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Estimated Quantities of Residual Materials in a KBS-3H Repository at Olkiluoto

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ABSTRACT

The quantities of residual materials in a KBS-3H type repository have been estimated in this report. The repository is assumed to be constructed at Olkiluoto in Eurajoki, Western Finland. Both the total quantities of the materials introduced into the repository and the quantities of materials that remain in the repository after closure have been calculated. The calculations are largely based on a similar work regarding the material quantities in the Finnish KBS-3V repository and the main goal has been to identify the differences between the KBS-3H and KBS-3V repositories with respect to the type and quantities of residual materials. As the design of the KBS-3H repository is not final yet, the results are only preliminary.

Several alternative designs were assumed in the calculations, resulting in different total quantities of materials. The design alternatives that had the greatest effect on the total material quantities were the two different tunnel backfill options, bentonite-crushed rock and Friedland clay. If Friedland clay is used instead of a bentonite-crushed rock mixture, the total quantity of pyrite remaining in the repository is 20 times larger and the quantities of organic materials and gypsum are also increased significantly.

The other design alternatives did not have a substantial effect on the total material quantities. The remaining quantity of cement can be reduced by some 20 % by selecting the silica grouting alternative in the sealing of the rock mass and low-pH cement in the shotcreting of the repository, instead of using the ordinary cement alternatives. If the total quantity of steel should be minimised, the use of the DAWE design alternative would be better than the Basic Design, although the total reduction would be less than 10 %. The main difference between the different drift end plug alternatives is related to the total remaining quantity of silica, which is some 80 % smaller if the rock plug is used instead of the LHHP (Low Heat High Performance) concrete plug. The total quantity of silica is, however, also clearly dependent on the grouting and shotcreting alternatives.

A comparison between the KBS-3H and KBS-3V repositories revealed that most of the total remaining material quantities are nearly the same or smaller in KBS-3H, the difference being typically −20 %. Only very few materials had a clearly larger remaining quantity in the KBS-3H repository. One main reason for the generally smaller material quantities in KBS-3H is the smaller total volume of the KBS-3H deposition drifts as opposed to KBS-3V deposition tunnels. Furthermore, the quantities can be smaller because the deposition drifts are not excavated by drill and blast, they do not have any rock support or conventional installations and they probably require less grouting due to their smaller cross-sectional area.

Keywords: Residual materials, KBS-3H, construction materials, Olkiluoto, nuclear waste, disposal, repository

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TIIVISTELMÄ

Tässä työssä on arvioitu vieraiden aineiden määriä KBS-3H-tyyppisessä loppusijoituslaitoksessa. Loppusijoitustilat on oletettu rakennettavan Eurajoen Olkiluotoon. Sekä tiloihin tuotavien materiaalien kokonaismäärät että tiloihin niiden sulkemisen jälkeen jäävät määrät on arvioitu. Laskelmat perustuvat pitkälti vastaavaan, KBS-3V-loppusijoituslaitosta koskevaan aikaisempaan työhön. Tavoitteena on ollut tunnistaa KBS-3H- ja KBS-3V-tilojen erot vieraiden aineiden koostumuksessa ja määrässä. Koska KBS-3H-tilojen suunnittelutyö on vielä kesken, esitetyt tulokset ovat alustavia.

Laskuissa käytettiin useita erilaisia suunnitteluvaihtoehtoja, jotka vaikuttivat aineiden kokonaismääriin eri tavoin. Kaikista suurin vaikutus oli tunnelin täyttövaihtoehdon – joko murske-bentoniittiseos tai Friedland-savi – valinnalla. Jos Friedland-savea käytetään murske-bentoniittiseoksen sijaan, tiloihin jäävän pyriitin kokonaismäärä kasvaa 20-kertaiseksi ja orgaanisten aineiden ja kipsin määrät kasvavat myös merkittävästi.

Muilla suunnitteluvaihtoehdoilla ei ollut yhtä huomattavaa vaikutusta aineiden kokonaismääriin. Tiloihin jäävän sementin määrää voidaan vähentää noin 20 %:lla valitsemalla silikapohjainen injektointiaine tilojen tiivistämisessä ja matalan pH:n sementti ruiskubetonoinnissa tavallisen sementin käytön sijaan. Jos raudan kokonaismäärä halutaan minimoida, DAWE-suunnitteluvaihtoehto on parempi kuin perusratkaisu (BD), vaikkakin raudan kokonaismäärä pienenee tällöin alle 10 %. Suurin ero kahden sijoitustunnelin tulppavaihtoehdon välilllä liittyy piidioksidin kokonaismäärään, joka on noin 80 % pienempi jos valitaan kivitulppa LHHP-betonitulpan (Low Heat High Performance) sijaan. Piidioksidin määrä on tosin voimakkaasti riippuvainen myös injektointi- ja ruiskubetonivaihtoehtojen valinnasta.

KBS-3H- ja KBS-3V-tilojen keskinäisen vertailun perusteella suurin osa tiloihin jäävien materiaalien kokonaismääristä on samaa luokkaa tai pienempi KBS-3H-tilossa, eron ollessa tyypillisesti –20 %. Vain harvojen materiaalien kohdalla tiloihin jäävät määrät olivat selvästi suurempia KBS-3H-tiloissa. Pienempiin materiaalimääriin on keskeisenä syynä se, että KBS-3H:n sijoitustunnelien kokonaistilavuus on pienempi kuin KBS-3V:n sijoitustunnelien. Lisäksi määrät voivat olla pienempiä siksi, että KBS-3H:n sijoitustunneleita ei louhita poraus-räjäytysmenetelmällä, niitä ei lujiteta eikä varusteta tavanomaisilla rakenteilla, ja ne todennäköisesti vaativat vähemmän injektointia pienemmän poikkipinta-alansa vuoksi.

Avainsanat: Vieraat aineet, KBS-3H, rakennusmateriaalit, Olkiluoto, ydinjäte, loppusijoitus, loppusijoitustilat

PREFACE

This report has been written within the KBS-3H project under the Design subproject managed by Jorma Autio at Saanio & Riekkola Oy. KBS-3H is a joint project between Swedish Nuclear Fuel and Waste Management Co (SKB) and Posiva Oy. The contact person at SKB has been Erik Thurner and the contact persons at Posiva Oy have been Jukka-Pekka Salo and Piia Juhola.

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1 INTRODUCTION

The quantities of residual materials that will be introduced into a KBS-3H repository and the quantities that remain in the repository after backfilling are estimated in this report. The KBS-3H repository is assumed to be constructed at Olkiluoto, Finland. The term *residual materials* is equivalent to the previously used terms *foreign materials* (e.g. Vuorio 2006, Hagros 2007) and *engineering and stray materials* (Hjerpe 2004), and it refers to all materials introduced – either intentionally or unintentionally – into the repository except for the nuclear waste, the materials of the multi-barrier system (engineered barriers and the backfilling material), the rock material and the groundwater. Some of the residual materials will be removed from the repository before its closure and some will not and, therefore, both the introduced quantities and the remaining quantities are estimated in this work. Although the bentonite used in the deposition drifts and the tunnel backfill material are – by definition – not residual materials, they may contain residual materials as impurities, and the quantities of their most significant impurities will also be estimated in this report. In order to allow the quantities of residual steel to be compared between the KBS-3H and KBS-3V concepts, the steel in the supercontainers and in other elements of the KBS-3H multibarrier system (except for the canisters) is, however, considered in this work.

This report will be largely based on similar work carried out for the KBS-3V disposal system (Hjerpe 2004, Hagros 2007). The purpose of this report is to identify the most significant differences between the KBS-3V and KBS-3H disposal systems with respect to the type and quantities of residual materials. The differences between the Finnish and Swedish KBS-3H repositories in terms of material use will also be briefly estimated.

The evaluation will be made for both the BD and the DAWE design alternatives of a KBS-3H repository. BD stands for Basic Design and DAWE for Drainage, Artificial Watering and air Evacuation. In the BD option, the gap between the distance blocks and the rock is made small to favour rapid sealing. The flow of groundwater draining along the floor of the drift may be interrupted by bentonite swelling around the distance blocks during the operational period, allowing water to accumulate in the void spaces around the supercontainers (Smith et al. 2007). In the DAWE option, the possibility of movement of the distance blocks and supercontainers and of piping and erosion is avoided by draining the drift during operations and by using artificial wetting to accelerate the swelling of the distance blocks (Smith et al. 2007). These design alternatives have been discussed in more detail by Autio (2007).

2 LIMITATIONS

As the main goal of this work is to make comparisons between the KBS-3H and the KBS-3V disposal concepts, the parts of these repositories that are considered similar will not be studied in detail. The only significant differences in the material quantities are assumed to be found in the KBS-3H deposition drifts, which are different from the KBS-3V deposition tunnels and holes, and in the central tunnels due to the fact that the total central tunnel length is larger in the current Olkiluoto-specific KBS-3H layout (Johansson et al. 2007) than in the latest KBS-3V layout (Kirkkomäki 2006). All other parts of the repository are identical with respect to layout and here they are also assumed to be identical with respect to material quantities.

As stated in Chapter 1, the following materials are not considered to be residual materials and their quantities will not be estimated in this report:

- nuclear waste
- the engineered barrier system, including the canister, the bentonite and the tunnel backfill materials (the bentonite and the tunnel backfill are, however, considered to include residual materials as impurities)
- the natural barrier, i.e. the bedrock (including groundwater and its constituents).

From the point of view of long-term safety, the quantities of materials that remain in the repository after backfilling are important and, accordingly, the materials that will be totally removed before backfilling will not be discussed in this report any further. These include materials related to the following activities:

- investigation and measurement activities
- installed electrical systems, as well as systems related to ventilation, water supply, drainage (except for the drainage pipes in the shotcrete), heating, monitoring and transport (except for the floors)
- solid parts of the canister transfer and emplacement system.

There are also materials that will not be totally removed from the repository but will not be considered here due to a lack of suitable information or because it is assumed that the quantities of these would be negligible as compared with the other material sources. These include

- microbes and decomposition products of microbes (see Hjerpe 2004)
- secondary materials created in processes acting on the introduced material, such as corrosion products and decomposition of additives of cement, e.g., superplasticisers
- materials produced by events such as major accidents, fires, natural disasters or sabotage
- materials used in the plugging of investigation boreholes
- chemicals used in different investigations and tests.

The types and quantities of some of these materials may need to be estimated later based on more extensive studies than what was possible here. It should be noted that although the quantities of microbes introduced into the repository are not estimated here, the quantities of several nutrients that affect the abundance of microbes are included in the estimations. Regarding the plugging of boreholes, it is, for example, known that in the plugging experiments in deep boreholes OL-KR24 and OL-KR38 at Olkiluoto, some 3,000 kg of foreign materials (mainly cement) were used, but these are expected to be totally removed during the raising of the two shafts at the locations of the boreholes (Vuorio 2006). The cement used in the plugging of the shafts will also not be considered here, because the plugs will be located near the ground surface and because the cement quantities in question are minor in comparison with the total quantities that remain in the repository.

3 ASSUMPTIONS ON THE DIMENSIONS OF THE REPOSITORY

In this work the repository is assumed to be based on the KBS-3H disposal concept. In the KBS-3H concept the waste canisters are emplaced in long horizontal deposition drifts that are bored from the central tunnels. The KBS-3H disposal concept has been described in more detail by Smith et al. (2007) and Autio (2007).

Regarding the layout of the repository, the results of the latest KBS-3H layout adaptation work at Olkiluoto (Johansson et al. 2007) are used. Accordingly, the repository is assumed to be constructed in one layer at the depth of 400–420 m in the central part of the Olkiluoto island. The main difference to a KBS-3V repository is that instead of deposition tunnels and deposition holes, there are horizontal deposition drifts (Figure 1).

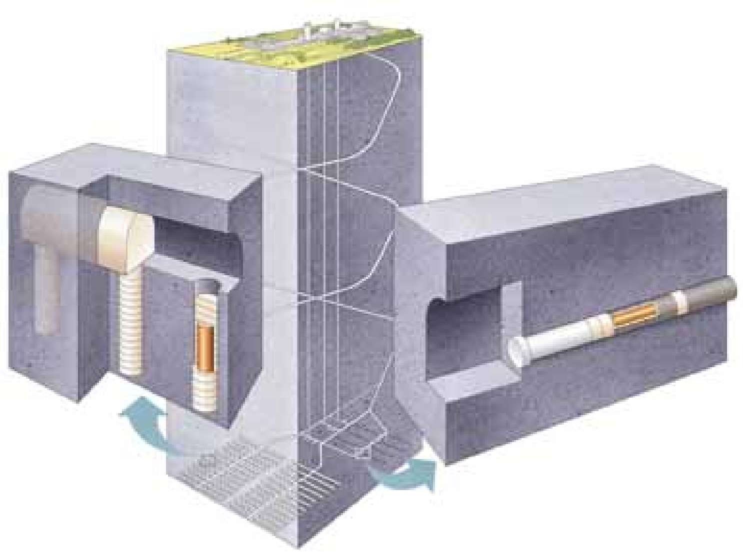

Figure 1. *The multi-barrier KBS-3 concept showing both the vertical deposition (KBS-3V) concept on the left and the horizontal deposition (KBS-3H) concept on the right.*

The layout by Johansson et al. (2007) is shown in Figure 2. The maximum length of the deposition drifts was specified as 300 m and the drifts were considered to start immediately from the central tunnels in order to be conform and comparable with similar KBS-3V design. This is a rough simplification which slightly over estimates the amount of residual materials, since the length of deposition drift starts from the deposition niche. However the difference was estimated acceptable considering the other uncertainties. Accordingly, the wider operation area at the start of each deposition drift (the so-called deposition niche) is considered here to be a part of the deposition drift of maximum length 300 m. Based on the layout, the dimensions of the deposition drifts are assumed to be the following:

- The total number of deposition drifts is 171.
- The total length is 46,432 m.
- The cross-sectional area is 2.69 m^2, except for the first 15 m (the deposition niche), which is a horseshoe-shaped tunnel with the following properties: the width is 8.5 m, the height is 6.65 m and the cross-sectional area is 50 m^2 (these values are preliminary; see, e.g., Thorsager & Lindgren 2004).

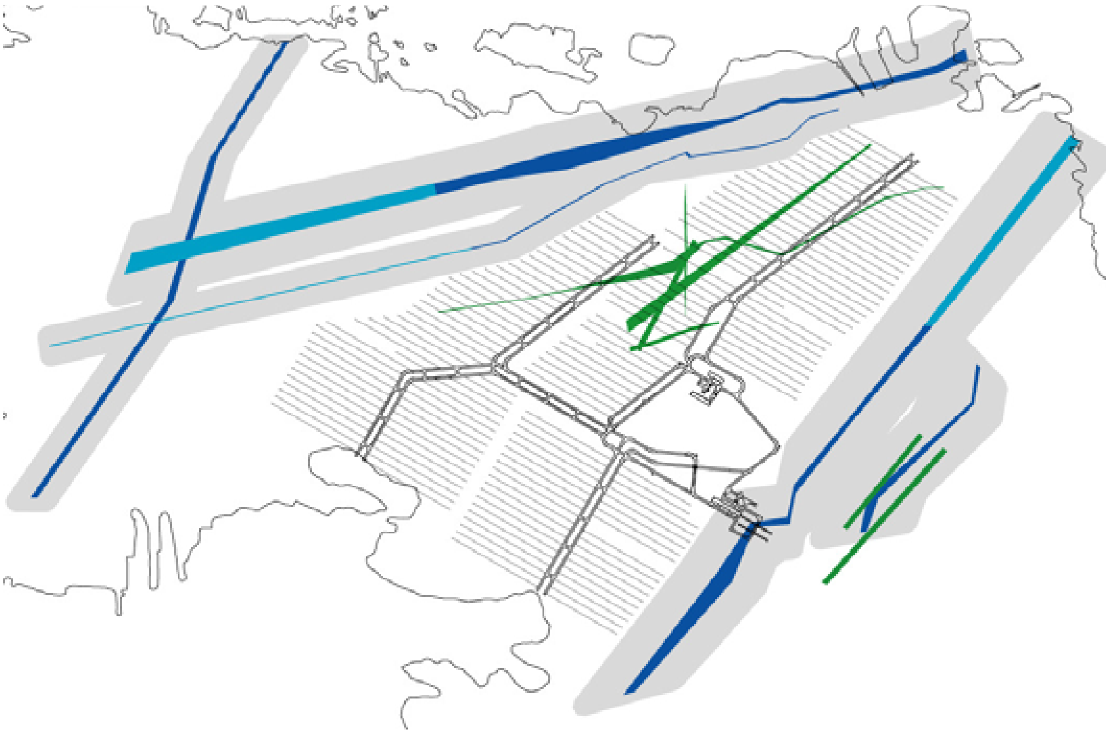

Figure 2. *KBS-3H layout with deposition drift orientation of 120°, level –420 m at Olkiluoto. Grey areas indicate the respect distances to the fracture zones. From Johansson et al. (2007).*

Accordingly, the total volume of the deposition drifts is estimated to be 246,166 m^3. This is 61 % smaller than the total volume of KBS-3V deposition tunnels and holes (in Kirkkomäki's (2006) KBS-3V layout).

The dimensions of the central tunnels are also clearly different between the 3H and 3V designs due to the larger total central tunnel length in the former. Based on the layout by Johansson et al. (2007), the dimensions of the 3H central tunnels are assumed to be the following:

- The total length of central tunnels (at −420 m level, excluding those that are part of the underground research facility ONKALO) is 8,399 m. This is 23 % larger than the total length of central tunnels in 3V.
- The total volume of the central tunnels is, accordingly, 309,644 m^3. The design employs the concurrent central tunnel concept (Malmlund et al. 2004); therefore the given lengths and volumes include both tubes of the double central tunnel as well as the connecting tunnels between them.

The dimensions of all other elements of the Finnish KBS-3H repository are the same as the KBS-3V (Hagros 2007). Accordingly, the total volume of Olkiluoto's underground research facility ONKALO is 362,039 m^3. The dimensions of the individual elements of ONKALO have not been updated and they are based on Hjerpe (2004). The openings belonging to the ONKALO are taken into account in this report, because ONKALO will later be a part of the repository.
The total volume of the repository (incl. ONKALO) is 1,016,290 m^3 and the total volume of the actual repository is, therefore, 654,251 m^3. The actual repository includes the deposition drifts, the central tunnels at the −420 m level and a total of 98,441 m^3 of other openings.

All volumes presented here are theoretical volumes, whereas the actual excavated volumes will probably be slightly larger (~10 %) due to over break. The theoretical volumes will be used, because the difference with actual volumes is minor compared to other uncertainties involved in the work, and because the data obtained from existing excavations are compiled on the basis of theoretical volumes. However, actual excavated volume is a very significant factor with regard to the estimation of quantities of tunnel backfill materials, and, as a result, the relevant theoretical volumes will be multiplied by a factor of 1.1 when the backfill materials are considered.

4 ASSUMPTIONS ON THE COMPOSITION OF THE DEPOSITION DRIFTS

When the quantities of the residual materials have been calculated, three different reference deposition drifts have been assumed for the three different canister types used in Finland (OL1-2, OL3 and LO1-2), based on the KBS-3H layout by Johansson et al. (2007). Each reference drift is assumed to be 300 m long and include one compartment plug section (consisting of two steel plugs and filling components), which occupies 30 m of the drift length. Compartment plugs are used to separate the drift into compartments in order to isolate the drift sections that are suitable for emplacement of canisters from significant water leaking zones (Figure 3).

The number of canisters in one drift varies because different canister types have different thermal canister spacing requirements, which in turn affect actual canister spacings. The rock mass properties are assumed to be similar in all three reference drifts. The details of the three reference drifts are given in Table 1. When estimating the total quantities of the materials in the drift end plugs, the total number of deposition drifts (171) presented in the layout by Johansson et al. (2007) has been assumed. The total number of compartment plug sections assumed in this work is, however, less than 171, because according to the layout, the average length of the deposition drifts is less than 300 m.

The number of all KBS-3H specific components in the deposition drifts is presented in Appendix 1, where 300 m long reference drifts are assumed for the three different canister types.

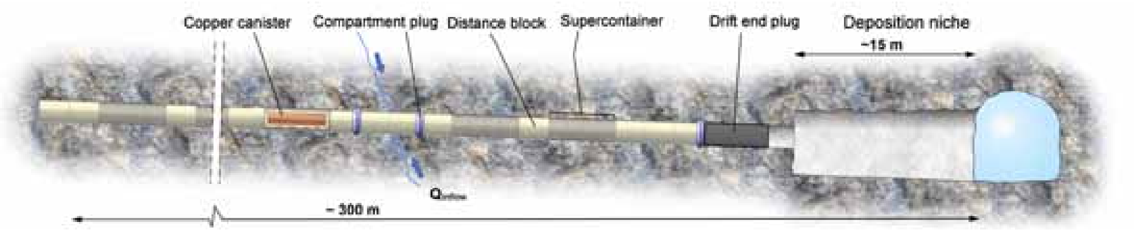

Figure 3. *General design of a KBS-3H drift. A significant water leaking section is isolated by a compartment plug including two steel plugs.*

Table 1. *Compositions of reference deposition drifts (with average properties) for the three different canister types (based on Johansson et al. 2007).*

Parameter/Canister type	**OL1-2**	**OL3**	**LO1-2**
Total length of drift	300 m	300 m	300 m
Unusable section in the beginning of the drift (incl. drift end plug arrangement)	25 m	25 m	25 m
Thermal canister spacing	11.0 m	10.6 m	9.1 m
Number of canisters in drift	17.5	18.2	21.2
Actual canister spacing*	15.7 m	15.1 m	13.0 m
Number / Total length of compartment plugs	1 / 30 m	1 / 30 m	1 / 30 m
Total length of blank zones	52 m	52 m	52 m

* The actual (average) canister spacing is larger than the thermal canister spacing due to sections with unsuitable rock mass conditions, which will not be used for canister positioning. These sections are assumed to make up 25 % of the rock mass at Olkiluoto outside major fracture zones and they are assumed here to include either compartments plugs or blank zones (see Johansson et al. 2007). The percentage is higher in the KBS-3H concept than in the KBS-3V concept in order to take into account the space requirements of the KBS-3H components (compartment plugs and blank zones) that will be used even when the unusable sections are rather narrow.

5 ASSUMPTIONS ON INDIVIDUAL MATERIALS

Below the different components and materials are discussed with emphasis on the differences between the KBS-3H and KBS-3V repositories. Other parts of the repository than the deposition drifts are not discussed here in detail and their materials are assumed to be those defined by Hagros (2007). The total length of the central tunnels based on the 3H layout is, however, taken into account, which will have the effect that the total material quantities in the central tunnels are larger in 3H than what they would be in a 3V repository. This applies to all materials that are present in the central tunnels and this updating will not be mentioned separately below with respect to these materials.

All calculated quantities refer to the mass of the dry materials, as water is not taken into account in this report.

The removal efficiencies for the different materials will be assumed to be the same as those used by Hagros (2007), unless otherwise stated in the text. The material quantities discussed in this Chapter refer to the *introduced quantities*, and the remaining quantities are calculated based on the removal efficiency (Chapter 6). In particular, the values related to the different components of the KBS-3H system are preliminary at this stage and may change during the course of future design work.

All bentonite used in the repository, in both BD and DAWE design alternatives, is assumed here to be of the type MX-80 and its composition is assumed to be as defined in the SR-Can Main Report (SKB 2006a).

The total quantities of materials discussed in Chapter 5.1, 5.2 and 5.4–5.7 are considered to be dependent on the total lengths of the deposition drifts. The quantities are first calculated for the three reference drifts shown in Table 1 (the results are presented in Appendix 1). After this, the total quantities in the whole repository can be obtained by multiplying the drift-specific quantities with the theoretical number of each type of drift. The total theoretical number of deposition drifts is 153.3 (if all drifts were 300 m long) instead of 171 (which is the number of drifts according to Johansson et. al. (2007), see Chapter 3) because all drifts are not 300 m long.

5.1 Steel cylinders in supercontainers

A supercontainer is composed of a perforated steel container (cylinder), a canister within the steel cylinder and bentonite buffer surrounding the canister. For supercontainers with OL1-2 canisters, the total mass of the steel cylinder is 1,031 kg. If the supporting feet are also taken into account, the total mass is 1,071 kg. The length of such a supercontainer (OL1-2) is 5.53 m. The supercontainers with OL3 canisters are 5.98 m long and the supercontainers with LO1-2 canisters are 4.33 m long. The mass of the steel in these two types of supercontainers were calculated assuming that the thickness of the steel plate is constant, 8 mm both in the endplates and in the side of the cylinder, but the endplates are not perforated. If feet are not taken into account, the mass of the supercontainers with OL3 canisters would then be approximately 1,100 kg and the mass of the supercontainers with LO1-2 canisters would be approximately 840 kg. Feet are assumed to be roughly similar in all cases, i.e. their mass is some 40 kg.

The supercontainers will not be removed before the closure of the repository and thus the removal efficiency is 0 %.

5.2 Compartment plugs

A compartment plug section consists of two steel plugs at both sides of a fracture zone intersection (or some other section that needs to be isolated) and some probably bentonite-based material in between the steel plugs and on both sides of them. For the purposes of this work, it will be assumed that this material is similar to the bentonite in the distance blocks (Chapter 5.7). This assumption is conservative if some of the bentonite is replaced by crushed rock or some other material that is not considered to contain significant quantities of foreign materials as impurities.

In the compartment plugs, some 20–30 m of drift length is filled with bentonite. Here it is conservatively assumed that 30 m of bentonite is required for each compartment plug. The total mass of the bentonite in a compartment plug section is, therefore, estimated to be some 130,000 kg, which is based on the assumption that the mass of bentonite per metre of drift is the same as in the distance blocks in the BD alternative. The dry density of the bentonite is assumed to be 1,560 kg/m^3.

MX-80 type bentonite includes several impurities, and the most important of them with regard to long-term safety will be considered here. The studied impurities and their content (weight-%) according to SKB (2006a) are organic carbon (0.2 %), pyrite (0.07 %), gypsum (0.7 %) and carbonates, i.e. calcite and siderite (0–1 %; 0.5 % is assumed here). Other bentonite impurities will not be considered here.

The steel plug is made of 10 mm steel plate and the reference value for the total mass of one steel plug is some 2,100 kg. As one compartment plug includes two steel plugs, the total mass of steel is 4,200 kg.

The steel plugs also require some fixing material, the amount of cement needed being 190 litres per steel plug. The cement is low-pH cement. The composition of the cement has not yet been defined, so here it is assumed to be similar to the cementitious materials used in the rock plugs (Chapter 5.3). The quantities of the related dry materials per one compartment plug (incl. two steel plugs) would be some 600 kg of cement, 40 kg of silica (SiO_2), 0.2 kg of organic material and 0.0008 kg of chloride (the latter two are part of the superplasticiser).

The removal efficiency is 0 %.

5.3 Drift end plugs

Several designs for the drift end plug that is used to seal the deposition drift have been proposed. Two design alternatives are considered in this work:

- steel-reinforced LHHP (Low Heat High Performance) concrete plug
- rigid rock cylinder as a kernel of the plug, with remaining voids being backfilled (material to be specified, probably low-pH cementitious material) (Gribi et al. 2007).

Both of these alternatives will be considered here. Figure 4 shows the layout of the drift end plug (rock cylinder type).

The volume of the low-pH concrete in the LHHP plug is 8 m^3. The plug includes approximately 780 kg of cement, 2,300 kg of amorphous silica (SiO_2), 860 kg of steel and 82 kg of organic materials. All quantities mentioned here refer to the mass of the dry materials (water is not taken into account in this report). A drift end plug also contains a considerable amount of sand and some other materials that have not been taken into account here due to their presumably negligible effect on long-term safety.

The rock plug has not yet been designed in detail. The rock itself is not considered to include any residual materials, so only the cementitious material that is used to fill the voids will be considered. The total volume of this material is assumed to be 1.2 m^3. The composition is not yet known but it is assumed here that 1.2 m^3 of the material includes the following dry materials: some 1,900 kg of cement, 120 kg of silica (SiO_2), 0.7 kg of organic material and 0.002 kg of chloride (the latter two are part of the superplasticiser).

According to the assumed design, a fixing ring and a steel plug similar to those in the compartment plug will be installed for stability reasons during the construction work of the drift end plug (Gribi et al. 2007). The materials related to the fixing ring will be considered in the respective Chapter (5.5). The additional steel plug will be considered as a separate component. As can be seen in Chapter 5.2, the total mass of one steel plug is 2,100 kg. In the required fixing material, the quantities of the dry materials would be some 300 kg of cement, 20 kg of silica (SiO_2), 0.1 kg of organic material and 0.0004 kg of chloride (cf. Chapter 5.2).

Any bentonite emplaced adjacent to the drift end plug is considered to be part of the distance blocks or blank zones (Chapter 5.7).

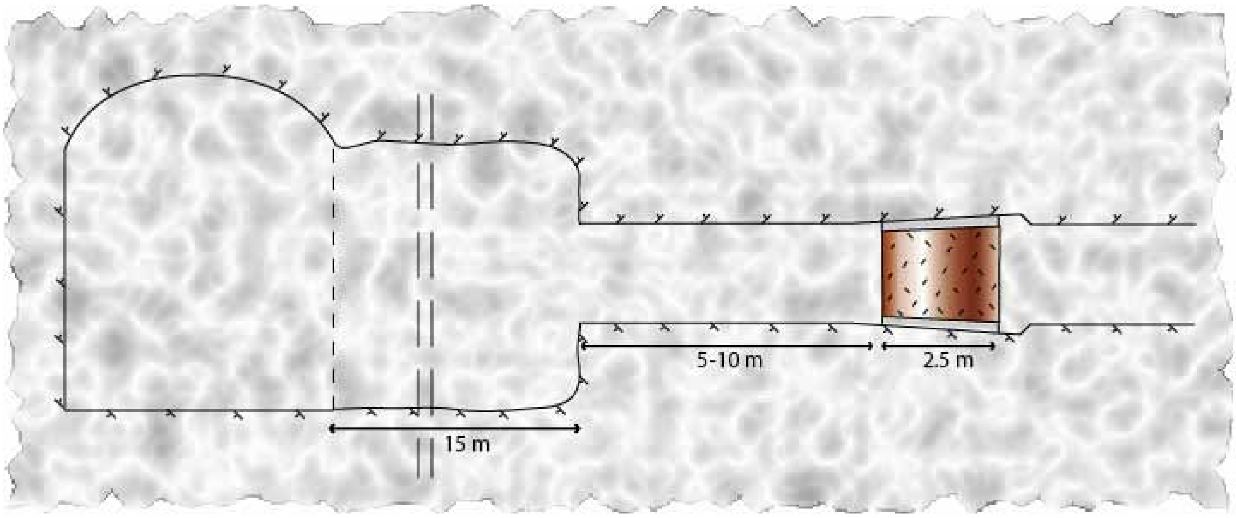

Figure 4. *Detailed view of the layout of the drift end plug (Gribi et al. 2007).*

The total number of drift end plugs is identical to the number of deposition drifts, which is 171 based on the layout by Johansson et al. (2007). The removal efficiency is 0 %.

5.4 Spray and drip shields

Spraying and squirting of water on the bentonite buffer is prevented by placing spray and drip shields on inflow points. The shields are composed of metal material, which is placed on top of the inflow point. In single inflow points the shielding can be implemented using stud type nipples. Spray and moisture shields are used in both design alternatives BD and DAWE (Gribi et al. 2007).

The assumed material to be used in the spray and drip shields is steel. Steel structures are thin (in mm range), the number of them is small and the steel can be assumed to corrode and disappear in relatively short time period when compared to the supercontainer.

The quantity of steel in a spray and drip shield (both BD and DAWE) is 0.6 kg. The number of spray and drip shields in one 300 m reference drift is assumed to be between 4 and 6, i.e. 5 is the assumed reference value. The removal efficiency is 0 %.

5.5 Fixing rings (BD only)

Fixing rings are used to keep the distance block in place at locations where enhanced groundwater flow is expected. An average 300 m deposition drift is assumed to include 4 or 5 fixing rings. This includes also the fixing ring adjacent to the drift end plug (Chapter 5.3). The total quantity of fixing rings is, therefore, assumed to be 4.5 per 300 m of deposition drift, i.e. some 690 fixing rings in the whole repository.

Fixing rings are not used in the DAWE design alternative (Gribi et al. 2007), so the following discussion relates only to the BD alternative.

In the design alternative BD, the material of the fixing rings is a 10 mm thick steel plate and the total mass of one fixing ring is 600 kg (Gribi et al. 2007).

The fixing material used in the fixing rings is low-pH cement. The quantity of the cement is 15 litres per one fixing ring. The composition of the cement has not yet been defined, so here it is assumed to be similar to the cementitious materials used in the rock plugs (Chapter 5.3). The quantities of the related dry materials per one fixing ring would be some 23 kg of cement, 1.5 kg of silica (SiO_2), 0.009 kg of organic material and 0.00003 kg of chloride (the latter two are part of the superplasticiser).

The removal efficiency is 0 %.

5.6 Drainage, wetting and air evacuation systems (DAWE only)

In the DAWE design alternative, the structural materials include a drainage system of inflowing water and an air evacuation system (Gribi et al. 2007).

All pipes related to these systems will be removed from the drifts, so their materials will not be considered further in this work, with the exception of the pipe props, which will remain. They contain 50 g of steel each and there will be one prop per 5 m of drift. The total quantity of steel would thus be some 3 kg per one 300 m long reference drift.

5.7 Impurities in the bentonite in supercontainers, distance blocks and blank zones

In the KBS-3H concept, bentonite is located inside the supercontainer and in distance blocks that are located between the supercontainers (these two bentonite components are jointly considered as the bentonite buffer). In addition, bentonite is located in blank zones where supercontainers cannot be emplaced due to unfavourable rock mass properties. The assumed dry density of bentonite is 1,560 kg/m^3 in all of these components. Bentonite is also included in the compartment plugs, but this was considered separately in Chapter 5.2.

When calculating the amount of bentonite used in the KBS-3H drifts, the properties of the average 300 m deposition drifts described in Chapter 4 are used. As such a drift includes 1 compartment plug, 1 drift end plug and 5.2 blank zones, a total of 107 m of the deposition drift is occupied by these structures and only 193 m is available for supercontainers and distance blocks. The number of supercontainers is slightly dependent on the canister type due to different thermal constraints. The number of supercontainers and, correspondingly, the number of distance blocks in all three reference drifts is equal to the number of canisters as given in Table 1 above.

The quantity of bentonite in the supercontainers is approximately 16,000 kg for supercontainers with OL1-2 canisters. For OL3 canisters, the quantity is some 17,000 kg and for LO1-2 canisters, it is some 13,000 kg. The differences are due to the different volume of bentonite, caused by the differing supercontainer and canister sizes.

In drifts with OL1-2 canisters, the quantity of bentonite in one distance block is some 23,000 kg. The diameter of the distance blocks is assumed to be 1.83 m in the BD alternative. The length of the distance blocks varies based on the type of fuel in the canisters. For Posiva BWR fuel (OL1-2 canisters), the distance blocks are 5.475 m long. In drifts with OL3 canisters the distance blocks are 4.625 m and in drifts with LO1-2 canisters they are 4.775 m long. Accordingly, the mass of the bentonite in the distance blocks of OL3 drifts is some 19,000 kg and the corresponding mass is some 20,000 kg in LO1-2 drifts in the BD alternative.

The diameter of the distance blocks is different in the DAWE design alternative (Gribi et al. 2007). Here it is assumed to be 1.77 m in DAWE and the quantity of bentonite in distance blocks is some 22,000 kg for OL1-2 canisters and some 19,000 kg for both OL3 and LO1-2 canisters.

All other spaces (blank zones) are assumed to be filled with filling blocks of bentonite. In reality, some permeable material such as crushed rock will probably also be used, so this assumption is conservative in terms of the quantities of bentonite impurities. In one 10 m long bentonite block (blank zone), some 42,000 kg of bentonite is assumed to be used, assuming that the quantity of bentonite per metre of drift is similar to that in the distance blocks in the BD alternative. The average number of 10 m long blank zones in a 300 m long deposition drift is 5.2 (Table 1).

The weight content of the significant impurities of MX-80 type bentonite are, according to SKB (2006a), 0.2 % for organic carbon, 0.07 % for pyrite, 0.7 % for gypsum and 0−1 % for carbonates, i.e. calcite and siderite (0.5 % is assumed here).

In addition to bentonite, the distance blocks include supporting feet (in the DAWE alternative only). The material is assumed to be steel and the total mass is 13.9 kg per one distance block (Gribi et al. 2007).

5.8 Impurities in the backfill material

The impurities in the bentonite used in the deposition drifts were discussed in Chapter 5.7. This section considers the backfill materials in the other parts of the repository. These can be assumed to be similar to those in a KBS-3V repository (Hagros 2007). The deposition niche, i.e. the wider first 15 m of each deposition drift is assumed to have the same tunnel backfill as the rest of the repository, so these sections are also included here. Two backfill concepts will be considered (based on Hagros 2007):

a) 30 wt-% bentonite (MX-80) and 70 wt-% crushed rock
b) 100 % Friedland clay.

These alternatives are assumed to be used in all repository openings (except for the small-diameter part of the deposition drifts), which may be a conservative assumption. The backfilling is assumed to be done with pre-compacted blocks. The assumed *average* dry density for the backfill with 30/70 mixture is 2,150 kg/m^3 and the corresponding value for the Friedland clay alternative is 1,950 kg/m^3. In both alternatives it is, however, assumed that 7 % of the volume is backfilled with a mixture of 15 wt-% bentonite (MX-80) and 85 wt-% crushed rock, which will be used in the backfilling of the floors (Keto & Rönnqvist 2006). The assumed dry density of the 15/85 mixture is 1,950 kg/m^3. The volumes of all openings to be backfilled are assumed to be 1.1 times the theoretical volumes that are based on the layout.

The crushed rock to be used in alternative a is assumed to include no significant amounts of impurities that should be considered here. Only the impurities in the bentonite and the Friedland clay are considered here. The bentonite impurities and their content were given in Chapter 5.7 above. The impurities of the Friedland clay that are considered and their content (weight-%) according to SKB (2006a) are organic carbon (0.6 %), pyrite (0.62 %) and gypsum (0.8 %). The removal efficiency for the impurities in the backfill is 0 %.

5.9 Explosives

The main part of the deposition drifts, i.e. the circular part with a small diameter, will be constructed by tunnel boring, so no explosives are assumed to be used in these parts.

The first 15 m of the drifts (the deposition niche, see Chapter 3) is assumed to be constructed by drill and blast and the consumption of explosives per excavated cubic metre is assumed to be the same as in the other parts of the repository (Hagros 2007). Accordingly, 3 kg of explosives is assumed to be used for each excavated cubic metre, and 0.0006 kg of NO_x gases are assumed to be produced per 1 kg of explosives.

5.10 Blasting caps and cords

The small-diameter part of the deposition drifts will be constructed by tunnel boring and no blasting caps or cords are assumed to be used in these parts.

In the deposition niche the consumption is assumed to be similar as in other parts of the repository (Hagros 2007). The consumption of aluminium in blasting caps is 0.0019 kg per excavated cubic metre and the consumption of plastic in the cords is 0.0020 kg per excavated m^3. These are based on the used quantities in the ONKALO (see Hagros 2007 for more detailed assumptions).

5.11 Support bolts

No bolts are assumed for the small-diameter part of the deposition drifts, as the KBS-3H concept assumes that these sections will not be supported. The deposition niche is assumed to require 1.4 bolts per 1 m of tunnel, i.e. 21 bolts in total per one drift. The bolting density of 1.4 is based on the consumption of bolts estimated in the KBS-3V work for openings of similar width (some 8 m) as in the tunnel sections considered here. The bolt lengths and composition are assumed to be the same as in Hagros (2007) (based on Hjerpe 2004). Accordingly, in the deposition niche, bolts with a length of 3.5 m are assumed to be used, and the consumption of related materials per one metre of tunnel would be 18.2 kg for steel, 0.35 kg of zinc and 7.1 kg of cement.

5.12 Anchor bolts

In KBS-3V, there would be anchor bolts in the deposition tunnels and they would be grouted with cement (Hagros 2007). In KBS-3H, no installations are planned for the small-diameter part of the deposition drifts, so they are assumed here to contain no anchor bolts. The deposition niche is assumed to have the same array of anchor bolts as the central tunnels. Accordingly, there would be 1 anchor bolt per 1 m of tunnel. The consumption of materials in anchor bolts would be 1.5 kg of steel and 0.31 kg of cement per 1 m of tunnel. See Hjerpe (2004) for more detailed assumptions.

5.13 Shotcrete

No shotcrete is assumed to be used in either the KBS-3V deposition tunnels or the KBS-3H deposition drifts. However, the deposition niche has a large span, and it may be assumed that this section requires supporting by shotcrete. Similarly to the KBS-3V repository (Hagros 2007), two different shotcreting alternatives are considered for these horseshoe-shaped sections of the deposition drifts:

A. Shotcrete with ordinary cement is used.
B. Shotcrere with low-pH cement is used.

The assumed composition of both types of shotcrete (incl. additives) is described in detail by Hagros (2007). The consumption of shotcrete is calculated based on the dimensions of the tunnel profile as proposed by Hjerpe (2004) and the thickness of the shotcrete layer is assumed to be similar to the openings of approximately the same size. Accordingly, the consumption of the related materials per one metre of tunnel would be some 710 kg for cement, 5.0 kg for organic materials, 29 kg for SiO_2, 2.1 kg for aluminium, 0.50 kg for iron (Fe(III)) and 0.036 kg for chloride in the shotcreting alternative A. For the alternative B, the corresponding quantities would be some 430 kg of cement, 3.0 kg of organic materials, 330 kg of SiO_2, 1.3 kg of aluminium, 0.30 kg of iron (Fe(III)) and 0.022 kg of chloride.

5.14 Steel mesh

In a KBS-3V repository, steel mesh is assumed to be used as a replacement of shotcrete in the deposition tunnels. In KBS-3H deposition drifts, no rock support is assumed to be used in the small-diameter part of the drifts. In the deposition niche, rock bolting and shotcreting is assumed to be used, as was discussed above. No steel mesh is, therefore, assumed to be used in a KBS-3H repository.

5.15 Grouting materials

Hagros (2007) assumed three different alternatives for the grouting strategy to be used in the repository (excluding ONKALO):

1) grouting with 100 % ordinary cement
2) grouting with 100 % low-pH cement
3) grouting with 100 % colloidal silica.

These three alternatives are assumed also in this work in order to calculate the quantities of the grouting materials to be used in the deposition drifts. All alternatives also include some use of additives, such as accelerators. Based on the same principles as was used by Hagros (2007), the consumption of grouting materials per excavated cubic metre in the deposition drifts in the three different alternatives would be

1) 0.17 kg of cement, 0.0017 kg of organic material, 0.017 kg of SiO_2 and 0.00017 kg of chloride per excavated cubic metre in the deposition niche. In the small-diameter parts of the drifts, the corresponding values would be 1.4 kg of cement, 0.014 kg of

organic material, 0.14 kg of SiO_2 and 0.0014 kg of chloride per excavated cubic metre.

2) 0.075 kg of cement, 0.0030 kg of organic material, 0.047 kg of SiO_2 and 0.000075 kg of chloride per excavated cubic metre in the deposition niche. In the small-diameter parts of the drifts, the corresponding values would be 0.60 kg of cement, 0.024 kg of organic material, 0.37 kg of SiO_2 and 0.00060 kg of chloride per excavated cubic metre.
3) 0.093 kg of SiO_2 and 0.0028 kg of chloride per excavated cubic metre in the deposition niche. In the small-diameter parts of the drifts, the corresponding values would be 0.74 kg of SiO_2 and 0.022 kg of chloride per excavated cubic metre. No cement or organic materials would be used in the groutings of the deposition drifts in this alternative.

No nitrate-bearing additives are assumed to be used in the deposition drifts, or anywhere in the actual repository. For more detailed assumptions and the groutings assumed for the ONKALO in these alternatives, see Hagros (2007).

5.16 Floors and miscellaneous constructions

No floors are planned for the small-diameter part of the deposition drifts. In the horseshoe-shaped deposition niche the floors are assumed to be similar to those planned for the central tunnels, i.e. concrete floors with steel mesh (Hjerpe 2004, Hagros 2007). The quantity of cement per one square metre of tunnel floor is some 36 kg and the corresponding quantity of steel is some 5.2 kg.

Miscellaneous constructions include walls, intermediate floors, doors etc. (Hjerpe 2004). These structures are not assumed to be constructed in the deposition drifts. As there are also no such structures in the KBS-3V deposition tunnels and holes, the related quantities for the whole repository are identical for both concepts, except when the quantities are dependent on the total central tunnel length, which is larger in 3H.

5.17 Drainage pipes

This section considers the drainage pipes between the rock surface and the shotcrete, and above it has been assumed that in the deposition niche, shotcrete would be used. Drainage pipes will, therefore, also be assumed for these sections and the assumptions are the same as those for central tunnels (Hjerpe 2004, Hagros 2007). Accordingly, the consumption of materials per one metre of tunnel is 0.29 kg for steel, 0.17 kg for polyethylene and 0.067 kg for polystyrene.

5.18 Emissions from vehicles and maintenance work

The residual materials in the emissions from underground traffic and construction and maintenance work can be grouped using the following categories based on origin (cf. Jones et al. 1999):

1) wear to tyres
2) exhaust fumes from diesel engines

3) diesel oil
4) battery acid
5) hydraulic and lubricating oils
6) degreasing agents and detergents
7) hard metals and metal fragments.

In a KBS-3V repository, the vast majority of such materials are produced in the access tunnel, central tunnels and the research tunnel (Hagros 2007), and the proportion of the deposition tunnels is typically only some 1 % of the total quantities. Due to this very small proportion the quantities in the deposition drifts were not estimated accurately and it was simply assumed that in the small-diameter part of the deposition drifts the quantities per excavated m^3 would be 0 (with the exception of steel fragments, see below) and in the deposition niche it would be the same as in the other parts of the repository except for the access tunnel, research tunnel and central tunnels, where it is generally higher than in the other parts. The increased central tunnel length was naturally taken into account. For detailed assumptions, see Hagros (2007) and Hjerpe (2004).

The residual materials originating from the deposition equipment are mainly stainless steel resulting from wear between the rock and the slide plate, rubber (polyurethane) caused by wear of wheels and possible oil spillage cause by unlikely failures of, e.g., gear boxes. The residual material quantities are assumed to be small but have not been estimated quantitatively. They are assumed here to be equivalent to the emissions originating from the deposition of canisters in a KBS-3V repository, which are included in the estimations of Hagros (2007).

The small-diameter part of the deposition drifts will be bored and the quantity of steel fragments originating from the drill bits may be assumed to be greater in tunnel boring than in drill and blast excavation. It was assumed here that the quantity of steel fragments per excavated m^3 would be 10 times higher in the small-diameter parts of the KBS-3H deposition drifts than they are in KBS-3V deposition tunnels.

5.19 Paints

In the KBS-3V work (Hagros 2007) it was assumed that the marking paints used underground include 80 % hydrocarbons and that the consumption of hydrocarbons in marking paints is 0.0054 kg per one excavated cubic metre in the deposition tunnels. This ratio is also suggested for the KBS-3H deposition drifts.

5.20 Urine and other human waste

The construction schedule of the KBS-3H repository has not yet been planned in detail, so it is not known whether the total construction time will be longer or shorter than in KBS-3V. The difference is assumed to be small here and, therefore, it is estimated that the total number of working shifts is approximately the same in KBS-3V and 3H. This may be a conservative assumption, as the total excavated volume of the KBS-3H repository is 25 % smaller than that of the KBS-3V repository, possibly indicating a shorter construction time. Nevertheless, the total quantities of human waste produced by the workers and visitors are assumed to be approximately the same in 3H as they are in 3V (Hjerpe 2004, Hagros 2007). As the total quantities are the same, the quantities per excavated cubic metre are slightly different. Accordingly, it is assumed here that 1.9 kg of carbamide is produced per one excavated cubic metre in the access tunnel, research tunnel and the central tunnels (length based on 3V) and the corresponding ratio is some 0.17 kg/m^3 for other parts of the repository, excluding the small-diameter parts of the deposition drifts, where the ratio is 0.09 kg/m^3. For other organic materials in human waste, the ratio is 1.19 kg/m^3 for the access tunnel, research tunnel and the central tunnels and 0.12 kg/m^3 for other parts, excluding the small-diameter parts of the deposition drifts, where the ratio is 0.07 kg/m^3. See Hjerpe (2004) for more detailed assumptions.

5.21 Impurities in ventilation air

Organic materials are considered here as significant impurities in the ventilation air. Assuming that the total construction schedule is approximately the same in both KBS-3V and 3H, the differences in the amount of ventilation air are caused only by the different total volumes of the two types of repositories. Even if the difference is rather large, i.e. the 3H repository is some 25 % smaller in total volume than the 3V repository based on the current layouts; the difference becomes small when the average open times of the different openings are taken into account. The main difference in the total volume is related to the KBS-3V deposition tunnels and holes (which are significantly larger in volume than the KBS-3H deposition drifts), the average open time of which is only some 7 years (Hjerpe 2004). Also the central tunnel volumes are different, and their average open time is some 45 years (Hjerpe 2004). When the volumes are weighted based on the average open times, the difference between 3V and 3H is only some 1 %, so the quantities of the impurities in the ventilation air are nearly the same in 3H and in 3V. For other assumptions, see Hjerpe (2004).

6 RESULTS FOR THE WHOLE REPOSITORY

6.1 Quantities per origin of materials

The estimated quantities of residual materials that remain in the repository (incl. ONKALO) after closure are presented in Table 2 for the BD design alternative and Table 3 for the DAWE alternative. In addition to the *remaining* quantities, the tables also show the estimated total quantities of materials *introduced* into the repository. Both types are presented on the basis of their most relevant chemical components. The estimated removal efficiencies are the same is in Hagros (2007). Similar to the approach used by Hagros (2007), the following components are not considered:

- water (H_2O)
- oxygen (O_2)
- nitrogen gas (N_2)
- carbon dioxide (CO_2)
- carbon monoxide (CO)
- rock minerals
- other substances which are considered to be of minor relevance for the long-term safety of the repository or which could not be calculated due to a lack of data.

As water is not taken into account, all values presented in the following tables refer to quantities of dry materials.

The quantities of materials in the 300 m long reference drifts are also presented in Appendix 1, where only the KBS-3H specific components and materials are included. The tables in Appendix 1 were used when the total quantities of these materials were estimated for the whole repository.

Table 2. *Estimated total quantities of residual materials in a KBS-3H repository (BD design alternative), listed by origin. Table continues on the next pages.*

Origin of the residual materials	Chemical components considered	Total introduced quantity [kg]	Removal efficiency [%]	Remaining quantity [kg]
1 Steel cylinders in supercontainers	Steel	3,000,000	0 %	3,000,000
2 Compartment plugs	Steel	640,000	0 %	640,000
	Cement	92,000	0 %	92,000
	Silica (SiO_2)	6,100	0 %	6,100
	Organic materials	40,000	0 %	40,000
	Chloride	0.1	0 %	0.1
	Pyrite	14,000	0 %	14,000
	Gypsum	140,000	0 %	140,000
	Carbonates (calcite + siderite)	100,000	0 %	100,000
3 Drift end plugs				
3.1 LHHP plug alternative	Cement	180,000	0 %	180,000
	Silica (SiO_2)	400,000	0 %	400,000
	Organic materials	14,000	0 %	14,000
	Steel	510,000	0 %	510,000
	Chloride	0.07	0 %	0.07
3.2 Rock cylinder alternative	Cement	380,000	0 %	380,000
	Silica (SiO_2)	20,000	0 %	20,000
	Organic materials	140	0 %	140
	Steel	360,000	0 %	360,000
	Chloride	0.4	0 %	0.4
4 Spray and drip shields	Steel	500	0 %	500
5 Fixing rings	Steel	410,000	0 %	410,000
	Cement	16,000	0 %	16,000
	Silica (SiO_2)	1,000	0 %	1,000
	Organic materials	6	0 %	6
	Chloride	0.02	0 %	0.02
6 Impurities in bentonite buffer (in supercontainers)	Organic carbon	89,000	0 %	89,000
	Pyrite	31,000	0 %	31,000
	Gypsum	310,000	0 %	310,000
	Carbonates (calcite + siderite)	220,000	0 %	220,000
7 Impurities in distance blocks	Organic carbon	120,000	0 %	120,000
	Pyrite	42,000	0 %	42,000
	Gypsum	420,000	0 %	420,000
	Carbonates (calcite + sid.)	300,000	0 %	300,000
8 Impurities in blank zones (bentonite blocks)	Organic carbon	67,000	0 %	67,000
	Pyrite	23,000	0 %	23,000
	Gypsum	230,000	0 %	230,000
	Carbonates (calcite + siderite)	170,000	0 %	170,000

Origin of the residual materials	**Chemical components considered**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
9 *Impurities in backfill material*				
9a Backfill alternative a (bentonite/crushed rock)	Organic carbon	1,200,000	0 %	1,200,000
	Pyrite	410,000	0 %	410,000
	Gypsum	4,100,000	0 %	4,100,000
	Carbonates (calcite + siderite)	2,900,000	0 %	2,900,000
9b Backfill alternative b (Friedland clay)	Organic carbon	10,000,000	0 %	10,000,000
	Pyrite	11,000,000	0 %	11,000,000
	Gypsum	14,000,000	0 %	14,000,000
	Carbonates (calcite + siderite)	100,000	0 %	100,000
10 Explosives	Nitrogen oxides (NO_x)	1,600	99 %	16
11 Blasting caps and cords	Aluminium	1,700	90 %	170
	Plastic	1,800	90 %	180
12 Support bolts	Steel	220,000	0 %	220,000
	Zinc	4,200	0 %	4,200
	Cement	86,000	0 %	86,000
13 Anchor bolts	Steel	50,000	40 %	30,000
	Cement	6,300	0 %	6,300
14 Shotcrete				
14A Shotcrete alternative A	Cement	6,900,000	95 %	350,000
	Aluminium	21,000	95 %	1,000
	Organic materials	49,000	95 %	2,400
	Silica (SiO_2)	280,000	95 %	14,000
	Iron (Fe(III))	4,900	95 %	200
	Chloride	300	95 %	17
14B Shotcrete alternative B	Cement	5,100,000	95 %	260,000
	Aluminium	15,000	95 %	800
	Organic materials	36,000	95 %	1,800
	Silica (SiO_2)	2,200,000	95 %	110,000
	Iron (Fe(III))	3,600	95 %	180
	Chloride	300	95 %	13

Origin of the residual materials	**Chemical components considered**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
*15 Grouting materials**				
15.1 Grouting alternative 1	Cement	780,000	20 %	620,000
	Organic materials	7,800	20 %	6,200
	Silica (SiO_2)	78,000	20 %	62,000
	Chloride	800	20 %	600
	Nitrate	1,000	20 %	800
15.2 Grouting alternative 2	Cement	590,000	20 %	480,000
	Organic materials	10,000	20 %	8,200
	Silica (SiO_2)	130,000	20 %	110,000
	Chloride	600	20 %	500
	Nitrate	900	20 %	700
15.3 Grouting alternative 3	Cement	420,000	20 %	340,000
	Organic materials	5,000	20 %	4,000
	Silica (SiO_2)	230,000	20 %	190,000
	Chloride	5,700	20 %	4,600
	Nitrate	800	20 %	600
16 Floors	Cement	5,200,000	98 %	100,000
	Steel	710,000	99 %	7,100
17 Miscellaneous constructions	Cement	4,500,000	98 %	89,000
	Steel	1,000,000	98 %	20,000
	Aluminum	100,000	98 %	2,000
	Zinc	6,800	98 %	140
18 Drainage pipes	Steel	5,800	95 %	300
	Polyethylene (PE)	3,500	95 %	180
	Polystyrene (EPS)	1,400	95 %	70
19 Wear to tyres	Rubber	160,000	90 %	16,000
20 Exhaust fumes from diesel engines	Nitrogen oxide	1,400,000	99 %	14,000
	Soot and ash	82,000	93 %	5,800
21 Diesel oil	Hydrocarbons	210,000	95 %	11,000
22 Battery acid	Sulphuric acid	3,200	90 %	300
23 Hydraulic and lubricating oils	Hydrocarbons	47,000	90 %	4,700
24 Degreasing agents and detergents	Hydrocarbons + other organic materials	70,000	95 %	3,600
25 Hard metals and metal fragments	Steel	520,000	98 %	10,000
	Tungsten and cobalt	2,800	99 %	30
26 Paints	Hydrocarbons	5,500	0 %	5,500
27 Urine	Carbamide	1,100,000	95 %	55,000
28 Miscellaneous human waste	Organic materials	700,000	98 %	14,000
29 Impurities in ventilation air	Organic materials	10,000,000	99 %	100,000

Table 3. *Estimated total quantities of residual materials in a KBS-3H repository (DAWE design alternative), listed by origin. Table continues on the next pages.*

Origin of the residual materials	**Chemical components considered**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
1 Steel cylinders in supercontainers	Steel	3,000,000	0 %	3,000,000
2 Compartment plugs	Steel	640,000	0 %	640,000
	Cement	92,000	0 %	92,000
	SiO_2	6,100	0 %	6,100
	Organic materials	40,000	0 %	40,000
	Chloride	0.1	0 %	0.1
	Pyrite	14,000	0 %	14,000
	Gypsum	140,000	0 %	140,000
	Carbonates (calcite + siderite)	100,000	0 %	100,000
3 Drift end plugs				
3.1 LHHP plug alternative	Cement	180,000	0 %	180,000
	SiO_2	400,000	0 %	400,000
	Organic materials	14,000	0 %	14,000
	Steel	510,000	0 %	510,000
	Chloride	0.07	0 %	0.07
3.2 Rock cylinder alternative	Cement	380,000	0 %	380,000
	SiO_2	20,000	0 %	20,000
	Organic materials	140	0 %	140
	Steel	360,000	0 %	360,000
	Chloride	0.4	0 %	0.4
4 Spray and drip shields	Steel	500	0 %	500
5 Drainage, wetting and air evacuation systems (only pipe props are considered)	Steel	500	0 %	500
6 Impurities in bentonite buffer (in supercontainers)	Organic carbon	89,000	0 %	89,000
	Pyrite	31,000	0 %	31,000
	Gypsum	310,000	0 %	310,000
	Carbonates (calcite + siderite)	220,000	0 %	220,000
7 Impurities and feet of distance blocks	Organic carbon	120,000	0 %	120,000
	Pyrite	40,000	0 %	40,000
	Gypsum	400,000	0 %	400,000
	Carbonates (calcite + siderite)	290,000	0 %	290,000
	Steel	39,000	0 %	39,000
8 Impurities in blank zones (bentonite blocks)	Organic carbon	67,000	0 %	67,000
	Pyrite	23,000	0 %	23,000
	Gypsum	230,000	0 %	230,000
	Carbonates (calcite + siderite)	170,000	0 %	170,000

Origin of the residual materials	**Chemical components considered**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
9 *Impurities in backfill material*				
9a Backfill alternative a (bentonite/crushed rock)	Organic carbon	1,200,000	0 %	1,200,000
	Pyrite	410,000	0 %	410,000
	Gypsum	4,100,000	0 %	4,100,000
	Carbonates (calcite + siderite)	2,900,000	0 %	2,900,000
9b Backfill alternative b (Friedland clay)	Organic carbon	10,000,000	0 %	10,000,000
	Pyrite	11,000,000	0 %	11,000,000
	Gypsum	14,000,000	0 %	14,000,000
	Carbonates (calcite + siderite)	100,000	0 %	100,000
10 Explosives	Nitrogen oxides (NO_x)	1,600	99 %	16
11 Blasting caps and cords	Aluminium	1,700	90 %	170
	Plastic	1,800	90 %	180
12 Support bolts	Steel	220,000	0 %	220,000
	Zinc	4,200	0 %	4,200
	Cement	86,000	0 %	86,000
13 Anchor bolts	Steel	50,000	40 %	30,000
	Cement	6,300	0 %	6,300
14 Shotcrete				
14A Shotcrete alternative A	Cement	6,900,000	95 %	350,000
	Aluminium	21,000	95 %	1,000
	Organic materials	49,000	95 %	2,400
	Silica (SiO_2)	280,000	95 %	14,000
	Iron (Fe(III))	4,900	95 %	200
	Chloride	300	95 %	17
14B Shotcrete alternative B	Cement	5,100,000	95 %	260,000
	Aluminium	15,000	95 %	800
	Organic materials	36,000	95 %	1,800
	Silica (SiO_2)	2,200,000	95 %	110,000
	Iron (Fe(III))	3,600	95 %	180
	Chloride	300	95 %	13

Origin of the residual materials	**Chemical components considered**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
15 Grouting materials				
15.1 Grouting alternative 1	Cement	780,000	20 %	620,000
	Organic materials	7,800	20 %	6,200
	Silica (SiO_2)	78,000	20 %	62,000
	Chloride	800	20 %	600
	Nitrate	1,000	20 %	800
15.2 Grouting alternative 2	Cement	590,000	20 %	480,000
	Organic materials	10,000	20 %	8,200
	Silica (SiO_2)	130,000	20 %	110,000
	Chloride	600	20 %	500
	Nitrate	900	20 %	700
15.3 Grouting alternative 3	Cement	420,000	20 %	340,000
	Organic materials	5,000	20 %	4,000
	Silica (SiO_2)	230,000	20 %	190,000
	Chloride	5,700	20 %	4,600
	Nitrate	800	20 %	600
16 Floors	Cement	5,200,000	98 %	100,000
	Steel	710,000	99 %	7,100
17 Miscellaneous constructions	Cement	4,500,000	98 %	89,000
	Steel	1,000,000	98 %	20,000
	Aluminum	100,000	98 %	2,000
	Zinc	6,800	98 %	140
18 Drainage pipes	Steel	5,800	95 %	300
	Polyethylene (PE)	3,500	95 %	180
	Polystyrene (EPS)	1,400	95 %	70
19 Wear to tyres	Rubber	160,000	90 %	16,000
20 Exhaust fumes from diesel engines	Nitrogen oxide	1,400,000	99 %	14,000
	Soot and ash	82,000	93 %	5,800
21 Diesel oil	Hydrocarbons	210,000	95 %	11,000
22 Battery acid	Sulphuric acid	3,200	90 %	300
23 Hydraulic and lubricating oils	Hydrocarbons	47,000	90 %	4,700
24 Degreasing agents and detergents	Hydrocarbons + other organic materials	70,000	95 %	3,600
25 Hard metals and metal fragments	Steel	520,000	98 %	10,000
	Tungsten and cobalt	2,800	99 %	30
26 Paints	Hydrocarbons	5,500	0 %	5,500
27 Urine	Carbamide	1,100,000	95 %	55,000
28 Miscellaneous human waste	Organic materials	700,000	98 %	14,000
29 Impurities in ventilation air	Organic materials	10,000,000	99 %	100,000

6.2 Total quantities in the BD design alternative

Total quantities of chemical components are presented in Tables 4 to 8 for the BD design alternative over different combinations of tunnel support, grouting, backfill and drift end plug alternatives. Low-pH grouting materials and support materials are the recommended materials for the deposition drift. For comparison also combinations of other materials have been presented.

- Table 4 features design alternative A1a[1] with an LHHP plug. Ordinary cement is assumed for use in both shotcreting (support alternative A) and grouting (grouting alternative 1). The backfill plan is based on bentonite/crushed rock mixture (backfill alternative a).
- In Table 5, other alternatives are the same as in Table 4, but the drift end plug is of the rock cylinder type.
- In Table 6, other alternatives are the same as in Table 4, but the backfill strategy is based on Friedland clay (backfill alternative b).
- In Table 7, low-pH cement is assumed for use in both shotcreting and grouting (shotcreting alternative B and grouting alternative 2). The backfill plan is based on a bentonite/crushed rock mixture (backfill alternative a) and the drift end plug is of the rock cylinder type.
- Table 8 is similar to Table 7, except that grouting is based on the use of silica grouts (grouting alternative 3).
- In Table 9, low-pH cement is assumed for use in both shotcreting and grouting (shotcreting alternative B and grouting alternative 2). The backfill plan is based on a bentonite/crushed rock mixture (backfill alternative a) and the drift end plug is a LHHP plug.
- In Table 10, low-pH cement is assumed for use in both shotcreting and grouting (shotcreting alternative B and grouting alternative 3). The backfill plan is based on a bentonite/crushed rock mixture (backfill alternative a) and the drift end plug is a LHHP plug.

In these Tables the results are categorised according to chemical components. It should be mentioned that, depending on the availability of data, some components have been considered in more detail than others and the categories are, therefore, not necessarily mutually exclusive. For example, the iron (Fe(III)) estimates only take shotcrete into account as a source (some shotcrete additives contain Fe_2O_3) but, clearly, other materials and categorised components contain iron as well. Most notably, iron is a major constituent of steel (metallic iron) but it can also be found also as Fe(II) in pyrite and siderite, which occur as impurities in bentonite. Iron is also a constituent of cement, but the chemical constituents of cement were not individually quantified in the Tables either.

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[1] Design alternative “A1a” signifies that the selected support alternate is A, the grouting alternative is 1 and the backfill alternative is a. For the actual repository (excl. ONKALO), the support (shotcrete) alternatives are explained in Chapter 5.13, the grouting alternatives in Chapter 5.15 and the backfill alternatives in Chapter 5.8. The groutings and shotcretings assumed in these alternatives for the ONKALO have been explained by Hagros (2007).

By using Table 2, it is possible to calculate the total material quantities for any combination of alternatives. Only five combinations are presented here for the BD concept, but the total number of possible combinations is 24.

Table 4. *Estimated total quantities of chemical components, sorted by remaining quantity, from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives BD and A1a (= support alternative A, grouting alternative 1, backfill alternative a) with an LHHP plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.1, 4, 5, 12, 13, 16, 17, 18, 25	7,100,000	32 %	4,800,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 5, 6, 7, 8, 9a, 14A, 15.1., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,700,000
Cement	2, 3.1, 5, 12, 13, 14A, 15.1, 16, 17	18,000,000	91 %	1,500,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.1, 5, 14A, 15.1	760,000	37 %	480,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14A, 17	120,000	97 %	3,200
Nitrate	15.1	1,000	20 %	800
Chloride	2, 3.1, 5, 14A, 15.1	1,100	43 %	600
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	4,900	95 %	200
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	3,500	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 5. *Estimated total quantities of chemical components from residual materials residual materials in a KBS-3H repository (including ONKALO), based on design alternatives BD and A1a (= support alternative A, grouting alternative 1, backfill alternative a) with a rock cylinder plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.2, 4, 5, 12, 13, 16, 17, 18, 25	6,900,000	32 %	4,700,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.2, 5, 6, 7, 8, 9a, 14A, 15.1., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,600,000
Cement	2, 3.2, 5, 12, 13, 14A, 15.1, 16, 17	18,000,000	90 %	1,700,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.2, 5, 14A, 15.1	390,000	72 %	110,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14A, 17	120,000	97 %	3,200
Nitrate	15.1	1,000	20 %	800
Chloride	2, 3.2, 5, 14A, 15.1	1,100	43 %	600
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	4,900	95 %	200
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	3,500	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 6. *Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives BD and A1b (= support alternative A, grouting alternative 1, backfill alternative b) with a LHHP plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9b	15,000,000	0 %	15,000,000
Steel	1, 2, 3.1, 4, 5, 12, 13, 16, 17, 18, 25	7,100,000	32 %	4,800,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9b	880,000	0 %	880,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 5, 6, 7, 8, 9b, 14A, 15.1., 21, 23, 24, 26, 28, 29	22,000,000	51 %	11,000,000
Cement	2, 3.1, 5, 12, 13, 14A, 15.1, 16, 17	18,000,000	91 %	1,500,000
Pyrite	2, 6, 7, 8, 9b	11,000,000	0 %	11,000,000
Silica (SiO_2)	2, 3.1, 5, 14A, 15.1	760,000	37 %	480,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14A, 17	120,000	97 %	3,200
Nitrate	15.1	1,000	20 %	800
Chloride	2, 3.1, 5, 14A, 15.1	1,100	43 %	600
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	4,900	95 %	200
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	4,000	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 7. *Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives BD and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a rock cylinder plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.2, 4, 5, 12, 13, 16, 17, 18, 25	6,900,000	32 %	4,700,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.2, 5, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,600,000
Cement	2, 3.2, 5, 12, 13, 14B, 15.2, 16, 17	16,000,000	91 %	1,500,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.2, 5, 14B, 15.2	2,400,000	90 %	250,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14B, 17	120,000	97 %	3,000
Nitrate	15.2	900	20 %	700
Chloride	2, 3.2, 5, 14B, 15.2	900	43 %	500
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	3,600	95 %	180
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	4,000	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 8. *Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives BD and B3a (= support alternative B, grouting alternative 3, backfill alternative a) with a rock cylinder plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.2, 4, 5, 12, 13, 16, 17, 18, 25	6,900,000	32 %	4,700,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.2, 5, 6, 7, 8, 9a, 14B, 15.3., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,600,000
Cement	2, 3.2, 5, 12, 13, 14B, 15.3, 16, 17	16,000,000	91 %	1,400,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.2, 5, 14B, 15.3	2,500,000	87 %	330,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14B, 17	120,000	97 %	3,000
Nitrate	15.3	800	20 %	600
Chloride	2, 3.2, 5, 14B, 15.3	6,000	23 %	4,600
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	3,600	95 %	180
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	4,000	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 9. *Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives BD and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a LHHP plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.1, 4, 5, 12, 13, 16, 17, 18, 25	6,900,000	32 %	4,550,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 5, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,614,000
Cement	2, 3.1, 5, 12, 13, 14B, 15.2, 16, 17	16,000,000	91 %	1,300,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.1, 5, 14B, 15.2	2,400,000	90 %	630,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14B, 17	120,000	97 %	3,000
Nitrate	15.2	900	20 %	700
Chloride	2, 3.1, 5, 14B, 15.2	900	43 %	500
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	3,600	95 %	180
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	4,000	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 10. *Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives BD and B3a (= support alternative B, grouting alternative 3, backfill alternative a) with a LHHP plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.1, 4, 5, 12, 13, 16, 17, 18, 25	6,900,000	32 %	4,550,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 5, 6, 7, 8, 9a, 14B, 15.3., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,614,000
Cement	2, 3.1, 5, 12, 13, 14B, 15.3, 16, 17	16,000,000	91 %	1,200,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.1, 5, 14B, 15.3	2,500,000	87 %	710,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14B, 17	120,000	97 %	3,000
Nitrate	15.3	800	20 %	600
Chloride	2, 3.1, 5, 14B, 15.3	6,000	23 %	4,600
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	3,600	95 %	180
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	4,000	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

6.3 Total quantities in the DAWE design alternative

Total quantities of chemical components are presented in Tables 11 - 13 for the DAWE design alternative for two combinations of tunnel support, grouting, backfill and drift end plug alternatives. Low-pH grouting materials and support materials are the recommended materials for the deposition drift. For comparison also combinations of other materials have been presented.

- Table 11 is similar to Table 4 in Chapter 6.2 except that DAWE is assumed instead of BD. The design alternative is A1a (ordinary cement in shotcreting and grouting and a bentonite/crushed rock backfill) and an LHHP plug is assumed to be used.
- In Table 12, low-pH cement is assumed to be used in both shotcreting and grouting (shotcreting alternative B and grouting alternative 2). The backfill plan is based on bentonite/crushed rock mixture (backfill alternative a) and the drift end plug is of the rock cylinder type. It is otherwise similar to Table 7 in Chapter 6.2 except that DAWE is assumed instead of BD.
- In Table 13, low-pH cement is assumed to be used in both shotcreting and grouting (shotcreting alternative B and grouting alternative 2). The backfill plan is based on bentonite/crushed rock mixture (backfill alternative a) and an LHHP plug is assumed to be used. It is otherwise similar to Table 9 in Chapter 6.2 except that DAWE is assumed instead of BD.

By using Table 3, it is possible to calculate the total material quantities for any combination of alternatives. Only three combinations are presented here for the DAWE concept, but the total number of possible combinations is 24.

***Table 11.** Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives DAWE and A1a (= support alternative A, grouting alternative 1, backfill alternative a) with a LHHP plug.*

Chemical components	**Origin (reference to Table 3)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.1, 4, 5, 7, 12, 13, 16, 17, 18, 25	6,700,000	33 %	4,500,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 6, 7, 8, 9a, 14A, 15.1., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,700,000
Cement	2, 3.1, 12, 13, 14A, 15.1, 16, 17	18,000,000	91 %	1,500,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.1, 14A, 15.1	760,000	37 %	480,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14A, 17	120,000	97 %	3,200
Nitrate	15.1	1,000	20 %	800
Chloride	2, 3.1, 14A, 15.1	1,100	43 %	600
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14A	4,900	95 %	200
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	3,500	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 12. *Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives DAWE and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a rock cylinder plug.*

Chemical components	**Origin (reference to Table 3)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.2, 4, 5, 7, 12, 13, 16, 17, 18, 25	6,500,000	34 %	4,300,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.2, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,600,000
Cement	2, 3.2, 12, 13, 14B, 15.2, 16, 17	16,000,000	91 %	1,500,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.2, 14B, 15.2	2,400,000	90 %	250,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14A, 17	120,000	97 %	3,000
Nitrate	15.2	900	20 %	700
Chloride	2, 3.2, 14B, 15.2	900	43 %	500
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14B	3,600	95 %	180
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	3,500	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

Table 13. *Estimated total quantities of chemical components from residual materials in a KBS-3H repository (including ONKALO), based on design alternatives DAWE and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a LHHP plug.*

Chemical components	**Origin (reference to Table 3)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	5,200,000	0 %	5,200,000
Steel	1, 2, 3.1, 4, 5, 7, 12, 13, 16, 17, 18, 25	6,500,000	34 %	4,150,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	3,700,000	0 %	3,700,000
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	13,000,000	87 %	1,614,000
Cement	2, 3.1, 12, 13, 14B, 15.2, 16, 17	16,000,000	91 %	1,300,000
Pyrite	2, 6, 7, 8, 9a	520,000	0 %	520,000
Silica (SiO_2)	2, 3.1, 14B, 15.2	2,400,000	90 %	630,000
Carbamide	27	1,100,000	95 %	55,000
Rubber	19	160,000	90 %	16,000
Nitrogen oxides (NO_x)	10, 20	1,400,000	99 %	14,000
Soot and ash	20	82,000	93 %	5,800
Zinc	12, 17	11,000	61 %	4,300
Aluminium	11, 14A, 17	120,000	97 %	3,000
Nitrate	15.2	900	20 %	700
Chloride	2, 3.1, 14B, 15.2	900	43 %	500
Sulphuric acid	22	3,200	90 %	300
Iron (Fe(III))	14B	3,600	95 %	180
Plastic	11	1,800	90 %	180
Polyethylene (PE)	18	3,500	95 %	180
Polystyrene (EPS)	18	1,400	95 %	70
Tungsten and cobalt	25	2,800	99 %	30

7 RESULTS FOR THE CANISTER NEAR-FIELD

7.1 Results for the BD design alternative

Estimates for quantities of residual materials in a single deposition drift of BD type are presented in Table 14 and Table 15. The analysed deposition drift in Table 14 is based on design alternative B2a, i.e., it incorporates low-pH cement for both shotcreting and grouting purposes and a bentonite/crushed rock mixture as a backfill alternative. A rock cylinder type drift end plug is assumed as well. The analysed deposition drift in Table 15 is otherwise similar to Table 14 except that the end plug is a LHHP plug.

Table 16 presents similar estimates for one deposition location, i.e. an 11 m section of the identical drift.

Table 14. *Estimated total quantities of residual materials in one 300 m long deposition drift, based on design alternatives BD and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a rock cylinder plug.*

Chemical components	Origin (reference to Table 2)	Total introduced quantity [kg]	Removal efficiency [%]	Remaining quantity [kg]
Gypsum	2, 6, 7, 8, 9a	10,000	0 %	10,000
Steel	1, 2, 3.2, 4, 5, 12, 13, 16, 17, 18, 25	31,000	9 %	28,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	7,500	0 %	7,500
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.2, 5, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	5,000	40 %	3,000
Cement	2, 3.2, 5, 12, 13, 14B, 15.2, 16, 17	15,000	74 %	3,800
Pyrite	2, 6, 7, 8, 9a	1,000	0 %	1,000
Silica (SiO_2)	2, 3.2, 5, 14B, 15.2	5,500	88 %	700
Carbamide	27	200	95 %	10
Rubber	19	6	90 %	0.6
Nitrogen oxides (NO_x)	10, 20	30	99 %	0.3
Soot and ash	20	2	93 %	0.1
Zinc	12, 17	5	0 %	5
Aluminium	11, 14B, 17	20	95 %	1
Chloride	2, 3.2, 5, 14B, 15.2	0.8	49 %	0.4
Sulphuric acid	22	0.1	90 %	0.01
Iron (Fe(III))	14A	5	95 %	0.2
Plastic	11	1	90 %	0.1
Polyethylene (PE)	18	3	95 %	0.1
Polystyrene (EPS)	18	1	95 %	0.05
Tungsten and cobalt	25	4	99 %	0.04

Table 15. *Estimated total quantities of residual materials in one 300 m long deposition drift, based on design alternatives BD and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a LHHP plug.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	10,000	0 %	10,000
Steel	1, 2, 3.1, 4, 5, 12, 13, 16, 17, 18, 25	31,000	9 %	28,860
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	7,500	0 %	7,500
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 5, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	5,000	40 %	3,080
Cement	2, 3.1, 5, 12, 13, 14B, 15.2, 16, 17	15,000	74 %	2,680
Pyrite	2, 6, 7, 8, 9a	1,000	0 %	1,000
Silica (SiO_2)	2, 3.2, 5, 14B, 15.2	5,500	88 %	2,880
Carbamide	27	200	95 %	10
Rubber	19	6	90 %	0.6
Nitrogen oxides (NO_x)	10, 20	30	99 %	0.3
Soot and ash	20	2	93 %	0.1
Zinc	12, 17	5	0 %	5
Aluminium	11, 14B, 17	20	95 %	1
Chloride	2, 3.1, 5, 14B, 15.2	0.8	49 %	0.4
Sulphuric acid	22	0.1	90 %	0.01
Iron (Fe(III))	14A	5	95 %	0.2
Plastic	11	1	90 %	0.1
Polyethylene (PE)	18	3	95 %	0.1
Polystyrene (EPS)	18	1	95 %	0.05
Tungsten and cobalt	25	4	99 %	0.04

Table 16. *Estimated total quantities of residual materials in one deposition location (an 11 m section of a deposition drift), based on design alternative BD and grouting alternative 2.*

Chemical components	**Origin (reference to Table 2)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	6, 7	300	0 %	300
Steel	1	1,100	0 %	1,100
Carbonates (calcite + siderite)	6, 7	200	0 %	200
Organic materials (incl. organic carbon and hydrocarbons)	6, 7, 15.2, 26, 28, 29	100	31 %	80
Cement	15.2	0.7	20 %	0.6
Pyrite	6, 7	30	0 %	30
Silica (SiO_2)	15.2	11	20 %	9
Carbamide	27	3	95 %	0.1
Chloride	15.2	0.02	20 %	0.01

The deposition drift of interest in Tables 14 and 15 is 300 m long and intended for OL1-2 canisters. The quantities of materials per excavated cubic metre (or per metre of tunnel) are considered to be average values for all deposition drifts. It was assumed here that the drift contains 18 canisters, i.e. 18 supercontainers and 18 distance blocks, as well as one compartment plug and blank zones (filled with bentonite) totaling 47 m in length. The deposition niche is also included.

The 11 m long deposition location considered in Table 16 includes one supercontainer (with an OL1/OL2 canister) and one distance block. Materials related to the drift end plug, the compartment plug and the blank zones are not taken into account.

Although design alternative B2a includes shotcrete alternative B, any associated materials have no effect on the results shown in Tables 14 and 15, as shotcrete will not be used in the small-diameter sections of the deposition drifts. Similarly, the backfill alternative has no effect on the displayed results either.

7.2 Results for the DAWE design alternative

Tables 17, 18 and 19 present results similar to those in Tables 14 - 16, with the exception that the DAWE design alternative is considered instead of the BD alternative. The discussion regarding the deposition drift and drift section found in Chapter 7.1 is relevant here as well.

Table 17. *Estimated total quantities of residual materials in one 300 m long deposition drift, based on design alternatives DAWE and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a rock cylinder plug.*

Chemical components	Origin (reference to Table 3)	Total introduced quantity [kg]	Removal efficiency [%]	Remaining quantity [kg]
Gypsum	2, 6, 7, 8, 9a	10,000	0 %	10,000
Steel	1, 2, 3.2, 4, 5, 7, 12, 13, 16, 17, 18, 25	28,000	9 %	26,000
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	7,400	0 %	7,400
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.2, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	5,000	40 %	3,000
Cement	2, 3.2, 12, 13, 14B, 15.2, 16, 17	14,000	74 %	3,700
Pyrite	2, 6, 7, 8, 9a	1,000	0 %	1,000
Silica (SiO_2)	2, 3.2, 14B, 15.2	5,500	88 %	700
Carbamide	27	200	95 %	10
Rubber	19	6	90 %	0.6
Nitrogen oxides (NO_x)	10, 20	30	99 %	0.3
Soot and ash	20	2	93 %	0.1
Zinc	12, 17	5	0 %	5
Aluminium	11, 14B, 17	20	95 %	1
Chloride	2, 3.2, 14B, 15.2	0.8	49 %	0.4
Sulphuric acid	22	0.1	90 %	0.01
Iron (Fe(III))	14A	5	95 %	0.2
Plastic	11	1	90 %	0.1
Polyethylene (PE)	18	3	95 %	0.1
Polystyrene (EPS)	18	1	95 %	0.05
Tungsten and cobalt	25	4	99 %	0.04

Table 18. *Estimated total quantities of residual materials in one 300 m long deposition drift, based on design alternatives DAWE and B2a (= support alternative B, grouting alternative 2, backfill alternative a) with a LHHP plug.*

Chemical components	**Origin (reference to Table 3)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	2, 6, 7, 8, 9a	10,000	0 %	10,000
Steel	1, 2, 3.1, 4, 5, 7, 12, 13, 16, 17, 18, 25	28,000	9 %	26,860
Carbonates (calcite + siderite)	2, 6, 7, 8, 9a	7,400	0 %	7,400
Organic materials (incl. organic carbon and hydrocarbons)	2, 3.1, 6, 7, 8, 9a, 14B, 15.2., 21, 23, 24, 26, 28, 29	5,000	40 %	3,080
Cement	2, 3.2, 12, 13, 14B, 15.2, 16, 17	14,000	74 %	2,580
Pyrite	2, 6, 7, 8, 9a	1,000	0 %	1,000
Silica (SiO_2)	2, 3.2, 14B, 15.2	5,500	88 %	2,880
Carbamide	27	200	95 %	10
Rubber	19	6	90 %	0.6
Nitrogen oxides (NO_x)	10, 20	30	99 %	0.3
Soot and ash	20	2	93 %	0.1
Zinc	12, 17	5	0 %	5
Aluminium	11, 14B, 17	20	95 %	1
Chloride	2, 3.2, 14B, 15.2	0.8	49 %	0.4
Sulphuric acid	22	0.1	90 %	0.01
Iron (Fe(III))	14A	5	95 %	0.2
Plastic	11	1	90 %	0.1
Polyethylene (PE)	18	3	95 %	0.1
Polystyrene (EPS)	18	1	95 %	0.05
Tungsten and cobalt	25	4	99 %	0.04

Table 19. *Estimated total quantities of residual materials in one deposition location (an 11 m section of a deposition drift), based on design alternative DAWE and grouting alternative 2.*

Chemical components	**Origin (reference to Table 3)**	**Total introduced quantity [kg]**	**Removal efficiency [%]**	**Remaining quantity [kg]**
Gypsum	6, 7	300	0 %	300
Steel	1, 7	1,100	0 %	1,100
Carbonates (calcite + siderite)	6, 7	190	0 %	190
Organic materials (incl. organic carbon and hydrocarbons)	6, 7, 15.2, 26, 28, 29	110	32 %	80
Cement	15.2	0.7	20 %	0.6
Pyrite	6, 7	30	0 %	30
Silica (SiO_2)	15.2	11	20 %	9
Carbamide	27	3	95 %	0.1
Chloride	15.2	0.02	20 %	0.01

8 COMPARISON WITH A SWEDISH KBS-3H REPOSITORY

8.1 Differences related to the dimensions of the repository

The quantities of the residual materials are probably slightly different in the Finnish and Swedish KBS-3H repositories. Some differences are likely to be due to the differences in the size and layout of the Finnish and Swedish repositories. The basic layout – a KBS-3H repository with an access ramp and three shafts – is largely similar in both Sweden (SKB 2006b) and Finland (Johansson et al. 2007), so the main differences arise from the different amount of spent fuel and a different approach to thermal dimensioning.

In the Swedish repository, the total number of canisters is 4,500 (SKB 2006b), which is 58 % greater than in Finland. The canister spacing is some 7–8 m, whereas in the Finnish repository it is some 9–11 m. The spacing between the deposition drifts is 40 m in Sweden whereas it is 25 m in Finland. If unusable sections of rock mass are not taken into account, the total disposal length of the deposition drifts is 16 % larger in the Swedish repository than it is in the Finnish repository (assuming an average canister spacing of 7.6 m for Sweden). Considering only the central tunnel lengths that are in any case required due to thermal constraints, the total central tunnel length is 85 % larger in Sweden than in Finland. This was calculated assuming that all deposition drifts are 300 m long and can be completely used for disposal, which is not the case at either site.

If it is assumed that the total length of deposition drifts is 16 % larger in Sweden than in the current layout for the Olkiluoto site and that the total central tunnel length is 85 % larger, the total volume of the deposition drifts and central tunnels would be 54 % larger in Sweden than in Finland, implying that the material quantities will probably be larger in Sweden. Since it has been assumed that the consumption of several materials is rather limited in the deposition drifts and the consumption per metre of tunnel is clearly larger in the central tunnels than in the deposition drifts, the difference in material quantities may be even larger than 54 %. On the other hand, the above calculations apply only if the Swedish central tunnel concept is similar to that in Finland, i.e. based on the so-called concurrent central tunnel concept (Malmlund et al. 2004). If there are only single central tunnels in the Swedish repository, the consumption of construction materials is significantly smaller than in the case of the double tunnels, although the quantities of other materials (such as emissions from traffic that is not directly related to excavation) are not very dependent on the central tunnel concept.

8.2 Differences related to individual materials

Due to a lack of data, it is not possible to estimate the material quantities in the Swedish KBS-3H repository accurately, although some differences between the Swedish and Finnish plans to use materials can be identified. Generally the materials to be used are largely similar, because there are no major differences in the construction methods that are planned to be used in the Finnish and Swedish repositories. Other parts of the repository except for the deposition drifts will probably be excavated by the drill and blast method in Sweden as well, and the planned rock support method is bolting or shotcreting. Other alternatives to the shotcrete are supporting nets of steel or plastics (SKB 2006b). In the Finnish repository, both bolting and shotcreting are used (steel mesh will not be used in a KBS-3H repository).

Regarding the planned use of materials, the following identified differences indicate a larger consumption of materials in the Swedish KBS-3H repository than in the Finnish one:

- The consumption of blasting caps and cords per excavated m^3 is estimated to be clearly larger in Sweden.
- The consumption of anchor bolts per metre of tunnel is twice as high in Sweden as in Finland and the diameter of the bolts is 25 % larger.
- The thickness of the shotcrete layer is generally greater in Sweden and the total consumption of shotcrete is also greater (SKB 2006b). Only low-pH shotcrete is, however, planned to be used in Sweden. The Swedish shotcrete contains about 70 kg of reinforcing steel fibres per one m^3 (SKB 2006b), and no steel fibres are assumed to be used in the Finnish repository.
- In Sweden, asphalt may be used in addition to concrete as a floor material in the access ramp (SKB 2002).

On the other hand, the material quantities may also be at least partly smaller in Sweden because of the following identified differences of material consumption:

- The length of the distance blocks is clearly smaller in Sweden than in Finland and even if the larger number of canisters is taken into account, the total quantity of bentonite in the distance blocks would is smaller in Sweden than in Finland.
- The estimated consumption of explosives per excavated m^3 is smaller in Sweden and the planned explosive produces less NO_x gases than those used in Finland.
- It may be that support bolts will not be used at all in the Swedish repository.
- It may be that shotcrete will not be used at all in the Swedish repository (it could be replaced by supporting nets of steel or plastics) (SKB 2006b).
- It is estimated that no battery acid remains in the Swedish repository.

It should, however, be remembered that according to current plans, there are no major differences in the construction methods used. If similar generic assumptions are used in both countries, the types of residual materials are largely the same and their total quantities are probably slightly larger in Sweden, assuming that the Swedish repository is larger than the Finnish one.

9 DISCUSSION

9.1 Conclusions on the different design alternatives

9.1.1 Differences between BD and DAWE

The selected KBS-3H design alternative – either Basic Design or DAWE design – may affect the quantities of several materials and such differences can be discerned by comparing, e.g., Tables 4 and 11. Such differences must be related to the materials in distance blocks, fixing rings or the DAWE pipe system, as all other components are assumed to be identical for both design alternatives.

Comparison between the rounded-off values shown in Tables 4 and 11 indicates that the only difference between the BD and DAWE design alternatives is related to the quantity of steel, the remaining quantity of which is slightly smaller in DAWE than in BD, the difference being less than 10 %. This difference is mainly ascribed to the lack of fixing rings in the DAWE concept. As the DAWE drainage, wetting and air evacuation systems can be essentially removed, they will have negligible effect on the remaining quantity of steel in the repository. The effect of the steel feet in the DAWE distance blocks is also minor and the smaller size of the DAWE distance blocks has a negligible effect on the total quantities of the bentonite impurities as well.

9.1.2 Differences between the different drift end plugs

The individual material quantities in the drift end plugs can be seen, e.g., in Table 2 and their effect on the total quantities in the repository by comparing Tables 4 and 5. Although the quantity of chloride is some five times larger in a rock cylinder plug, this has, in practice, no effect on the total quantities in the repository, due to its very small quantity in the drift end plugs. The quantity of organic materials is 100 times larger in the LHHP plug, but this has also only a very minor effect (less than 1 %) on the total quantity of organic materials in the repository. The quantity of cement is approximately twice as large in the rock plug as in the LHHP plug, and this causes a 12 % increase in the total cement quantity in the repository. When the total quantities in the repository are considered, the greatest difference between the plug types is related to the quantity of silica, which is significantly smaller in the rock plug alternative, causing a 78 % reduction in the total quantity of silica in the repository.

9.1.3 Differences between shotcreting and grouting alternatives

The effect of the two different shotcreting alternatives and the three different grouting alternatives can be examined by comparing Tables 7 and 8 with Table 5, where only ordinary cement is assumed to be used in shotcreting and grouting. Table 7 assumes the use of low-pH cement in both shotcreting and grouting in the actual repository, and Table 8 assumes mainly silica grouting, being otherwise similar to Table 7.

When low-pH cement is used in shotcreting and grouting (Table 7), the greatest (relative) difference is associated with the quantity of silica. The total quantity of silica is some 130 % higher in alternative B2a (= shotcrete alternative B, grouting alternative

2, backfill alternative a) than in alternative A1a with ordinary cement. Furthermore, the total quantity of cement is reduced by some 10 %, and also the total quantities of aluminium, nitrate, chloride and iron (Fe(III)) are reduced, all by some 5−15 %.

If silica grouts are used instead of low-pH cement grouts, there are some further differences. By comparing Table 8 with Table 7, it can be seen that the quantity of silica is further increased by some 30 %, if silica grouts are used. The quantity of cement reduces by little over 5 % as compared to the low-pH cement alternative and the quantity of nitrate by some 15 %. However, the quantity of chloride is some 8 times higher in alternative B3a (i.e. with silica grouting) than in B2a, related to the high consumption of chloride-based accelerators in silica grouts (see Hagros 2007).

If alternative B3a is compared with alternative A1a, the total change in the cement quantities amounts to a reduction of almost 20 % and the total increase in silica quantities is 200 %.

9.1.4 Differences between tunnel backfill alternatives

The selection of the tunnel backfill alternative affects the quantities of the bentonite impurities, and the size of this effect can be seen when comparing Tables 4 and 6. The differences in the total material quantities are very large in these Tables, both the relative differences and the differences in kg. If Friedland clay (alternative b) is used instead of bentonite/crushed rock mixture (alternative a) as the tunnel backfill option, the total quantity of pyrite remaining in the repository is increased by 2000 %, i.e. the total quantity is some 20 times higher in alternative b. The total remaining quantity of organic materials is increased by some 600 % and the total quantity of gypsum is increased by almost 200 %. The quantity of carbonates also changes; based on Tables 4 and 6, the total quantity of carbonates is reduced by some 75 %, due to the fact that the Friedland clay was not assumed to include any carbonates.

9.1.5 Overall conclusions on total quantities

The total remaining quantity of all materials – or actually of the specific chemical components considered here – is some 17,000,000−18,000,000 kg in all cases except when Friedland clay (backfill alternative b) is used as the tunnel backfill material (Table 6), resulting in a total quantity of some 45,000,000 kg. Accordingly, the alternative that has the greatest effect on the quantities of the residual materials is the tunnel backfill alternative. As can be concluded based on the Chapters above, the differences related to other alternatives are not equally great.

If the total quantity of cement needs to be minimised, the best alternative would be to use silica grouts in the sealing of the rock mass (grouting alternative 3) and low-pH cement in the shotcreting of the repository (shotcrete alternative B). This would reduce the cement quantity by some 20 % or 300,000 kg. The selection of the rock cylinder plug alternative instead of the LHHP plug would, however, increase the total quantity of cement by some 200,000 kg.

If the total quantity of steel should be minimised, the use of the DAWE design alternative would be better than the Basic Design, although the total reduction would be less than 10 %. In terms of mass, the reduction is, however, approximately 400,000 kg in total.

In terms of mass, the Friedland clay alternative increases the quantity of both pyrite and gypsum by some 10,000,000 kg and the quantity of organic materials by some 9,000,000 kg. The quantity of carbonates is, however, reduced by some 3,000,000 kg.

9.2 Comparison with a KBS-3V repository

Both disposal concepts – KBS-3H and KBS-3V – include components and materials that are not included in the other concept. The KBS-3H repository assumed in this work includes the following components and materials that are not present in a KBS-3V repository:

- steel cylinder in supercontainers
- compartment plugs
- spray and drip shields
- fixing rings (BD only)
- drainage, wetting and air evacuation systems (DAWE only)
- distance blocks
- bentonite blocks in blank zones.

The KBS-3V repository assumed by Hagros (2007) includes the following components and materials that are not present in a KBS-3H repository:

- concrete bottom plates in the deposition holes
- steel mesh in the deposition tunnels.

In addition, the composition of the drift end plugs (KBS-3H) and concrete plugs (KBS-3V) are different in the two concepts. Also, the quantity of bentonite in the KBS-3H supercontainers is 37 % smaller than the quantity of the bentonite buffer in 3V. Furthermore, the quantities of several other materials in the deposition drifts are smaller in KBS-3H due to the fact that the small-diameter parts of the deposition drifts are not excavated by drill and blast, they do not have any rock support or conventional installations, they probably require less grouting due to smaller cross-sectional area and they do not have any tunnel backfill material.

Table 20 shows a comparison between the remaining quantities of all residual materials considered in this work and in the KBS-3V report by Hagros (2007). The table assumes the B2a design alternative (shotcreting and grouting mainly with low-pH cement, bentonite/crushed rock mixture as tunnel backfill) in both concepts and the BD design alternative with a rock plug with respect to the KBS-3H specific options. Most of the total material quantities are nearly the same (± 5 %) or smaller in KBS-3H, the difference being typically −20 %, at most −100 % (with respect to copper, which is present in the KBS-3V concrete plugs). The following materials have, however, more than 5 % larger remaining quantity in 3H than in 3V:

- steel: some 210 % larger quantity in 3H than in 3V, mainly due to the steel cylinders in supercontainers but also due to steel plugs and fixing rings
- iron (Fe(III)): some 30 % larger quantity in 3H, due to higher consumption of shotcrete as the total central tunnel length is larger in 3H and also the deposition niches are assumed to have shotcrete
- polyethylene and polystyrene: some 20 % larger quantity in 3H, due to the higher consumption of drainage pipes related to shotcrete
- nitrogen oxides, rubber and soot and ash: slightly larger quantity in 3H, due to larger total length of central tunnels.

Table 20. *Estimated remaining quantities of chemical components, included in the residual materials, in a KBS-3H and -3V repository (based on Hagros 2007). The design alternative is B2a (= support alternative B, grouting alternative 2, backfill alternative a) in both concepts. The KBS-3H repository is based on the design alternative BD with a rock cylinder plug.*

Chemical components	Remaining quantity in KBS-3H [kg]	Remaining quantity in KBS-3V [kg]	Relative difference (KBS-3H compared with KBS-3V)
Gypsum	5,200,000	6,500,000	-19 %
Steel	4,700,000	1,500,000	+210 %
Carbonates (calcite + siderite)	3,700,000	4,600,000	-19 %
Organic materials (incl. organic carbon and hydrocarbons)	1,600,000	2,000,000	-19 %
Cement	1,500,000	5,800,000	-74 %
Pyrite	520,000	650,000	-19 %
Silica (SiO_2)	250,000	270,000	-7 %
Carbamide	55,000	55,000	0 %
Rubber	16,000	15,000	+6 %
Nitrogen oxides (NO_x)	14,000	13,000	+7 %
Soot and ash	5,800	5,400	+7 %
Zinc	4,300	140,000	-97 %
Aluminium	3,000	2,800	+4 %
Nitrate	700	700	+2 %
Chloride	500	500	0 %
Sulphuric acid	300	300	+6 %
Iron (Fe(III))	180	140	+33 %
Plastic	180	300	-31 %
Polyethylene (PE)	180	140	+23 %
Polystyrene (EPS)	70	60	+23 %
Tungsten and cobalt	30	40	-25 %
Copper	0	12,000	-100 %

In all, it can be concluded that the KBS-3H disposal concept is a better alternative if the total quantities of the remaining materials need to be minimised. The total quantity of all materials listed in Table 20 is some 20 % smaller in 3H than in 3V. The smaller quantities in 3H are mainly due to the fact that the deposition drifts are much smaller than the KBS-3V deposition tunnels and they are not constructed and furnished in the same way as the 3V deposition tunnels. In particular, the lack of 3V type concrete plugs causes a major reduction in the total quantity of cement in a 3H repository. The 3H drift end plugs contain a significantly smaller quantity of cement than the 3V concrete plugs. This applies to both the rock cylinder plug and the LHHP plug. If cement is not taken into account, the total quantity of materials listed in Table 20 is nearly the same for both concepts.

9.3 Discussion on uncertainties

The estimation of the quantities of residual materials is difficult and major uncertainties are involved. This relates particularly to the materials, the quantities of which cannot easily be monitored in a repository as they are produced. Such materials include the emissions from vehicles and maintenance work (Chapter 5.18), urine and other human waste (Chapter 5.20) and the impurities in the ventilation air (5.21). The introduced quantities of the actual construction materials have, however, been monitored in the ONKALO and the obtained values form a basis for the estimation of these materials also in this work (see, e.g., Vuorio (2006) for the monitoring results and Hagros (2007) for how they were considered in the estimation of future quantities).

The quantities of materials that can be monitored as they are introduced into the repository can be estimated with increasing reliability as the construction of the repository proceeds. The data from the monitoring considered by Hagros (2007) and also in this work relate, however, to the very beginning of the ONKALO, as only some 5−6 % of the whole repository volume had been excavated when the data were acquired. Major uncertainties are, therefore, related also to the estimation of the quantities of the construction materials.

Regardless of whether introduced quantities can be monitored or not, the remaining quantities are difficult to estimate, because the correct removal efficiencies are usually not known. If the removal efficiency is 99 % instead of 99.99 %, the remaining quantity is 100 times larger. The results are thus heavily dependent on the assumed removal efficiencies. Fairly reliable results can only be obtained if it is known that the removal efficiency is in any case small, such as with respect to the KBS-3H specific components (e.g., supercontainers and compartment plugs) that are intended to be completely left in the repository (removal efficiency 0 %) or with respect to grouting materials which are known to spread in the bedrock outside the tunnel profile and this spreading can also be partly verified by measuring the grout take (a removal efficiency of 20 % has been assumed in this work). Other materials with small removal efficiencies are backfill materials (0 %), support bolts (0 %), anchor bolts (40 % for steel, 0 % for cement) and paints (0 %). In this work, the removal efficiencies are generally considered rather conservative, so it appears likely that the actual remaining quantities will be smaller than what has been estimated here.

Uncertainties are also caused by the assumed repository layout, which may change significantly due to, for example, unexpected rock mass conditions or changed criteria on rock mass quality that can be accepted for disposal. The criteria assumed in the current layout have been discussed by Johansson et al. (2007) and the consideration of potential low-quality rock mass was slightly conservative. The layout is, however, dependent on the assumed fracture zone model, and the number of fracture zones is far more likely to increase than to decrease in the future due to more detailed investigations and excavations. The effect of this could be that the tunnel lengths are significantly increased, resulting in larger total quantities of residual materials.

Some uncertainty is also caused by the potentially uneven distribution of materials in the repository. This does not affect the total material quantities, but it affects the quantities that can be found in a single drift or single deposition location (Chapter 7). Jones et al. (1999) have partly quantified this uncertainty by providing the maximum values of material quantities in addition to mean values that are expected to be found in one canister location and in a 40 m section of a central tunnel. The relative difference in these values may be applicable also to a KBS-3H repository.

A significant uncertainty as to the total quantities is caused by the unknown composition of some materials and the possible changes of design, as the KBS-3H design is being further developed and a new design will be published in the near future. The exact composition of any material is not yet completely defined (e.g., the bolt types and grouting recipes may change in the future, and steel may be partly replaced by titanium, nickel or copper), but the largest uncertainties are associated with the following materials:

- There appears to be a great uncertainty regarding the composition of MX-80 bentonite, which is probably due to the fact that the bentonite is not completely homogeneous. Also it is by no means certain that the bentonite to be used in the repository will be of the MX-80 type.
- The crushed rock used in the tunnel backfill material is not assumed to include any significant impurities (residual materials), but this is probably far from the truth. It was not possible to consider such impurities in this work, because it is not known, whether the crushed rock to be used as tunnel backfill is originated from the construction of the repository or from some other source and because factors such as the average time of storage (which affects the accumulation of organic and air-borne impurities) and the cleaning process were also unknown.
- The various KBS-3H specific components such as drift end plugs and distance blocks are still being designed and their final composition, dimensions and layout (e.g. effective length of drift) may be different from that presented in this report. The results concerning especially the BD alternative may include significant uncertainties and should be regarded merely as indicative.

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APPENDIX 1. KBS-3H SPECIFIC COMPONENTS IN THE REFERENCE DRIFTS

KBS-3H Residual materials - Basic Design (BD) alternative, Drift plug: LHHP alternative

KBS-3H specific components and materials introduced into an average 300 m deposition drift

1) Deposition drifts with OL1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	17.5	MX-80 Bentonite	16000	280000
Steel cylinder (supercont.), incl. feet	17.5	Steel	1071	18742.5
Distance blocks	17.5	MX-80 Bentonite	23000	402500
		-	0	0
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO_2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	780	780
		SiO_2	2300	2300
		Steel	860	860
		Organic materials	82	82
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO_2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	4.5	Steel	600	2700
		Cement	23	104
		SiO_2	1.5	6.8
		Organic materials	0.009	0.041
		Chloride	0.00003	0.00014
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	0	-	0	0

2) Deposition drifts with OL3 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	18.2	MX-80 Bentonite	17000	309400
Steel cylinder (supercont.), incl. feet	18.2	Steel	1140	20748
Distance blocks	18.2	MX-80 Bentonite	19000	345800
		-	0	0
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	780	780
		SiO2	2300	2300
		Steel	860	860
		Organic materials	82	82
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	4.5	Steel	600	2700
		Cement	23	103.5
		SiO2	1.5	6.75
		Organic materials	0.009	0.0405
		Chloride	0.00003	0.000135
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	0	-	0	0

3) Deposition drifts with LO1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	21.2	MX-80 Bentonite	13000	275600
Steel cylinder (supercont.), incl. feet	21.2	Steel	880	18656
Distance blocks	21.2	MX-80 Bentonite	20000	424000
		-	0	0
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	780	780
		SiO2	2300	2300
		Steel	860	860
		Organic materials	82	82
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	4.5	Steel	600	2700
		Cement	23	103.5
		SiO2	1.5	6.75
		Organic materials	0.009	0.0405
		Chloride	0.00003	0.000135
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	0	-	0	0

KBS-3H Residual materials - Basic Design (BD) alternative, Drift plug: Rock cylinder alternative

KBS-3H specific components and materials introduced into an average 300 m deposition drift

1) Deposition drifts with OL1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	17.5	MX-80 Bentonite	16000	280000
Steel cylinder (supercont.), incl. feet	17.5	Steel	1071	18742.5
Distance blocks	17.5	MX-80 Bentonite	23000	402500
		-	0	0
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	1900	1900
		SiO2	120	120
		Organic materials	0.7	0.7
		Chloride	0.002	0.002
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	4.5	Steel	600	2700
		Cement	23	104
		SiO2	1.5	6.8
		Organic materials	0.009	0.041
		Chloride	0.00003	0.00014
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	0	-	0	0

2) Deposition drifts with OL3 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	18.2	MX-80 Bentonite	17000	309400
Steel cylinder (supercont.), incl. feet	18.2	Steel	1140	20748
Distance blocks	18.2	MX-80 Bentonite	19000	345800
		-	0	0
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	1900	1900
		SiO2	120	120
		Organic materials	0.7	0.7
		Chloride	0.002	0.002
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	4.5	Steel	600	2700
		Cement	23	103.5
		SiO2	1.5	6.75
		Organic materials	0.009	0.0405
		Chloride	0.00003	0.000135
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	0	-	0	0

3) Deposition drifts with LO1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	21.2	MX-80 Bentonite	13000	275600
Steel cylinder (supercont.), incl. feet	21.2	Steel	880	18656
Distance blocks	21.2	MX-80 Bentonite	20000	424000
		-	0	0
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	1900	1900
		SiO2	120	120
		Organic materials	0.7	0.7
		Chloride	0.002	0.002
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	4.5	Steel	600	2700
		Cement	23	103.5
		SiO2	1.5	6.75
		Organic materials	0.009	0.0405
		Chloride	0.00003	0.000135
Spray and drip shields	5	Steel	0.6	3
Drainage, wetting and air evacuation system (DAWE only)	0	-	0	0

KBS-3H Residual materials - DAWE Design alternative, Drift plug: LHHP alternative

KBS-3H specific components and materials introduced into an average 300 m deposition drift

1) Deposition drifts with OL1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	17.5	MX-80 Bentonite	16000	280000
Steel cylinder (supercont.), incl. feet	17.5	Steel	1071	18742.5
Distance blocks	17.5	MX-80 Bentonite	22000	385000
		Steel	13.9	243
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	780	780
		SiO2	2300	2300
		Steel	860	860
		Organic materials	82	82
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	0	-	0	0
		-	0	0
		-	0	0
		-	0	0
		-	0	0
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	1	Steel	3	3.0

2) Deposition drifts with OL3 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	18.2	MX-80 Bentonite	17000	309400
Steel cylinder (supercont.), incl. feet	18.2	Steel	1140	20748
Distance blocks	18.2	MX-80 Bentonite	19000	345800
		Steel	13.9	252.98
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	780	780
		SiO2	2300	2300
		Steel	860	860
		Organic materials	82	82
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	0	-	0	0
		-	0	0
		-	0	0
		-	0	0
		-	0	0
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	1	Steel	3	3.0

3) Deposition drifts with LO1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	21.2	MX-80 Bentonite	13000	275600
Steel cylinder (supercont.), incl. feet	21.2	Steel	880	18656
Distance blocks	21.2	MX-80 Bentonite	19000	402800
		Steel	13.9	294.68
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	780	780
		SiO2	2300	2300
		Steel	860	860
		Organic materials	82	82
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	0	-	0	0
		-	0	0
		-	0	0
		-	0	0
		-	0	0
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	1	Steel	3	3.0

KBS-3H Residual materials - DAWE Design alternative, Drift plug: Rock cylinder alternative

KBS-3H specific components and materials introduced into an average 300 m deposition drift

1) Deposition drifts with OL1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	17.5	MX-80 Bentonite	16000	280000
Steel cylinder (supercont.), incl. feet	17.5	Steel	1071	18742.5
Distance blocks	17.5	MX-80 Bentonite	22000	385000
		Steel	13.9	243
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	1900	1900
		SiO2	120	120
		Organic materials	0.7	0.7
		Chloride	0.002	0.002
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	0	-	0	0
		-	0	0
		-	0	0
		-	0	0
		-	0	0
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	1	Steel	3	3.0

2) Deposition drifts with OL3 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	18.2	MX-80 Bentonite	17000	309400
Steel cylinder (supercont.), incl. feet	18.2	Steel	1140	20748
Distance blocks	18.2	MX-80 Bentonite	19000	345800
		Steel	13.9	252.98
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	1900	1900
		SiO2	120	120
		Organic materials	0.7	0.7
		Chloride	0.002	0.002
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	0	-	0	0
		-	0	0
		-	0	0
		-	0	0
		-	0	0
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	1	Steel	3	3.0

3) Deposition drifts with LO1-2 canisters

Component of the KBS-3H system	Number of components in one 300 m drift	Materials (that are or may include residual materials)	Quantity of material per component (kg)	Quantity of material in one 300 m drift (kg)
Bentonite buffer (in supercontainers)	21.2	MX-80 Bentonite	13000	275600
Steel cylinder (supercont.), incl. feet	21.2	Steel	880	18656
Distance blocks	21.2	MX-80 Bentonite	19000	402800
		Steel	13.9	295
Bentonite blocks (blank zones)	5.2	MX-80 Bentonite	42000	218400
Compartment plug	1	Steel	4200	4200
		Cement	600	600
		SiO2	40	40
		Organic materials	0.2	0.2
		Chloride	0.0008	0.0008
		MX-80 Bentonite	130000	130000
Drift end plug	1	Cement	1900	1900
		SiO2	120	120
		Organic materials	0.7	0.7
		Chloride	0.002	0.002
Steel plug (adjacent to drift end plug)	1	Steel	2100	2100
		Cement	300	300
		SiO2	20	20
		Organic materials	0.1	0.1
		Chloride	0.0004	0.0004
Fixing rings (BD only)	0	-	0	0
		-	0	0
		-	0	0
		-	0	0
		-	0	0
Spray and drip shields	5	Steel	0.6	3.0
Drainage, wetting and air evacuation system (DAWE only)	1	Steel	3	3.0