Öppen

Promemoria (PM)

DokumentID	Version	Status	Reg nr	Sida
1389153	1.0	Godkänt		1 (1)

Författare	Datum
Anders Lindblom	2013-03-27
Kvalitetssäkrad av	**Kvalitetssäkrad datum**
Olle Olsson Saida Engström	2013-03-28 2013-03-31
Godkänd av	**Godkänd datum**
Helene Åhsberg	2013-04-01

Errata till rapporter som ingår i ansökan – Slutförvarsanläggning för använt kärnbränsle

Sedan ansökan om tillstånd enligt kärntekniklagen – Slutförvarsanläggning för använt kärnbränsle lämnades in den 16 mars 2010 har en del mindre tryckfel upptäckts i rapporter som ingår i ansökansmaterialet. De rapporter där felaktigheter hittats har löpande uppdaterats med erratablad, uppdateringarna publiceras också under publikationer på www.skb.se.

Nedan anges de i ansökan ingående rapporter som hittills uppdaterats med erratablad:

- TR-11-01 Volym I errata 2011-10, errata 2011-12, errata 2012-12
- TR-11-01 Volym II errata 2011-10, errata 2011-12, errata 2012-12
- TR-11-01 Volym III errata 2011-10, errata 2012-12
- TR-10-09 errata 2011-10, errata 2013-01
- TR-10-13 errata 2011-12
- TR-10-14 errata 2011-12, errata 2013-01
- TR-10-15 errata 2011-12
- TR-10-17 errata 2011-12
- TR-10-45 errata 2013-02
- TR-10-47 errata 2011-10
- TR-10-48 errata 2011-10, 2013-02
- TR-10-49 errata 2011-10
- TR-10-51 errata 2013-01
- TR-10-52 errata 2011-10
- TR-10-53 errata 2011-10
- TR-10-54 errata 2013-02

Errata för dessa rapporter bifogas.

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ISSN 1404-0344
SKB TR-10-09

ID 1269178

Updated 2013-01

Biosphere analyses for the safety assessment SR-Site – synthesis and summary of results

Svensk Kärnbränslehantering AB

December 2010

Keywords: Assessment context, Biosphere object, Discharge areas, Features, events and processes (FEP), Interaction matrix, Landscape development, Landscape dose conversion factors (LDF), Non-human biota (NHB), Radionuclide transport, Sensitivity analysis, Site description, Surface ecosystems, Uncertainty analysis.

Update notice

The original report, dated December 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-10

Location	Original text	Corrected text
Page 121, Table 10-3	Wrong numbers in the table	Table updated with correct numbers
Page 139, Table 12-1	Wrong numbers in the table	Table updated with correct numbers

Updated 2013-01

Location	Original text	Corrected text
Page 153, reference Galson and Khursheed 2007	PAMINA Milestone Report M2.1.1, Galson Sciences Ltd. Oakham, UK.	PAMINA Milestone Report M1.2.1, European Commission.

Errata 2011-12

SKB TR-10-13

Spent nuclear fuel for disposal in the KBS-3 repository

In the earlier distributed report, there are errors that have now been corrected. The corrected pages 26, 43, 44, 59, 66, 74, 79, 81, 83, 85, 87, 89, 91, 93 are enclosed. The changed text is marked with a vertical line in the page margin. An updated pdf version of the report, dated 2011-12, can be found at www.skb.se/publications.

Reference SKBdoc 1179234 has been changed to SKBdoc 119314 on the following pages: 31, 42, 51, 52, 53, 67, 68, 69, 73, 78, 80, 82, 84, 86, 88, 90 and 92.

Reference SKBdoc 1193244 has been changed to SKBdoc 1221579 on page 45.

Reference SKBdoc 1222975 has been changed to SKBdoc 1221579 on page 51.

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The sensitivity analyses are based on the assumption that the insert is made of nodular cast iron with an iron content of at least 90%. The iron in the insert acts as a neutron reflector. Alloying elements occurring in nodular iron that are more potent neutron reflectors than iron are silicon (Si) and carbon (C). In the analysis it was concluded that the content of these substances shall be kept below 6% (C) and 4% (Si) in order not to increase the propensity for criticality.+ Further, the propensity for criticality increases if the assemblies are placed close together. The loading curves presented in Section 4.4.1 are based on the closest possible distances based on the acceptable distances between the channel tubes for the reference design of the canister.

The following requirement and criterion are set for the selection of fuel assemblies to be encapsulated.

- Requirement on handling: *The fuel assemblies to be encapsulated shall be selected with respect to enrichment, burnup, geometrical configuration and materials in the canister so that criticality will not occur during the handling and storage, even if the canister is filled with water.*
- Criterion: *The effective multiplication factor (*k_{eff}*) must not exceed 0.95 including uncertainties.*

3.1.3 Dimensions and spacing devices

The dimensions of the BWR and PWR fuel assemblies, including alterations that may occur as a result of the irradiation in the nuclear reactor, shall be considered in the design of the canister inserts. Two types of canister inserts with the same length and diameter provided with channel tubes with different inner dimensions to accommodate BWR and PWR fuel assemblies, respectively, will be manufactured; see the **Canister production report**.

SKB has decided that it shall be possible to encapsulate all spent fuel from the Swedish nuclear power programme, i.e. also the Ågesta fuel, the swap MOX fuel, the Studsvik fuel residues and the special boxes containing fuel rods, in either BWR or PWR canisters, and the following design requirement is set for the canister.

- Design requirement: *The dimensions of the fuel channel tubes of the insert shall be adapted to the dimensions of the spent fuel to be deposited.*
- Design premises: *The length of the longest BWR or PWR assembly, including induced length increase. The cross section of the largest BWR and PWR fuel assemblies, including deviations due to deformations during operation.*

The measures that shall be used in the design of the channel tubes of the insert are given in Table 3-1.

Table 3-1. Design measures for the fuel channel tubes of the insert.

Detail	BWR	PWR	Comment
Longest assembly	4,441 mm		Before irradiation.
Induced length increase	14 mm		When determining the length of the longest assembly the length before irradiation and the induced length increase is considered.
Largest cross section	141×141 mm	214×214 mm	Before irradiation.
Deviations due to deformations during operation	145.5×145.5 mm	228×228 mm	Cross sections of BWR transport cask, and PWR storage canister respectively. All assemblies in Clab have been placed in these casks or canisters, i.e. these cross sections are sufficient with respect to occurring deviations due to deformations during operation.

Table 6-1. The total inventory in BWR and PWR assemblies of thirteen radionuclides (Bq) of importance for radiotoxicity and calculated long-term risk (alphabetic order). The inventories are calculated for the calendar year 2045.

Radio-nuclide	Radionuclide inventory (Bq)									
	BWR assemblies				PWR assemblies					
	47,637 BWR UOX[1] 40.4 Mwd/kgU		267 BWR MOX[2] 50 MWd/kgHM		6,016 PWR UOX 44.8 MWd/kgU			33 PWR MOX 34 MWd/kgHM		
	Fuel	Constr. materials/ crud	Fuel	Constr. materials/ crud	Fuel	Constr. materials/ crud	Control rods	Fuel	Constr. materials/ crud	Total activity
Am-241	1.2E+18	1.1E+11	4.8E+16	2.4E+09	4.9E+17	6.6E+10		4.5E+15	3.4E+08	1.7E+18
C-14	1.1E+14	2.9E+14	6.2E+11	2.1E+12	3.4E+13	6.9E+13	3.7E+12	9.7E+10	3.3E+11	5.1E+14
Cl-36	1.8E+12	2.8E+10	1.2E+10	2.1E+08	4.9E+11	8.0E+09	1.1E+09	1.4E+09	3.8E+07	2.3E+12
Cs-137	1.7E+19	5.2E+12	8.5E+16	2.7E+10	6.3E+18	1.1E+12	0.0E+00	1.0E+16	3.3E+09	2.3E+19
I-129	1.0E+13	0.0E+00	9.6E+10		3.8E+12			1.3E+10		1.4E+13
Nb-94	4.6E+10	3.6E+13	6.2E+08	2.6E+11	1.7E+10	8.9E+14	3.2E+11	8.8E+07	4.3E+12	9.3E+14
Pu-238	9.5E+17	9.7E+10	2.1E+16	1.3E+09	3.7E+17	6.0E+10		1.6E+15	1.7E+08	1.3E+18
Pu-239	1.0E+17	9.2E+11	2.7E+15	5.3E+09	3.8E+16	2.8E+11	0.0E+00	2.2E+14	1.5E+09	1.4E+17
Pu-240	1.9E+17	1.2E+10	6.4E+15	3.2E+08	6.1E+16	8.2E+09		5.9E+14	3.9E+07	2.5E+17
Pu-241	7.4E+18	6.4E+11	1.3E+17	6.3E+09	3.0E+18	4.0E+11		9.3E+15	7.1E+08	1.1E+19
Sr-90	1.1E+19	4.8E+12	2.8E+16	2.5E+10	4.2E+18	1.0E+12	0.0E+00	3.6E+15	3.1E+09	1.6E+19
U-234	4.0E+14	3.5E+07	3.8E+12	3.5E+05	1.9E+14	2.3E+07		3.3E+11	1.1E+05	6.0E+14
U-238	9.7E+13	7.9E+06	6.5E+12	4.3E+04	3.2E+13	4.4E+06		1.0E+11	2.5E+04	1.3E+14

[1] Includes 222 assemblies from Ågesta.

[2] Includes 184 Swap BWR MOX.

Table 6-2. Assumed radionuclide inventories in the miscellaneous fuels.

Fuel type	Number	Radionuclide inventory
Spent fuel from Ågesta	222	Set to the same as in the average burnup BWR assembly.
Swap BWR MOX fuel assemblies	184	Set to the same as for the BWR MOX assemblies from Oskarshamn.
Swap PWR MOX	33	Matrix inventory calculated for a swap MOX assembly with a burnup of 34 MWd/kgHM.
Special boxes with fuel residues from Studsvik	25	Set to the same as in the average burnup PWR assembly.

The assumptions in Table 6-2 will result in an overestimation of the radionuclide inventories of the miscellaneous fuels since they contain a smaller amount of heavy metal and have an essentially lower burnup than the average BWR and PWR assemblies and the BWR MOX assemblies from Oskarshamn. However, since the miscellaneous fuels comprise in total 464 assemblies out of about 54,000 assemblies, the impact of their divergent inventories on the total inventory can be neglected.

6.2.3 The type canister approach

At the time for the closure of the final repository when the encapsulation and deposition is finished, the burnup, irradiation and power history and age of the assemblies in each canister will be known and the radionuclide inventory can be calculated for each individual canister. However, at this stage it is not reasonable to calculate the inventory in individual canisters. Therefore, a set of type-canisters has been defined based on the assumption that the criteria for maximum allowed total decay power in a canister will restrict the possible variation in radionuclide inventory. The type-canisters shall provide a representative and adequate description of the canisters' content of fuel, its burnup and age and the resulting radionuclide inventory in each canister.

The radionuclide inventory in each canister will depend on:

- the number of assemblies in the canister,
- the burnup of the assemblies,
- the age of the assemblies when they are encapsulated.

The burnup and the number of assemblies will be the parameters of most importance for the radionuclide inventory. In a long-term perspective, the age of the fuel at deposition is of minor importance for the radionuclide inventory since the short lived nuclides of importance for the decay power will successively decay and no longer remain in the canister.

The part of the inventory located at the fuel grain boundaries and in the gap between the fuel and the cladding is correlated to the fission gas release and power history. This part of the radionuclide inventory is discussed in Section 6.3.

To illustrate the range of burnup and, thus, radionuclide inventory, a set of canisters with reasonable combinations of burnup/age of the assemblies have been selected so that the total decay power in the canisters will not exceed 1,700 W. The ages and burnups of the assemblies are based on the results from the simulation of the encapsulation presented in Section 5.2. The set of canisters and their total activity are presented in Table 6-3. The inventory in the fuel matrix of thirteen radionuclides of importance for decay power, radiotoxicity and calculated long-term risk are given in Table 6-4.

As can be seen from Table 6-3 and Table 6-4 both the total activity content and radionuclide inventory varies within the same order of magnitude. For full PWR canisters, the average and combined canisters have similar total activity and radionuclide inventory. This illustrates that the decay power criterion will restrict the variation in radionuclide content.

Table 6-3. The total activity in the fuel matrix in a set of reasonable BWR and PWR canisters with a total decay power of 1,700 W at time for encapsulation /SKBdoc 1221579/.

Canister	Number of assemblies	Burnup (MWd/kgU))	Age of assemblies (years)	Total activity (10^{16} Bq/canister)
BWR low	12	30.7	20	2.1
BWR average	12	40.4	37	1.6
BWR high a	12	47.8	48	1.4
BWR high b	12	57	60	1.2
BWR unfilled	9	47.8	32	1.6
BWR-MOX	11	37.7	43	1.4
	1	50	50	
PWR low	4	34.2	20	2.0
PWR average	4	44.8	38	1.6
PWR high	4	57	55	1.3
PWR combination a	1	57	20	1.7
	3	34.2	40	
PWR combination b	2	57	51	1.5
	1	57	20	
PWR-MOX	3	44.8	32	1.6
	1	34.8	57	

7 References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications. References to SKB's unpublished documents are listed separately at the end of the reference list. Unpublished documents will be submitted upon request to document@skb.se.

Canister production report, SKB 2010. Design, production and initial state of the canister. SKB TR-10-14, Svensk Kärnbränslehantering AB.

Design premises long-term safety, SKB 2009. Design premises for a KBS-3V repository based on results from the safety assessment SR-Can and some subsequent analyses. SKB TR-09-22, Svensk Kärnbränslehantering AB.

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Nordström E, 2009. Fission gas release data for Ringhals PWRs. SKB TR-09-26, Svensk Kärnbränslehantering AB.

Oldberg K, 2009. Distribution of fission gas release in 10×10 fuel. SKB TR-09-25, Svensk Kärnbränslehantering AB.

SKB, 2006. Measurements of decay heat in spent nuclear fuel at the Swedish interim storage facility, Clab. SKB R-05-62, Svensk Kärnbränslehantering AB.

SKB, 2009. Plan 2008. Costs starting in 2010 for the radioactive residual products from nuclear power. Basis for fees and guarantees in 2010 and 2011. SKB TR-09-23, Svensk Kärnbränslehantering AB.

SKB, 2009. Design premises for a KBS-3V repository based on results from the safety assessment SR-Can and some subsequent analyses. SKB TR-09-22, Svensk Kärnbränslehantering AB.

Werme L, Johnson L H, Oversby V, King F, Spahiu K, Grambow B, Shoesmith D W, 2004. Spent fuel performance under repository conditions: A model for use in SR-Can. SKB TR-04-19, Svensk Kärnbränslehantering AB.

Unpublished documents

SKBdoc id, version	Title	Issuer, year
1077122, 2.0	Strålskärmsberäkningar för kopparkapslar innehållande BWR, MOX och PWR bränsleelement	SKB, 2009
1172138, 1.0	Kontroll av kärnämnen inom KBS-3-systemet	SKB, 2009
1193244, 4.0	Criticality safety calculations of disposal canisters	SKB, 2010
1198314, 1.0	Källstyrkor för bränsleelement under driftskede för Clink, slutförvarsanläggning och slutförvar	SKB, 2009
1221567, 2.0	Simulering av fyllning av kapslar för slutförvaring av utbränt kärnbränsle	SKB, 2010
1221579, 2.0	Aktivitetsinnehåll i kapslar för slutförvar	SKB, 2010
1222975, 2.0	Beräkning av fissionsgasfrigörelse för bränslet i slutförvaret	SKB, 2010

Table B-2. Impurities in the fuel matrix /SKBdoc 1221579/.

Element	Assumed in calculations (ppm)	Representative values for fuel matrices[1] (ppm)	
Ag	0.05	<0.05	
Al	6	3–6	
B	0.05	<0.05	
Bi	0.5	<0.5	
Ca	3	<3	1/3 above LRV
Cd	0.233	average 0.233	min 0.2 max 0.6
Co	0.5	<0.5	
Cr	1	<1	10% above LRV
Cu	0.5	average 0.5	min 0.2 max 7
F	2	<2	20% above LRV
Fe	5	<5	20% above LRV
In	0.3	<0.3	
Li	0.05	<0.05	
Mg	1	<1	
Mn	2	<2	
Mo	5	<5	
N[2]	14	–	
Ni	–	<1	
Pb	0.6	<0.6	20% above LRV
Si	10	<10	
Sn	0.8	0.6–0.8	
Ti	10	<10	
V	0.3	<0.3	
Zn	25	<25	
Dy	10	<10	
Eu	0.02	<0.02	
Gd	0.06	<0.06	
Sm	0.04	<0.04	
C	8.4	average 8.4	min 3 max 28
Cl	2	2	
Ni	5	5	
W	0.2	0.2	

(LRV_Lowest reported value)

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[1] Personal communication Westinghouse.

[2] Assumed in accordance with /SKBdoc 1198314/.

BWR:

- UO2-values from /SKBdoc 1221579, Table 14/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 40.4 MWd/kg U.
  (Data from appendix: folder 'IndAct-Ett element-rev3', files '88_Ind-B38-000.xls' and '89_Ind-B60-000.xls'.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 40.4 MWd/kg U.
  (Data from appendix: folder 'CrudAct-Ett element-rev3', files '95_Crud-B38-000.xls' and '96_Crud-B60-000.xls'.)
- Average age for BWR assemblies 36.3 years and BWRmox assemblies 50 years.

PWR:

- UO2-values from /SKBdoc 1221579, Table 13/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 44.8 MWd/kg U.
  Assumption: At any given burnup or age the construction material data is the same for PWR and PWRMOX.
  (Data from appendix: folder 'IndAct-Ett element-rev3', files '90_Ind-P30-000.xls' and '91_Ind-P60-000.xls'.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 44.8 MWd/kg U.
  Assumption: At any given burnup or age the crud data is the same for PWR and PWRMOX.
  (Data from appendix: folder 'CrudAct-Ett element-rev3', files '97_Crud-P30-000.xls' and '98_Crud-P60-000.xls'.)
- Inventory for control rods from /SKBdoc 1179234, appendix: folder 'Styrstavar-rev3', file '110_PWR-ss.xls'/.
- Average age for PWR assemblies 36.9 years and PWRmox assemblies 57 years.

2,208 BWR I canisters:

- UO2-values from /SKBdoc 1221579, Table 14/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 40.4 MWd/kg U.
  (Data from appendix: folder 'IndAct-Ett element-rev3', files '88_Ind-B38-000.xls' and '89_Ind-B60-000.xls'.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 40.4 MWd/kg U.
  (Data from appendix: folder 'CrudAct-Ett element-rev3', files '95_Crud-B38-000.xls' and '96_Crud-B60-000.xls'.)

1,024 PWR I canisters:

- UO2-values from /SKBdoc 1221579, Table 13/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 44.8 MWd/kg U.
  (Data from appendix: folder ‘IndAct-Ett element-rev3’, files ‘90_Ind-P30-000.xls’ and ‘91_Ind-P60-000.xls’.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 44.8 MWd/kg U.
  (Data from appendix: folder ‘CrudAct-Ett element-rev3’, files ‘97_Crud-P30-000.xls’ and ‘98_Crud-P60-000.xls’.)
- Inventory for control rods from /SKBdoc 1179234, appendix: folder ‘Styrstavar-rev3’, file ‘110_PWR-ss.xls’/.

321 BWR II canisters:

- UO2-values from /SKBdoc 1221579, Table 14/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 47.8 MWd/kg U.
  (Data from appendix: folder ‘IndAct-Ett element-rev3’, files ‘88_Ind-B38-000.xls’ and ‘89_Ind-B60-000.xls’.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 47.8 MWd/kg U.
  (Data from appendix: folder ‘CrudAct-Ett element-rev3’, files ‘95_Crud-B38-000.xls’ and ‘96_Crud-B60-000.xls’.)

1,655 BWR III canisters:

- UO2-values from /SKBdoc 1221579, Table 14/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 47.8 MWd/kg U.
  (Data from appendix: folder 'IndAct-Ett element-rev3', files '88_Ind-B38-000.xls' and '89_Ind-B60-000.xls'.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 38 and 60 MWd/kg U to find inventory at 47.8 MWd/kg U.
  (Data from appendix: folder 'CrudAct-Ett element-rev3', files '95_Crud-B38-000.xls' and '96_Crud-B60-000.xls'.)

267 BWRMOX canisters:

- UO2-values from /SKBdoc 1221579, Table 14/.
- Inventory for construction material from /SKBdoc 1198314/ at 38 MWd/kg U for 11 BWR assemblies and 50 MWd/kg U for 1 MOX assembly.
  (Data from appendix: folder 'IndAct-Ett element-rev3', files '88_Ind-B38-000.xls' and '93_Ind-M50-000.xls'.)
- Inventory for Crud from /SKBdoc 1198314/ at 38 MWd/kg U for 11 BWR assemblies and 50 MWd/kg U for 1 MOX assembly.
  (Data from appendix: folder 'CrudAct-Ett element-rev3', files '95_Crud-B38-000.xls' and '100_Crud-M50-000.xls'.)

38 PWR II canisters:

- UO2-values from /SKBdoc 1221579, Table 13/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 57 MWd/kg U.
  (Data from appendix: folder 'IndAct-Ett element-rev3', files '90_Ind-P30-000.xls' and '91_Ind-P60-000.xls'.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 57 MWd/kg U.
  (Data from appendix: folder 'CrudAct-Ett element-rev3', files '97_Crud-P30-000.xls' and '98_Crud-P60-000.xls'.)
- Inventory for control rods from /SKBdoc 1179234, appendix: folder 'Styrstavar-rev3', file '110_PWR-ss.xls').

557 PWR III canisters:

- UO2-values from /SKBdoc 1221579, Table 13/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 57 MWd/kg U.
  (Data from appendix: folder ‘IndAct-Ett element-rev3’, files ‘90_Ind-P30-000.xls’ and ‘91_Ind-P60-000.xls’.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 57 MWd/kg U.
  (Data from appendix: folder ‘CrudAct-Ett element-rev3’, files ‘97_Crud-P30-000.xls’ and ‘98_Crud-P60-000.xls’.)
- Inventory for control rods from /SKBdoc 1179234, appendix: folder ‘Styrstavar-rev3’, file ‘110_PWR-ss.xls’/.

33 PWRMOX canisters:

- UO2-values from /SKBdoc 1221579, Table 13/.
- Inventory for construction material from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 44.8 MWd/kg U.
  Assumption: At any given burnup or age the construction material data is the same for PWR and PWRMOX.
  (Data from appendix: folder 'IndAct-Ett element-rev3', files '90_Ind-P30-000.xls' and '91_Ind-P60-000.xls'.)
- Inventory for Crud from /SKBdoc 1198314/ by linear interpolation between 30 and 60 MWd/kg U to find inventory at 44.8 MWd/kg U.
  Assumption: At any given burnup or age the crud data is the same for PWR and PWRMOX.
  (Data from appendix: folder 'CrudAct-Ett element-rev3', files '97_Crud-P30-000.xls' and '98_Crud-P60-000.xls'.)
- Inventory for control rods from /SKBdoc 1179234, appendix: folder 'Styrstavar-rev3', file '110_PWR-ss.xls'/.

Table C-14. Contribution from predominant radionuclides to the total decay power at time for encapsulation /SKBdoc 1221579/.

Radionuclide	Decay power (W)							
	BWR I	BWR II	BWR III	BWR MOX	PWR I	PWR II	PWR III	PWR MOX
Am- 241	270	315	211	404	294	355	238	331
Am- 243	2	3	2	3	2	4	3	3
Ba- 137m	423	381	420	349	411	349	386	387
Cm-242	1	1	1	2		1		1
Cm-243	1	1	1	1	1	1	1	1
Cm-244	80	103	147	108	87	121	185	114
Co-60								1
Cs-134							2	
Cs-137	127	114	126	105	123	105	116	116
Eu-154	8	4	11	5	7	3	13	10
Kr-85	3	2	4	2	3	1	4	4
Pu-238	213	278	238	232	220	316	267	216
Pu-239	21	21	16	28	21	21	16	22
Pu-240	39	45	34	54	34	42	31	41
Pu-241	2	1	2	1	2	1	2	2
Sr-90	88	74	84	70	85	66	75	78
Y-90	420	355	401	334	407	314	358	373

ISSN 1404-0344
SKB TR-10-14
ID 1198199
Updated 2013-01

Design, production and initial state of the canister

Svensk Kärnbränslehantering AB

December 2010

Keywords: Canister, Safety report, Design premise, Verification, Verifying analysis, Reference design, Production, Manufacturing, Inspection, Initial state.

Update notice

The original report, dated December 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-12

Location	Original text	Corrected text
Page 29, section 3.1.1, paragraph 2	- iron content in nodular cast iron shall be > 90% - carbon content in nodular cast iron shall be < 4.5% - silicon content in nodular cast iron shall be < 6%	- iron content in nodular cast iron shall be > 90% - carbon content in nodular cast iron shall be < 6% - silicon content in nodular cast iron shall be < 4%
Page 50, section 4.7, paragraph 2	The content of these elements shall therefore be kept below 6% (Si) and 4.5% (C).	The content of these elements shall therefore be kept below 6% (C) and 4% (Si).
Page 55, section 4.11.5, paragraph 1, last line	The content of these elements shall therefore be kept below 6% (Si) and 4.5% (C).	The content of these elements shall therefore be kept below 6% (C) and 4% (Si).
Page 102, Table 7-1, first line	Carbon content (%); <4.5%; <4.5% Silicon content (%); <6%; <6%	Carbon content (%); <6%; <6% Silicon content (%); <4%; <4%
Page 108, section 7.1.6, paragraph 3	The carbon content is below 4.5% and the silicon content is below 6% in all manufactured inserts.	The carbon content is below 6% and the silicon content is below 4% in all manufactured inserts.
Page 110, section 7.2.5, paragraph 2	The iron (> 90%), silicon (< 6%) and carbon (< 4.5%) content in the insert is verified by conventional material analyses during production.	The iron (> 90%), silicon (< 4%) and carbon (< 6%) content in the insert is verified by conventional material analyses during production.

Updated 2013-01

Location	Original text	Corrected text
Page 24, Table 2-2 , third column, second line	Fe > 90%, C < 4.5% and Si < 6%	Fe > 90%, C < 6% and Si < 4%
Page 90, Table 5-12, line S, column Specification	< 2	< 12

ISSN 1404-0344
SKB TR-10-15

ID 1177185

Updated 2013-01

Design, production and initial state of the buffer

Svensk Kärnbränslehantering AB

December 2010

Keywords: Buffer, Safety report, Design premise, Verification, Verifying analysis, Reference design, Production, Manufacturing, Inspection, Initial state.

Update notice

The original report, dated December 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-12

Location	Original text	Corrected text
Page 50, Table 5-2, line Density and dimensions of pellets, colums Required property; Design parameter; Parameter inspected in the production	"Density and dimensions of pellets; Bulk density separate pellets, Dimensions; Weight and dimensions of individual pellets, Thickness of individual pellet, Width of individual pellet, Length of individual pellet "	"Density and dimensions of pellets; Dimensions; Thickness of individual pellet, Width of individual pellet, Length of individual pellet "
Page 51, Figure 5-2, line Density and dimensions of pellets	Bulk density seperate pellets; Dimensions; Bulk density loose filling	Dimensions; Bulk density loose filling
Page 80, Table 6-6, headline, colum 1	"Allowed increase in widht of pellet filled gap (mm)"	"Allowed increase in widht of pellet filled gap (m)"

Updated 2013-01

The original report, dated December 2010, was found to contain editorial errors which have been corrected in this updated version.

Errata 2011-12

SKB TR-10-17

Design, production and initial state of the closure

In the earlier distributed report, there are errors that have now been corrected. The corrected page 30 is enclosed. The changed text is marked with a vertical line in the page margin. An updated pdf version of the report, dated 2011-12, can be found at www.skb.se/publications.

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3.5 Borehole sealing

A number of investigation boreholes, both holes drilled from the surface and holes drilled from underground openings have to be sealed, at the decommissioning of the final repository facility. With respect to that the closure shall "*prevent that water conductive channels that may jeopard*ise *the barrier functions of the rock, are formed between the repository and the surface",* only boreholes going deeper than the top sealing (thus passing –200 meter) have to be sealed. In the layout of the final repository facility the locations of the boreholes are considered in order to avoid that boreholes connected to the surface intersect underground openings. Deposition tunnels must not be intersected by investigation boreholes connected to the surface, and deposition holes must not be intersected by any investigation boreholes.

The geometry of a borehole seal is mainly determined by the dimensions of the drilled holes. The length of surface-based boreholes ranges from a few metres to more than 1,000 metres and the diameter will range from 56 to 120 mm. The tunnel-based boreholes are expected to have a length of a few hundred metres and a diameter of 56 to 76 mm. The shallowest parts of the boreholes may have larger diameters. Some boreholes may be more or less horizontal.

In addition a large number of grouting holes and holes for installation of rock support will be drilled during construction of the repository, see the **Underground openings construction report**. However, they do not need to be sealed.

SKB has studied and developed several concepts for borehole sealing. The main principles for sealing boreholes as well as results from tests and experiments are summarised in /Pusch and Ramqvist 2007/.

3.5.1 Reference design of borehole sealing

To conform to the design premises for borehole sealing (see Table 2-1) the following reference design is applied.

Highly compacted bentonite is used where tight seals are needed and cement-stabilised plugs are cast where the boreholes pass through fracture zones, see Figure 3-6 and 3-7. For the reference design MX-80 bentonite is chosen. To prevent erosion during the installation phase the clay shall be pre-dried to a water content of about 6% and then compacted to a dry density of 1,900 kg/m^3. The clay blocks are contained in perforated copper tubes that are jointed as they are inserted into the holes. The copper tubes provide mechanical protection against abrasion in the installation phase. The reference borehole has a diameter of 80 mm (investigation holes with a original diameter of 76 mm have to be enlarged) and the perforated copper tube an outer diameter of 76.1 mm and an inner diameter of 72.1 mm (which is a standard dimension). The tubes have a perforation ratio of 50% with 10 mm diameter holes in order to allow the clay to swell into the volume between the tube and the rock.

Along sections where the borehole passes water-conducting fracture zones the clay could potentially erode. In such positions the holes are therefore filled with silica concrete, which is a permeable and erosion-resistant material, see Figure 3-6. These plugs do not need to have a low conductivity but must be physically stable for supporting the surrounding rock and the clay plugs that rest on them or are located below them. In the construction phase they must be stable and rapidly become strong enough to carry overlying clay plugs without settling. This is attained by using a fast curing cement binder. To minimise the negative impact of cement contacting clay plugs, the cement content will be very low and low-pH cement will be utilised. Further details are found in /Pusch and Ramqvist 2007/.

The upper part of boreholes connected to the surface will be sealed with material that can sustain the swelling pressure exerted by the clay part and offer resistance to mechanical impact like intrusion, erosion and glaciations. For the reference design the concept illustrated in Figure 3-5 is selected. The main components are: rock cylinders, concrete plugs cast on site and anchored in reamed recesses and well compacted till /Pusch and Ramqvist 2007/.

ISSN 1404-0344
SKB TR-10-45

ID 1271388

Updated 2013-02

FEP report for the safety assessment SR-Site

Svensk Kärnbränslehantering AB

December 2010

Keywords: FEP, KBS-3, Spent fuel repository, Safety assessment, SR-Site.

Update notice

The original report, dated December 2010, was found to contain factual errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2013-02

Location	Original text	Corrected text
Page 40, Table 5-6, line Ge25	3.6.3	6.2

Errata 2011-10

SKB TR-10-47

Buffer, backfill and closure process report for the safety assessment SR-Site

In the earlier distributed report, there are errors that have now been corrected. The corrected pages 21, 22, 28, 31, 32, 118, 150, 165, 179, 211, 224, 225, 227, 235, 237, 246, 251, 281, 303, 328, 334, 339 and 344 are enclosed. The changed text is marked with a vertical line in the page margin. An updated pdf version of the report, dated 2011-10, can be found at www.skb.se/publications.

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Table 2-4. Process table for the buffer describing how buffer processes are handled in different time frames and for the special case of an earthquake. Green fields denote processes that are neglected or not relevant for the time period of concern. Red fields denote processes that are quantified by modelling in the safety assessment. Orange fields denote processes that are neglected subject to a specified condition. White fields (in the earthquake column) denotes processes where the authors have been unable to judge the significance of the process.

	Resaturation/ "thermal" period	Long-term after saturation and "thermal" period	Earthquakes	Notes
Intact canister				
Bu1 Radiation attenuation/ heat generation	🟩 Neglected since dose rate is too low to be of importance for the buffer	🟩 Neglected since dose rate is too low to be of importance for the buffer	🟩 Not relevant	
Bu2 Heat transport	🟥 System model	🟥 System model	🟩 Not relevant	
Bu3 Freezing	🟩 Neglected, since this requires permafrost conditions	🟧 Neglected if buffer temperature > -4°C. Otherwise bounding consequence calculation	🟩 Not relevant	Repository temperature in long term obtained from permafrost depth modelling
Bu4 Water uptake and transport for unsaturated conditions	🟥 THM model	🟩 Not relevant by definition	🟩 Not relevant	
Bu5 Water transport for saturated conditions	🟩 Neglected under unsaturated conditions. For saturated conditions the treatment is the same as for "Long-term"	🟧 Neglected if hydraulic conductivity $< 10^{-12}$ m/s since diffusion would then dominate	⬜ Consider pressure transients	The consequences of a buffer with high hydraulic conductivity are evaluated. Two different cases are studied: the buffer acts as a porous medium with high conductivity (mass loss) the buffer is fractured (alteration)
Bu6 Gas transport/ dissolution	🟩 Through dissolution	🟩 (Through dissolution) No gas phase is assumed to be present	🟩 (Through dissolution) No gas phase is assumed to be present	
Bu7 Piping/Erosion	🟥 Model study	🟩 Not relevant, see also Bu18	🟩 Not relevant	Loss of buffer mass is calculated
Bu8 Swelling/mass redistribution	🟥 THM modelling including interaction buffer/backfill and thermal expansion System model (final swelling)	🟥 Integrated evaluation of erosion, convergence, corrosion products, creep, swelling pressure changes due to ion exchange and salinity, canister sinking	🟥 Part of integrated assessment of buffer/canister/rock	Need to also consider deviations in amount of buffer initially deposited
Bu9 Liquefaction	🟩 Not relevant in an unsaturared material	🟩 Neglected since liquefaction from a short pulse cannot occur in a high density bentonite, due to high effective stresses	🟩 Neglected since liquefaction from a short pulse cannot occur in a high density bentonite, due to high effective stresses	
Bu10 Advective transport of species	🟥 Simplified assumptions of mass transport of dissolved species during saturation	🟧 Neglected if hydraulic conductivity $< 10^{-12}$ m/s	⬜ Consider pressure transients	See "Water transport for saturated conditions"

	Resaturation/ “thermal” period	**Long-term after saturation and “thermal” period**	**Earthquakes**	**Notes**
Bu11 Diffusive transport transport of species	Chemistry model (thermal, saturated phase; unsaturated phase disregarded)	Chemistry model	Consider altered geometry (diffusion pathways)	Consider varying groundwater compositions The initial thermal gradient is considered
Bu12 Sorption (including ion-exchange)	Chemistry model (thermal, saturated phase; unsaturated phase disregarded)	Chemistry model	Not specifically treated	
Bu13 Alteration of impurities	Chemistry model (thermal, saturated phase; unsaturated phase disregarded)	Chemistry model	Not specifically treated	
Bu14 Aqueous speciation and reactions	Chemistry model (thermal, saturated phase; unsaturated phase disregarded)	Chemistry model	Not specifically treated	
Bu15 Osmosis	Evaluation through comparison with empirical data.	Evaluation through comparison with empirical data	Not specifically treated	Handling of long-term intrusion of saline water
Bu16 Montmorillonite transformation	Model calculations (thermal, saturated phase; unsaturated phase disregarded)	Estimate based on evidence from nature	Part of integrated assessment of buffer/canister/rock	
Bu17 Iron-bentonite interaction	Neglected since no iron will be in contact with the bentonite	Only considered for failed canister. Possible loss of buffer efficiency	Only considered for failed canister. Possible loss of buffer efficiency	
Bu18 Montmorillonite colloid release	Neglected if total cation charge is > 4 mM. Otherwise modelled	Neglected if total cation charge is > 4 mM. Otherwise modelled	Not specifically treated	Loss of buffer mass is calculated See also water transport under saturated conditions
Bu19 Radiation-induced transformations	Neglected since dose rate outside canister is too low to have any effect	Neglected since dose rate outside canister is too low to have any effect	Neglected since dose rate outside canister is too low to have any effect	
Bu20 Radiolysis of porewater	Neglected since dose rate outside canister is too low to have any effect	Neglected since dose rate outside canister is too low to have any effect	Neglected since dose rate outside canister is too low to have any effect	
Bu21 Microbial processes	Neglected under unsaturated conditions, since the extent of aqueous reactions is limited. For saturated conditions the treatment is the same as for “Long-term”	Quantitative estimate of sulphate reduction, limited by supply of microbe nutrients in groundwater	Not specifically treated	
Bu22 Cementation	Discussed together with Process Bu16 “Montmorillonite transformation”	Discussed together with Process Bu16 “Montmorillonite transformation”	Part of integrated assessment of buffer/canister/rock	

	Resaturation/ "thermal" period	Long-term after saturation and "thermal" period	Notes
BfT14. Osmosis	Hydraulic conductivity in THM model chosen so as to handle osmosis	Evaluation through comparison with empirical data	Handling of long-term intrusion of saline water
BfT15. Montmorillonite transformation	Model calculations (thermal, saturated phase; unsaturated phase disregarded)	Model calculations	
BfT16. Colloid release	Neglected if total cation charge is > 4 mM Otherwise modelled	Neglected if total cation charge is > 4 mM Otherwise modelled	Loss of backfill is calculated
BfT17. Radiation-induced transformations	Neglected, since dose rate in backfill is too low to have any effect	Neglected, since dose rate in backfill is too low to have any effect	
BfT18. Microbial processes	Excluded, (the effect on oxygen consumption is not considered)	Mass balance considerations	
Failed canister			
BfT5 Failed can. Gas transport/ dissolution	Neglected, since gas volumes (from buffer) assumed to be too low to reach backfill during this period	Neglected, pessimistically since transport would delay radioactive releases and decrease buffer pressure. The backfill would act as a sink for gas.	Gas release from canister
BfT19. Colloid formation and transport	See geosphere (no failures are expected this period)	See geosphere	Called "colloid transport" for buffer Reference to corresponding geosphere process
BfT20. Speciation of radionuclides	Assumptions based on empirical data (no failures are expected this period)	Assumptions based on empirical data	
BfT21. Transport of radionuclides in water phase	COMP23 (no failures are expected this period)	COMP23	
BfT22. Transport of radionuclides in gas phase	By-passed (no failures are expected this period)	By-passed	

2.4 Tunnel plug

2.4.1 Initial state of the tunnel plug

The plug is in itself not a barrier but it is a necessary ingredient to help the backfill in the deposition tunnel to maintain its barrier function. The main requirements of the plug are listed below.

- The plug shall seal the deposition tunnel and keep the backfill in place during the operational phase until the deposition and transport tunnels have been backfilled and water saturated, and have regained their hydrostatic water pressure.
- The plug shall resist the hydrostatic water pressure at repository level and the swelling pressure from the backfill and the bentonite seal.
- The plug shall limit water flow from the deposition tunnel past the plug to such an extent that no harmful backfill erosion takes place from the deposition tunnel.
- The plug shall not significantly impair the barrier function of the other barriers.
- The movement of the plug due to pressure shall be within sufficiently small to avoid a drop in backfill density in the vicinity of the plug.

2.4.3 Summary of handling of tunnel plug processes in SR-Site

Table 2-12 summarises the handling of tunnel plug processes in the safety assessment SR-Site, as suggested in the Process Report. In the table, the process is either “mapped” to a model by which it will be quantified or a brief verbal description of how it will be handled is provided. Since the initial evolution, characterised by unsaturated conditions and elevated temperatures is in many respects different from the long-term, saturated phase, the description in the table has been divided accordingly.

Table 2-12. Process table for the tunnel plugs describing how tunnel plug processes are handled in different time frames. Green fields denote processes that are neglected or not relevant for the time period of concern. Red fields denote processes that are quantified by modelling in the safety assessment. Orange fields denote processes that are neglected subject to a specified condition.

	Resaturation/ “thermal” period	Long-term after saturation and “thermal” period	Notes
Intact canister			
Pg1 Heat transport	Temperature as a function of distance from deposition holes is calculated. However, no specific estimate of the temperature in the plugs is done. The temperature in this component will under all circumstances remain relatively low	Temperature as a function of distance from deposition holes is calculated. However, no specific estimate of the temperature in the plugs is done. The temperature in this component will under all circumstances remain relatively low	
Pg2 Freezing	Neglected, since this requires permafrost conditions	Neglected, since there are no long-term performance requirements on the plugs	
Pg3 Water uptake and transport under unsaturated conditions	THM model	Not relevant by definition	
Pg4 Water transport under saturated conditions	Assumed to be a part of the tunnel with high hydraulic conductivity	Assumed to be a part of the tunnel with high hydraulic conductivity	
Pg5 Gas transport/ dissolution	THM model	Neglected – any effect from the plugs on gas migration would be positive, since they could act as sinks. However, the effect is impossible to quantify	
Pg6 Piping/erosion	The plug is a part in the integrated treatment of piping. However, no assessment of piping in the plug itself is done	Neglected, since piping only occurs during the early part of the repository evolution	
Pg7 Swelling/mass redistribution	THM-model	Neglected, since there are no long-term performance requirements on the plugs	
Pg8 Advective transport of species	Assumed to be a part of the tunnel with high hydraulic conductivity	Assumed to be a part of the tunnel with high hydraulic conductivity	
Pg9 Diffusive transport of species	Neglected since advection will dominate	Neglected since advection will dominate	
Pg10 Sorption	Sorption will occur in the plugs, but is pessimistically neglected	Sorption will occur in the plugs, but is pessimistically neglected	
Pg11 Alteration of concrete	Separate modelling of concrete degradation	Separate modelling of concrete degradation	
Pg12 Aqueous speciation and reactions	Separate modelling of concrete degradation	Separate modelling of concrete degradation	

	Resaturation/ "thermal" period	Long-term after saturation and "thermal" period	Notes
Pg13 Osmosis	Osmotic effects are neglected due to the lack of an osmotic flow in the tunnel	Osmotic effects are neglected due to the lack of an osmotic flow in the tunnel	
Pg14 Montmorillonite transformation	Neglected, since there are no long-term performance requirements on the plugs	Neglected, since there are no long-term performance requirements on the plugs	
Pg15 Montmorillonite colloid release	Neglected, since there are no long-term performance requirements on the plugs	Neglected, since there are no long-term performance requirements on the plugs	
Pg16 Microbial processes	Neglected under unsaturated conditions, since the extent of aqueous reactions is limited. For saturated conditions the treatment is the same as for "Long-term"	Microbial effects in tunnel plugs will be included in the description of the geochemistry in the repository	
Failed canister			
Pg5 Failed canister. Gas transport/dissolution	Assumed to be a part of the tunnel with high hydraulic conductivity (no failures expected in this period)	Assumed to be a part of the tunnel with high hydraulic conductivity	
Pg17 Speciation of radionuclides	Assumptions based on empirical data (no failures are expected this period)	Indirectly accounted for through the selection of parameters for radionuclide transport	
Pg18 Transport of radionuclides in water phase	Assumed to be a part of the tunnel with high hydraulic conductivity (no failures are expected this period)	Assumed to be a part of the tunnel with high hydraulic conductivity	

2.5 Central area

2.5.1 Initial state of the central area

The central area is the assembled part of the sub-surface of the KBS-3 repository facility comprising rock cavities for operation, logistics and maintenance. The rock cavities of the central area shall house transfer of canisters, storage and transhipment of rock masses, buffer, backfill and closure material, storage of equipment etc, garages and workshops, spaces for personnel and visitors and spaces for technical systems.

The central area will be filled with crushed rock. The following is an overview description of the initial state of the central area (Figure 2-4). The initial state for this component is defined as the state at the closure of the repository. A more formal and exhaustive account is given in the production line report for the closure /SKB 2010g/. The repository part that is included in this description is the central area at the repository level where the ramp and shafts for transporting material and personnel start.

The total volume of this area is 125,000 m^3. The entire volume is filled with crushed rock from the site. The final density and porosity will be 1,900 kg/m^3 and 27% (in the compacted rock fill; 100% in the crown space) respectively. Since crushed rock is a non-swelling material there will be an open gap of about 10 cm in the top of the central area.

2.5.2 Definition of central area variables

Each component in the EBS is described by a specified set of physical variables, selected to allow an adequate description of the long-term evolution of the component in question in the safety assessment.

The central area is bounded on one side by the plugs separating the transport tunnels from the central area and on the other side by the plugs separating the backfill in the ramp and shaft from the central area. The central area is surrounded by the surface of the rock.

in homogeneous aqueous solutions; see e.g. /Sposito 1981, 1984, Stumm and Morgan 1996/. Accordingly, most studies concerning surface reactions on these minerals focus on sorption, whereas much fewer studies have been published that systematically investigate the degree of reversibility in sorption experiments. On the other hand, the pertinent literature offers several examples where some type of irreversibility was observed. Below, in the Model studies/experimental studies section, several examples are examined and their relevance with respect to radionuclide sorption on clays is evaluated. While this discussion is not based on an exhaustive review of the literature, it shows that sorption on clays and clay-like substrates is typically found to be reversible if the experimental boundary conditions are carefully evaluated.

Dependencies between process and buffer variables

Table 3-12 shows how the process influences and is influenced by all buffer variables.

Table 3-12. Direct dependencies between the process "Sorption" and the defined buffer variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Buffer geometry	No	(Total buffer mass is a parameter in the RN-transport model)	No	
Pore geometry	Possibly indirectly through influence on EDL properties		Possibly indirectly, through influence on EDL properties/swelling	
Radiation intensity	Possibly indirectly, through influence on mineral properties		No	
Temperature	Influence of temperature on sorption must be acknowledged, but effect is not clear		No	
Water content	Indirectly through porewater composition		No	
Gas content	Indirectly through porewater composition (CO_2)		Possibly indirectly, through influence of Ca-exchange on carbonate equilibria	
Hydrovariables (pressure and flows)	Indirectly through porewater composition		Possibly indirectly, through porewater composition/swelling	
Stress state	Indirectly through influence on porewater composition and EDL properties		Indirectly through influence on porewater composition and EDL properties/swelling	
Bentonite composition	Yes	Used for derivation of K_d	Yes	Included in geochemical transport model
Montmorillonite composition	Yes	Used for derivation of K_d	Yes	Included in geochemical transport model
Porewater composition	Yes	Used for derivation of K_d	Yes	Included in RN-transport model (Section 3.6.2) and geochemical transport model (Section 3.5.6)
Structural and stray materials	No stray materials are assumed to be present within the buffer		Indirectly through influence on porewater composition and related mineral equilibria	

Table 3-17. Direct dependencies between the process "Iron – bentonite interaction" and the defined buffer variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Buffer geometry	Yes, through transport of dissolved species and total buffer mass	Included in mass balance	Yes, for extreme unexpected transformation	Separate scenario
Pore geometry	Yes, through transport of dissolved species and ion equilibrium	Included in model/ expression used	Yes, by definition	Separate scenario
Radiation intensity	No		No	
Temperature	Yes	Neglected, since the reaction will occur late in the repository evolution	No	
Water content	Yes, through transport of dissolved species	Full saturation assumed	Yes, for extreme unexpected transformation	Neglected, importance is minor
Gas content	Yes, through transport of dissolved species	Neglected, since the reaction will occur late in the repository evolution	No	
Hydrovariables (pressure and flows)	Yes, minor through transport of dissolved species	Neglected since the major source of iron is present inside the canister	Yes, for extreme unexpected transformation	Separate scenario
Stress state	No, pressures are too small to be significant		Yes, for extreme unexpected transformation	Separate scenario
Bentonite composition	Yes, through available species in accessory minerals	Neglected, due to small effect compared to other sources	Yes	Precipitation of iron phases can be calculated
Montmorillonite composition	Yes, by definition	Included in model/ expression used	Yes, at extreme unexpected transformation	Separate scenario
Porewater composition	Yes, by definition	Included in model/ expression used	Yes, by definition	Included in model/ expression used
Structural and stray materials	Yes, determines availability of iron	No iron is assumed to be present as stray material in buffer	(No)	

Model studies/ experimental studies

Most of the published results are based on experiments were the kinetic limitations have been reduced in some way. The most common ways to speed things up is to increase the temperature, increase the liquid/solid ratio or to increase the reactive surface area by intimately mixing iron and clay powders. However the experimental results are very sensitive to the conditions and hence the results from the studies are rather scattered /Mosser-Ruck et al. 2010/.

Typical experimental results are the following examples:

(i) Iron powder mixed with different bentonites in deionised water was heated at 80ºC for 45 days. Ion exchange was noticed, and also magnetite and 7 Å phyllosilicate formation /Lantenois et al. 2005/.

(ii) Carbon steel (coupons and wires) in compacted MX80 bentonite was heated (30 and 50ºC) with artificial groundwater for up to 900 days. No transformation of the montmorillonite was observed. Magnetite, hematite and goethite were identified as corrosion products. The results were consistent with sodium to iron ion exchange of the montmorillonite /Carlson et al. 2007/.

(iii) FoCa7 bentonite was mixed with various ratios of powdered metallic iron in Evian water and heated for 45 days at 80ºC. The ratio of clay and iron seems to have an impact on the new phases formed. SiAlFe gels were created, which matured into Fe-rich phyllosilicates (identified as odinite or greenalite) /Perronet et al. 2008/.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	**Handling of influence (How/Why not)**	**Influence present? (Yes/No) Description**	**Handling of influence (How/Why not)**
Temperature	Yes. Microbial activity is positively correlated with temperature and will be higher during the thermal period compared to the ambient temperature period	Maximal possible production of sulphide and gas is calculated for high and low temperatures and the amounts produced are compared with the amount needed to corrode a copper canister	No	
Water content	Yes. Decreasing water availability reduces the diversity and the possibilities for microbial activity. At the same time, increasing water content increase the stress state (swelling pressure)	Maximal possible production of sulphide and gas is calculated for all possible water contents and the amounts produced are compared with the amount needed to corrode a copper canister	No	
Gas content	Yes Microbial activity is possible with hydrogen and methane as sources of energy	Maximal possible production of sulphide is calculated for all possible gas contents and the amounts produced are compared with the amount needed to corrode a copper canister	Yes. Microbial activity may result in the production of carbon dioxide and methane	Only effects on the buffer/canister are considered
Hydrovariables (pressure and flows)	(No)		Yes induced gas pressure induces water flow	Neglected since the effect is very small
Stress state	Yes. Microbial activity decreases exponentially with increasing buffer densities and approach zero at densities above 2,000 kg/m^3	Maximal production of sulphide is calculated for all possible pore geometries and the amounts produced are compared with the amount needed to corrode a copper canister	No	
Bentonite composition	Yes. Organic carbon can be utilised and several types of commercial bentonites contain viable bacteria including thermophilic sulphate reducing bacteria	Microbial activity can be possible.Maximal production of sulphide is calculated for the bentonite in use and the amounts produced are compared with the amount needed to corrode a copper canister	Yes.	Neglected since the effect is very small
Montmorillonite composition	Yes. Iron reducing bacteria can use Fe(III) in smectite as an electron acceptor in their respiration	The risk maximum layer charge change is evaluated for the bentonite used	Yes. Iron reducing bacteria may degrade montmorillonite which will decrease the swelling properties of the bentonite	The risk for illitisation is evaluated for different combinations of bentonite process variables. Discussed in the bentonite transformation scenario
Porewater composition	Yes	Maximal production of sulphide and gas is calculated for all possible porewater compositions and the amounts produced are compared with the amount needed to corrode a copper canister	Yes	Only the indirect effects on the buffer/canister are considered
Structural and stray materials	Yes	No stray materials are assumed to be present within the buffer material	Yes	No stray materials are assumed to be present within the buffer material

Table 3-27. Direct dependencies between the process "Transport of radionuclides in the gas phase" and the defined buffer variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Buffer geometry	Yes. The buffer volume determines the transport	See 3.3.3	No	
Pore geometry	No. Only for dissolved gases. Indirectly through stress state		No	
Radiation intensity	No		No	
Temperature	Yes, but the thermal phase will be over before high enough gas pressures can be reached	Neglected	No	
Water content	Yes.	The process is assumed to occur only when the buffer is saturated	No	
Gas content	Yes.	The process is assumed to occur only when the buffer is saturated	Yes	Output from transport estimate
Hydrovariables (pressure and flows)	Yes. The gas pressure will be dependent on the hydrostatic pressure	The pressure build up determines the time for gaseous releases	No	
Stress state	Yes. The opening pressure is dependent on the swelling pressure	The pressure build up determines the time for gaseous releases	No	
Bentonite composition	Indirectly via stress state		No	
Montmorillonite composition	Indirectly via stress state		No	
Porewater composition	Yes and also indirectly via stress state that affects solubility/ speciation of gases, especially CO_2	Pessimistically neglected	No	
Structural and stray materials	No		No	

Handling in the safety assessment SR-Site

Radionuclide transport in a gas phase is treated as a separate case in SR-Site. The handling is based on the experiment by /Harrington and Horseman 2003/ presented in Section 3.3.3. It is assumed that if gas production exceeds the ability of the surrounding groundwater to take it into solution and transport it away from the container, a pressure will build up within and adjacent to the container. The bentonite is assumed to ultimately open and release gas when the internal pressure exceeds 20 MPa. A rapid outflow will occur until the pressure falls to 10 MPa. This means that half of the gas inside the canister will be released instantaneously together with the radionuclides contained in that amount of gas. The only important radionuclides that can be transported in a gas phase are C-14 and Rn-222. Since its half-life is of C-14 is 5,568 years, neither the buffer nor the geosphere is expected to significantly delay the transport to the biosphere. Isotope dilution in a gas phase is not considered. Rn-222 has a very short half-life, but is always present inside the canister. Hence, delay in the geosphere could affect the releases, but is pessimistically neglected in SR-Site.

Table 4-9. Direct dependencies between the process "Diffusive transport of species" and the defined tunnel backfill variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Temperature	Yes	The temperature dependence of the diffusivity is not included in the transport calculations. The importance is regarded as small	No	
Water content	Yes.	Saturated conditions assumed.	No	
Gas content	Yes, by affecting pore space available for diffusion	Saturated conditions assumed.	No, but indirectly through porewater composition and dissolved gases such as CO_2 or CH_4, which may come out of solution	
Hydro-variables (pressure and flows)	Yes.	Saturated conditions assumed	No	
Backfill geometry	Yes	Backfill dimensions are included in calculations	No	
Backfill pore geometry	Yes	Defines the magnitude of the diffusivities	No, but possibly indirectly through influence on porewater composition and swelling	
Stress state	No, but indirectly through pore geometry		No, but possibly indirectly through influence on porewater composition and swelling	
Backfill materials – composition and content	Through porewater composition	Defines the magnitude of the diffusivities	No, but indirectly through influence on porewater composition	
Backfill porewater composition	Extent of EDL depends on ionic strength	Defines the magnitude of the diffusivities	Through diffusive transport of main constituents	See 4.4.4
Structural and stray materials	Indirect on the geometry (through influence on physical pore width)		Possibly indirectly through influence on porewater composition	

Model studies/experimental studies

While a large number of investigations are described in the literature concerning diffusion experiments in bentonite and similar smectite-rich clays (see /Yu and Neretnieks 1997/ for an overview), much less work has been done for natural clays poor in smectite and bentonite/ballast mixtures. Some data relevant for such materials are compiled in /Yu and Neretnieks 1997, Nagra 2002/, but no data are available specifically for IBECO RWC-BF.

Most diffusion studies are performed as transient in-diffusion experiments. These experiments yield D_a, which is a lump-sum representation of all processes relevant for radionuclide migration, including diffusion and sorption. This holds in particular for moderately and strongly sorbing radionuclides. Steady-state (or transient) through-diffusion studies, which can directly yield D_e and porosity, are largely restricted to relatively mobile tracers (alkaline ions, HTO, anions) or low degrees of compaction. Few attempts have been made so far to derive diffusion coefficients through semi-mechanistic models. Some examples are discussed in Section 3.5.3 in the context of anion exclusion and enhanced cation diffusion.

Table 4-13 . Direct dependencies between the process "Montmorillonite transformation" and the defined tunnel backfill variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Backfill geometry	Yes, determines total mass available, indirectly through transport of dissolved species	Included in evaluation	Yes at extreme transformation	–
Backfill pore geometry	No, indirectly through transport of dissolved species and ion equilibrium		Yes, direct consequence	Included in transformation evaluation
Temperature	Yes, major impact	Included in transformation expression	No	
Water content	No, indirectly through transport of dissolved species and ion equilibrium	No credit taken	Yes, possible but not necessary	
Gas content	No, indirectly through water content		No	
Hydrovariables (pressure and flows)	Yes, controls supply of dissolved species (mass balance)	Included in transformation evaluation	Yes, change in hydraulic conductivity	Effect on hydraulic conductivity can be evaluated
Stress state	No, pressures are to small		Yes, direct consequence	Loss of swelling is evaluated as a case with a high conductivity backfill
Backfill materials – composition and content	Yes, through available species in accessory minerals	Included in transformation expression	Yes, by definition	Included in transformation expression
Backfill porewater composition	Yes, major impact	Included in transformation expression	Yes, major impact	Only effects on the backfill itself are considered
Structural and stray materials	No, but indirectly through porewater and dissolved species. Especially pH effects from cement	Discussed in the buffer alteration scenario.	No	

Adequacy of references supporting the suggested handling in the safety assessment SR-Site

Montmorillonite alteration is one of the most studied processes in clay mineralogy and the above argumentation is supported by numerous peer reviewed articles and conference papers that are available in the open literature. The above cited ones represent only a minor fraction of what is available and the key issues are rather the relevance and relative quality of the peer reviewed material. A literature study with special respect to KBS-3 conditions including a validation of alteration models, especially quantitative, was made by SKB /Karnland and Birgersson 2006/ in order to address these issues. This report may be seen as a comprehensive exposition of the adequacy of references.

Uncertainties

The uncertainties are the same as for the corresponding buffer process (Section 3.5.9).

4.4.8 Backfill colloid release

Overview/general description

Water uptake by the tunnel backfill material and its resultant swelling is limited by the tunnel walls, and a swelling pressure is developed in the backfill material. Fractures intersecting the tunnel imply that no swelling restrictions are present, and that swelling continues until a thermodynamic equilibrium is reached without the development of swelling pressure. This free swelling may lead to separation of individual montmorillonite layers, or small groups of mineral layers (dispersion). The same principles are valid for the backfill system as for the buffer (see section 3.5.11) with the following exceptions.

Deposition holes will not be placed in rock volumes with larger fractures or severe groundwater flow. The option to fully avoid such zones may not be present in the placement of deposition tunnels. The tunnel backfill material may thereby be exposed to more adverse conditions than the buffer material both with respect to fracture apertures and flow rates.

The tunnel backfill material will have lower content of montmorillonite or other swelling minerals compared to the buffer material. Colloid release leads to replacement of lost montmorillonite by swelling of the remaining montmorillonite, which leads to a successive deterioration of the sealing properties. In principle, high quality bentonite materials will thereby stay relatively homogeneous and the sealing properties will decrease generally but slowly. In contrast, accessory minerals in low quality bentonite materials may serve as a filter and prevent replacement of lost material. This potential filter effect may reduce the loss of montmorillonite, but it may also lead to high local hydraulic conductivity in the depleted part of the backfill. The content and the grain size distribution of the accessory material will determine the extent of such a filter function.

Dependencies between process and tunnel backfill variables

Table 4-14summarises how the process influences and is influenced by all backfill variables and how these effects are treated in SR-Site.

Table 4-14. Direct dependencies between the process "Colloid release" and the defined tunnel backfill variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence? (How/Why not)	Influence present? (Yes/No) Description	Handling of influence? (How/Why not)
Backfill geometry	Amount of backfill present	Included in modelling	Yes, at extreme colloid release	Included in modelling
Backfill pore geometry	Yes, governs the dispersing forces	Included in modelling	Yes, by definition	Included in modelling
Temperature	No, negligible		No	
Water content	Yes, by definition	Included in modelling	Yes, by definition	Included in modelling
Gas content	Yes, no dispersion possible from unsaturated clay	Boundary condition	No	
Hydrovariables (pressure and flows)	Yes, groundwater flow may determines the mass loss	Included in modelling	Yes, indirect trough pore geometry, central impact	Evaluated from modelling results
Stress state	Yes, by definition	Included in modelling	Yes, major impact	Included in modelling
Backfill materials – composition and content	Yes, impurities may govern the ion type and concentrations	Included in modelling	Yes, selective loss of the montmorillonite content	Included in modelling
Backfill porewater composition	Yes, major importance both with respect to cation type and concentration	Included in modelling	No, but indirectly through pore geometry which affects the counterion concentration	Included in modelling
Structural and stray materials	No, but indirectly through porewater composition. Especially concrete may support with calcium ions		Indirectly, a minor effect of calcium uptake from cement structures could be imagined	

pronounced or as good as absent with respect to radiation, and continued microbial activity will be possible. On the other hand, the consequences of microbial activity is rather positive than negative in this part of the repository because of the oxygen reducing and redox-lowering effects caused by most active microorganisms.

Dependencies between process and tunnel backfill variables

Table 4-15 summarises how the process influences and is influenced by all backfill variables and how these effects are treated in SR-Site.

Table 4-15 . Direct dependencies between the process "Microbial processes" and the defined tunnel backfill variables and a short note on the handling in SR-Site.

Variable	**Variable influence on process**		**Process influence on variable**	
	Influence present? (Yes/No) Description	**Handling of influence (How/Why not)**	**Influence present? (Yes/No) Description**	**Handling of influence (How/Why not)**
Backfill geometry	No		No	
Backfill pore geometry	No		Growth of microbes generate biomass that may clog pores	Neglected due to limited amounts of organic carbon
Temperature	Yes Most microbes have an ideal temperature range in which they thrive. Maximum temperature for life is 113°C.	The microbial effects are treated with a mass-balance.	No	
Water content	Yes Water is needed for active life.	Full saturation is assumed	No	
Gas content	Yes Hydrogen and methane can be consumed by microbes that will grow and produce biomass; largest effect is obtained if oxygen is present. Some microbes produce acetate with hydrogen and carbon dioxide	The microbial effects are treated with a mass-balance.	Microbes both produce and consume gases	Neglected, since gas in the backfill is of limited concern
Hydro-variables (pressure and flows)	No		Yes Gas pressure may lead to advective flow	Neglected, since extent is limited
Stress state	No		No	
Backfill materials – composition and content	Organic impurities will have an effect	The microbial effects are treated with a mass-balance.	No	
Backfill porewater composition	Microbes are sensitive to the geochemical situation, and may utilise porewater components for growth	The microbial effects are treated with a mass-balance.	Microbial activity may change the composition, e.g. by consumption of methane, sulphate and organic carbon and production of acetate, sulphide and carbon dioxide	The possibility of microbial reactions will be considered. See 3.5.14
Structural and stray materials	Organic parts of this material and hydrogen from corroding metal will be a source of carbon and energy for microbes with growth as the result.	The microbial effects are treated with a mass-balance.	Microbes may oxidise organic components in this material and hydrogen from anaerobic corrosion.	The microbial effects are treated with a mass-balance. However, these materials serve no long term function

Table 5-2 . Direct dependencies between the process "Water uptake and transport under unsaturated conditions" in the bentonite seal in the plug and the defined tunnel plug variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Plug geometry	Yes	Geometry included in the models	No	
Pore geometry	Yes. Via void ratio (density) and void geometry	Variable in the model	(Yes) If erosion takes place (secondary effect)	See erosion
Temperature	Yes. Indirect through water viscosity and hydrovariables in a temperature gradient	Negligible	Yes Wetting and drying affects thermal conductivity	Negligible
Water content	Yes. Via degree of saturation and retention properties	Variable in the model	Yes	Variable in the model
Gas content	Yes. Via the gas pressure and degree of saturation	Variable in the model	Yes	Variable in the model
Hydrovariables (pressure and flows)	Yes. Basic variables.	Variable in the model	Yes	Variable in the model
Stress state	Yes	Variable in the model	Yes	Variable in the model
Plug materials – composition and content	Yes. Hydraulic conductivity and retention curve etc.	Sensitivity analyses	(Yes). If erosion takes place (secondary effect)	See Section 5.2.4
Porewater composition	Yes	Controls some parameters in the model	Yes	See Section 5.4

Boundary conditions

Interaction with the rock: A key issue for the saturation process is the interaction between rock and backfill. Water is conducted to the backfill in the water-bearing fractures and the rock matrix, which means that water saturation can be both uneven and take a long time for a sparsely fractured rock. If there is a highly permeable excavation-disturbed zone (EDZ) at the wall of the tunnel, which distributes water from the fractures along the rock wall, the wetting will be faster and more even. This interaction is identical to the interaction with the backfill in the tunnels.

Interaction with the other parts within the plug: The bentonite seal in the plug has a wall of concrete beams on each side, which in turn are in contact with the drainage material and the concrete plug. The grain size distribution and compaction in the drainage material is designed such that the filter can collect and drain water so that the concrete plug will not be exposed to high water pressures until it has gained sufficient strength. It is designed and verified in accordance with conventional geotechnical procedures. When the drainage of the filter is closed a water pressure may build up and axial wetting may also take place.

Since the plug is demanded to be water tight also before the bentonite seal is water saturated, water flow and water pressure derived from the backfill inside the plug will be stopped and the leaking fractures sealed by the bentonite in the seal.

Model studies/experimental studies

All studies performed on wetting are done for the backfill and the buffer (see Sections 3.3.1 and 4.2.1).

Table 5-3 . Direct dependencies between the process "Water transport under saturated conditions" and the defined tunnel plug variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Plug geometry	Yes	The process is neglected based on the discussion in this section	No	The process is neglected based on the discussion in this section
Pore geometry	Yes. void ratio (density) and void geometry	Negligible	(Yes) If erosion takes place (secondary effect)	See Section 5.2.4
Temperature	Yes. affects water viscosity	Negligible	No	
Water content	Indirect through pore geometry (density)		No	
Gas content	No, there is no gas phase in a saturated plug.		No	
Hydrovariables (pressure and flows)	Yes. Basic variables.	Negligible since very local influence	Yes	Assumed to be a local part of the tunnel with high hydraulic conductivity
Stress state	Yes	Negligible	Yes	Dimensioning. The plug must be able to withstand hydraulic water pressure.
Plug materials – composition and content	Yes. Hydraulic conductivity	Negligible since very local influence	(Yes). If erosion takes place (secondary effect)	Neglected, since extent is limited
Porewater composition	Yes through viscosity	Negligible	Yes, from degrading substances	Negligible

Boundary conditions

Only outer boundaries exist. There are three types of outer boundaries of the plug:

- The rock surface of the tunnel,
- The interface between the backfill and the drainage section,
- The interface between the outer backfill of crushed rock (or bentonite in some parts) and the concrete plug.

Model studies/experimental studies

Only studies of buffer and backfill material have been done and special studies of the plug function after saturation is not required.

Natural analogues/observations in nature

Not applicable

Time perspective

When full water saturation and hydrostatic pressure has been reached, which may take up to 100 years, the plug has no function. There may be a period after which full saturation in the plug and the bentonite seal has been reached when there is still a high hydraulic gradient across the plug due to possible very slow wetting inside the plug at dry tunnels. However, this situation is more favourable than if the plug and the bentonite seal are not saturated and will not be further dealt with.

CO_2, due to the sealing produced by calcite precipitation at the cement-water interface. An external groundwater containing dissolved sulphate could also have a large impact on the longevity of concrete material /Höglund 2001/ due to ettringite precipitation. The reason is that ettringite has the ability to bind crystal ("adsorbed") water, resulting in a large molar volume of this mineral phase, which results in cracking and mechanical deterioration of the cement paste. Chloride concentration of the groundwater can also affect the long-term behaviour of the cement paste due to the precipitation of Friedel salts (i.e. aluminium and calcium chlorides).

Dependencies between process and tunnel plug variables

Table 5-7 shows how the process influences and is influenced by all tunnel plug variables.

Plug geometry: The geometry of the plug affects the process by considering the total mass of concrete and the reactive phases it contains. Therefore, the total pool of these mineral phases will affect the geochemical evolution of the system.

Pore geometry: The solid-to-liquid ratio will affect the degradation of concrete, at higher ratios the degradation will be slower, as a minor mass of minerals dissolved is needed to attain saturation. On the other hand, the dissolution – precipitation of cement mineral phases can modify the pore geometry and the total porosity of the system, and thus, modifying the degradation rate of concrete.

Temperature: Thermodynamic constants of chemical reactions are highly dependent of the temperature. However, temperatures in concrete plug are not expected to vary significantly, and therefore, minimal effects on the geochemical processes are foreseen.

Water content: This variable will affect the dissolution of cement phases as reactions can only take place in wetted surfaces. However, the process only considers full water saturation, as minimal changes are expected to occur until that time.

Table 5-7. Direct dependencies between the process "Alteration of concrete" and the defined tunnel plug variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	**Handling of influence (How/Why not)**	**Influence present? (Yes/No) Description**	**Handling of influence (How/Why not)**
Plug geometry	Yes	Plug mass considered	The degradation will reduce the mass	Plug mass considered
Pore geometry	Yes	The solid-to-liquid ratio is considered.	Yes. Dissolution – precipitation of solid phases can modify the porosity of the system.	Porosity changes due to dissolution – precipitation reactions is considered.
Temperature	Yes, temperature effect on thermodynamic constants.	Constant temperature assumed	No	
Water content	Yes, Could affect concentrations	Saturated conditions assumed	No	
Gas content	No		No	
Hydrovariables (pressure and flows)	Yes. Effect on reaction rates and transport of chemical components	Included in mass balance	No	
Stress state	No		No	
Plug materials – composition and content	Yes, reactivity with minerals. Cement mineralogy	Included in modelling	Yes, modification of mineral composition. Concrete degradation	Included in modelling
Porewater composition	Yes, Affecting reactivity of system components	Included in modelling	Yes, reaction with minerals results in changes in porewater composition	Included in modelling

Dependencies between the process and the tunnel plug variables

Table 5-8 shows how the process influences and is influenced by all tunnel plug variables.

There are two main influences from the structural material variable on microbial processes.

1. Microbial sulphate reduction during microbial growth on plastisisers will result in sulphide. The sulphide may accumulate as iron sulphide inside the plugs. During the open phase, oxygen will oxidise the sulphide and sulphuric acid can form. Local acid attacks on the concrete may occur. This effect will diminish after backfilling on both sides of the plug, when oxygen is consumed, but it may introduce a problem during the open phase.
2. Excess amounts of organic material in aquifers will trigger growth of opportunistic microorganisms that will increase in numbers. Several groundwater microorganisms produce complexing agents that very efficiently mobilise trace elements, including many radionuclides /Kalinowski et al. 2004, 2006, Johnsson et al. 2006, Essén et al. 2007, Moll et al. 2008/. Given the large amount of added organic carbon where grouting have been performed, it is possible that the microbial production of complexing agents will be significant which may notably reduce the retardation effects accounted for by the rock and the rock matrix.

Table 5-8. Direct dependencies between the process "Microbial processes" and the defined tunnel plug variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Plug geometry	No		No	
Pore geometry	No		Growth of microbes generate biomass that may clog pores	This effect is not considered in SR-Site
Temperature	Yes, microbial activity increases with temperature	This effect is not considered in SR-Site	No	
Water content	Yes, availbility of water	Saurated conditions assumed	No	
Gas content	Indirectly through water content		No	
Hydrovariables (pressure and flows)	Yes, water is needed for growth of microbes and growth on hydrogen and methane is possible. Pressure is not important	This effect is not considered in SR-Site	Yes, microbes may form methane and hydrogen	This effect is not considered in SR-Site
Stress state	No		No	
Plug materials – composition and content	Yes, the content of organic carbon and microbes in different backfill clays varies	This effect is not considered in SR-Site	No	
Porewater composition	Yes, microbes are sensitive to the geochemical situation, and may utilise porewater components for growth	This effect is not considered in SR-Site	Yes, microbial activity may change the composition, e.g. by consumption of methane, sulphate and organic carbon and production of sulphide and carbon dioxide.	This effect is not considered in SR-Site

Table 6-9. Direct dependencies between the process "Alteration of the central area backfill" and the defined central area variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Central area geometry	Yes, important from mass-balance point of view, connects to water conducting fractures as well as to other repository parts	Included in modelling/evaluation (mass-balance)	No	
Central area pore geometry	Yes. Gives solid/liquid ratio Indirectly through hydraulic conductivity	Included in modelling	May be affected by dissolution precipitation	Neglected, since hydraulic conductivity always will remain high
Temperature	Yes, temperature effect on thermodynamic constants and kinetic rates.	Neglected since the temperature variations in the central area will b eminor	No	
Water content	Yes, reactions only take place in the saturated domain.	Neglected, only saturated conditions are considered	No	
Gas content	No, but indirectly through water composition by affecting content of dissolved gases		Potentially, if a gas phase would form	Neglected, since the formation of a gas phase is of no concern
Hydrovariables (pressure and flows)	Yes, determines the turn-around rate of water	Included in modelling	No	
Stress state	No		No	
Central area materials – composition and content	Yes	Included in modelling	Yes	Included in modelling
Central area porewater composition	Yes	Included in modelling	Yes	Included in modelling
Structural and stray materials	Yes	Included in modelling	Yes	Neglected

The increase in reactive surface area of minerals and porosity will mainly affect the dissolution kinetic rates of both rock-forming minerals and fracture-filling minerals. As the present-day groundwater at repository depth has been interacting with all these minerals for a long period of time, increasing the surface area of such minerals will have a minor effect on the chemical composition of the groundwater. On the other hand, it is expected that initially, after filling the tunnels and shaft with crushed rock, all the void spaces will be filled with air, leading to an increase in the dissolution rate of those minerals able to oxidise (i.e. pyrite and iron-bearing silicates). Then, the increased mineral surface areas and the larger water-to-solid ratios will help to consume the oxygen faster, thus neutralising the possible effect of having oxidant waters at the repository depth.

Although the dissolution – precipitation of minerals can modify the pore geometry, the high initial total porosity is not expected to change significantly due to this process.

Temperature: Thermodynamic constants of chemical reactions are highly dependent of the temperature. However, temperatures in the central area are not expected to vary significantly, and therefore, minimal effects on the geochemical processes are foreseen.

Table 7-5. Direct dependencies between the process "Advective transport of species" and the defined top seal variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	**Handling of influence (How/Why not)**	**Influence present? (Yes/No) Description**	**Handling of influence (How/Why not)**
Top seal geometry	Yes, major impact		No	
Top seal pore geometry	Yes, indirectly through the hydraulic conductivity. Unfilled tunnel with gaps in e.g. roof will increase the transport capacity		Indirectly, dissolution and precipitation reactions may increase or reduce the porosity, respectively.	Neglected
Temperature	Indirectly through temperature induced gradients and hydraulic conductivity. Freezing is of major importance		No	
Water content	Yes, by definition		No	
Gas content	Yes, dissolved gas is transported with flow. Indirectly through flow properties due to gas pressure, gas dissolution and precipitation.		Yes, dissolved gas transported away	Neglected
Hydrovariables (pressure and flows)	Yes, by definition		Yes, density effects may induce flow	Neglected
Stress state	No, or insignificant		No, insignificant	
Top seal – composition and content	Yes, indirectly through sorption, precipitation and dissolution reactions		Yes, indirectly through sorption, precipitation and dissolution reactions	Neglected
Top seal porewater composition	Yes, by definition		Yes, by definition	Neglected
Structural and stray materials	Yes, indirectly through dissolution of concrete, reinforcement etc.		Yes, indirectly through deterioration of the materials	Neglected

Handling in the safety assessment SR-Site

The top seal is included in the hydrogeological large scale model as a feature with high hydraulic conductivity, see the Geosphere Process Report /SKB 2010i/. This model provides the evolution of the salinity field, but also data on the transport and mixing of water types.

Adequacy of references supporting the suggested handling in the safety assessment SR-Site

See Section 7.2.1 Water transport under unsaturated conditions.

7.4.2 Diffusive transport of species

Overview/general description

A basic description of this process in the central area is given in Section 6.4.2 and in the buffer in Section 3.5.3. Because of the hydraulic situation in the top seal, diffusion is of no importance in this system part.

Table 8-8. Direct dependencies between the process "Microbial processes" and the defined bottom plate variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Bottom plate geometry	No		No	
Concrete pore geometry	No		No	
Temperature	Yes, microbial activity increases with temperature	This effect is not considered in SR-Site	No	
Hydro-variables (pressures & flows)	Yes, water is needed for growth of micro-organisms. Microbes grow on hydrogen and methane. Pressure is not important	This effect is not considered in SR-Site	Yes, microbes may form methane and hydrogen	Limited growth is assumed due to low availability of water and nutrients
Water content	Yes, availbility of water	Saurated conditions assumed	No	
Gas content	Indirectly through water content		No	
Stress state	No		No	
Materials – composition and content	Yes, if concrete is added with substances that dissolve and support microbial activity	Limited growth is assumed due to low availability of water and nutrients	Yes, if acids are produced from degradation of concrete additions	Limited growth is assumed due to low availability of water and nutrients
Porewater composition and content	Yes, if dissolved organic components are present, microbes can grow	Limited growth is assumed due to low availability of water and nutrients	Yes, decomposition of organic dissolved components may occur, pH may be influenced	Limited growth is assumed due to low availability of water and nutrients

Boundary conditions

The boundary condition for the process is the amount of dissolved organic compounds from the low pH cement and the bentonite at the interface between the copper plate, concrete, rock and buffer.

Model studies/experimental studies

Not available.

Natural analogues/observations in nature

Growth and activity of microbes have been observed at pH above 12 /Pedersen et al. 2004/.

Time perspective

Microbial processes will start when water is available. The process rates will probably be largest in the peripheral slot with interfaces between buffer, the copper plate, rock and concrete during a wet oxygenic stage, before full swelling and reducing conditions occur.

Handling in the safety assessment SR-Site

In the treatment of the geochemical evolution in the bottom plate, microbial reactions need to be considered. Production of sulphide in the bottom plate will be considered in the assessment of canister corrosion.

Water flow from the induced suction gradient can be estimated by identifying swelling pressure with suction:

$$\nabla\psi = -\nabla P_s = -\frac{\partial P_s}{\partial T}\nabla T \qquad (9\text{-}1)$$

where ψ is suction (see Section 3.3.1). The derivative $\frac{\partial P_s}{\partial T}$ has an estimated value of 1 MPa/°C for temperatures below 0°C (see Section 3.2.2).

A typical geothermal temperature gradient is 0.025°C/m and using this value together with a value of the hydraulic conductivity of 10^{-13} m/s, the corresponding water flux is $2.5\cdot10^{-13}$ m/s or approximately 8 μm/y, which is also the estimated ice lens growth.

Table 9-1 summarises how the process influences and is influenced by all borehole seal variables and how these effects are treated in SR-Site.

Boundary conditions

When freezing of the bentonite in the borehole seals occurs, the water in the surrounding rock will be in ice form. Hence, transfer of water between rock and bentonite at the same level will be very limited. The slowly varying temperatures of the rock surrounding the seals also constitute a boundary condition.

Table 9-1. Direct dependencies between the process "Freezing" and the defined borehole seal variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Borehole geometry	Yes, determines the thermal boundary conditions	Included in the assessment	No	
Pore geometry	Yes	Included in the assessment	No	
Temperature	Yes	Included in the assessment	No	
Water content	Yes, via freezing point and transport capacity	Included in the assessment	Yes, If freezing takes place redistribution of water	Neglected
Gas content	(Yes)	A gas content would affect the process but the bentonite will be completely saturated when freezing	No	
Hydrovariables (pressure and flows)	Yes, freezing induces water transport	Included in the assessment	Yes	Included in the assessment
Stress state	Yes, Influences the freezing point to a small degree	Included in the assessment	Yes. Swelling pressure affected also before ice formation	Included in the assessment
Sealing materials – composition and content	Yes, via the specific surface area	Included in the assessment	No	
Porewater composition	Yes, via the specific surface area and types of counter ions	Neglected, effect assumed to be small	No	
Structural and stray materials	No		No	

Table 9-3. Direct dependencies between the process "Water transport under saturated conditions" and the defined borehole seal variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Borehole geometry	Yes, mainly by the flow path.	Given as input data.	Yes, during swelling since water flow into the voids makes the bentonite swell if there is space available.	Included in the mechanical model
Pore geometry	Yes, determines the hydraulic conductivity	Included in the value of the hydraulic conductivity as a function of the density. The pore geometry can be affected by a mineral transformation or a change in porewater composition.	Yes, during swelling since water flow into the voids makes the bentonite swell if there is space available.	Included in the mechanical model
Temperature	Yes, through water viscosity and at temperature below 0 (see Freezing).	This will be neglected in SR-Site	Insignificantly.	No
Water content	Influenced via density (pore geometry)	Determines the hydraulic conductivity, which is included in the model.	Yes, during swelling since water flow into the voids makes the bentonite swell if there is space available.	Included in the mechanical model
Gas content	Insignificantly (dissolved gases)	Excluded since it would reduce hydraulic conductivity	No	
Hydrovariables (pressure and flows)	Yes, main variables.	Included in the flow model	Yes	Included in the flow model
Stress state	Yes. If the effective stress on the bentonite deviates from the swelling pressure the bentonite will change volume and water will flow into or out from it.	Included in the mechanical model.	Yes	Included in the mechanical model
Sealing materials – composition and content	Yes, determines the hydraulic conductivity	Included in the model	No	
Porewater composition	Yes, determines the hydraulic conductivity	Included in the model	Yes	Replacement of porewater is discussed in 3.5.6
Structural and stray materials	(Insignificant)		No	

Handling in the safety assessment SR-Site

As illustrated by the time perspective the water flow along the holes can be neglected as long as the bentonite remains its low hydraulic conductivity. This case will thus not be further handled in SR-Site. If there is a risk that a large part of the bentonite will be lost or transformed to obtain other properties, these cases must be handled. Cases with unsealed boreholes are discussed in the Geosphere Process Report /SKB 2010i/.

The primary handling of these cases will be to consider how the hydraulic conductivity could vary for the evolving conditions in the bentonite seal throughout the assessment period.

Advective transport is of importance in the bentonite part of the borehole seals during the saturation period. Under saturated conditions, the transport of solutes in the bentonite porewater is expected to be dominated by diffusion, see Section 9.4.2. Advective flow will probably be significant in the cement/sand parts of the seals in the long term perspective due to cement degradation.

Dependencies between process and borehole seal variables

Table 9-5 summarises how the process influences and is influenced by all borehole seal variables and how these effects are treated in SR-Site.

Boundary conditions

The external boundary condition for this process is the hydraulic gradient and the concentration gradients for species across borehole seals. In principle, the difference between two fractures intersected by a plug is of main interest, since the difference within one fracture will be insignificant on the length scale of the borehole seal.

Model studies/experimental studies

Field studies of borehole seals are ongoing by SKB and Posiva in Äspö and Olkiluoto.

Table 9-5. Direct dependencies between the process "Advective transport of solutes" and the defined borehole seal variables and a short note on the handling in SR-Site.

Variable	Variable influence on process		Process influence on variable	
	Influence present? (Yes/No) Description	Handling of influence (How/Why not)	Influence present? (Yes/No) Description	Handling of influence (How/Why not)
Borehole geometry	The geometry of the boreholes determines the cross-section available for advection.	Included in model	Yes, through dissolution/ precipitation	Of no concern
Pore geometry	Yes, dominating effect through hydraulic conductivity in both bentonite and concrete		Yes, through dissolution/ precipitation	Included in model
Temperature	Insignificant		Insignificant	
Water content	Yes, by definition	Assumed to be saturated	Insignificant	
Gas content	Yes, by reduction of transport paths, through dissolution/ precipitation of gas	Assumed to be saturated	Yes, dissolution/ release of gas	Assumed to be saturated
Hydrovariables (pressure and flows)	Yes, by definition	Included in model	Yes, through osmosis	Advection only considered after loss of bentonite
Stress state	Indirectly through pore geometry		Yes, through osmosis in the bentonite	Advection only considered after loss of bentonite
Sealing materials – composition and content	The content of montmorillonite is of decisive importance in the bentonite part. Indirectly through dissolution/precipitation process in the concrete part	Advection only considered after loss of bentonite	Yes, through precipitation/ dissolution and ion exchange processes	Of no concern
Porewater composition	Yes, by definition	Advection only considered after loss of bentonite	Yes, by definitions	Only radionuclide transport considered
Structural and stray materials	(Insignificant)		No	

ISSN 1404-0344
SKB TR-10-48

ID 1260876

Updated 2013-02

Geosphere process report for the safety assessment SR-Site

Svensk Kärnbränslehantering AB

November 2010

Update notice

The original report, dated November 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-10

Location	Original text	Corrected text
Page 75, paragraph 5, line 6	/Hartley et al. 200a, Section 5.2/	/Hartley et al. 2006a, Section 5.2/
Page 107, paragraph 2	...$4 \cdot 10^{-10}$ y^{-1}...	...$1 \cdot 10^{-10}$ y^{-1}...

Updated 2013-02

Location	Original text	Corrected text
Page 64, paragraph 2	...operation phases – Laxemar /Svensson and Follin 2010b/.	...operational phases – Laxemar /Svensson and Rhén 2010/.
Page 64, paragraph 6, line 2	/Svensson and Follin 2010a, b, Svensson et al. 2010/	/Svensson and Follin 2010, Svensson and Rhén 2010, Svensson et al. 2010/
Page 157, paragraph 1, last line	...Sandström et al. 2008a/	...Sandström et al. 2010/
Page 158, paragraph 3, line 11 and 12	/Sandström et al. 2008a,	/Sandström et al. 2010,
Page 265	Sandström B, Annersten H, Tullborg E-L, 2008a. Fracture-related hydrothermal alteration of metagranitic rock and associated changes in mineralogy, geochemistry and degree of oxidation: a case study at Forsmark, central Sweden. International Journal of Earth Sciences, 99, pp 1–25.	Sandström B, Annersten H, Tullborg E-L, 2010. Fracture-related hydrothermal alteration of metagranitic rock and associated changes in mineralogy, geochemistry and degree of oxidation: a case study at Forsmark, central Sweden. International Journal of Earth Sciences, 99, pp 1–25.
Page 270	Svensson U, Follin S, 2010b. Groundwater flow modelling of the excavation and operation phases – Laxemar. SKB R-09-23, Svensk Kärnbränslehantering AB.	Svensson U, Rhén I, 2010. Groundwater flow modelling of the excavation and operational phases – Laxemar. SKB R-09-23, Svensk Kärnbränslehantering AB
Page 271	Vidstrand P, Follin S, Zugec N, 2010b. Groundwater flow modelling of periods with periglacial and glacial conditions – Laxemar. SKB R-09-25, Svensk Kärnbränslehantering AB.	Vidstrand P, Rhén I, Zugec N, 2010b. Groundwater flow modelling of periods with periglacial and glacial conditions – Laxemar. SKB R-09-25, Svensk Kärnbränslehantering AB.

ISSN 1404-0344
SKB TR-10-49
ID 1263140
Updated 2013-02

Climate and climate-related issues for the safety assessment SR-Site

Svensk Kärnbränslehantering AB

December 2010

Keywords: Climate, Glacial, Ice sheet, Periglacial, Permafrost, Sea level, Global warming, Safety assessment, SR-Site.

Update notice

The original report, dated December 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-10

Location	Original text	Corrected text
Page 198, paragraph 2, line 1	…starts about 8 kyrs after present…	…starts about 7 kyrs after present…
Page 199, Figure 4-28, figure text line 5	...starts to grow around 8 kyrs…	...starts to grow around 7 kyrs…
Page 208, Table 4-5, line 7, column 2	7400 after present (AP) (9400 AD)	7000 after present (AP) (9000 AD)

Updated 2013-02

Location	Original text	Corrected text
Page 159, paragraph 6, line 5	/SKB 2010e Section 5.1.2/	/Lindborg 2010 Section 5.1.2/
Page 282, reference Jaquet et al. 2010	SKB TR-10-46	SKB R-10-46
Page 295, reference SKB 2006b	SKB TR-09-19	SKB TR-06-19
References	SKB, 2010d. Landscape Forsmark, SR-Site Biosphere. SKB TR-10-05, Svensk Kärnbränslehantering AB.	Lindborg T (ed), 2010. Landscape Forsmark – data, methodology and results for SR-Site. SKB TR-10-05, Svensk Kärnbränslehantering AB.

ISSN 1404-0344
SKB TR-10-51
ID 1265002
Updated 2013-01

Model summary report for the safety assessment SR-Site

Svensk Kärnbränslehantering AB

December 2010

Update notice

The original report, dated December 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Location	Original text	Corrected text
Page 26, Heading 3.2.6	“Rationales for using the code in SR-Can“	“Rationales for using the code in SR-Site“
Page 54, second last paragraph, line 2	/Grivé et al. 2010/.	/Grivé et al. 2010b/.
Page 55, paragraph 2, line 1	/Grivé et al. 2010/.	/Grivé et al. 2010b/.
Page 55, paragraph 3, last line	/Grivé et al. 2010/.	/Grivé et al. 2010b/.

Errata 2011-10

SKB TR-10-52

Data report for the safety assessment SR-Site

In the earlier distributed report, there are errors that have now been corrected. The corrected pages 293, 422 and 448 are enclosed. The changed text is marked with a vertical line in the page margin. An updated pdf version of the report, dated 2011-10, can be found at www.skb.se/publications.

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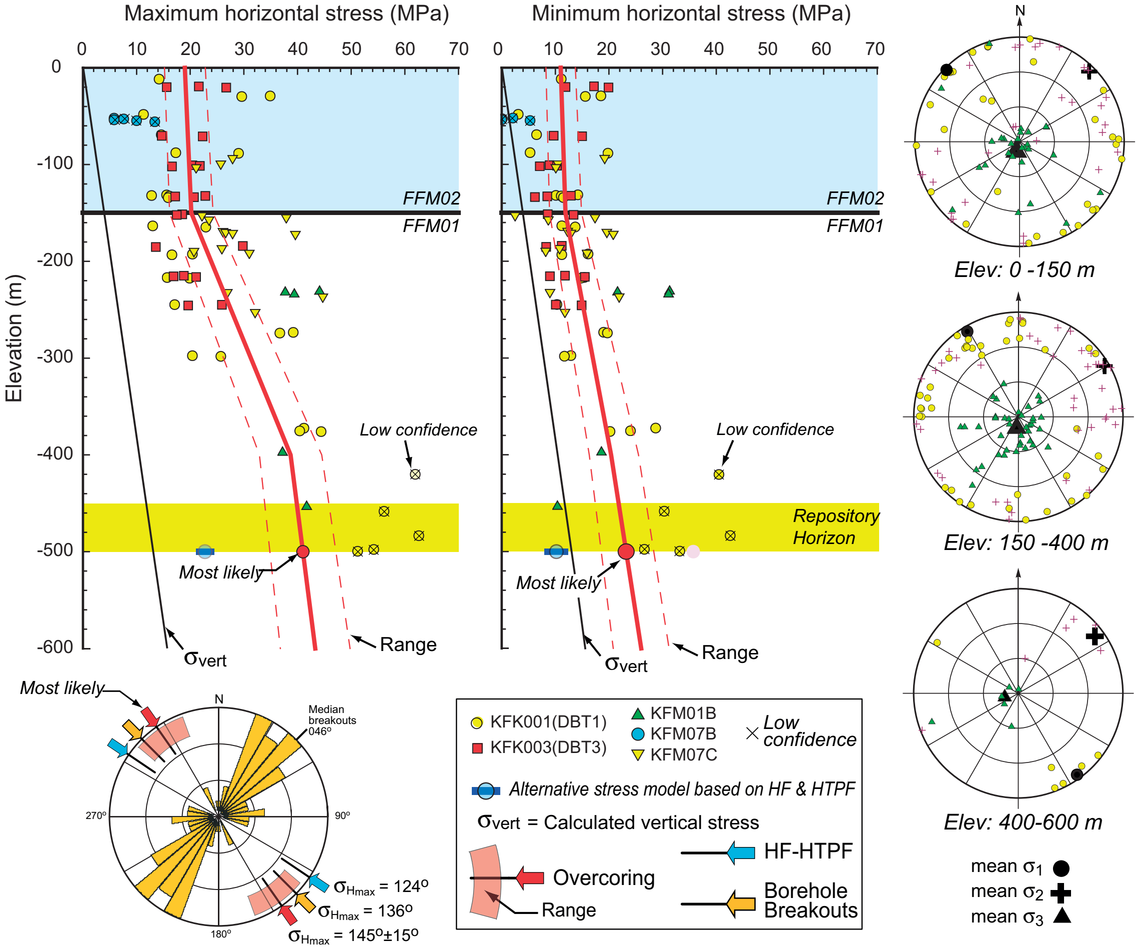

Figure 6-48. *In situ stress model for fracture domains FFM01 and FFM02, cf. Table 6-51, with measurement data. Reproduced from Figure 7-18 of* ***Site description Forsmark****.*

Table 6-50. Generic rock mass density used to estimate the vertical stress gradient. This value is consistent with the densities of the most common rock types in rock domains RFM029 and RFM045 given in /Stephens et al. 2007/.

Parameter	Unit	Value
Density (ρ)	kg/m^3	2,700

Table 6-51. Stress models for domains FFM01, FFM02, FFM03, and FFM06 at Forsmark /Glamheden et al. 2007/.

Domain	σH (MPa)	σH, orientation (°)	σh (MPa)	σv (MPa)
FFM01 and FFM06 (150–400 m)	9.1+0.074z±15%	145±15	6.8+0.034z±25%	0.0265z±2%
FFM01 and FFM06 (400–600 m)	29.5+0.023z±15%	145±15	9.2+0.028z±20%	0.0265z±2%
FFM02 (0–150 m)	19+0.008z±20%	145±15	11+0.006z±25%	0.0265z±10%
FFM03	5+0.075z±20%	145±15	2.5+0.0375z±25%	0.0265z±10%

Table 6-52. Proposed Maximum Stress Model for the repository elevation –450 to –475 m /SKB 2009d/.

Depth range (m)	σH (MPa)	σH, orientation (°)	σh (MPa)	σh, orientation (°)	σv (MPa)
450–475	56±6	145±15	35±8	55	0.0265z±0.0005z

7.2.9 Correlations

The model that has been used for derivation of *LDF* values, i.e. the radionuclide model described in /Avila et al. 2010/, relies on several element- and radionuclide-specific parameters that are correlated with each other. This means that *LDF*s obtained for different radionuclides might also be correlated. However, the delivered *LDF*s have been obtained from independent deterministic simulations for each radionuclide and parameter correlations have not been considered. Furthermore, parameter correlations have not been considered in the probabilistic simulations carried out within the sensitivity and uncertainty analyses discussed above. In summary, no correlation needs to be propagated to the SR-Site main project.

7.2.10 Result of supplier's data qualification

The *LDF*s recommended for use in SR-Site are supplied in Table 7-13 for the temperate, periglacial, and glacial climate domains, and for the global warming case.

Table 7-13. LDF's (Sv/y per Bq/y) for assessment of long-term releases under different climate conditions: temperate, permafrost, glacial, and the global warming case. Data reproduced from /Avila et al. 2010/.

Radionuclide	Temperate *LDF*	Periglacial *LDF*	Glacial *LDF*	Global warming *LDF*
Ag-108m	$7.05\cdot10^{-13}$	$8.75\cdot10^{-15}$	$4.60\cdot10^{-16}$	$7.05\cdot10^{-13}$
Ac-227	$8.0\cdot10^{-12}$	$8.92\cdot10^{-16}$	$6.44\cdot10^{-17}$	$8.0\cdot10^{-12}$
Am-241	$1.46\cdot10^{-12}$	$1.10\cdot10^{-14}$	$1.57\cdot10^{-17}$	$1.46\cdot10^{-12}$
Am-243	$1.53\cdot10^{-12}$	$1.95\cdot10^{-13}$	$1.41\cdot10^{-15}$	$1.60\cdot10^{-12}$
C-14	$5.44\cdot10^{-12}$	$5.40\cdot10^{-12}$	$8.51\cdot10^{-13}$	$5.44\cdot10^{-12}$
Ca-41	$9.90\cdot10^{-14}$	$9.25\cdot10^{-15}$	$1.92\cdot10^{-16}$	$9.90\cdot10^{-14}$
Cl-36	$5.84\cdot10^{-13}$	$4.36\cdot10^{-13}$	$2.22\cdot10^{-17}$	$5.84\cdot10^{-13}$
Cm-244	$8.74\cdot10^{-13}$	$8.14\cdot10^{-19}$	$2.18\cdot10^{-20}$	$8.74\cdot10^{-13}$
Cm-245	$1.58\cdot10^{-12}$	$2.20\cdot10^{-14}$	$3.59\cdot10^{-16}$	$1.64\cdot10^{-12}$
Cm-246	$1.55\cdot10^{-12}$	$1.59\cdot10^{-14}$	$2.10\cdot10^{-16}$	$1.57\cdot10^{-12}$
Cs-135	$3.96\cdot10^{-14}$	$3.02\cdot10^{-13}$	$4.33\cdot10^{-17}$	$2.85\cdot10^{-13}$
Cs-137	$1.20\cdot10^{-13}$	$9.47\cdot10^{-18}$	$3.67\cdot10^{-20}$	$1.20\cdot10^{-13}$
Ho-166m	$5.90\cdot10^{-14}$	$8.42\cdot10^{-16}$	$1.48\cdot10^{-18}$	$5.90\cdot10^{-14}$
I-129	$6.46\cdot10^{-10}$	$2.61\cdot10^{-11}$	$1.70\cdot10^{-13}$	$6.46\cdot10^{-10}$
Nb-94	$4.00\cdot10^{-12}$	$1.06\cdot10^{-13}$	$2.12\cdot10^{-17}$	$1.15\cdot10^{-11}$
Ni-59	$7.39\cdot10^{-14}$	$1.31\cdot10^{-15}$	$3.99\cdot10^{-18}$	$1.99\cdot10^{-13}$
Ni-63	$1.21\cdot10^{-15}$	$6.30\cdot10^{-18}$	$1.86\cdot10^{-20}$	$1.21\cdot10^{-15}$
Np-237	$4.83\cdot10^{-11}$	$2.21\cdot10^{-11}$	$8.67\cdot10^{-15}$	$4.83\cdot10^{-11}$
Pa-231	$8.10\cdot10^{-12}$	$1.71\cdot10^{-13}$	$2.77\cdot10^{-15}$	$1.27\cdot10^{-11}$
Pb-210	$5.07\cdot10^{-12}$	$2.60\cdot10^{-17}$	$2.19\cdot10^{-18}$	$5.07\cdot10^{-12}$
Pd-107	$6.73\cdot10^{-15}$	$2.68\cdot10^{-15}$	$4.63\cdot10^{-18}$	$9.42\cdot10^{-15}$
Po-210	$8.86\cdot10^{-12}$	$3.10\cdot10^{-20}$	$9.28\cdot10^{-21}$	$8.86\cdot10^{-12}$
Pu-239	$1.94\cdot10^{-12}$	$2.01\cdot10^{-13}$	$6.35\cdot10^{-15}$	$2.04\cdot10^{-12}$
Pu-240	$1.88\cdot10^{-12}$	$1.25\cdot10^{-13}$	$4.10\cdot10^{-15}$	$1.89\cdot10^{-12}$
Pu-242	$1.89\cdot10^{-12}$	$2.32\cdot10^{-13}$	$7.20\cdot10^{-15}$	$2.17\cdot10^{-12}$
Ra-226	$3.75\cdot10^{-12}$	$9.79\cdot10^{-13}$	$4.46\cdot10^{-15}$	$3.77\cdot10^{-12}$
Se-79	$1.21\cdot10^{-9}$	$5.79\cdot10^{-11}$	$9.55\cdot10^{-13}$	$1.21\cdot10^{-9}$
Sm-151	$7.16\cdot10^{-16}$	$1.01\cdot10^{-20}$	$4.58\cdot10^{-22}$	$7.16\cdot10^{-16}$
Sn-126	$2.47\cdot10^{-11}$	$6.14\cdot10^{-13}$	$1.55\cdot10^{-14}$	$1.09\cdot10^{-10}$
Sr-90	$2.19\cdot10^{-13}$	$7.18\cdot10^{-17}$	$1.96\cdot10^{-19}$	$2.19\cdot10^{-13}$
Tc-99	$8.98\cdot10^{-13}$	$2.80\cdot10^{-13}$	$1.58\cdot10^{-15}$	$8.98\cdot10^{-13}$
Th-229	$3.61\cdot10^{-12}$	$6.95\cdot10^{-14}$	$9.58\cdot10^{-17}$	$3.68\cdot10^{-12}$
Th-230	$1.31\cdot10^{-11}$	$1.50\cdot10^{-11}$	$1.74\cdot10^{-14}$	$6.42\cdot10^{-11}$
Th-232	$1.72\cdot10^{-12}$	$4.53\cdot10^{-13}$	$1.18\cdot10^{-16}$	$2.59\cdot10^{-12}$
U-233	$2.50\cdot10^{-12}$	$2.52\cdot10^{-12}$	$1.96\cdot10^{-15}$	$1.91\cdot10^{-11}$
U-234	$3.62\cdot10^{-12}$	$1.06\cdot10^{-11}$	$4.46\cdot10^{-15}$	$7.14\cdot10^{-11}$
U-235	$2.76\cdot10^{-12}$	$1.33\cdot10^{-13}$	$5.64\cdot10^{-16}$	$1.99\cdot10^{-11}$
U-236	$1.85\cdot10^{-12}$	$2.92\cdot10^{-14}$	$1.93\cdot10^{-17}$	$1.05\cdot10^{-11}$
U-238	$1.85\cdot10^{-12}$	$8.05\cdot10^{-13}$	$1.03\cdot10^{-16}$	$1.58\cdot10^{-11}$
Zr-93	$2.77\cdot10^{-14}$	$6.50\cdot10^{-16}$	$8.17\cdot10^{-17}$	$1.06\cdot10^{-13}$

Åkesson M, Börgesson L, Kristensson O, 2010a. SR-Site Data report. THM modelling of buffer, backfill and other system components. SKB TR-10-44, Svensk Kärnbränslehantering AB.

Åkesson M, Kristensson O, Börgesson L, Dueck A, Hernelind J, 2010b. THM modelling of buffer, backfill and other system components. Critical processes and scenarios. SKB TR-10-11, Svensk Kärnbränslehantering AB.

Unpublished documents

SKBdoc id, version	Title	Issuer, year
1198314 ver 1.0	Källstyrkor för bränsleelement under driftskede för Clink, slutförvarsanläggning och slutförvar	Alara Engineering, 2010
1222975 ver 2.0	Beräkning av fissionsgasfrigörelse för bränslet i slutförvaret	SKB, 2010

ISSN 1404-0344
SKB TR-10-53

ID 1271388

Updated 2013-02

Handling of future human actions in the safety assessment SR-Site

Svensk Kärnbränslehantering AB

December 2010

Keywords: FHA, Spent fuel repository, Safety assessment, SR-Site.

Update notice

The original report, dated December 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-10

Location	Original text	Corrected text
Page 7, paragraph 2, line 1	...500 mSv/hour.	...130 mSv/hour.
Page 43, last paragraph before 6.1, line 2	/SKI 2002/	/SSM 2008a/
Page 45, last paragraph, line 2	/SKI 2002/	/SSM 2008a/
Page 57, paragraph 6, line 3	After a couple of hours of exposure,	After about eight hours of exposure,
Page 62, paragraph 2, line 2	/SKI 2002/	/SSM 2008a/
Page 75, Figure 6-19	Positive powers of y-axis	Figure 6-19 updated Negative powers of y-axis
Page 77, line 3 from bottom	...value below background radiation.	...value below 1 mSv/hour.

Updated 2013-02

The original report, dated December 2010, was found to contain editorial errors which have been corrected in this updated version.

ISSN 1404-0344
SKB TR-10-54

ID 1265223

Updated 2013-02

Comparative analysis of safety related site characteristics

Svensk Kärnbränslehantering AB

December 2010

Keywords: Site selection, Post-closure safety, Forsmark, Laxemar.

Update notice

The original report, dated December 2010, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2013-02

Location	Original text	Corrected text
Appendix on CD – Appendix A1, page 13, Reference Smellie and Tullborg 2009	SKB R-08-11	SKB R-08-111

ISSN 1404-0344
SKB TR-11-01

ID 1271590

Updated 2012-12

Long-term safety for the final repository for spent nuclear fuel at Forsmark

Main report of the SR-Site project

Volume I

Svensk Kärnbränslehantering AB

March 2011

Keywords: Safety assessment, Long-term safety, Final repository, Spent nuclear fuel, Forsmark.

Update notice

The original report, dated March 2011, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-10

Location	Original text	Corrected text
Page 38, paragraph 4 from bottom	...value below background radiation.	...value below 1 mSv/hour.
Page 67, paragraph 4	...in the scenario selection in a....	...in the scenario analyses in a....
Page 67, paragraph 5	This is described briefly in Section 6.2.1 and in more detail when applied in the scenario selection, Chapter 11 and the analysis of FHA scenarios, Section 14.2.	This is described in the analysis of FHA scenarios, Section 14.2.
Page 97, paragraph 3, line 3	...in Chapter 13.	...in Chapter 11.
Page 111, text to figure 4-8, last line	...of the target area,	...of the candidate area,
Page 168, Table 5-8	Wrong data in table	Table updated with correct data
Page 186, Table 5-15, column 1	(mm)	(m)
Page 245, Table 7-7, column 3	FARF31	FARF31, MARFA
Page 246, Table 7-8, column 3	DarcyTools	PhreeqC
Page 246, Table 7-8, column 3	DarcyTools	ConnectFlow
Page 246, Table 7-8, column 3	FARF31	FARF31, MARFA
Page 259, paragraph 2, last sentence	...material properties of these components, (see Section 5.5.3 and, for details, /Karnland et al. 2006/) and since, in particular for the backfill, alternative materials are to be evaluated in the assessment, no specific criterion is given here.	...material properties of these components (see Section 5.5.3 and, for details, /Karnland et al. 2006/).
Page 269, Figure 8-4	Arrow from box “Rock stresses” to “Shear at deposition hole?”	Figure 8-4 updated Arrow from box “Fracture structure in host rock” to “Shear at deposition hole?”.

Updated 2011-12

Location	Original text	Corrected text
Page 179, Figure 5-11	Width of pellet filled gap 60 mm	Figure 5-11 updated Width of pellet filled gap 50 mm

Updated 2012-12

Location	Original text	Corrected text
Page 58, paragraph 1, line 4	...Canister production report /SKB 2010a/, see...	...Canister production report, see...
Page 246, Table 7-8, column 5	SKB 2006	SKB 2006c

ISSN 1404-0344
SKB TR-11-01
ID 1271591
Updated 2012-12

Long-term safety for the final repository for spent nuclear fuel at Forsmark

Main report of the SR-Site project

Volume II

Svensk Kärnbränslehantering AB

March 2011

Keywords: Safety assessment, Long-term safety, Final repository, Spent nuclear fuel, Forsmark.

Update notice

The original report, dated March 2011, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-10

Location	Original text	Corrected text
Page 294, paragraph 1, line 7	Chapter 4	Chapter 5
Page 318, paragraph 4 last line	Section 15.4	Section 15.5
Page 330, last paragraph	...and generic stress-transmissivity models,	...and fracture normal stiffness data given in the **Data report,**
Page 334, Figure 10-21, last line in figure text	Figur 6-18	Figur 6-21
Page 337, paragraph 8, last line	Section 15.4.	Section 15.5.15
Page 347, Figure 10-31	$\log_{10}$ m(Fr) (yrs/m)	Figure 10-31 updated $\log_{10}$ (Fr) (yrs/m)
Page 389, second last paragraph, last line	Section 10.3.10.	Section 10.3.11.
Page 417, paragraph 2, line 1	According to the maximum chloride concentration of any time frame is < 0.4 M in the Forsmark groundwater.	According to Table 10-6, the maximum chloride concentration of any time frame is < 0.4 M at repository level in the Forsmark groundwater
Page 424, paragraph 2, line 1	...the initial thermal period,	...the initial temperate period,
Page 424, paragraph 3, line 1	...during the thermal period.	...during the temperate period.
Page 430, paragraph 1, line 8	Section 15.4	Section 15.5.15
Page 430, paragraph 5, last line	Section 15.4.	Section 15.5.15.
Page 436, paragraph 9, line 3	...erosion, few, if any, deposition holes will reach advective...	...erosion, no deposition holes will reach advective conditions...
Page 436, paragraph 10, line 5	...could be lost,	... could be lost in a million year perspective,
Page 454, second last paragraph, last line	Section 3.4.1	Section 10.4.1
Page 459, paragraph 1, line 5	...in the range 40-45 GPa, presented in the Site description, the results...	...in the range 40-45 GPa, suggested to be valid for large scale models of the bedrock surrounding the Forsmark site, the results...
Page 463, paragraph 3, line 1	...hydraulic jacking is...	...hydraulic jacking in front of an advancing ice sheet is...
Page 512, last paragraph, line 2	...network of deformation zones.	...network of fractures.
Page 525, paragraph 1, line 1 and 2	...during the advance or retreat of an ice sheet in highly transmissive deformation zones cannot be discarded.	...in highly transmissive deformation zones during the advance or retreat of an ice sheet cannot be discarded.
Page 526, last paragraph, line 7	Furthermore, the backfill	Furthermore, the repository closure, which, in accordance with the reference design, is similar to the backfill in the deposition tunnels,
Page 529, paragraph 3, last line	...canister integrity	...canister integrity since no deposition holes will be located there.
Page 537, paragraph 5, line 1	...buffer swelling pressure is sufficiently high around a canister.	....buffer density is high.
Page 537, paragraph 5, line 3	...density range, the swelling pressure criterion is judged to be fulfilled with ample margin, also for groundwater salinities that can be expected during the reference glacial cycle, see Section 10.4.8.	...density range, this safety function is fulfilled.
Page 537, paragraph 5, line 6	For a deposition hole that has experienced loss of buffer mass due to erosion/colloid release and to the extent that advective conditions prevail, this safety function can, however, not be guaranteed.	For a deposition hole that has experienced substantial loss of buffer mass due to erosion/colloid release, this safety function can, however, not be guaranteed.
Page 538, paragraph 6, last line	...estimated to be 43 MPa.	...estimated to be 43.5 MPa.

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Location	Original text	Corrected text
Page 538, last paragraph, last line	...safety function R3a...	...safety function R3b...
Page 540, paragraph 4 (c), line 2	...periods of glacial conditions...	...periods of temperate and glacial conditions...
Page 541, paragraph 6, line 1	...preliminary quantitative evaluations...	...quantitative evaluations...
Page 542, paragraph 1, line 1	...the buffer swelling pressure is high.	...the buffer density is high.
Page 542, paragraph 1, line 2	...buffer density, the swelling pressure criterion is fulfilled with ample margin, also for groundwater salinities that can be expected during the assessment period, see Section 10.4.8.	...buffer density, this safety function is fulfilled.
Page 542, paragraph 1, line 5	…experienced loss of buffer mass due to erosion/colloid release and to the extent that advective conditions prevail, this safety function can, however, not be guaranteed.	...experienced substantial loss of buffer mass due to erosion/colloid release, this safety function can, however, not be guaranteed.
Page 542, paragraph 5, line 2	...with ample margin for the reference glacial cycle.	...with ample margin.
Page 543, paragraph 4	Between zero and two canisters....	On average less than one canister...
Page 548, paragraph 1, line 1	...and towards the South-East of the candidate repository	...and south-east of the candidate repository
Page 548, paragraph 3, line 3	...less than 200 mg/L	...less than 200 μg/L

Updated 2011-12

Location	Original text	Corrected text
Page 403, last paragraph, line 6	...time, four tunnel intersecting...	...time, five tunnel intersecting...
Page 403, last paragraph, line 11	...only four positions...	...only five positions...
Page 403, Figure 10-73	300 tonnes in 25 % of 1,000,000 years 300 tonnes in 100 % of 1,000,000 years	Figure 10-73 updated 220 tonnes in 25 % of 1,000,000 years 220 tonnes in 100 % of 1,000,000 years

Updated 2012-12

Location	Original text	Corrected text
Page 383, Table 10-4 heading text	/Åkesson et al. 2010/.	/Åkesson et al. 2010a/.

ISSN 1404-0344
SKB TR-11-01

ID 1271592

Updated 2012-12

Long-term safety for the final repository for spent nuclear fuel at Forsmark

Main report of the SR-Site project

Volume III

Svensk Kärnbränslehantering AB

March 2011

Keywords: Safety assessment, Long-term safety, Final repository, Spent nuclear fuel, Forsmark.

Update notice

The original report, dated March 2011, was found to contain both factual and editorial errors which have been corrected in this updated version. The corrected factual errors are presented below.

Updated 2011-10

Location	Original text	Corrected text
Page 594, paragraph 6, heading	Quantitative consequence analysis/discussion – containment and retardation	Quantitative consequence analysis/ discussion
Page 596, paragraph 5, line 6	...criterion of 1 MPa, which is most unlikely.	...criterion of 1 MPa, where advection conditions need to be considered, which is most unlikely.
Page 638, paragraph 2, last line	...in the central corrosion case (see Section 13.5.4).	...in e.g. the corrosion scenario (see Section 13.5.4).
Page 640, paragraph 1, line 1	In the central corrosion case,...	In e.g. the central corrosion case,...
Page 654, paragraph 2, line 1	The handling assumes...	The handling of pulse releases assumes...
Page 743, second last paragraph, line 2 and 3	...as SSI in the general guidelines to their regulations /SSI 2008b/	...as SSM in the general guidelines to their regulations /SSM 2008b/
Page 744, last paragraph, line 1	/SKI 2002/.	/SSM 2008a/.
Page 746, paragraph 6, line 1	Can1, Ensure containment	Can1, Provide corrosion barrier; ensure containment
Page 748, paragraph 1, line 4	...is calculated to be 500 mSv/hour...	...is calculated to be 130 mSv/hour...
Page 748, last paragraph, last line	...would be about 15 mSv/hour.	...would be about 4 mSv/hour.
Page 751, second last paragraph, line 3	After a couple of hours of exposure	After about eight hours of exposure
Page 755, paragraph 4, line 2	/SKI 2002/.	/SSM 2008a/.
Page 755, paragraph 5, line 2	Can1, Ensure containment	Can1, Provide corrosion barrier; ensure containment
Page 755, paragraph 5, line 5	Bf1	BF1
Page 760, Figure 14-5	Positive powers of y-axis	Figure 14-5 updated Negative powers of y-axis
Page 770, paragraph 1, line 1	The travel paths of solutes...	The length of the travel paths of solutes...
Page 810, paragraph 4, line 2	...travel paths of solutes in the groundwater will increase with...	...length of the travel paths of solutes in the groundwater will increase with...
Page 873, under heading A1.2, paragraph 1, line 3	(SSMFS 2002:1)	(SSMFS 2008:21)

Updated 2012-12

Location	Original text	Corrected text
Page 664, paragraph 4		Text in paragraph 4 updated
Page 665, all text and figure 13-20		All text and figure 13-20 updated, last paragraph is new
Page 666, paragraph 1		New paragraph
Page 723, paragraph 2, line 1	/SKB 2006g, h/	/SKB 2006g, a/
Page 723, Table 13-1, heading	/SKB 2006g, h/.	/SKB 2006g, a/.
Page 730, paragraph 2, line 2	/Bond et al. 2007/	/Bond et al. 1997/
Page 846		*New reference*: Bradbury and Baeyens, 2005
Page 847		*New reference*: Bäckblom et al. 2004