a scabbler will be attached to the demolition machine in combination with a suction truck hose to remove dust and some bentonite fragments, finishing needs to be done with plain suction hose. In some cases a bucket or grabble can also be used to remove larger items from the deposition hole.

With a demolition machine the following items can be removed from the deposition hole in error situations:

- Irregularly shaped bentonite clods (grabble, bucket, scabbler and/or suction)
- Gravel like small bentonite pieces (suction)
- Bentonite pellets (suction)
- Bentonite dust (suction)
- Slurry from bentonite/bentonite water mix (suction)
- Small rocks (suction)
- Rubber moisture protection shield and pieces of it (suction)
- Complete bentonite blocks (scabbler and suction)
- Broken bentonite blocks (scabbler and suction)
- Machine parts, nuts, bolts, pins (suction, grabble)
- Contaminated blocks (scabbler and suction)
- Water (suction)

3.8.3. Human operated tools for blocks before canister installation

Commercial lifting hook attachment methods will be selected and tested for dismantling purposes. Methods to be tested are chemical anchor and suitable screw anchors. On top of this testing of hammer drills and vacuum cleaner capacity will be tested.

Generally, a human operator with suitable tools is able to remove all sorts of unknown objects with a minimal disruption to machine placement or operations.

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