BUFFER AND BACKFILL WORKSHOP REPORT

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Prepared by

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: None.

ANALYSES AND CODES: None.

1 BUFFER AND BACKFILL WORKSHOP SUMMARY

A one-day workshop on buffer and backfill was held on August 17, 2011, at the U.S. Nuclear Regulatory Commission (NRC) in Rockville, Maryland. This workshop focused on discussions of processes and characteristics of potential buffer and backfill materials in the near field of geologic repositories to isolate high-level nuclear wastes (HLW) from the biosphere. The function and type of materials used for seals were also discussed in the workshop. Additionally, discussions included summaries of experiences gained in HLW and spent nuclear fuel (SNF) disposal programs outside of the United States. The objective of the workshop was to provide a higher level understanding of the near-field barrier knowledge base that can help identify possible gaps for assessing the long-term performance of near-field barriers for isolating nuclear wastes. The workshop helped identify gaps in understanding of the long-term performance of buffers and backfills, and is part of a broader effort to prepare NRC for developing an integrated regulatory framework to address potential changes in national high-level nuclear waste policy. The technical issues identified in this report will help NRC (i) further refine the issues as they pertain to any changes in national policy and (ii) develop detailed planning of future staff activities.

The workshop was attended by NRC, the Center for Nuclear Waste Regulatory Analyses (CNWRA®), and Galson Sciences, Ltd. Specific areas presented and discussed during the workshop were

- Fundamental features of buffer, backfill, and seals
- Properties of buffer
- Buffer performance topics
- Seals and backfills
- International activities
- Representation of buffer and backfill in performance assessment models
- Summary of key uncertainties

The following sections summarize the workshop discussions. The order of the sections generally follows the agenda, which is provided in Appendix A. Most sections also include a list of selected references used as information resources for the relevant topic. In keeping with the objectives and guidelines of the workshops, direct citations of statements and conclusions in the text of this summary report are not provided. In addition, four recent special volumes of journal articles covering the full range of topics for bentonite buffers are listed in Appendix B.

2 FUNDAMENTAL FEATURES OF BUFFER, BACKFILL, AND SEALS

The primary functions of a buffer are to provide physical, chemical, hydrologic, and biological isolation of wastes; minimize radionuclide release to the biosphere; and protect waste packages from host rock displacements (especially in crystalline rock). The primary functions of a backfill are to isolate the engineered barrier system (EBS) hydrologically, keep buffer materials intact, and keep access tunnels/shafts mechanically stable. The primary functions of seals are to isolate the EBS hydrologically, provide physical support for backfill materials and various access tunnels/shafts, retard the migration of radionuclides, allow separation of deposition tunnels/shafts from other access tunnels/shafts, discourage inadvertent human intrusion, and close exploratory drilling/boreholes.

In addition to discussions about buffer, backfill, and seal functions, there were discussions of potential design concepts for disposing SNF and HLW. Designs discussed were vertical (Swedish and Finnish) and horizontal (French and Swiss) disposal tunnels/shafts. The Belgian supercontainer (concrete buffer instead of bentonite buffer) and the prefabricated EBS modular design concepts also were discussed.

Selected sources of information include: ANDRA (2005a); OECD/NEA (2003a); Posiva Oy (2006); and SKB (2010, 2011).

3 PROPERTIES OF BUFFER

The structure of aluminosilcate clay minerals was outlined because knowing their structure helps explain their properties. The swelling of smectite clay minerals is affected by the net negative electrical charge caused by isomorphic substitution of the central cation in the tetrahedronal and octahedronal units, valence of counter cations, and ionic strength of pore water. The high swelling pressure of bentonite, which contains a large fraction of the smectite clay mineral montmorillonite, will affect buffer pore sizes. The low hydraulic conductivity of bentonite will help restrict water movement. The high surface area and cation exchange capacity of montmorillonite ensure that bentonite can effectively retard the transport of cationic radionuclides. In addition, cation exchange can potentially affect the swelling capacity of the bentonite.

Clay minerals are typically in equilibrium with their environment. When conditions change, there is the potential for their properties to change. Important factors affecting the long-term performance of a bentonite buffer are decreased swelling, formation of fast flow paths, decreased sorption potential, and increased saturated hydrologic conductivity. For long-term performance evaluation, assessment of potential changes to buffer material properties is needed for estimating buffer material performance under existing and future site conditions.

Also discussed were pore water chemistry, potential redox conditions, and potential colloid formation in bentonite. Furthermore, bentonite–sand mixtures were discussed, as well as proposed installation methods for buffers. Additionally, constitutive models linking hydrologic and mechanical properties were discussed. There was consensus that constitutive models are needed to link or couple hydrologic, thermal, chemical, and mechanical processes to predict the behavior of clayey material.

Selected information sources include: Alonso, et al. (1990); Bradbury and Baeyens (2002); Dixon (1977); Fernández and Villar (2010); Grim (1968); Jussila (2007); Laine and Karttunen (2010); Lempinen (2011); Neretnieks, et al. (2009); Pabalan, et al. (1998); Rutqvist, et al. (2011); Sanchez, et al. (2011); Turner, et al. (1998); and Wersin, et al. (2003).

4 BUFFER PERFORMANCE TOPICS

Issues related to how the effectiveness of a bentonite buffer may be compromised were discussed, along with issues associated with the evolution of bentonite over time.

The degree to which the various countries rely on a buffer to isolate SNF and HLW appears to depend on the host rock. Typically, countries that propose to construct repositories in crystalline host rock place more emphasis on buffer performance than countries that propose to construct repositories in argillite. In crystalline rock, potential transport in the far field may be significantly higher than transport in argillite. Buffers in argillite repositories are generally for mechanical stability rather than for limiting transport because the host rock offers many of the same beneficial transport features as the bentonite.

Discussions on buffer performance revolved around processes in which a bentonite buffer may not perform as designed. The first discussion provided an overview, context, and description of buffer evolution. The second, third, and fourth discussions focused on limiting groundwater flow, evolution of the geochemical environment, and waste package/buffer interactions. Processes during the thermal period may create fast pathways where advective transport may dominate over the expected diffusive transport. The pathways may be created by heterogeneities in the emplaced buffer (e.g., stacking of compacted bricks), stress field, saturation state, gas generation, and the geochemical processes of precipitation, dissolution, and mineral alteration. The reversibility and timing of potential resealing of pathways are important uncertainties. The thermal management of a potential repository was stressed as a major factor because above-boiling conditions significantly reduce clay swelling. The evolution of a bentonite buffer is affected by the composition of the clay minerals in the bentonite (Na-montmorillonite versus Ca-montmorillonite), composition of water during wetting and subsequent periods, temperature, and the diffusion and flow rates through the bentonite. Waste package/buffer interactions are affected by the geochemical environment adjacent to the waste packages as well as microbial activity. Corrosion of steel waste packages may generate hydrogen gas that may affect buffer performance by creating mechanical disruptions that could facilitate later advective water flow. The fifth discussion focused on interactions of a bentonite buffer with cement and steel. Key safety and feasibility issues with a Portland cement buffer in the Belgian supercontainer design concept were also discussed.

The extent and duration of fast paths prior to resealing by clay swelling, extent of changes in properties of bentonite, and long-term stability from possible erosion of buffer materials were listed as areas of uncertainty important to buffer performance. There also was uncertainty with regard to effects of localized corrosion and stress corrosion cracking on waste packages because the majority of prior investigations have focused only on uniform corrosion.

Selected information sources include:

- Safety Functions, Buffer Evolution, and Performance Issues and Limiting Ground Water Flow includes: ANDRA (2005a); and SKB (2011); Posiva Oy (2006); OECD/NEA (2003a).

- Evolution of Buffer Geochemical Environment includes: Eberl (1978); Jo (2004); Karnland and Birgersson (2006); Laine and Karttunen (2010); Neretnieks, et al. (2009); Pusch and Karnland (1988); and Savage, et al. (2007).

- Buffer-Waste Package Interactions includes: ANDRA (2005a,b,c); Hedin (2010); King, et al. (2001); Kursten, et al. (2004); Shoesmith (2009) ; Videla and Herrera (2005) ; Wersin, et al. (1994); Yang, et al. (2004).

- Bentonite Buffer – Interactions with Cement and Steel includes: OECD/NEA (2003b); Towler, et al. (2009); Wacquier, et al. (2011); and Wickham (2008).

5 SEALS AND BACKFILL

The functions and type of materials used for seals and backfill were discussed. In repository designs, materials for seals and backfills often include bentonite or bentonite-sand mixtures, but can also include concrete, crushed rock, and compacted soil. For the bentonite components, some of the same processes may occur in seals and backfill as occurs in buffers, though processes affected by temperature should be prominently reduced.

Associated performance issues were addressed. Seals and backfill can be used for several purposes. The major functions of seals and backfill are to provide hydrologic and physical isolation from other tunnels/shafts, to provide mechanical stability of the tunnel/shaft, and to limit access to areas. A major performance issue is flow bypassing the excavation damaged zone (EDZ) around the contact of the seal/backfill with the tunnel/shaft. Another issue is forming tight compacted packs of material; there is generally limited space available to do this. Using preformed bentonite blocks may leave openings between the blocks, resulting in preferred flow pathways with advective flow conditions.

Selected information sources include: Dixon, et al. (2007); Martino, et al. (2007); and SKB (2010).

6 INTERNATIONAL ACTIVITIES

This discussion focused on international projects related to buffers, backfill, and seals and underground field tests. The first portion focused on activities at underground facilities and international collaboration opportunities. Important prior, ongoing, and proposed tests in Belgium, Switzerland, France, Sweden, Japan, Korea, Canada, Spain, China, and the Czech Republic were presented in tables. Several active field and laboratory tests on buffers and seals were discussed, including proposed tasks for the international collaboration DECOVALEX-2015 (i.e., HE-e test at Mont Terri and SEALEX test at Tournemire). The second portion of the discussion focused on the types of bentonite clay used in field tests and the tests indicating the extent (or lack thereof) of mineral alteration of the smectite clays in bentonite at temperature conditions above boiling. Some countries' repository designs are constrained to temperatures below the boiling point of water. Some field thermal tests extend to temperatures above boiling, but are below approximately 135 °C [275 °F]. At temperatures above boiling, both desaturation of intergranular water and illitization (dehydration of smectite clays) more readily occur; both of these processes lead to reduced swelling of the clays. The extent of illitization is dependent on time (kinetics) and temperature. The primary uncertainties are the extent of and the reversibility of features caused by evaporation of water or mineral alteration.

NRC involvement in the next phase of the DECOVALEX international collaborative project is thought to provide a good opportunity for furthering knowledge on bentonite buffer performance and leveraging international expertise and experience. Another collaborative group focusing on clay is the Clay Club, which was established by the Nuclear Energy Agency (NEA) as a working group on argillaceous media.[1] An important issue for bentonite buffer performance is the expected peak temperature and duration above boiling, because the U.S. program is currently not constrained to a thermal strategy that limits peak temperatures to below boiling. Staff identified a possible gap in the extent of data supporting desaturation of buffer and alteration of smectite clay at temperatures above the boiling point of water. Evaluating the results of the laboratory tests in Sweden is an avenue to resolving the gap. Another avenue may be to perform laboratory tests on FEBEX-type bentonite at temperatures well above the boiling point of water.

[1] http://www.oecd-nea.org/rwm/clayclub/

Selected information sources include: Manepally, et al. (2011); Laine and Karttunen (2010); Pusch, et al. (2010); Lee, et al. (2010); and Gomez-Espina and Villar (2010).

7 REPRESENTATION OF BUFFER AND BACKFILL IN PERFORMANCE ASSESSMENT MODELS

Discussions focused on (i) how other countries address buffers in performance models; (ii) the NRC approach to performance assessment [Scoping of Options and Analyzing (SOAR)]; and (iii) important buffer-related processes to consider, whether by detailed modeling or abstractions, in a performance assessment. The approaches by Sweden, Switzerland, and France were given more attention because these countries have conducted performance assessments. Diffusive transport through buffer material was the primary mechanism these countries considered. Typically, detailed process modeling was conducted to develop parameters that could be employed in more simplistic performance models of the near and far field. Potential failure modes for the Swedish performance assessment were fluid flow by advection, frozen conditions, and clay transformation into a less swelling clay mineral. The latter two failure modes were not considered in any numerical analyses, because they were thought to have a very low probability and could be bounded by other considerations. In the Swedish performance assessment, the advection fluid flow scenario was modeled by assuming that the buffer did not offer any retardation of radionuclide migration away from a failed waste package. The performance approaches of other countries can be summarized as (i) subsystem performance metrics and criteria supported by detailed process-level modeling, (ii) reference case total performance where the buffer performs as designed, and (ii) alternate or altered state scenario analysis where buffer performance is degraded due to identified conditions or processes.

Recently, NRC developed SOAR model to provide insights into an efficient and effective regulatory program for SNF and HLW disposal. The buffer submodel in SOAR that considers radioactive transport through a diffusive barrier (i.e., the buffer) was discussed in detail. The nominal case considers diffusive transport; the degraded case considers advective transport. Disruptive events also are considered. Results of the simulations are used to evaluate risk significance of issues and features. In the future, SOAR may be revised to consider processes or events not currently modeled.

Important considerations in any performance assessment model for the thermal period are thermal conductivity and hydrologic property alterations and associated mechanical effects. Other factors to consider are saturation of the buffer, gas entrapment, and microbial activity. Important considerations for the postclosure period are resaturation of the buffer after any thermal pulse (clay swelling and sealing of voids), long-term transformation of clay minerals and associated effects, attainment of anaerobic conditions, and microbial activity.

Selected information sources include: SKB (2011); NAGRA (2002); and ANDRA (2005a,c).

8 SUMMARY OF KEY UNCERTAINTIES

Workshop attendees had opportunities to discuss, add, or expand on uncertainties that may help staff develop efficient resolution or understanding of key technical issues, or create more robust products that consider multiple viewpoints. Key uncertainties are those that may be important to performance of a repository. Some of the key uncertainties identified, both during the topical discussions and at a round-table discussion at the end of the workshop, are

- Extent and spatial variability of potential changes in bentonite clay properties due to geochemical and thermal conditions (important properties are swelling, fast flow path development, sorption potential, and saturated hydraulic conductivity)

- Prioritization of performance issues associated with the spatially nonuniform bentonite buffer caused by emplacement method, saturation field, stress field, mineral alteration, precipitation/dissolution of minerals, ion exchange, and gas buildup

- Development of constitutive models that link mechanical-geochemical-hydrological properties for incorporation in numerical codes for predicting radionuclide migration through porous media

- Kinetics of smectite-to-illite-type transformations for temperatures above the boiling point of water

- Effect of enhanced flow and transport through an EDZ

- Effects on localized and stress corrosion cracking of waste packages caused by conditions at bentonite contact with waste package

- Potential for and extent of erosion of bentonite buffers in fractured crystalline rock repositories

- Estimating water flow through backfill openings

- Continual updating of database of current information, such as new designs of international programs and performance assessments, results of laboratory and field tests, and their implications

- Effects of gas generation from waste package corrosion on buffer material

- Likelihood of microbial activity, especially at lower temperatures

- Assessment of adequacy of abstractions used in performance assessment models, especially SOAR, for evaluating potential risks of complex processes

- Range of bentonite properties, especially those that are readily incorporated into SOAR to reflect buffer evolution and processes (this may best be accomplished by development of a database of properties for common bentonite buffer material)

Furthermore, involvement in international collaborative programs, such as DECOVALEX, and participation in other groups, such as the NEA Clay Club, are approaches to understand ongoing and future investigations and development activities to address knowledge gaps and uncertainties.

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APPENDIX A

AGENDA FOR NRC/CNWRA BUFFER AND BACKFILL MEETING
AUGUST 17, 2011

Executive Blvd. Building; NRC Headquarters, Rockville, Maryland
NRC: Videoconference Room EBB–2–C19
CNWRA: Videoconference Room A237

The purpose is to evaluate gaps in the understanding and areas of high uncertainty in the long-term performance of barriers so that an integrated regulatory framework can quickly be developed to address any potential change in the national spent nuclear fuel and high-level nuclear waste programs.

Visitors to NRC check in at guard desk at 8:30 am (ET)

Time (ET)	Topic
9:00 am	Introduction (R. Lenhard)
9:10 am	Fundamental Features of Buffer, Backfill, and Seals (C. Manepally)
9:30 am	Properties of Buffer Material (R. Lenhard)
10:10 am	Break
10:20 am	Buffer Performance Topics
	Safety Functions, Buffer Evolution, and Performance Issues (R. Fedors)
	Limiting Groundwater Flow Bentonite Buffer (R. Fedors)
	Evolution of Buffer Geochemical Environment (R. Pabalan)
	Bentonite Buffer – Interactions with Cement and Steel (D. Galson)
	Buffer-Waste Package Interaction (K. Chiang)
12:30 pm	Lunch
1:30 pm	Seals and Backfill (G. Ofoegbu)
1:50 pm	International Activities (R. Fedors)
2:10 pm	Bentonite Clay in Underground Research Laboratory Tests (J. Bradbury)
2:35 pm	Break
2:50 pm	Representation of Buffer and Backfill in Performance Assessment (PA) Models (C. Markley)
	Representation of the Buffer in PA in other Countries (D. Galson)
3:30 pm	Summary of Key Uncertainties
4:30 pm	Adjourn

APPENDIX B

SPECIAL JOURNAL VOLUMES

Landais, P. and J.F. Aranyossy. "Clay in Natural and Engineered Barriers for Radioactive Waste Confinement—Part 1." *Physics and Chemistry of the Earth, Parts A/B/C*. Vol. 32. Issues 1–7. 2007.

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