Overview of Features, Events, and Processes Affecting the Postclosure Performance of a Deep Borehole Disposal Facility - 17168

Laura Price*, Geoff Freeze**, and Ernest Hardin***
* Sandia National Laboratories (llprice@sandia.gov)
**Sandia National Laboratories (gafreez@sandia.gov)
***Sandia National Laboratories (ehardin@sandia.gov)

ABSTRACT

The United States Department of Energy's Office of Nuclear Energy (DOE-NE) is evaluating the feasibility of disposing of smaller DOE-managed waste forms in 5-km deep boreholes drilled in crystalline rock. It is thought that both the depth and the geological conditions at that depth will serve to isolate the waste from the accessible environment after the disposal facility is closed. This paper discusses the features, events, and processes (FEPs) that could affect the postclosure performance of a deep borehole disposal (DBD) facility and identifies those that would likely need to be considered in the context of conducting a performance assessment analysis.

INTRODUCTION

Some of the wastes that must be managed by the United States Department of Energy have been identified as good candidates for DBD in crystalline rock [1]. In particular, 1,936 capsules containing cesium (Cs) and strontium (Sr) are good candidates for disposal in a deep borehole in crystalline rock because of their size and shape; all 1,936 capsules could be disposed of in a single borehole. Applicable disposal requirements have not yet been identified; however it is reasonable to assume that the requirements will include conducting postclosure performance assessment analyses. The postclosure period for DBD would begin after packages are emplaced in the borehole and the borehole has been sealed and plugged. The performance assessment analyses would likely require inclusion of all FEPs that could potentially affect the postclosure performance of the capsule-containing borehole. The purpose of this paper is to discuss these FEPs and identify those that would likely need to be considered in the postclosure performance assessment analyses.

DISCUSSION

At its most basic, the DBD concept consists of drilling a large diameter borehole to a depth of 5,000 m in crystalline basement rock, emplacing waste packages in the lower 2,000 m of the borehole, and then sealing the upper 3,000 m of the borehole with a combination of bentonite, cement plugs, and cement/crushed rock backfill. As shown in Figure 1, the DBD system is intended to be several times deeper than typical mined repositories. For reference, the dashed blue line shows the typical maximum depth of fresh groundwater resources.

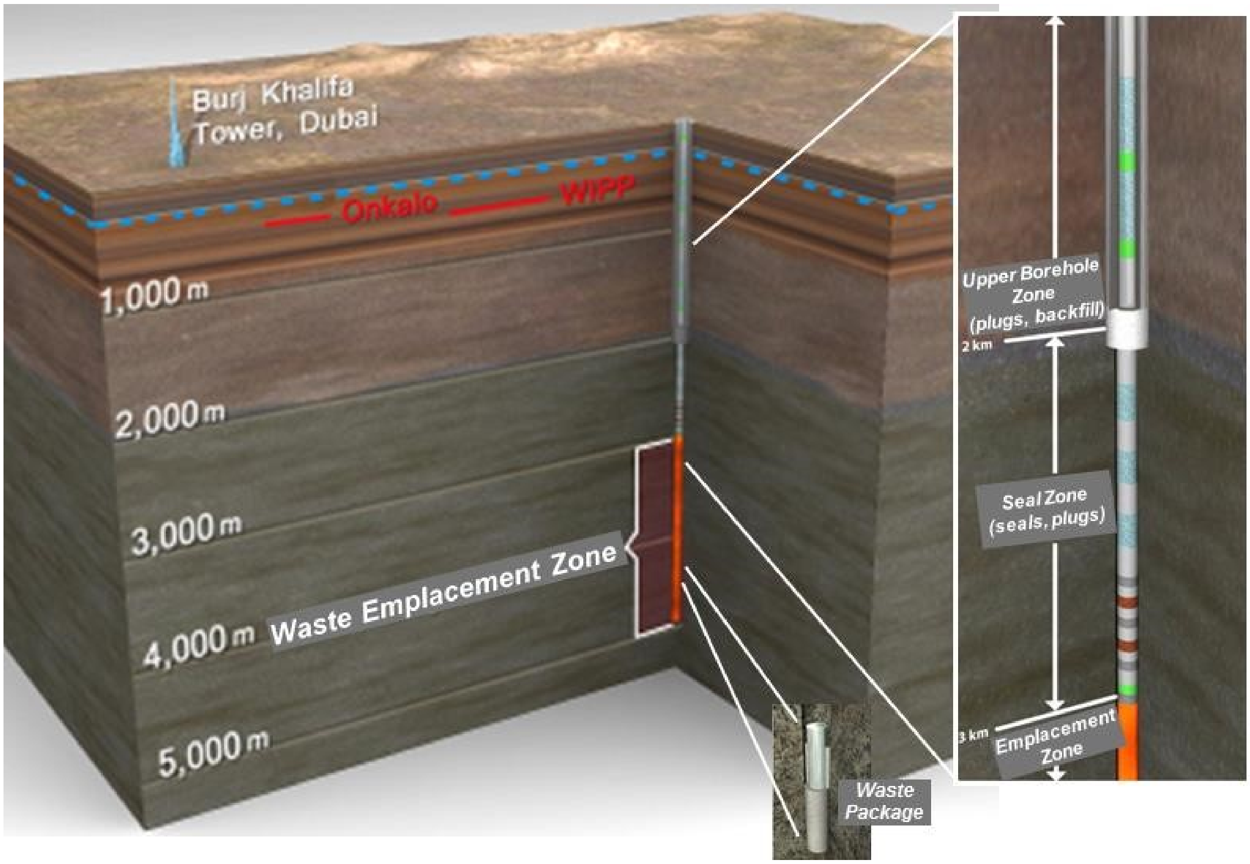

Fig. 1. Generalized Schematic of the Deep Borehole Concept [2]

Waste packages disposed of in a deep borehole would have to withstand an extreme environment. The ambient temperature at a depth of 5,000 m may be as high as 170°C (340°F) [3]. The hydrostatic pressure at a depth of 5,000 m is expected to be between 50 MPa (490 atm) and 65 MPa (640 atm). The fluids at a depth of 5,000 m are expected to consist of high ionic strength chloride brines, and reducing conditions are also expected to prevail [4].

Waste packages must also be small enough to fit in the borehole and accommodate the selected emplacement method. For a 5,000 m borehole, several different bottom-hole diameters have been suggested, ranging from 22 cm (8.5 in.) to 56 cm (22 in.) [5]. After accounting for the casing that would be installed in the emplacement zone of the borehole, this bottom-hole diameter would accommodate a waste package with an outer diameter ranging from 11 cm (4.5 in.) to 36 cm (14.2 in.) [5].

For the purposes of this paper, it is assumed that applicable disposal requirements will require that the postclosure performance assessment analyses provide a quantitative estimate of (i) radiological exposures to members of the public, and (ii) radiological releases to the accessible environment. This quantitative comparison to safety standards includes an analysis of the FEPs that could affect the release of radionuclides to members of the public and to the accessible environment. A formal FEP analysis includes [6]:

- FEP identification – the development and classification of a comprehensive list of FEPs that cover the entire range of phenomena that are potentially relevant to the long-term performance of a repository system, and
- FEP screening – the specification of a subset of important FEPs that individually, or in combination with other FEPs, contribute to long-term performance of a repository system.

A set of FEPs for a range of generic disposal systems being investigated by DOE-NE is identified by [7] and [8]. These generic FEPs were derived from other previously developed lists [9, 10, and 11]. These generic FEPs were modified to create a set of FEPs applicable to DBD. The modifications included: (1) re-organizing the UFD FEPs in accordance with a new organizational structure, the FEP classification matrix [6, 12], and (2) creating a set of DBD-specific FEPs from the generic matrix-based FEPs. A modified FEP classification matrix for DBD is shown in Table I. The check marks in Table I indicate that a FEP or set of FEPs has been identified for the associated feature and process or event.

FEP screening may involve quantitative analyses and/or reasoned arguments. The important FEPs must be included in (screened in) the post-closure PA model. The exclusion of a FEP from the performance assessment model (e.g., by low probability, by low consequence, or by inconsistency with regulation) must be supported by a defensible rationale or justification. The preliminary screening decisions discussed below are based on the non-site-specific DBD reference case and the current performance assessment model implementation [2]. The FEP screening decisions will be iteratively updated as design and site-specific information become more refined. For this preliminary, generic DBD reference case, five categories of screening decisions are used:

- Included – A FEP that is likely to be screened in to the performance assessment model, based on the reference design, engineered and/or natural barriers, and is in the current performance assessment model implementation.
- Included (Deferred) – A FEP that may need to be included in the performance assessment model, but the implementation is deferred to a future iteration of the performance assessment model.
- Excluded (Low Consequence) – A FEP that is likely to be screened out of the performance assessment model because it is not expected to have a significant effect on on post-closure repository performance, based on the reference design/design factors, site selection criteria, and/or engineered and/or natural barriers.

TABLE I. FEP Matrix Structure for DBD (adapted from [6])

Characteristics, Processes, and Events / Features / Components		Processes											Events					
	Characteristics	Mechanical and Thermal-Mechanical	Hydrological and Thermal-Hydrologic	Chemical and Thermal-Chemical	Biological and Thermal-Biological	Transport and Thermal-Transport	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities (Long Timescale)	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities (Short Timescale)	Other
	CP	**TM**	**TH**	**TC**	**TB**	**TT**	**TL**	**RA**	**LG**	**CL**	**HP**	**OP**	**NC**	**EF**	**SM**	**IG**	**HE**	**OE**
Waste and Engineered Features																		
Waste Form and Cladding	✓	✓	✓	✓	✓	✓	✓	✓		✓					✓	✓		
Waste Package and Internals	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	
Emplacement Zone Workings	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	
Seals and Plugs	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	
Geosphere Features																		
Host Rock	✓	✓	✓	✓	✓	✓			✓	✓			✓		✓	✓	✓	
Overlying Geologic Units	✓	✓	✓	✓	✓	✓			✓	✓					✓	✓	✓	
Surface Features																		
Biosphere	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓		
System Features																		
Repository System	✓	✓	✓	✓										✓			✓	✓

- <u>Excluded (Low Probability)</u> – A FEP that is likely to be screened out of the performance assessment model because it is expected to have a low probability of occurrence based on the reference design/design factors, site selection criteria, and/or engineered and/or natural barriers.
- <u>Excluded (by regulation)</u> – A FEP that is likely to be screened out of the performance assessment model because it is inconsistent with conditions expected to be specified in the regulations.

A preliminary screening of these DBD FEPs is summarized, organized by the major features and components of the DBD system shown in Table I. A complete discussion can be found in Appendix E of [2].

It should be noted that human intrusion is commonly addressed by a stylized calculation, typically specified by regulation. Regulations for human intrusion at a DBD facilityhave yet to be specified; however, consideration of human intrusion is likely to be limited to *inadvertent* intrusion. Therefore, *deliberate* human intrusion is excluded by regulation.

Waste Form and Cladding

In the DBD reference case, the waste form consists of Cs and Sr capsules. These capsules contain CsCl (1,335 capsules) and SrF_2 (601 capsules). The CsCl was melt-poured and is glass-like, while the SrF_2 is a compacted granular salt. The waste inside the capsules is doubly-encapsulated (i.e., a capsule within a capsule). The capsules are made of either 316L stainless steel or Hastelloy®[1] C-276; the caps on the end of the capsules have been welded in place. The outer diameter of the capsules ranges between 5.72 cm (2.25 in.) and 8.26 cm (3.25 in.), while the length of the capsules ranges between 48.39 cm (19.05 in.) and 55.44 cm (21.83 in.). Information regarding the power, radioactivity, and dose rate characteristics of the Cs and Sr capsules is shown in Table II. The isotopes of concern are Cs-137, mBa-137, Cs-135, Sr-90, and Y-90. mBa-137 is in secular equilibrium with its parent, Cs-137, and Y-90 is in secular equilibrium with its parent, Sr-90. The half-lives of Cs-137 and Sr-90 are about 30 years, making them primarily a concern for storage, transfer, transportation, and the preclosure phases of disposal. The half-life of Cs-135 is 2,300,000 years, making it of concern primarily for the postclosure period. It is estimated that each capsule contains, on average, 245 g of Cs-135 [2]. These isotopes are not fissile; therefore, criticality is not possible and is excluded on the basis of low probability for all features and components.

Because the waste form is the Sr and Cs capsules, no events and processes related to SNF and cladding or to vitrified HLW are included; only those events and processes related to the Cs and Sr capsule waste form are considered for inclusion in the postclosure performance assessment.

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[1] Hastelloy is a registered trademark of Haynes International, Inc.

TABLE II. Radioactivity, Heat Generation, and Dose Rate Characteristics of Cs and Sr Capsules as of January 1, 2016 [13]

Capsule Type	Number of Capsules	Statistical Parameter	Power (W)	Cs or Sr Activity (Ci)	Surface Dose Rate[b] (rem/h)	Dose Rate at 3 ft from Capsule[b] (rem/h)
CsCl	1335	Average	118.6	2.51×10^4	6.34×10^5	4.81×10^3
		Standard Deviation	11.6	2.5×10^3	6.31×10^4	4.79×10^2
		Minimum	13	2.8×10^3	7.07×10^4	5.37×10^2
		Maximum	161	3.42×10^4	8.63×10^5	6.56×10^3
SrF_2	600[a]	Average	157.1	2.35×10^4	2.92×10^4	6.50×10^2
		Standard Deviation	82.4	12.3×10^3	1.53×10^4	3.40×10^2
		Minimum	18	2.7×10^3	3.36×10^3	7.46×10^1
		Maximum	411	6.14×10^4	7.64×10^4	1.70×10^3

[a] Does not include one SrF_2 capsule that is a tracer and contains no radioactive Sr and, thus, emits no heat.

[b] Dose rate estimations performed at Oak Ridge National Laboratory.

For the postclosure performance assessment analyses, the characteristics of the waste form will be included: geometry, radionuclide inventory in 2050, radioactive decay and ingrowth, heat generation from radioactive decay, chemistry, waste form materials, etc. Because the CsCl and SrF_2 are salts and are not likely to act as a barrier or an impediment to radionuclide dissolution and transport, it is assumed that the radionuclides are available for instantaneous and complete dissolution in the fluid in the emplacement zone once the waste package is breached. No solubility limit is imposed for CsCl or SrF_2, and both isotopes of Cs are assumed to be completely dissolved. Likewise, the metal capsules currently containing the salt are not assumed to act as a barrier or an impediment to radionuclide dissolution and transport. Conduction and convection of the heat generated by the waste are included in the performance assessment calculations, as is the temperature dependence of fluid density and viscosity.

Colloids may be present once the waste package fails and could transport radionuclides; however, colloidal transport was not included in the current postclosure performance assessment model. Therefore, the transport of radionuclides on colloids is included but deferred. In addition, alteration of water chemistry from radiolysis and from chemical interactions with the metal capsule components of the waste form were not included in the current postclosure performance assessment model, but could be if their effects are found to be significant. Therefore, alteration of water chemistry from radiolysis and from chemical interactions with the metal components of the waste form are included but deferred.

Once the waste package fails, the waste form will be in a liquid-saturated environment; therefore, events and processes related to fluid flow and radionuclide transport in an unsaturated environment are excluded on the basis of low probability. Generation of H_2 (e.g., from corrosion of metal components) is excluded on the basis of low consequence because it is expected that the borehole design, disturbed rock zone, and host rock properties will permit dissipation of gas such that overpressurization does not occur. Events and processes related to microbial activity are excluded on the basis of low probability because the expected temperature in the waste form (up to 240°C with decay heat) [2] exceeds the maximum temperature at which known microorganisms can exist in an active state, 110°C [14]. Disruptive processes and events (e.g., low probability igneous events) were excluded on the basis of low probability because their effects would be precluded by the site selection criteria [2]. The waste produces neither neutrons nor alpha particles, so events and processes related to neutron activation and helium generation from alpha decay are excluded on the basis of low probability.

Waste Package and Internals

The waste package reference design assumes 18 Cs or Sr capsules per waste package, stacked in six layers of three capsules, as shown in Figure 2. The cylindrical part of the waste package is to be constructed of oilfield casing, which is available in a variety of materials. Although final material selection will depend on site-specific properties such as formation temperature and fluid chemistry, the reference design assumes carbon steel casing (P110 grade) with an outside diameter of 0.219 m (8.625 in) and an inside diameter of 0.171 m (6.751 in), which has sufficient strength to withstand hydrostatic pressure at the base of the borehole [15]. The reference design waste package length is 4.76 m, which includes 3.76 m for the 6 layers of capsules, a 0.3-m long fishing neck, and a 0.7-m-long impact limiter. For the reference design, 108 such waste packages are necessary to dispose of all Cs/Sr capsules: 74 containing the 1,335 Cs capsules and 34 containing the 601 Sr capsules.

For the postclosure performance assessment analyses, the characteristics of the waste package will be included as necessary; current performance assessment calculations are based on the assumption that the waste package fails at the beginning of the postclosure period (i.e., right after the borehole is closed). At the time of waste package breach, the entire inventory of radionuclides in that waste package is assumed to be dissolved in the fluid in the waste package; solubility limits are not imposed for any isotopes. The thermal properties of the waste package materials are included in the thermal analyses.

As in the waste form, transport of radionuclides on colloids in the waste package is included but deferred, as is alteration of the emplacement fluid chemistry from radiolysis and from chemical interactions with metal components of the waste package. Because waste packages are assumed to fail at the beginning of the postclosure period, events and processes associated with early failure of the waste package (e.g., manufacturing defects) are not currently modeled; however, these events and processes may be included in future postclosure performance assessment models.

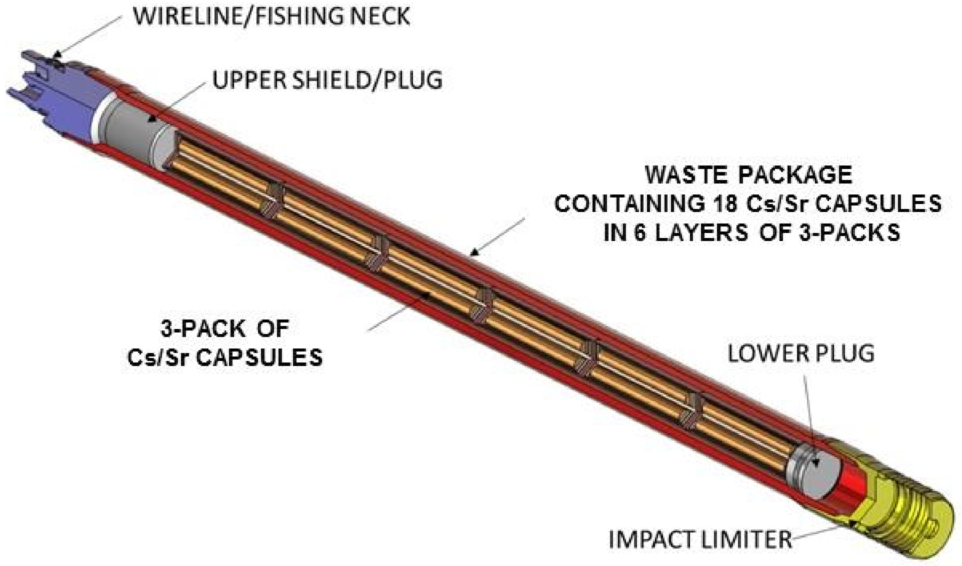

Fig. 2. Schematic of a Waste Package for Cs/Sr Capsules [2]

Because the waste package is assumed to fail right after the borehole is closed, the various *in situ* processes and events that contribute to waste package failure (e.g., mechanical damage) are not modeled explicitly; their effects are “included” by assuming failure of the waste package one year into the postclosure period. However, these *in situ* events and processes may be included in future postclosure performance assessment models. In addition, the waste package is similar to the waste form in that events and processes related to fluid flow and radionuclide transport in an unsaturated environment are excluded on the basis of low probability, as are microbial processes, and disruptive processes and events, and processes and events related to neutron activation and helium generation from alpha decay. Generation of H_2 is excluded on the basis of low consequence, for reasons similar to those discussed above for the waste form.

Emplacement Zone Workings

The emplacement zone workings include the emplacement fluid, the liner that is emplaced prior to waste package emplacement, and 10-m high cement plugs that are installed after every set of 40 waste packages. In the DBD reference design, the emplacement fluid is a high density brine, the liner is fabricated from steel, and the cement plugs consist of low permeability cement.

In the current postclosure performance assessment analyses, the liner is not represented in the model. Instead, the entire annular space between the waste package and the borehole wall is modeled as being filled with the emplacement fluid. Otherwise, the characteristics of the emplacement zone are included:

geometry, materials, chemistry, and flow and transport properties. Upward flow of emplacement fluid from thermal expansion and buoyant convection is included. Transport of radionuclides from the waste package through the emplacement zone via advection, dispersion, and diffusion is included, as is radionuclide decay and ingrowth. As with the waste form and the waste package, the isotopes of interest are assumed to be dissolved in the fluid; solubility limits are not imposed. Although there is very little water in the tight host rock, dilution of emplacement fluid by water from the host rock is included. The cement plugs placed between stacks of waste packages are assumed to be degraded; this is represented by using an enhanced cement permeability. Conduction and convection of heat generated by the waste through the emplacement zone, both in the emplacement fluid and the cement plugs, is included.

As in the waste form and waste package, transport of radionuclides on colloids in the emplacement zone is included but deferred, as is alteration of the emplacement zone chemistry from radiolysis and from chemical interactions with metal components of the waste package. Interactions with organic complexants in the emplacement zone will be included if necessary, but is deferred. Alteration of emplacement fluid chemistry and cement chemistry because of interaction with the host rock is also included but deferred. Hydrologic and chemical effects of borehole breakout are included but deferred. Sorption of Sr and Cs is not currently included in the emplacement zone, although it might be included in a future iteration. Finally, potentially important events and processes related to the emplacement zone liner, which is not included in the current postclosure performance assessment model, are included but deferred.

In addition, the emplacement zone is similar to the waste package and the waste form in that events and processes related to fluid flow and radionuclide transport in an unsaturated environment are excluded on the basis of low probability, as are microbial processes and disruptive processes and events. Generation of H_2 is excluded on the basis of low consequence, for reasons similar to those discussed above for the waste form. Mechanical effects of borehole breakout are excluded on the basis of low consequence, as the waste package has already failed.

Seals and Plugs

The seals and plugs include the bentonite seals, cement plugs, ballast (crushed rock backfill), casing, and casing cement that are emplaced in the borehole above the emplacement zone. Seals and plugs will be present in the seal zone (against the crystalline rock) and in the upper borehole zone (against the sediments overlying the crystalline rock) (see Figure 1). The current postclosure performance assessment model includes only the 1,000-meter interval of the seal zone directly above the emplacement zone, which is assumed to be saturated.

For the postclosure performance assessment analyses, the characteristics of the seals and plugs will be included: geometry, materials and their properties, fluids and their properties, fluid flow and radionuclide transport properties. Upward flow of emplacement fluid from thermal expansion and buoyant convection is included, which means that the temperature dependence of fluid density is also included. Transport of radionuclides from the waste package in fluid through the seals and plugs zone via advection, dispersion, and diffusion is included, as is radionuclide decay and ingrowth. As with the waste form and the waste package, the isotopes of interest are assumed to be dissolved in the fluid; solubility limits are not imposed. Although the effect is small, dilution of emplacement fluid by water from the host rock is included. The seals and plugs are assumed to be degraded; this is currently represented by using an enhanced permeability. Sorption of both Cs and Sr onto bentonite is included in the postclosure performance assessment model; sorption onto other materials in the seals and plugs is included but deferred. Conduction and convection of heat generated by the waste through the seals and plugs is included.

For any portions of the seals and plugs that may be in an unsaturated environment, events and processes related to fluid flow and radionuclide transport in an unsaturated environment will be included as needed. For portions of the seals and plugs that are shallow enough to be affected by surface events and processes (e.g., infiltration), these events and processes will be included as needed. Microbial activity is excluded for portions of the seals and plugs with a temperature above 110°C, and included as needed for portions of the seals and plugs with lower temperatures. Interactions with organic complexants in the seals and plugs will be included if necessary, but is deferred.

As in the waste form, the waste package, and the emplacement zone, transport of radionuclides on colloids in the seals and plugs is included but deferred, as is alteration of the emplacement fluid chemistry from radiolysis and from chemical interactions with components in the seals and plugs. Alteration of emplacement fluid chemistry and the chemistry of seals and plugs because of interaction with the host rock is also included but deferred. Hydrologic and chemical effects of borehole breakout are included but deferred. Damage to seals and plugs from seismic activity is included but deferred.

The radionuclides of concern are not expected to exist in the gas phase under the conditions expected in unsaturated portions of the seals and plugs; therefore, gas phase transport is excluded on the basis of low probability. Disruptive processes and events, and processes and events related to neutron activation and helium generation from alpha decay are also excluded on the basis of low probability, for reasons discussed previously. Generation of H_2 is excluded on the basis of low consequence, for reasons discussed above for the waste form. Alteration of the seals from thermal effects is excluded on the basis of low consequence as the maximum temperature increase in the seals and plugs is estimated to be 15°C at a point 2.5 m above the uppermost waste package [2].

Host Rock

The host rock includes the disturbed rock zone and the crystalline basement. The disturbed rock zone is the portion of the host rock adjacent to the borehole that experiences durable (but not necessarily permanent) changes due to the drilling/presence of the borehole (e.g., mechanical alteration due to drilling and borehole breakout, thermal-chemical effects from waste). In the current postclosure performance assessment model, the disturbed rock zone is assumed to extend 0.15 m beyond the borehole wall [2].

For the postclosure performance assessment analyses, the characteristics of the host rock will be included: geometry, stratigraphy, regional features, rock and fluid properties, groundwater chemistry. Upward flow of fluid from thermal expansion and buoyant convection is included, which means that the temperature dependence of fluid density is also included. Transport of radionuclides from the waste package through the host rock via advection, dispersion, and diffusion is included, as is radionuclide decay and ingrowth. As with the waste form and the waste package, the isotopes of interest are assumed to be dissolved in the fluid; solubility limits are not imposed in the current postclosure performance assessment model. Dilution of emplacement fluid by water from the host rock is included. The permeability of the disturbed rock zone is greater than that of the undisturbed host rock to reflect the changes in the rock from drilling or the presence of the borehole. Sorption of both Cs and Sr onto the host rock is included in the current postclosure performance assessment model. Conduction and convection of heat generated by the waste through the host rock is also included.

As in the waste form, the waste package, and the emplacement zone, transport of radionuclides on colloids in the host rock is included but deferred, as is alteration of the fluid chemistry from radiolysis and from chemical interactions with the host rock. Transport of radionuclides through discrete fractures is included but deferred. Damage to the host rock from seismic activity or non-intrusive human activity is included but deferred. For portions of the host rock that are shallow enough to be affected by surface events and processes (e.g., infiltration), these events and processes will be included as needed, but are deferred. For any portions of the host rock that may be in an unsaturated environment, events and processes related to fluid flow and radionuclide transport in an unsaturated environment will be included as needed, but are deferred. Interactions with organic complexants in the host rock will be included if necessary, but are deferred.

Microbial activity is excluded for portions of the host rock with a temperature above 110°C, and included (but deferred) as needed for portions of the host rock with lower temperatures. The radionuclides of concern are not expected to exist in the gas phase under the conditions expected in the host rock; therefore, gas phase transport is excluded on the basis of low probability. Disruptive processes and events (e.g., uplift and folding) and processes and events related to neutron activation and helium generation from alpha decay are also excluded on the basis of low probability, for reasons discussed previously. Generation of H_2 is excluded on the basis of low consequence, for reasons discussed above for the waste form.

Overlying Geologic Units

The overlying geologic units are assumed to be sedimentary in nature, and may contain aquifers or unsaturated units. Overlying geologic units were not included in the current postclosure performance assessment model because all radionuclides were contained within the host rock or seals and plugs for 10^8 years [2]; therefore, the following discussion of included or excluded processes and events pertains only to a future model in which it may be necessary to model overlying geologic units.

For the postclosure performance assessment analyses, the characteristics of the host rock will be included: stratigraphy, regional features, rock and fluid properties, groundwater chemistry, and presence of organic complexants, microbes, and colloids. Fluid flow in the overlying geologic units would be included; the nature of that flow will be site-specific. Transport of radionuclides through overlying units via advection, dispersion, and diffusion will be included, as would radionuclide decay and ingrowth. As with the waste form and the waste package, the isotopes of interest are assumed to be dissolved in the fluid present in the overlying units. Sorption of both Cs and Sr onto the overlying sediments would be included. Surface events and processes (e.g., recharge) will be included as necessary. Damage to the overlying geologic units from non-intrusive human activity would be included. Microbial activity would be included, as would radionuclide transport on colloids and the effects of organic complexants. For any unsaturated portions of the overlying geologic units, events and processes related to fluid flow and radionuclide transport in an unsaturated environment will be included as needed. For any portions of the overlying geologic units that serve as aquifers, human use and agricultural use of the water in the aquifer would be included.

Conduction and convection of heat generated by the waste through the overlying geologic units is excluded on the basis of low consequence because of the distance between the waste and the overlying geologic units, the amount of heat generated by the waste, and the half-lives of the heat-generating radionuclides. The radionuclides of concern are not expected to exist in the gas phase under the conditions expected in the overlying geologic units; therefore, gas phase transport is excluded on the basis of low probability. Disruptive processes and events (e.g., uplift and folding) and processes and events related to neutron activation and helium generation from alpha decay are also excluded on the basis of low probability, for reasons discussed previously. Generation of H_2 is excluded on the basis of low consequence, as H_2 would not be confined by sedimentary units.

Biosphere

The biosphere includes surface and near surface media and materials, flora and fauna, humans, and food and drinking water. These features are necessary for calculating dose to the receptor, which may include radionuclide movement above the subsurface. The biosphere was not included in the current postclosure performance assessment model because all radionuclides were contained within the host rock or seals and plugs for 10^8 years [2]; therefore, the following discussion of included or excluded processes and events pertains only to a future model in which it may be necessary to model the biosphere.

The biosphere would include surface effects as needed (e.g., seasonal freeze/thaw, filtration and recharge, transpiration); transport of radionuclides in air (as particulates or aerosols), in surface water, in soil or sediments, and in biosphere media (e.g., plants); human characteristics and lifestyle; and radiation doses to humans from ingestion, inhalation, an external exposure. The decision to include or exclude these events and processes would need to be made based on site-specific information.

Repository System

The repository system includes the assessment basis, preclosure and operational systems, and other systems. Characteristics of the borehole would be included, as would mechanical effects from emplacement and closure operations.

CONCLUSIONS

Using a reference DBD concept for Cs and Sr capsules, a comprehensive set of FEPs has been qualitatively evaluated to determine which of the FEPs should be included in a postclosure performance assessment analysis. In the absence of site-specific information, some processes can be identified as likely to be included: thermal conduction and convection, fluid flow from thermal expansion and buoyant convection; radionuclide transport in that fluid; radionuclide decay and ingrowth; radionuclide sorption on certain materials; and degradation of cement plugs and seals. Other processes and events are environment specific: microbial activity and unsaturated zone flow and transport. Still other FEPs require further site-specific information: the presence of colloids and radionuclide transport via colloids, the presence of organic complexants, and biosphere characteristics. Performing this preliminary FEPs screening provides a basis for future data collection as the DBD project moves forward.

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