Errata 2011-10

SKB TR-11-01

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

Main report of the SR-Site project

Volume III

In the earlier distributed report, there are errors that have now been corrected. The corrected pages 594, 596, 638, 640, 654, 743, 744, 746, 748, 751, 755, 760, 770, 810, 873 and 891 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.

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 250, SE-101 24 Stockholm
Tel +46 8 459 84 00

The only identified cause for route 4 is ventilation of the deposition hole for an extended period of time. The consequences of drying of the rock and its effect on the thermal properties of the buffer are discussed in Section 10.3.8. There is no foreseen evolution of the near field that could lead to those conditions and drying of the buffer is not considered further.

High pH

High pH groundwaters in contact with the buffer could occur if the quality control system for repository construction fails or malfunctions. The possible routes could either be a misjudgement of the pH arising from the cement used, or the use of a wrong cement mixture.

Thermal gradient

The thermal gradient is dependent on the thermal power from the canister and the thermal properties of the rock. However, the sensitivity to the parameters is small and the conclusions from the reference evolution are expected to be valid for all possible conditions.

Interaction with metallic iron

This process will occur if the canister insert gets in contact with the buffer material. Recent laboratory experiments under repository conditions have shown that reactions between montmorillonite and metallic iron in an oxygen-free environment may be relatively fast and in some cases also lead to a general breakdown of the montmorillonite structure /Lantenois et al. 2005/.

Another possibility would be if stray equipment or material containing iron or steel was left in a deposition hole during buffer emplacement. However, in SR-Site it is assumed that the QC system will ensure that the deposition holes are cleaned before the buffer is deposited.

Quantitative consequence analysis/discussion

The effect of the thermal period on the buffer is described in Section 10.3.10. The conclusion is that the expected temperature increase will have no significant effect on the buffer properties.

A buffer temperature exceeding the function indicator could lead to the following consequences.

1. A transformation of the montmorillonite in the buffer to non-expandable minerals (illite). This would give a higher hydraulic conductivity and a decrease in swelling pressure.
2. An accumulation of impurities in the buffer on the hot (or cold) side. This would be caused by temperature-dependent solubilities. This accumulation could potentially lead to clogging of the pore space and a change in the rheological or/and the hydraulic properties.

The transformation of montmorillonite to illite is discussed in Section 10.3.10. It is evident that the transformation is very slow even if repository timescales are considered. /Karnland and Birgersson 2006/ undertook a review of different kinetic models for smectite to illite conversion. Figure 12-13 shows the results from different models. The models of Cuadros /Cuadros and Linares 1996/ (Cuadros 1) estimate a much faster alteration rate than the one that was used in the SR-Can assessment (Huang). However, the Cuadros experimental work did not include specific determinations of all rate-determining constants and parameters, as was done by /Huang et al. 1993/. Cuadros, therefore, used natural analogues to adjust their model (Cuadros 5) in order to represent the conditions in nature, where bentonite persists over geological time scales.

There are two kinds of data uncertainties for this process.

- Uncertainties in the temperature calculation. This is described in the section above.
- Uncertainties in the data used in the alteration calculation /Karnland and Birgersson 2006/ and in the reactive transport calculation.

The potentially most critical data uncertainties are in the frequency factor for a first order reaction (Arrhenius equation) and the activation energy in the kinetic expression for the alteration rate.

Using the Huang model, a temperature of 125°C for 10,000 years would not have any significant effect on the swelling pressure and hydraulic conductivity function indicators /Karnland and Birgersson 2006/. However, the experimentally achieved model parameters have to be determined at temperatures

An effect of steam on the properties of bentonite has been identified by /Couture 1985/ and is discussed by /Pusch 2000a/ and /Karnland and Birgersson 2006/. There is an observed effect of vapour that could influence the maximum free swelling of the bentonite. However, no obvious mineral alteration was identified by Couture although the experiments were performed at temperatures significantly higher than the maximum temperature in a repository. The consequence of steam on the long-term performance of the buffer is thereby expected to be limited.

High pH

If high pH (pH > 11) groundwaters were to contact the buffer, some alteration or dissolution would be expected. The extent of the transformation is dependent on the actual pH of the water, the local hydrologic situation and the amount of cement producing the high pH (mass balance). However, in SR-Site it is assumed that the quality control systems will be sufficient to avoid the introduction of cements that could give rise to high pH waters in the repository.

Thermal gradient

The effect of the temperature gradient on the redistribution of impurities has been calculated by /Sena et al. 2010/ and /Karnland and Birgersson 2006/. This process has been shown to have a very limited effect. The temperature gradient is only affected by the absolute temperature to a limited degree, and the dependence of this process on the temperature is, therefore, limited.

Interaction with metallic iron

Currently, a mechanistic understanding is lacking and a quantitative model does not exist. However, no interaction between buffer bentonite and metallic iron is expected to occur as long as the copper canister is intact.

Summary

Since there still are some uncertainties on the effect of high temperatures on the long-term performance of the buffer, a case with an altered buffer zone next to the canister cannot be entirely excluded. The consequences of such a case would be a loss of swelling pressure next to the canister, and a correlated consolidation of this part due to the swelling pressure in the remaining buffer. However, a major part of the buffer has to be transformed in order for the buffer swelling pressure to fall below the pressure criterion of 1 MPa, where advection conditions need to be considered, which is most unlikely. If such a low pressure occurred, this would mean that it could be possible for sulphate-reducing bacteria to survive and sulphide corrosion to be enhanced.

The interaction between iron and buffer material is still under investigation. It is likely that only the region closest to the insert would be affected, assuming that there was any contact between the insert and the buffer, and the overall transport properties of the buffer would be maintained. However, today it cannot be excluded that the entire diffusion barrier could be lost. This, however, would have consequences only for retardation.

Global warming variant and other climate cases

There is nothing connected to the global warming variant (essentially 60,000 years before first permafrost) that would make buffer transformation worse. The climate on the surface has no bearing on any of the processes discussed in this section. The issue is therefore not further treated for the global warming variant. Nor do any of the other climate cases described in Section 12.1.3 have any relevance for the buffer transformation scenario.

Categorisation as "less probable" or "residual" scenario

High temperature, high pH and high temperature gradients are not expected to have any significant effect on buffer stability under any plausible conditions. Transformations of buffer material to such an extent that the beneficial containment and retardation properties are affected are, therefore, considered as a residual scenario.

If the buffer gets in contact with metallic iron some alteration will occur. The extent of this is currently unknown. The process can only occur after copper canister failure. It is not relevant for failures when buffer is missing.

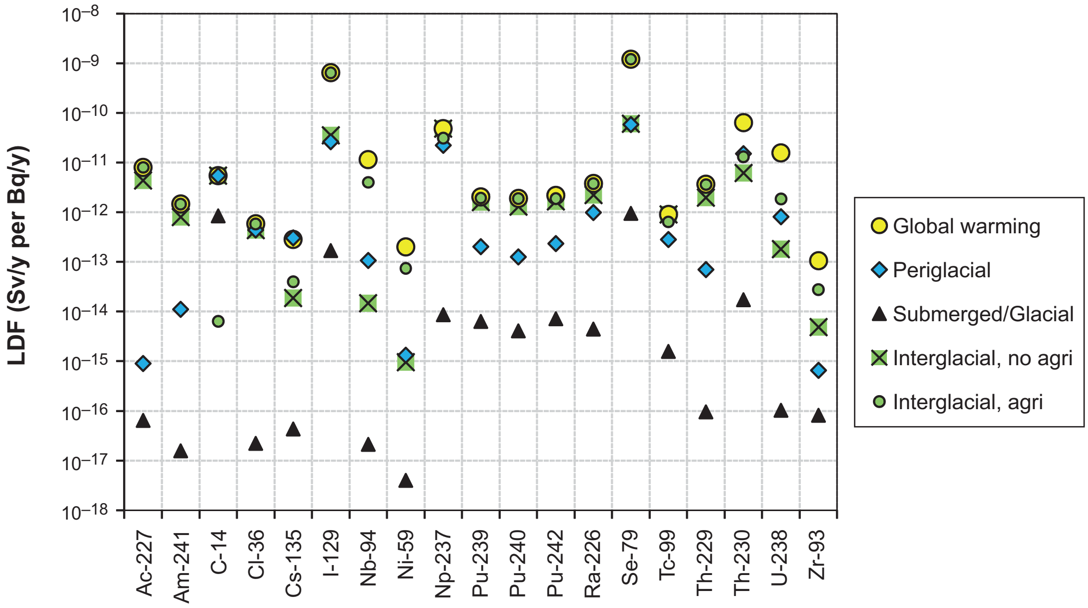

***Figure 13-7.** Resulting LDFs (i.e. the highest LDF over time among all biosphere objects) for different climate conditions /Avila et al. 2010/. LDFs for the initial submerged period were used to represent glacial conditions in the assessment. The effect on the LDFs of using agricultural products as food is visualised by including and excluding food from arable land during the interglacial period.*

The LDFs are consistently higher for the interglacial period than for any of the other climate domains in the reference glacial cycle (Figure 13-7). For instance, LDF values for glacial conditions are less than the values for interglacial conditions by two orders of magnitude or more, and also LDFs for periglacial conditions are lower than the corresponding values for the interglacial period, although they are higher than the LDFs for glacial conditions. For most radionuclides, the LDFs for the interglacial period differ marginally between the situations with and without agriculture (Figure 13-7). However, for a few radionuclides (i.e. C-14, I-129, Nb-54, Ni-59, U-238), the LDFs differ by more than an order of magnitude between these two situations (see further the **Biosphere synthesis report** and /Avila et al. 2010/).

Thus, the highest doses from a constant release rate from the repository are expected under interglacial conditions when humans are exposed to radionuclides that have accumulated in a wetland that has been converted to arable land, and when contaminated well water is utilised by human inhabitants and livestock. The only exception is C-14, for which the LDF also is highest in the interglacial period, but the maximum LDF occurs when agriculture is not possible. Accordingly, the LDFs for the interglacial period are the maximum values applicable during the reference glacial cycle and have been used for the dose assessments in e.g. the corrosion scenario (see Section 13.5.4).

The global warming climate case is represented by a 50,000 year extension of temperate conditions. Consequently, radionuclides that do not reach steady state activity concentrations within the initial temperate period (–9000 to 9400 AD) will continue to accumulate during the extended temperate period. However, most radionuclides have approached steady state at 9400 AD, and additional accumulation and the associated increase in LDF is marginal for dose-dominating radionuclides (exemplified for biosphere object 121-3 in Figure 13-8). Therefore, the LDFs for most radionuclides calculated for the global warming case do not differ significantly from those for reference glacial cycle. However, two radionuclides, Cs-135 and U-238 (the latter not included in the figure), have maximum LDFs approximately an order of magnitude larger in the global warming climate case than under the reference glacial cycle, which can be explained by several factors as discussed in /Avila et al. 2010/. However, due to the small contributions of Cs-135 and U-238 to the total risk estimate resulting from a long term release (see Section 13.5.4), this tenfold increase in the LDFs of these nuclides would not affect the final risk estimates significantly. It is therefore concluded that, from the perspective of the biosphere, the global warming case is not significantly different than the reference glacial cycle.

In e.g. the central corrosion case, a fraction of the inventory in a canister is assumed to be instantaneously released from the fuel upon water contact, propagated through the geosphere, and released to the biosphere as a pulse with a duration of years to hundreds of years (see Section 13.5.2). The modified LDF values for radionuclides that may be present in pulse releases are presented in Table 13-2. The values correspond to the maximum annual doses obtained in a simulation with a pulse unit release of 1 year duration, occurring at any time point within a period with temperate conditions.

Comparison of the SR-Site LDFs with results from earlier studies

The method used for calculating landscape dose factors in SR-Site has been updated in several important ways since the last two biosphere assessments of a deep repository (i.e. SR-Can /SKB 2006a/ and SR 97 /SKB 1999a/), and data from the site have been used to modify parameters from values used in the past, with improved justification for the values used in the present assessment. The changes in methodology and parameter values, and their consequences for exposure, are discussed in detail in /Avila et al. 2010/.

The maximum values of the ecosystem specific dose conversion factors (EDF) used in SR 97 /Bergström et al. 1999/ were systematically higher than the LDFs calculated in the present assessment, with the exception of a few radionuclides (e.g. C-14) (Figure 13-10). These differences are attributable to important methodological differences between the two assessments, including the delineation of the sub-catchment, assumptions on where a release will reach discharge areas and enter the ecosystems, as well as differences in the approach to evaluate the well /Avila et al. 2010/. Moreover, in the SR 97 assessment, generic parameter values were used in most cases, whereas site-specific data obtained during the site investigation programme have been broadly applied in the SR-Site assessment.

13.2.5 Approach and methods for assessment of radiological effects on the environment

To ensure the protection of the environment, adverse effects on non-human biota from a potential radionuclide release in the Forsmark area were assessed (see details in /Torudd 2010/). The assessment was carried out using the approach developed within the European projects FASSET /FASSET 2004/, ERICA /Beresford et al. 2007/ and PROTECT /Howard et al. 2010/, and recommended by ICRP /ICRP 2007/. Thus, the potential effects were evaluated of a radionuclide releases on individual specimens of a variety of types of organism occurring at the site. This approach is based on the rationale that if there are no detrimental effects at the level of individuals, then negative consequences at the population or ecosystem levels can also be excluded see /Torudd 2010/.

Table 13-2. Modified landscape dose conversion factors derived for pulse releases (from /Avila et al. 2010/). Asterisk denotes the radionuclides contributing most to dose in the pulse release cases (see Section 13.5.4).

Radionuclide	LDF pulse Sv/y per Bq
Se-79*	$9.7\cdot10^{-14}$
I-129*	$5\ 6\cdot10^{-14}$
Cl-36	$4.3\cdot10^{-15}$
Tc-99	$2.8\cdot10^{-15}$
Sn-126	$2.3\cdot10^{-15}$
Ag-108m	$5.1\cdot10^{-16}$
Nb-94	$3.2\cdot10^{-16}$
Cs-135	$1.8\cdot10^{-16}$
Ni-59	$9.7\cdot10^{-18}$

Note also that it is pessimistically assumed that the development of the canister failure is such that all the fuel rods become accessible simultaneously, i.e. a sudden breaching of the cladding for all fuel rods is assumed.

The handling of pulse releases assumes that if several canisters fail, no two canisters will affect the same biosphere object simultaneously. This is justified by the fact that on average less than one canister fails due to advection/corrosion and further since calculated failure times are spread over hundreds of thousands of years.

13.5.3 Input data to transport models

Input data to the transport models for the corrosion scenario are summarised in Table 13-3. All data in the table are qualified in the **Data report**, except the failure times that are obtained as output from the erosion/corrosion calculations reported in Section 12.6.2 and in detail in /SKB 2010d/. However, the input to those latter calculations is qualified in the **Data report**.

Table 13-3. Input data for the corrosion cases.

Entity	Nuclide/ Element specific	Data	Section in Data report
Number of failed canisters	–	As calculated with corrosion model, see Section 12.6.2.	–
Failure times	–	As calculated with corrosion model, see Section 12.6.2.	–
Radionuclide inventory	N	Mean inventory taken over all fuel types.	3.1
Instantaneous release fraction of inventory	N	Distributions according to the **Data report**.	3.2
Corrosion release fraction of inventory	N	Distributions according to the **Data report**.	3.2
Corrosion release rate	–	Log-triangular (10^{-4}/yr, 10^{-3}/yr, 10^{-2}/yr)	3.2
Fuel dissolution rate	–	Log-triangular (10^{-8}/yr, 10^{-7}/yr, 10^{-6}/yr)	3.3
Concentration limits	E	Calculated distribution based on distribution of several groundwater compositions*	3.4
Rock porosity	–	Constant = 0.0018	6.8
Rock diffusivities	–	Log-normal distributions; mean values: Cations: $6.6\cdot10^{-7}$ m²/yr Anions: $2.1\cdot10^{-7}$ m²/yr	6.8
Rock partitioning coefficients	E	Truncated log-normal distributions	6.8
Hydrogeological data related to flow and transport Darcy flux at deposition hole (U_0) Rock transport resistance, *F*, for paths beginning at release point Q1 Rock advective travel time, t_w, for paths beginning at release point Q1	–	Correlated distributions from several DFN model calculations propagated from hydrogeological analyses: **Uncorrelated model** Base case and 5 additional realisations **Semi-correlated model** Base case and 10 additional realisations **Fully correlated model** Base case and 5 additional realisations Only deposition holes where failures occur are included.	6.7
Rock Peclet number	–	Constant = 10	6.7
Max. penetration depth in rock matrix	–	Constant = 12.5 m	6.7
Biosphere LDF factors	N	Calculated LDF values, see Section 13.2.	7.2

* As noted above, concentration limits are not applied in the central corrosion case, with the exception of U. Concentration limits for U, and for other elements to be used in other calculation cases, are calculated probabilistically by using distributions of groundwater compositions for either temperate, permafrost, glacial or submerged conditions and combining the calculated distributions into the one distribution used in the transport calculation. See further the **Radionuclide transport report**, where also sensitivities to different groundwater types, thermodynamic data etc. are analysed.

Analysis of societal factors

Prevailing societal conditions are of importance both for the possible occurrence of inadvertent human actions impairing repository safety and for evaluation of their consequences. Important issues are why the disruptive action is being carried out and contemporary societal conditions such as general knowledge and regulations. These primarily humanistic and socio-economic questions were analysed at a workshop for SR 97 (see the **FHA report** and /SKB 2006e, Morén et al. 1998, SKB 1999a/). Experts in the fields of cultural geography, history of science and technology and systems analysis participated in this workshop. So called framework scenarios that describe plausible societal contexts for future human actions with an influence on the radiological safety of the deep repository were formulated. The framework scenarios were developed by means of morphological field analysis /Morén et al. 1998, Ritchey 1997/, a group- and process-oriented interactive method for structuring and analysing complex problem fields that are non-quantifiable, contain non-determinable uncertainties and require a judgmental approach.

From the study of societal aspects, it was concluded that it is difficult to imagine inadvertent intrusion, given a continuous development of society and knowledge. Owing to the long time horizon, however, it is not possible to rule out the possibility that the repository and its purpose will be forgotten, even if both society and knowledge make gradual progress. Nor is it possible to guarantee that institutional control over the repository site will be retained in a long time perspective. With a discontinuous development of society, where the development of society and technology contains a sudden, large change, it seems likely that knowledge will be lost and institutions will break down. It is also reasonable to assume that knowledge is lost if society degenerates.

14.2.4 Choice of representative cases

Sealed repository

It is probable that the repository site will be used by people in the future. Human actions that influence radiological safety and are carried out without knowledge of the repository and/or its purpose cannot be ruled out. Actions that influence the containment or the function indicators for containment are the most severe, followed by actions that influence retardation or the function indicators for retardation. Changes in the biosphere may result in an increase in the doses to which human beings may be exposed if the containment has been violated and there are leaking canisters in the repository.

A KBS-3 repository will be situated at a minimum depth of 400 metres in the rock, and the suggested repository depth is below 450 m at Forsmark. One reason for this is the wish to locate the repository in an environment where the containment of the fuel will be retained even in the event of extensive changes on the surface. Changes considered in the determination of the depth for a KBS-3 repository are natural changes and changes caused by man. Examples of natural changes are change of the repository's location in relation to the sea, and the presence of permafrost and ice sheets, see further Sections 5.2.2 and 14.3.4. These natural changes will also influence factors of importance for future human actions at the site e.g. settlement, society and man's opportunities to use the repository site.

Large uncertainties are associated with the development of technology and society. To reduce speculation, the NEA working group on assessment of future human actions /NEA 1995/ as well as SSM in the general guidelines to their regulations /SSM 2008b/ suggested an approach based on present-day knowledge and experience. However, applying this approach literally or with consistency there would be no inadvertent human actions yielding radiological consequences. The current activities at the repository site will not impact the safety. Drilling to great depth is solely performed to investigate the site for repository construction. If this were to result in hazardous conditions or circumstances, measures to avoid or minimise consequences for man and environment would be taken. There is another dilemma in the assessment of future human actions. In order to quantify the consequences, detailed descriptions of the human actions are required. Such descriptions will inevitably include speculations as to the course of actions which always can be questioned. However, both the technical and societal analyses can, even if they do not depict conditions that exist today, be said to be based on current practise and their results can be used for the selection of representative cases. When describing scenarios based on the selected cases, speculation is avoided by assuming the most severe among simplified and plausible alternatives.

All actions in Table 14-1 influence the migration of radionuclides in the biosphere. However, actions that are performed on or near the surface, down to a depth of a few tens of metres, are judged not to be able to directly affect the technical barriers and the containment of the fuel. This applies to the actions

T4, H2, H3, H4, H5, H6, H7, H8, M3, M4, C2, C3, C4 and C5 (though some of them could include drilling of relatively deep wells). Activities near the surface that belong to categories M and H are deemed to have less influence on the repository than natural changes in conjunction with future climate change. Of the actions that entail a chemical influence (C2–C5), acidification of air and land (C3) has been studied in most detail. In realistic cases of acidification by atmospheric sulphur and carbon dioxide, the environment at repository depth is not affected /Nebot and Bruno 1991, Wersin et al. 1994b/. Soil layers and bedrock are judged to work efficiently as both a filter and buffer against other chemical compounds as well.

Bombing or blasting on the ground surface above the repository (M5) cannot affect the containment of the spent fuel, except if blasting is done with a powerful nuclear weapon. Such an event implies a nuclear war and the consequences of the war and the blast itself would be much greater than the consequence of the hypothetical leakage from the repository. However, sub-surface testing of nuclear bombs (M6) close to the repository may violate the containment in a similar way to an earthquake. The test would need to be carried out close to the deposited canisters. Testing of bombs could be combined with identified societal contexts to form a plausible scenario. However, tests of nuclear bombs require knowledge of nuclear fission and its associated risks and are carried out below the surface to avoid environmental impact. Since measurements are carried out in connection with the tests it is plausible that if a detectable leakage from the repository exists, it would be distinguished from the releases from the bomb and handled by a society performing sub-surface weapon tests.

Some of the actions in Table 14-1 can, besides influencing radionuclide transport, indirectly influence the containment of the spent fuel if they affect the capability of the geosphere to provide favourable hydrological or chemical conditions. Such actions would have to be performed directly above or very close to the repository and include drilling and/or construction in the rock (M1, M2). These categories include actions that have to do with heat extraction (T1, T2, T3), well drilling (H1) and disposal of hazardous waste in the rock (C1). Hydropower plants (H5) and open-cast mines and quarries (M3) may also involve drilling or rock works at great depth. Before a rock facility is built, drilling is carried out to investigate the rock. Therefore, if present day technology is applied, all these cases involve drilling in the rock.

Large rock facilities adjacent to the repository are deemed to be out of the question in a short time perspective, i.e. within a few hundred years, for several reasons. For example, the repository is itself a large rock facility, the only one of its kind in Sweden that is very unlikely to be forgotten over such a short time span. Institutional control can be expected to endure on this timescale. The enumerated actions that encompass major rock works are less likely at the repository site, based on current technology and economics. In a slightly longer time perspective, i.e. a few or several hundred years or more, it is difficult to predict how knowledge, technology and society will develop, and thereby how, where and why rock facilities will be built. Based on current practice, rock facilities at depth down to around 50 metres may very well occur and actually exist at Forsmark (the SFR facility, a repository for low- and intermediate level radioactive waste). In the far future, the potential ore resources to the south-west of the investigated area in Forsmark may be exploited.

Of the actions in Table 14-1, "Drill in the rock" is judged to be the only one that can directly lead to penetration of the copper canister and breach of waste containment, while at the same time being inadvertent, technically possible, practically feasible and plausible. "Drill in the rock" is furthermore a conceivable action in the light of the results of the societal analysis. Even if it is possible to build a rock cavern, tunnel or shaft or to excavate an open-cast mine which leads to penetration of the copper canister, doing so without having investigated the rock in such a way that the repository is discovered, i.e. without knowledge of the repository, is not considered to be technically plausible. However, the construction of a rock facility at shallow depth or a mine in the vicinity of the Forsmark site may occur in the future. Therefore, the cases "Canister penetration by drilling" and "Rock facility in the vicinity of the repository" and "Mine in the vicinity of the Forsmark site" were selected as representative cases for scenarios related to a sealed repository, and which should be further described and analysed.

Unsealed or incompletely sealed repository

According to regulations, it is also necessary to define and analyse a case that illustrates the consequences of an unsealed repository /SSM 2008a/. Since the repository is gradually excavated and operated, the water, which also cools the drill. The water with cuttings is usually spread on the ground around the borehole. When the drilling is finished, the cores are sent to core mapping and the borehole is abandoned. If the hole has passed a zone with high water flow, so that a great deal of water is brought up to the surface, the borehole may be backfilled. This is generally only done if the flow entails a problem for local residents.

The direction of the borehole varies depending on the purpose and what is known about the rock volume to be investigated. In general the drill is inclined; the angle with the ground plane is usually 60–85 degrees. If there are no known obstacles or underground facilities, the drillers always try to continue the drilling even if they run into problems. If the drill reaches the buffer and the canister these may very well be penetrated and the drilling continued and not stopped until the drill core is inspected, or the agreed depth is reached. If penetration of the backfilled deposition tunnel occurs, the water cooling the drill and bringing the cuttings to the surface will be glutted with fine-grained material. The usual procedure is then to try to flush the fine grained material away. If this does not succeed, which is plausible if trying to drill through the backfill, the borehole is frequently grouted and the drilling continued though the concrete.

It is assumed that the purpose of the drilling is to reach great depth and that the drill rig therefore is placed at a low point in the terrain. The drilling angle is assumed to be 85° and the cuttings are assumed to be spread on the ground. When the backfilled tunnel is reached the borehole is assumed to be grouted and the drilling continued. The buffer is assumed to be grouted as well, the drilling continued and the canister penetrated. When the drill core containing canister material and spent fuel is brought to the surface the anomalous situation is taken to be recognised and the drilling is stopped.

Since the assessment should not only consider the impact to the intruder, but also assess how the safety functions of the repository may be impaired, the following additional assumptions are made: The site and the borehole are abandoned without further measures. About a month later, a family moves to the site and operates a domestic production farm there. The abandoned borehole is used as a well by the family. The consequences for the repository and the annual effective doses to the family as well as the dose to the drilling personnel are assessed.

Function indicator(s) considered

Because this drilling case presumes that one canister as well as the buffer and backfill above the canister are penetrated by a borehole, function indicators related both to containment and retardation properties of the canister, buffer and deposition tunnel backfill are affected. In addition, the function indicators related to the capacity of the geosphere to provide favourable hydraulic and chemical conditions may be affected. Therefore, the following function indicators are considered in this drilling case:

- Can1, Provide corrosion barrier; ensure containment.
- Buff1, Limit advective transport in buffer; ensure tightness and self-sealing.
- BF1, Counteract buffer expansion; high density and self-sealing of backfill.
- R1, Provide favourable chemical conditions; ensure reducing conditions.
- R2, Provide favourable hydrologic and transport conditions; ensure high transport resistance in fractures and low equivalent flow rate at buffer/rock interface.

Further, the safety function Buff 5, Prevent canister sinking may be affected if sufficiently much buffer material is lost. However, if this occurs, the other buffer safety functions will have already been violated.

Qualitative description of the consequences of unintentionally penetrating a canister when drilling

It is assumed that one canister has been penetrated by core drilling. The borehole above the penetrated canister is assumed to be grouted and the buffer's capability to prevent advective transport, self seal and prevent colloid transport are lost in the grouted area. Some buffer and backfill material is lost, but excluding the grouted parts both backfill and buffer are assumed to retain their safety functions. The water containing the cuttings from the drilling is brought the surface and spread on the ground on a circular area.

Table 14-2. Compilation of data used in the analysis of dose consequences of unintentionally penetrating a canister when drilling.

Parameter	Value/assumption	Comment/reference
Time of drilling	300 years after closure of the repository or later	
Time the exposed individual in the family spends in the middle of the contaminated area	365 hours	One hour per day every day of the year
Radionuclide inventory	Average canister	**Data report**, Section 3.1
IRF	Included in the inventory left on the ground	Median values according to **Data report**, Section 3.2
Portion of fuel in the canister brought to surface	0.03	**FHA report**, Appendix B
Fuel alteration rate	10^{-7} per year	**Data report**, Section 3.3
Corrosion rate of metal parts in fuel	10^{-3} per year	**Data report**, Section 3.2
Water flow through deposition hole	0.1 m^3 per year	**FHA report**, Appendix B
Elemental solubility limits	Representative for site conditions in the period 2000 to 3000 AD	**FHA report**, Section 6.3.
Volume of initially contaminated soil	2.8 m^3 (radius 3 m, thickness 0.1 m)	–
Dose conversion factors for contaminated ground	Dose factors for external irradiation, inhalation and ingestion of food cultivated at the site	/Nordén et al. 2010/
Sorption coeffecients	Element specific sorption coefficients for soil in the irrigated area	/Nordén et al. 2010/
Density of agricultural soil	323 kg dry weight/m^3	/Löfgren 2010/
Area of land used to grow vegetables	102 m^2	Large enough to produce vegetables for 5 persons, assuming a fraction of 2.5% vegetables in the diet.
Productivity of vegetables on irrigated land	0.135 kgC per m^2 and year	/Löfgren 2010/
Productivity of root crops on irrigated land	0.127 kgC per m^2 and year	/Löfgren 2010/
Productivity of cereals on irrigated land	0.114 kgC per m^2 and year	/Löfgren 2010/
Dust concentration in the air	$5 \cdot 10^{-8}$ kg dry weight/m^3	/Nordén et al. 2010/
Inhalation rate	1 m^3 per hour	/Nordén et al. 2010/
Yearly intake of carbon	110 kg carbon per year	/Nordén et al. 2010/
Yearly intake of water	0.6 m^3/year	/Nordén et al. 2010/
Volume of irrigation water used each year	0.15 $m^3/(m^2\ y)$	/Nordén et al. 2010/
Number of irrigation events per year	5	/Nordén et al. 2010/
Runoff	0.186 m/y	/Löfgren 2010/
Well capacity	82,502 m^3/year	/Löfgren 2010/

Dose to drilling personnel

The dose to the drilling personnel originates from the radionuclides in cuttings, drilling water and fuel pieces spread on the ground around the borehole. The dose rate that a member of the drilling personnel would be exposed to while working in the highly contaminated area 300 years after repository closure is calculated to be 130 mSv/hour and the dose rate is totally dominated by exposure to Ag-108m, see the **FHA report**. If drilling occurs at c. 5,000 years after repository closure, the dose rate has decreased to values below 1 mSv/hour and is dominated by exposure to Nb-94 and Sn-126.

These calculated dose rates are very high. This is primarily a result of the cautious assumption regarding the amount of Ag-108m brought to the surface when drilling. In the spent fuel, Ag-108m is contained in the Ag-In-Cd alloy of the control rods, but in the calculations assumed to be part of the radionuclides that are instantly released when a canister is penetrated and therefore the entire amount is taken to be brought to the surface. In the case of drilling intrusion Ag-108m would not be instantaneously released, so 3% instead of 100% of the inventory of Ag-108m would be brought to the surface when drilling. Due to the total dominance of Ag-108m in determining the dose rate, this would reduce the dose rate to workers to 3% of the value, i.e. the dose rate 300 years after repository closure would be about 4 mSv/hour.

Another major uncertainty relates to the availability in, and loss of, radionuclides from the contaminated soil. The whole radionuclide inventory in the contaminated area is assumed to be instantaneously available for transfer to the agricultural production and air with contaminated dust. This assumption leads to a pessimistic value of the annual effective dose, since most likely only a fraction of the inventory will be available from the beginning. Further, it is assumed that there are no losses of radionuclides from the contaminated area other than by radioactive decay. However, in reality, other loss processes, such as leaching in percolating waters, are likely to be of importance. Note that the calculated annual effective dose from the radionuclides brought to the surface is valid only for the first year after the intrusion given these assumptions and that the land is assumed to be cultivated during that year.

It is not certain that the family finds the borehole and uses it as a well. Current practice is to place the pump just above the borehole for the well. Non-manual pumps are most often covered and some space is left around them to allow maintenance. Manual pumps require some space for pumping. The combination of using the borehole as a well and the contaminated soil from the area around it for cultivation therefore seems unlikely. Based on current practice the most likely situation seems to be that the contaminated area will either be used for cultivation or the borehole will be used as a well. Consequently, the person can be assumed to either receive the dose from the use of the contaminated area for agricultural purposes or from using the borehole as a well.

Uncertainties in the analyses of the impact of the borehole on parts of the repository other than the deposition hole directly affected by the borehole are judged as small compared to those associated with the calculations of dose from the canister penetrated by the drilling. The conclusion that a borehole through the backfill above, and buffer in, the deposition hole hit by drilling does not affect the backfill and the buffer in a neighbouring deposition hole, is based on results of analyses reported by /Åkesson et al. 2010a, Appendix F/. These analyses addressed loss of backfill above a deposition hole or in the middle between two deposition holes. Although the results reported by /Åkesson et al. 2010a/ are associated with uncertainties, their results in combination with the situation in this case, where a potential loss of backfill occurs still further away from a deposition hole, seem firm enough for the conclusion drawn. There are also uncertainties in the analyses of the impact of open boreholes on the groundwater flow in and around the repository, but these uncertainties are judged to not significantly affect the results, see the **FHA report**.

Conclusions

If a canister is penetrated and the borehole is used as a well for drinking and irrigation, the annual effective doses to representative members of critical groups will exceed the individual limit on annual effective dose for members of the public but not the annual effective dose due to background radiation. Assuming the site-specific median water yield of percussion holes drilled in the repository rock at Forsmark, the dose corresponding to the regulatory risk limit is exceeded if the intrusion occurs during the first c. 35,000 years after repository closure.

If the instant release fraction and crushed material, pieces, and even unbroken fuel rods, from the fuel elements are brought to the surface by drilling, the persons executing the drilling will receive very high doses. After about eight hours of exposure, the threshold of 1 Sv for suffering from radiation sickness is exceeded. Further, if the contaminated soil surrounding the borehole is used for agricultural purposes, the exposed persons in the case illustrated may be severely injured. However, as discussed above, the case analysed involves a number of simplified and cautious assumptions. Therefore, the calculated annual effective doses should be seen as illustrations of possible consequences rather than estimations of what the consequences would be.

An open borehole might affect the long-term properties of the backfill in the deposition tunnel in the vicinity of the borehole but the effect on the backfill above neighbouring deposition holes is assessed as negligible. This implies that the buffer surrounding canisters in neighbouring deposition holes in the deposition tunnel is also unaffected by the borehole. An open borehole through the backfill will also change the pattern of flow paths in the rock beneath the highly transmissive fractures in the upper part of the bedrock. However, the new paths established have similar transport characteristics as those prevailing without an open borehole through the backfill. Therefore, it is judged that even though drilling a borehole that penetrates a canister will severely affect the deposition hole hit by

Assessment of the consequences of a mine in vicinity of the Forsmark candidate area

If a mine, or other sub-surface rock excavation, were to be constructed in the vicinity of the Forsmark site, it may be assumed that the greatest influence on the repository for spent nuclear fuel would occur if the construction took place at the same depth and in close proximity to the repository for spent nuclear fuel. Since the south-westernmost part of the repository is located west of Lake Bolundsfjärden (Figure 14-4), the closest distance between the repository and a hypothetical mine in the potential area for mineralisation (Figure 14-4) would be on the order of 1 to 1.5 km.

In order to assess the potential influence on the repository, results from analyses of the hydraulic impact of an open repository are used. Calculations of the effects of water inflow to an open repository show that the drawdown of the hydraulic head is large in the rock close to the repository at a depth of 450 m /Mårtensson and Gustafsson 2010, Figure 7-20 lower insert/. However, the drawdown decreases rapidly with distance from the open repository in a westerly direction to about 50 m within tens of metres from the repository and at distance of c. 1 km from the repository, the drawdown at 450 m depth is negligibly small. The reason for the small radius of influence is the low hydraulic conductivity of the rock mass volumes at depth in proximity to the repository. This constraining hydraulic condition is valid also for a potential future mine outside the tectonic lens. Therefore, it is reasonable to expect a very limited hydraulic impact from the mine on the repository because of the low-conductive bedrock in the target volume.

Conclusions

The assessment indicates that exploitation of the potential mineral resources in the vicinity of the Forsmark site would not impact the safety functions of the repository. The design consideration to locate the repository at a site without natural resources is, therefore, considered to be fulfilled.

14.2.8 Incompletely sealed repository

Introduction and specification of the case analysed

According to regulations, it is also necessary to define and analyse a case that illustrates the consequences of an unsealed repository /SSM 2008a/. The basic assumption in the case selected as representative for scenarios related to an unsealed or incompletely sealed repository is that the repository is abandoned when all canisters are deposited and all deposition tunnels backfilled and sealed, but the main and transport tunnels as well as the central area, repository access (ramp and shafts) and the ventilation shafts in the deposition area (see Figures 5-21 and 10-7) are still open due to, for example, political decisions not to seal completely. This assumption is based on the strategy for deposition of canisters, which implies that deposition tunnels are successively filled with canisters and then backfilled and sealed as soon they are filled. Abandoning the repository in the middle of this process is judged as rather unlikely because this would mean that canisters are left at the surface where they would constitute a larger risk than if emplaced in the repository.

Function indicator(s) considered

This case relates to the following function indicators:

- Can1, Provide corrosion barrier; ensure containment.
- Buff1, Limit advective transport in buffer; ensure tightness and self-sealing.
- Buff2, Reduce microbial activity.
- BF1, Counteract buffer expansion; high density and self-sealing of backfill.
- R1, Provide favourable chemical conditions; ensure reducing conditions.
- R2, Provide favourable hydrologic and transport conditions.

Qualitative description of the consequences of an incompletely sealed repository

If the repository is abandoned when the main and transport tunnels, central area, repository access and ventilation shafts in the deposition area are still open, these open volumes will successively be water filled. Water will flow through the open volumes with a magnitude and direction dependent on the magnitude and direction of the hydraulic gradient. In addition, the open volumes may affect the groundwater flow pattern in the repository bedrock.

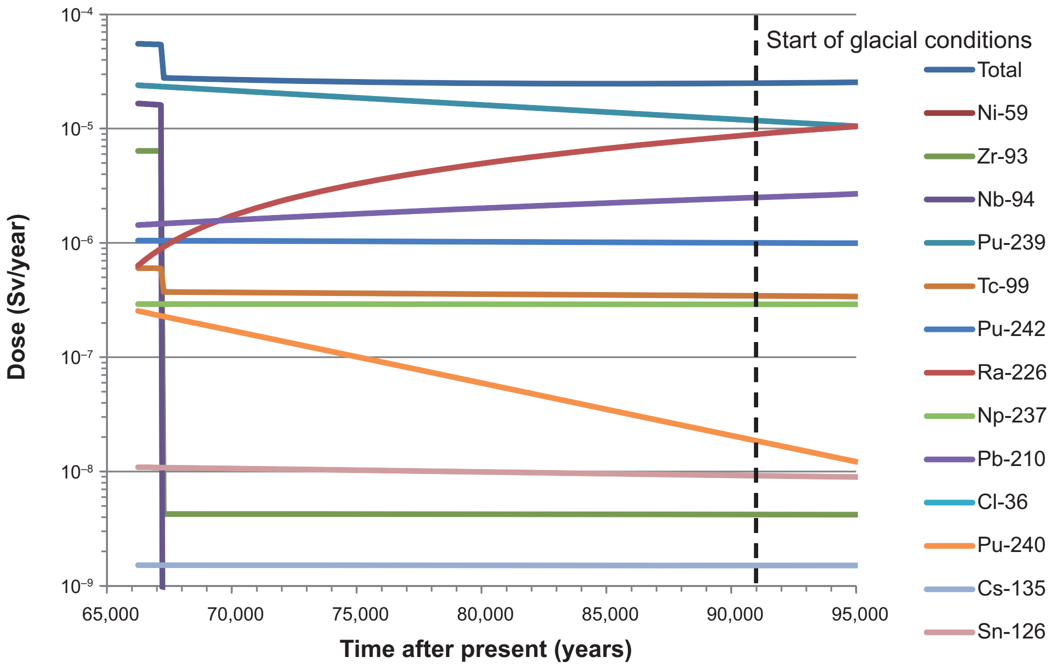

***Figure 14-5.** Calculated effective dose from using water in the open shafts and ramp as drinking water and for irrigation (Figure 6-19 in the **FHA report**).*

Uncertainties

The uncertainties in the analyses of expansion of deposition tunnel backfill are rather large. The friction angle is a function of the swelling pressure and increases with decreasing swelling pressure. The values at low swelling pressure are not well known, but laboratory measurements indicate that the friction angle is higher than 20 degrees at low density and that the lateral stresses (corresponding to the normal stresses towards the rock surface) are higher than the stress in the swelling direction. This means that the resisting force from friction is probably larger than that modelled, which implies that the results are probably pessimistic in the sense that the swelling and thus density loss would be smaller than modelled /Åkesson et al. 2010a/.

There are a number of uncertainties in the analyses of the impact on groundwater flow of open tunnels in the repository, especially for the simulations with glacial conditions. One important uncertainty relates to the accessibility of water. In reality the flow in an open tunnel below the ice front will probably be limited by the supply of subglacial melt water in the transmissive subglacial layer at the ice-subsurface interface. If the supply of water is insufficient, there will be a drawdown of the pressure and the flow will decrease. In order to give such a high flow as adopted above, the tunnel entrances have to coincide with a major melt water tunnel under the ice. It should also be noted that the calculations assume a worst case location of the ice front in terms of hydraulic gradient. The hydraulic gradient below the ice sheet when the repository is completely covered by ice may be even lower than during the temperate conditions /Vidstrand et al. 2010/.

Several simplified assumptions are made in the calculations of oxygen supply to the canister surface. The only transport resistance accounted for is that in the buffer surrounding the canister, whereas transport resistances in the backfill on top of the buffer in the deposition hole and in the deposition tunnel as well as in fractures in the rock are neglected. This is judged as very pessimistic, at least for temperate conditions. Even if the tunnel backfill expands out into the main tunnel and the density of the backfill above a deposition hole is significantly reduced, the transport resistance in the deposition tunnel should still be significant. This is supported by the results of the hydrogeological modelling that indicate that the hydraulic gradients are directed towards the open tunnels in the repository. Any oxygen transport from the open tunnels to the deposition holes then has to take place in a direction opposite to the hydraulic gradient. Other pessimistic assumptions concern the oxygen concentration and that it remains constant over a long time period. There are both biotic and abiotic processes that may consume oxygen in the repository environment.

Lengths and transport resistances of hydraulic travel paths to and from the repository

Safety function R2a "Transport resistance in fractures, F" is affected by repository depth. The length of the travel paths of solutes in the groundwater will increase with increasing depth, but the resulting impact on the transport resistance would only be marginal, i.e. increasing depth by 100 m would only imply an increase in path length by about 25%. More importantly, the transport resistances offered by these paths would increase with depth if the hydraulic conductivity decreases with depth at the site, see further below.

Fracture frequency and fracture transmissivity

Both safety functions R2a "Transport resistance in fractures, F" and R2b "Equivalent flow rate in buffer/rock interface, Q_{eq}" are affected by repository depth, since fracture frequency and fracture transmissivity show depth dependence. However, the selected repository depth is well below the depth at about 400 m where the already low frequency of water conducting fractures drops dramatically. Nothing in the data suggests that this extremely low frequency would drop further at realistically reachable greater depths. In summary, the chosen repository depth below 450 m is sufficient to reach the low fracture frequency and low permeability volumes of Forsmark, and there does not seem to be any advantage in going deeper.

Groundwater pressure

Groundwater pressure, safety function R3a, contributing to the isostatic load on the canister, increases with depth. However, compared with the buffer swelling pressure and hydrostatic pressures from a glacial overburden, the increased pressures are of marginal importance. An increased pressure will also increase the inflow to the repository during construction, unless this is counteracted by grouting – this is however mainly an issue for repository engineering. Furthermore, there will only be limited needs for grouting at depth in Forsmark, since the frequency of water conducting fractures and deformations zones is very low.

Rock stress

Rock stress indirectly affects safety function R2b "Equivalent flow rate in buffer/rock interface, Q_{eq}", since the in situ stress determines the potential for spalling. Stress in general increases with depth, but as concluded in the **Underground openings construction report** (and its underlying references), below 300 m depth, there appears to be little evidence that the horizontal stress magnitudes in fracture domain FFM01 increase significantly with depth. Hence placing the repository at 400 m or 500 m depth does not significantly increase the risk for spalling in the deposition holes.

Initial temperature

The *in situ* temperature, relates to safety function R4 "Provide favourable thermal conditions". Temperature increases with depth, although the thermal gradient is relatively low in the considered depth range. This needs to be considered in the repository layout, when determining the necessary canister spacing that would ensure that the peak buffer temperature lies below stipulated limits, and this means that the canister spacing needs to increase with depth, leading to a larger footprint for a deeper location. However, given that this is considered in the repository design, there are no other detrimental effects of the elevated *in situ* temperature with depth.

Freezing

A colder future climate may in principle ultimately lead to freezing and relates to safety function R4 "Provide favourable thermal conditions, of the buffer and the deposition tunnel backfill". Such freezing could in turn have detrimental effects on the canister and the near-field rock. The likelihood of freezing decreases with increasing depth. The analyses in SR-Site have, however, demonstrated that freezing of the buffer can be considered as a residual scenario, i.e. no reasonable way that this could occur has been identified for a depth of 450 m at Forsmark. For an eroded buffer, the freezing point is higher than for an intact buffer. At the current depth it is unlikely but cannot be fully ruled out. The effects are, however, not assessed to threaten the integrity of the canister. As demonstrated in Section 12.3 freezing of the deposition tunnel backfill at these depths can also be ruled out.

repository construction and operation and by application of the observational method using findings from the underground based detailed investigations and by applying the design premises for accepting deposition holes, as discussed above. Thus, the question as to whether the repository layout is BAT can at this stage only be assessed based on these design premises. More specific feedback on these is given in Section 15.5.

Repository depth

As concluded from the assessment of the adequacy of the selected repository depth, presented in Section 14.3.4, the depth has mainly been decided by considering the hydraulic conditions at the Forsmark site, i.e. frequency and occurrence of transmissive fractures and their dependence on depth, whereas the constructability is mainly related to rock mechanical issues, e.g. the likelihood and extent of spalling in deposition holes prior to emplacement. More detailed conclusions are given below.

- Factors relating to the chemical stability safety function R1, "Provide chemically favourable conditions", are generally favourable at the selected depth. The only remaining chemical stability issues of concern for repository safety relate to the potential for a few deposition holes to experience groundwater with too low an ionic strength and to the presence of sulphide. Generally, the risk of penetration of dilute waters would decrease with increased repository depth. However, the few occurrences of such potential penetration are related to the scarce occurrence of highly transmissive migration paths in the generally very tight rock. There is no evidence that a practically realistic increase of the depth (i.e. in the order of a 100 m) would dramatically reduce the occurrence of such isolated paths – and it seems a better strategy to try to avoid them locally. Furthermore, there is no indication that the occurrence of sulphide is correlated to depth.
- Safety function R2a "Transport resistance in fractures, F" is affected by repository depth. The length of the travel paths of solutes in the groundwater will increase with increasing depth, but the resulting impact on the transport resistance would only be marginal.
- Both safety functions R2a "Transport resistance in fractures, F" and R2b "Equivalent flow rate in buffer/rock interface, Q_{eq}" are affected by repository depth, since fracture frequency and fracture transmissivity show depth dependence. However, the chosen repository depth below 450 m is sufficient to reach the low fracture frequency and low permeability rock volumes at Forsmark, and there does not seem to be any advantage in going deeper.
- Groundwater pressure, safety function R3a, increases with depth. However, compared with the buffer swelling pressure and hydrostatic pressures from a glacial overburden, the increased pressures are of marginal importance.
- Rock stress indirectly affects safety function R2b "Equivalent flow rate in buffer/rock interface, Q_{eq}", since the in situ stress determines the potential for spalling. Stress in general increases with depth, but placing the repository at 400 m or 500 m depth does not significantly increase the risk for spalling in the deposition holes.
- The in situ temperature relates to safety function R4 "Provide favourable thermal conditions". The temperature increases with depth and this needs to be considered in the repository layout. However, given that this is considered in the repository design, there are no other detrimental effects of the elevated in situ temperature with depth.
- The likelihood of freezing, safety function R4, decreases with increasing depth. The analyses in SR-Site have, however, demonstrated that freezing of the buffer can be considered as a residual scenario and also freezing of the deposition tunnel backfill at these depths can be ruled out.
- Surface denudation (erosion and weathering) of the host rock is has been estimated to generally be limited to a few metres or less per glacial cycle for the Forsmark repository site and some tens of metres for 1 million years. Therefore, surface denudation does not have to be considered when determining repository depth within the reference interval 400–700 metres.
- The probability of inadvertent human intrusion into the repository decreases with increasing depth. In general, intrusion to several hundred metres is considered unlikely in rock poor in resources.

In conclusion, the selected repository depth is adequate and changing the depth is not deemed to significantly reduce the calculated risk. Furthermore, a shallower location, e.g. above the 400 m level, might increase the risk, since the frequency of water conducting fractures is higher there.

Appendix 1

The following shall be reported with regard to analysis methods:

– how one or several methods have been used to describe the passive system of barriers in the repository, its performance and evolution over time; the method or methods shall contribute to providing a clear view of the features, events and processes that can affect the performance of the barriers and the links between these features, events and processes,

Handling in SR-Site: *The format for system description is discussed in Chapter 5 (initial state), Chapter 6 (external conditions) and Chapter 7 (processes). The description of system evolution is related to the entire assessment and is analysed in detail as a reference evolution in Chapter 10. Variants of this evolution are analysed for a number of scenarios in Chapter 12.*

– how one or several methods have been used to identify and describe relevant scenarios for sequences of events and conditions that can affect the future evolution of the repository; the scenarios shall include a main scenario that takes into account the most probable changes in the repository and its environment,

Handling in SR-Site: *The scenario selection method for SR-Site is described in Section 2.5.8 and its implementation in Chapter 11.*

– the applicability of models, parameter values and other conditions used for the description and quantification of repository performance as far as reasonably achievable,

Handling in SR-Site: *This is done in the* ***Model summary report****, see e.g. Section 7.5 and the* ***Data report****, see Chapter 9.*

– how uncertainties in the description of the functions, scenarios, calculation models and calculation parameters used in the description as well as variations in barrier properties have been handled in the safety assessment, including the reporting of a sensitivity analysis which shows how the uncertainties affect the description of barrier performance and the analysis of consequences to human health and the environment.

Handling in SR-Site: *The management of uncertainties permeates the safety assessment. A plan for the management of uncertainties is given in Section 2.8.3. Sensitivity analyses occur in a number of places in the reference evolution and the analyses of different scenarios, see e.g. Sections 12.2.2, 12.6.2, 13.5.11 and 13.6.2. Sensitivity of the main risk contributors to various conceptual uncertainties is analysed in Section 13.10.*

The following shall be reported with respect to the analysis of post-closure conditions:

– the safety assessment in accordance with 9 § comprising descriptions of the evolution in the biosphere, geosphere and repository for selected scenarios; the environmental impact of the repository for selected scenarios, including the main scenario, with respect to defects in engineered barriers and other identified uncertainties.

Handling in SR-Site: *This is essentially the reporting of the analyses of the reference evolution in Chapter 10 and of the selected scenarios in Chapter 12.*

A1.2 Excerpts from the General Recommendations in SSMFS 2008:21

The Swedish Radiation Safety Authority's General Recommendations concerning the Application of the Regulations concerning Safety in connection with the Disposal of Nuclear Material and Nuclear Waste (SSMFS 2008:21)

The following is the unabbreviated Recommendations relevant to 9 and 10 § and Appendix of SSMFS 2008:21, i.e. those sections that concern the safety assessment.

On 9 § and Appendix

The safety of a repository after closure is analysed quantitatively, primarily by estimating the possible dispersion of radioactive substances and how it is distributed in time for a relevant selection

RN	Radionuclide.
Saalian	The penultimate glacial, preceding the Eemian interglacial.
SAFE	The renewed safety assessment of the low level waste repository (SFR) at Forsmark.
Safety function	A role through which a repository component contributes to safety.
Safety function indicator	A measurable or calculable property of a repository component that indicates the extent to which a safety function is fulfilled.
Safety function indicator criteria	A quantitative limit such that if the safety function indicator to which it relates fulfils the criterion, the corresponding safety function is achieved.
SCC	Stress Corrosion Cracking.
SDM	Site Descriptive Model. A synthesis of geology, rock mechanics, thermal properties, hydrogeology, hydrogeochemistry, bedrock transport properties and surface system properties of the site for the planned spent nuclear fuel repository.
SDM-Site	Short name for the Site Descriptive Model resulting from the completed surface based investigations.
SFR	Repository in Forsmark for low-and intermediate-level radioactive waste.
Sheet joints	Fractures that are oriented sub-parallel to the topographic surface at the time of unloading and lack alteration associated with hydrothermal alteration, i.e. sheet joints.
Silica sol	A suspension of nano-sized silica particles that may be converted into a gel by adding a concentrated salt solution. Silica sol may be used as an injection grout that has near-neutral pH.
Site description	A model of the site providing descriptions of the present geosphere and biosphere conditions. It is the same as site descriptive model (SDM).
SKI	Swedish Nuclear Power Inspectorate. SKI and SSI were merged into the Swedish Radiation Safety Authority (SSM) 1 July 2008.
Skin effect	Disturbance of the flow conditions of the interface between the formation (fractured rock) and the tunnel. It is described by the skin factor, which may be positive or negative depending on whether the permeability of the interface is reduced (positive skin factor) or increased (negative skin factor) in relation to the initial permeability of the formation.
SMOW	Standard Mean Ocean Water, a water standard defining the isotopic composition of water.
Sorption	In this report the term is used to designate all processes by which a dissolved species is retained at a solid surface.
Spalling	Rock surface failure in which rock chips are shed from the rock wall.
SR 97	Safety Report 97. The previous safety assessment to SR-Can.
SRB	Sulphate-reducing bacteria.
SR-Can	The preliminary safety assessment for the planned spent nuclear fuel repository, published in 2006.
SSI	Swedish Radiation Protection Authority. SSI and SKI were merged into the Swedish Radiation Safety Authority (SSM) 1 July 2008.
SSM	Swedish Radiation Safety Authority. SSI and SKI were merged into the Swedish Radiation Safety Authority 1 July 2008.
SSMFS	Regulations of the Swedish Radiation Safety Authority.
STUK	Finnish Radiation and Nuclear Safety Authority.
Sub-catchment	The drainage area of a biosphere object minus the drainage area of the inlet(-s) to the object.
Talik	A layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrological, hydrogeological, or hydrochemical conditions.
TASQ-tunnel	Tunnel at the Äspö Hard Rock Laboratory.
TASS-tunnel	Tunnel at the Äspö Hard Rock Laboratory.
TDS	Total Dissolved Solids.
Tectonic lens	A lenticular rigid body of rock that is surrounded by deformation zones.
Temperate domain	Regions without permafrost or ice sheet conditions. It is dominated by a temperate climate in a broad sense. Within the temperate domain, a site may also at times be submerged by the sea or by an ice dammed lake.
Tertiary	Geologic period 65 million to 2.6 million years ago.
Thermally induced spalling	Spalling induced by the stresses resulting from the added thermal load from the canister heat.
THM	Thermo-Hydro-Mechanical.
Till	Dominantly unsorted and unstratified material, generally unconsolidated, deposited directly by a glacier or an ice sheet.
t_w	Advective travel time.
UCS	Uniaxial Compressive Strength.