

RAI Volume 3, Chapter 2.2.1.2.1, Fourth Set, Number 44:

The FEP 2.2.08.03.0A Geochemical Interactions and Evolution in the SZ is excluded from the performance assessment model based on low consequence (SAR Section 2.2 Table 2.2-5; SNL, 2008[b]). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

RAI #44: Assess the consequence of temporal changes in chemical composition of the groundwater on radionuclide concentrations resulting from changes in sorption/desorption reactions in the saturated zone. This information is needed to verify compliance with 10 CFR 63.114 (e).

Basis: The performance assessment model assumes constant K_d s at all locations in the saturated zone for each individual realization. Consequently, the effect of temporal changes in chemical composition of the groundwater on radionuclide concentrations in the saturated zone is not considered in the performance assessment model. The effect of temporal variability in K_d on radionuclide concentrations has not been evaluated in the screening argument for the FEP 2.2.08.03.0A Geochemical Interactions and Evolution in the SZ. Spatial variations in groundwater compositions can produce temporal variations when water moves along flowpaths. The FEP screening argument, however, does not assess the impact of the temporal variation of bulk water chemistry on radionuclide concentrations arising from changes in sorption/desorption reactions in the saturated zone.

1. RESPONSE

In support of the exclusion justification on the basis of low consequence to system performance for FEP 2.2.08.03.0A (Geochemical Interactions and Evolution in the SZ), this response addresses the potential for changes in groundwater composition to effect temporal changes to sorption in the saturated zone. The sorption distribution coefficient distributions used in the total system performance assessment (TSPA) are shown to include variability in groundwater composition and rock types that span the ranges observed along potential flow paths. Causes of temporal changes to sorption are explored and are shown to be inconsequential to performance. No realistic future scenarios have been identified whereby the magnitude of the changes to groundwater composition could cause a significant change to sorption/desorption in the saturated zone that would substantially affect dose to the reasonably maximally exposed individual (RMEI).

1.1 SORPTION IN THE SATURATED ZONE

Radionuclide sorption in the saturated zone is modeled using a sorption distribution coefficient, K_d , which represents the ratio of sorbed concentration to aqueous concentration for a specific rock type and radionuclide and assumes local equilibrium between sorbed radionuclides and

aqueous radionuclides (SAR Section 2.3.9.3.2.2). A high K_d value implies a high sorbed fraction and causes a pronounced retardation of radionuclide transport relative to groundwater velocity.

In the saturated zone transport model, two primary rock types are defined, tuff and alluvium. Cumulative distribution functions for K_d values were established for each radionuclide for each of these rock types. These distributions were largely determined based on the results of sorption measurements and were supplemented by PHREEQC chemical speciation modeling with additional external data that assessed the impacts of potential variations in groundwater chemistry (SAR Section 2.3.9.3.2.2). Uncertainties in the value of the sorption coefficients that arise from variabilities in mineral and groundwater compositions were included in these distributions, as explained in Section 1.1.1. Propagation of these uncertainties is discussed in Section 1.1.2.

1.1.1 Effects of Mineral and Groundwater Composition on Sorption

Variability of mineral and groundwater compositions and, especially, their potential effects on K_d values, is accounted for through the selection of K_d cumulative distribution functions used in the TSPA (SNL 2008a, Appendix A). These K_d distributions were developed by including information gathered from a large number of experimental sorption measurements that used different groundwater compositions from the site and rock samples collected from various cores in the saturated zone. K_d distributions account for measurements on zeolitic, devitrified, and vitric tuff samples and on alluvium samples having varying proportions of secondary minerals. The use in sorption experiments of two contrasting groundwater compositions, a relatively dilute groundwater from well UE-25 J-13 and a carbonate-rich groundwater from well UE-25 p#1, accounts for potential extremes in sorption behavior due to variability in water compositions. The bicarbonate concentration, which is approximately 130 mg/L for UE-25 J-13 and approximately 700 mg/L for UE-25 p#1 (SNL 2008a, Appendix I), plays an important role in both the solubility and sorption of radionuclides. In addition, the K_d distributions include pH uncertainty by including sorption measurements in which the pH varied from minimum values often around 6 or 7 to maximum values often around 9 or 10. To prevent overestimating adsorption in the saturated zone, the K_d ranges selected for most radionuclides are low relative to experimentally determined ranges (SNL 2008a, Section A8).

Chemical and isotopic compositions exhibit spatial variability that may be related to mixing of older and younger waters (SNL 2007a, Section A6.3.4). Mixing may occur when: (1) groundwater from adjacent flow paths is spread by dispersion and diffusion, (2) the groundwater passes beneath a recharge area, (3) deep groundwater moves upward because of head gradients, faults, or hydraulic barriers, or (4) groundwater from different areas converges toward either natural discharge areas or toward wells.

Groundwater pH

Groundwater pH in wells in the immediate vicinity and downgradient of the repository varies between about 7 and 9.2 (Table 1-1). Although pH values show no consistent trend along likely flow paths emanating from Yucca Mountain, values slightly higher than those observed in the vicinity of Yucca Mountain tend to occur more commonly near the southern boundary of the

saturated zone site-scale flow model (SNL 2007a, Figure A6-14, p. A-103). The highest pH values occur in the northernmost part of Fortymile Wash. Groundwater pH along Fortymile Wash shows an overall increase from values of about 7.2 to 7.6 directly east of Yucca Mountain to values greater than 8 near Fortymile Wash in the Amargosa Desert.

Anions

Groundwater analyses indicate low spatial variability for dissolved concentrations of bicarbonate (HCO_3^-), sulfate (SO_4^{2-}), and to a lesser degree, chloride (Cl^-) and fluoride (F^-), with concentrations remaining approximately constant or increasing southward along likely flow paths emanating from beneath the repository (Table 1-1). Yucca Mountain groundwaters generally have bicarbonate concentrations below about 175 mg/L, with the highest bicarbonate concentrations (greater than 200 mg/L) found near Solitario Canyon and near where Fortymile Wash meets the Amargosa Valley. Sulfate concentrations remain relatively constant along flow paths emanating from Yucca Mountain, with the highest concentrations found in wells near the southern boundary of the saturated zone site-scale flow model. Fluoride concentrations are highest in the vicinity of Yucca Mountain, decreasing to less than about 1.5 mg/L at the boundary. Chloride concentrations are lower near Yucca Mountain and marginally higher towards the southern boundary of the saturated zone site-scale flow model.

Cations

Groundwater concentrations of calcium, magnesium, and potassium tend to increase towards the south (SNL 2007a, Figures A6-20, A6-21, and A6-23). Calcium concentrations in Yucca Mountain groundwaters found along flow paths emanating from beneath the repository horizon average about 25 mg/L (Table 1-1). Dissolved calcium tends to increase away from Yucca Mountain towards the south, with calcium concentrations along Fortymile Wash less than 20 mg/L east and southeast of Yucca Mountain, increasing slightly near the southern boundary of the saturated zone site-scale flow model.

Magnesium concentrations along flow paths emanating from Yucca Mountain range from 0 to 3.3 mg/L with an average of 1.1 mg/L (Table 1-1). As is true for calcium, dissolved magnesium concentrations trend to slightly higher values towards the south.

Dissolved potassium concentrations along flow paths emanating from beneath the repository range between about 1 and 9 mg/L, with an average of 3.7 mg/L (Table 1-1). Dissolved potassium concentrations tend to increase along the length of Fortymile Wash east of Yucca Mountain and in the Amargosa Desert. Like calcium and magnesium, the trend for dissolved potassium is to increase slightly towards the south, although slightly elevated values (6 to 9 mg/L) have been measured in wells just east and southeast of Yucca Mountain.

Groundwater Ages

Changes in flow regime or dramatic changes in meteoric influx are potential mechanisms by which groundwater chemistry might change in the future. Isotopic compositions of groundwaters are discussed in *Saturated Zone Site-Scale Flow Model* (SNL 2007a, Appendix A),

where the ages of groundwaters, though not rigorously constrained, are consistent with being on the order of 10,000 to 15,000 years (SNL 2007a, Table A6-7, p. A-173), suggesting stable long-term flow regimes with relatively little mixing from younger waters. Small fractions of “young” water (less than 1,000 years old) may be present in the saturated zone downgradient from the repository area, with estimates ranging from a low of about 2% to greater than 15% (SNL 2007a, p. A-175).

Redox Conditions

Redox potential (Eh) has a strong effect on the K_d values of redox-sensitive radionuclides such as actinides. Evidence exists for localized reducing zones in the saturated zone east of Yucca Mountain (SNL 2008a, Appendix F). In reducing environments, redox-sensitive radionuclides such as technetium, neptunium, uranium, and plutonium are much less soluble and have much higher K_d values. Data indicate that retardation coefficients for neptunium under reducing conditions are three orders of magnitude higher than they are under oxidizing conditions (SNL 2008a, Appendix F). Similar differences in retardation coefficient values under reducing conditions are likely for plutonium, technetium, and uranium. To ensure that radionuclide adsorption is not overestimated and radionuclide solubility is not underestimated, the TSPA assumes that groundwater along the transport path to the boundary of the accessible environment is oxidizing. In accordance with this assumption, the K_d distributions do not include sorption measurements performed under reducing conditions. Though local reduction zones might actually exist, these zones are not expected to be oxidized during the entire 10,000 years after repository closure. Thus, a large-scale change in oxidation state from that measured currently at Yucca Mountain is excluded on the basis of low consequence (SNL 2008b, p. 6-987).

Table 1-1. Variability of pH and Major Ions (mg/L) from 61 Wells Intersecting Likely Groundwater Flow Path(s) Emanating from below the Repository Horizon

	pH	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	CO ₃	F	SiO ₂
Min	7.1	0.2	0	37	1.1	5.2	14	110	0	0.9	(27)*
Max	9.2	25	3.3	120	(8.9)*	(12)*	(44)*	(274)*	(23)*	(6.7)*	62
Ave.	8.0	10.5	1.1	62.7	3.7	6.9	21.8	157.8	3.0	2.2	52.2
St. Dev.	0.5	7.0	1.1	23.3	1.5	1.4	5.0	36.3	5.8	1.2	7.0

Source: SNL 2007a, Appendices A and B, Tables A6-3 and B4-2.

* Extreme outlier (greater than three standard deviations above or below the mean).

1.1.2 TSPA Implementation and Results

In the TSPA, uncertainty in sorption is quantified and propagated through the performance assessment analyses by establishing and sampling from probability distributions of K_d values for each radioelement in volcanic tuff and in alluvium (SAR Table 2.3.9-4). These values were held constant for a given realization for each of the 200 radionuclide mass breakthrough curves that are generated using the saturated zone flow and transport abstraction model as input to the TSPA calculations, and for the saturated zone one-dimensional transport model that is also used for decay products in the performance assessment calculations (SNL 2008c, Section 8.1; SAR Section 2.3.9.1). It should be noted, therefore, that the performance assessment model does not

assume constant K_d values at all locations in the saturated zone for each individual realization because different values are defined for the tuff and alluvium.

The results of the TSPA calculations indicate that the principal contributors to the mean annual dose during the first 10,000 years after repository closure, ranked from highest to lowest, are: ^{99}Tc , ^{14}C , ^{239}Pu , ^{129}I , ^{36}Cl , ^{240}Pu , ^{79}Se , and ^{237}Np . The single largest contributor is ^{99}Tc , which accounts for about 51% of the maximum total mean dose; contributions from ^{99}Tc , ^{14}C , ^{129}I , and ^{36}Cl account for about 80% of the maximum total mean annual dose (SAR Section 2.4.2.2.1.1.3, Figure 2.4-20(a)). Note that ^{99}Tc , ^{14}C , ^{129}I , and ^{36}Cl are all nonsorbing radionuclides (SAR Section 2.4.2.3.2.1.10), so temporal variation in sorption reactions, if included in TSPA calculations, would not change the dose to the RMEI from these top contributors.

Of the remaining four radionuclides, contributions from ^{239}Pu , ^{240}Pu , and ^{237}Np account for about 17% of the maximum total mean annual dose (SAR Figure 2.4-20(a)). It should be noted that release rates of plutonium and neptunium from the saturated zone to the biosphere in the igneous intrusion modeling case are only very slightly sensitive to their respective K_d values in volcanics but not sensitive to their respective K_d values in alluvium (SNL 2008d, Figures K6.5.1-8(a) and K6.5.1-11(a)). ^{79}Se contributes about 3% to the maximum total mean annual dose (SAR Figure 2.4-20(a)).

1.2 TEMPORAL CHANGES TO SORPTION

Temporal changes are typically defined as changes at a specific location over time. Spatial changes are changes relative to an aliquot of water as it migrates along a flow path, and are included in the model by assigning different K_d values to different hydrostratigraphic units (volcanic and alluvium) along the flow path. Analyses show that K_d variation along the flow path within a unit is adequately represented by an effective K_d for the entire unit (SNL 2008a, Appendix C).

A temporal change in K_d values at a given location will either increase or decrease sorption at that location. Increased sorption is not a concern because it would enhance waste isolation if it were significant. No credit is taken in the TSPA model for excluding the potential for temporal increases in sorption. Alternatively, a temporal decrease in sorption would cause a net desorption of radionuclides and would act to increase radionuclide mobility. The TSPA model does not consider temporal decreases in sorption; however, if it did, the effect would be negligible as explained below.

1.2.1 Causes of Temporal Changes to Sorption

Changes to a K_d value at a specific location are caused by changes in the sorbent concentrations and/or changes in the groundwater composition. Relevant changes in sorbents include changes to mineral abundances and surface site concentrations. Relevant changes for groundwater include changes in pH, ionic strength, and concentrations of ions that compete for sorption sites and form aqueous radionuclide complexes. Changes in redox conditions (Eh) are excluded based on low consequence (Section 1.1.1), and changes in temperature are either too gradual or too

inconsequential to have a significant effect on groundwater compositions and sorption (Section 1.2.2).

Changes to mineral abundances and surface site concentrations in a porous or fractured medium involve mineral dissolution and/or precipitation. Core samples at Yucca Mountain indicate that the tuff minerals, predominantly alkali feldspars and silica minerals, slowly alter to secondary minerals, mostly zeolites and clays (Murphy and Pabalan 1994, Section 4.2.2). The presence of clays and zeolites in the tuff and alluvium tends to increase K_d values (SNL 2007b, Section A2). Therefore, alteration of tuff minerals to more thermodynamically stable secondary minerals is a process that tends to inhibit radionuclide transport.

For a decrease in sorption at a specific location over time, a temporal mineralogical change must involve a reduction in sorption site concentrations or alteration to minerals with sorption sites that have lower affinities for the radionuclides. This reduction could be caused by dissolution of secondary phases or alteration of these phases to less sorbent mineral assemblages. However, changes like these are not likely to occur without a major and sustained change in local conditions such as groundwater composition. First, secondary phases are generally stable and persistent as indicated by their formation and abundance in fractures. Second, although Ostwald ripening of secondary phases tends to generate minerals with decreased sorption capacity due to decreases in specific surface areas and sorption site concentrations, much of this ripening has already occurred, as evidenced by the increasing replacement of tridymite by cristobalite or quartz in fractures with depth (Murphy and Pabalan 1994, Section 4.2.1). In addition, poorly crystalline secondary phases with high specific surface areas and high sorption site concentrations are constantly being generated as the tuff continuously alters over time. Because a near-equilibrium steady-state condition controlled by slow alteration has been established for secondary minerals along potential flow paths over thousands of years, the secondary phases observed in core samples are not expected to change rapidly without a major change in the inputs that control the system.

The quasi-steady state at a particular location with respect to secondary phases can be disrupted by a major change in the incoming groundwater composition. For example, a shift in the pH of the incoming fluid could cause previously stable secondary phases to dissolve and new secondary phases to precipitate. However, such reactions are generally buffered by existing minerals. For example, albite ($\text{NaAlSi}_3\text{O}_8$), a common secondary mineral in the saturated zone (Murphy and Pabalan 1994, Section 4.2.1), when exposed to lower pH can be replaced with kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) according to the reaction:



However, this reaction slows and stops as protons are consumed and pH rises. Therefore, not only does the alteration require an increase in proton concentration, it also requires a sustained source of these protons to counteract the pH-buffering effect of the reaction. In other words, a small change in pH or key reactant concentration will have little or no effect on a mineral assemblage and its sorption properties unless the change can be sustained long enough to overcome the buffering capacity of an existing mineral assemblage.

Despite the buffering effect of mineral reactions, the resulting aqueous composition nevertheless will change if the incoming groundwater composition changes. If, for example, the steady-state pH at a given location decreases, due for example to kinetically limited buffering reactions, a temporal change in K_d may occur without a major change in the mineral assemblage because the sorption of radionuclides onto a given mineral surface is often pH dependent. Similarly, a temporal change in K_d may occur if there is a major change in the concentrations of ions competing for surface sites or if there is a major change in the ionic strength. The importance of such changes in groundwater composition depends on the resulting magnitude and direction of the K_d change. If the K_d is reduced for a given radionuclide, a net desorption of the radionuclide will result.

If the pH buffering reactions are rapid relative to the groundwater velocity, the pH front will be sharp, but if they are relatively slow, the front will be spread out. A sharp front has the potential to generate a sharp increase in the aqueous concentration of the desorbing radionuclide in the vicinity of the front as the front migrates downgradient. However, a sharp front is unlikely due to the variety of potential pH buffering reactions along the flow path, some of which may be slow relative to groundwater velocity. This assertion is supported by the fact that groundwater along potential flow paths does not currently exhibit sharp changes in groundwater composition even though the ages of the various groundwater samples vary from the Holocene to the Pleistocene. Figures 1-1 to 1-3 show general trends in bicarbonate concentrations, pH, and uranium concentrations in the saturated zone along potential flow paths that indicate a relationship to the age of the groundwater. No sharp changes are apparent despite the climate changes that have occurred over this time period. These figures also indicate that younger water, indicated by higher values of percent modern carbon, has smaller ranges in pH, bicarbonate concentrations, and uranium concentrations. It is the younger water that is more likely to be characteristic of compositional variability along flow paths that move fast enough to be important to 10,000-year dose calculations. Based on these data, little variation in groundwater composition is observed in the younger samples.

In the case of a change in the ionic strength or an increase in the concentration of an ion that competes for the same sorption sites, these changes would also have to be large enough to significantly affect the radionuclide K_d values along the flow path. However, such a future scenario is not expected. If the effect on K_d values is small or does not propagate fast enough, changes in groundwater composition will have little effect on the overall dose.

1.2.2 Potential for Major Temporal Changes

The preceding sections affirm that without a major temporal change in the groundwater composition, temporal changes in sorption will not occur. This section further demonstrates that a major temporal change in groundwater composition is not expected.

One possible mechanism for producing temporal change in groundwater composition is an igneous event in which the dike that is formed intersects the saturated zone in the region of the projected path of radionuclide transport. The possibility of an igneous intrusion altering groundwater compositions such that radionuclide sorption/desorption reactions would be affected was considered in the FEPs screening process. In particular, excluded

FEP 1.2.04.02.0A, Igneous Activity Changes Rock Properties, and excluded FEP 1.2.10.02.0A, Hydrologic Response to Igneous Activity, consider the effects of a dike on mineral alteration in the saturated zone (SNL 2008b, pp. 6-135 and 6-136; pp. 6-209 and 6-210). Citing studies showing that alteration is limited to a zone less than 10 m away from the intrusion/host rock contact, both FEPs justifications conclude that the small volume of igneous-altered rock would have little impact on the characteristics of saturated zone water chemistry along groundwater flow paths, given the much larger volume of the saturated zone that is unaffected by the dike (SNL 2008b, pp. 6-135 and 6-136; pp. 6-209 and 6-210). Therefore, igneous intrusion is not a viable mechanism for producing temporal changes in groundwater composition that are of concern to the performance assessment.

Another possible mechanism for producing a temporal change in groundwater composition is a change in climate. Climate change is included in the performance assessment based on the record of climate changes in the past, and consists of changes in precipitation and temperature (BSC 2004, pp. 7-1 and 7-2). While changes in precipitation and temperature can affect the magnitude of the flux of groundwater through the saturated zone and the water composition of surface lakes (BSC 2004, Section 6.5.1), large changes in groundwater composition are not apparent in current data. Groundwater along likely flow paths beneath the repository to the southern boundary ranges in age from the Holocene to the Pleistocene. Figures 1-1 through 1-3 show plots of bicarbonate concentrations, pH, and uranium concentrations versus percentage modern carbon in groundwater samples collected along likely flow paths (SNL 2007a, Appendices A and B). These figures indicate that older waters tend to have higher pH and bicarbonate, which is consistent with prolonged exposure to mineral weathering reactions. Higher uranium concentrations correlate with higher pH and bicarbonate concentrations as expected due to the increased stability of uranyl carbonate complexes at higher pH. These data indicate gradual changes in groundwater composition consistent with slow mineral weathering processes over many thousands of years. In comparison, effects of past climate changes on groundwater compositions are not detected in these data. Thus, a major temporal change in groundwater composition induced by climate change can be dismissed from further consideration.

A third possible mechanism for producing a temporal change in groundwater composition is a pulse of effluent from the repository horizon. One such event is addressed in excluded FEP 2.2.07.06.0A, Episodic or Pulse Release from Repository, which analyzes the accumulation of water in a waste package, followed by the corrosion failure of that waste package and the ensuing sudden water release (SNL 2008b, pp. 6-937 and 6-938). This event was excluded from the performance assessment because it was concluded that matrix imbibition, sorption, and diffusion processes will damp out the effects of this episodic process (SNL 2008b, p. 6-938). Thus, the pulse will have been dampened by the time it reaches the saturated zone and will not affect the groundwater composition. Another such event is addressed in excluded FEP 2.2.07.14.0A, Chemically-Induced Density Effects on Groundwater Flow, which analyzes a short-duration pulse of brackish water (as much as 5,000 to 10,000 mg/L dissolved solids) that may drain through the host rock when the dry salts left behind by evaporation during the thermal pulse are redissolved and flushed downward as the repository cools (SNL 2008b, pp. 6-958 and 6-959). This event was excluded from the performance assessment because “the flux of the

concentrated water reaching the saturated zone will be only a very small fraction of the horizontal flux in the saturated zone resulting from infiltration of dilute water and horizontal flux from through-flowing water” (SNL 2008b, p. 6-959). Percolation through the unsaturated zone model is about 1% of the flow through the lateral boundaries of the saturated zone site-scale flow model domain (SNL 2007a, Section 6.4.3.9). Thus, the brackish water will undergo substantial dilution when it reaches the saturated zone. A third such event is addressed in excluded FEP 2.1.06.01.0A, Chemical Effects of Rock Reinforcement and Cementitious Materials in EBS, which examined the possible enhancement of transport that might result from an alkaline plume (SNL 2008b, pp. 6-504 to 6-507). This plume would result from leaching of cementitious material located not in the waste emplacement drifts, but in turnout intersections, exhaust air (ventilation) turnouts, and access ramps, and could enhance radionuclide transport to the accessible environment. This event was excluded from the performance assessment because any high-pH plumes originating from the cementitious material are expected to be short-lived and rapidly neutralized in the unsaturated zone by the readily available CO₂ (SNL 2008b, p. 6-506). Therefore, pulses of effluent from the repository horizon, whether from a breached waste package, from the redissolution of salts deposited during the thermal period, or from an alkaline plume, can be dismissed from further consideration.

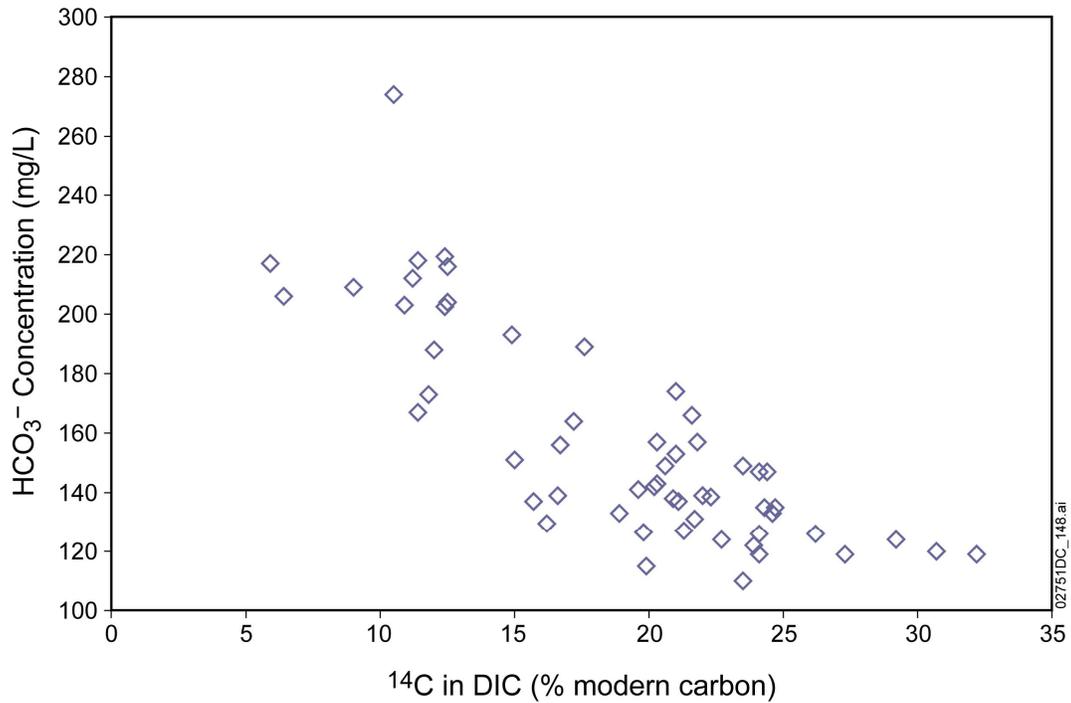
A fourth possible mechanism for producing a temporal change in groundwater composition is the heating of the saturated zone that results from propagation of the thermal pulse from the repository. The average maximum temperature at the water table occurs approximately 6,000 years after waste emplacement and is approximately 63°C, representing an increase of about 33°C compared to ambient conditions (SNL 2008b, p. 6-1079). The question is whether a temporal temperature increase of this magnitude is sufficient to change the groundwater composition enough to affect radionuclide sorption. This question was addressed in excluded FEP 2.2.10.08.0A, Thermo-Chemical Alteration in the SZ (Solubility, Speciation, Phase Changes, Precipitation/Dissolution) (SNL 2008b, p. 6-1079). The answer was that available data show little statistical variation in the sorption coefficient values for temperatures up to 80°C (SNL 2008b, p. 6-1079). As temperatures at the water table do not exceed 80°C, the thermal impact on sorption coefficients will not be significant. Therefore, the local transient increase in temperature at the water table will not cause the spatial variation in sorption coefficients in the saturated zone to exceed that which is already accounted for in the saturated zone flow and transport abstraction model (see Section 1.1.1).

A fifth possible mechanism for producing a temporal change in groundwater composition is a change in the source waters for the saturated zone or a change in the saturated zone flow paths. This could result from large-scale tectonic activity, such as uplift or slip along a fault, or smaller-scale seismic activity. The effects of large-scale tectonic activity were examined in excluded FEP 1.2.01.01.0A, Large-Scale Tectonic Activity (SNL 2008b, p. 6-74). An analysis of the various large-scale tectonic activities that have occurred in the region of Yucca Mountain concluded that the rates of large-scale tectonic activity are low, leading to small magnitude effects. For example, slip rates for active faults in the Yucca Mountain vicinity were found to range from 0.001 to 0.05 mm/yr (SNL 2008b, p. 6-76). Over 10,000 years, such slip rates would result in displacements ranging from 0.01 m to 0.5 m, which is not enough to cause a change in the source waters for the saturated zone or a change in the saturated zone flow paths. As another

example, if subsidence related to faulting occurred at a rate of 0.01 mm/yr, the net subsidence over 10,000 years would be 0.1 m. Even for a rate of 1 mm/yr, the total subsidence over 10,000 years would be only 10 m (SNL 2008b, p. 6-78), which, again, is not enough to cause a change in the source water for the saturated zone or a change in the saturated zone flow path. A third example involves seismic activity, which has the potential to change the elevation of the water table and change the hydraulic gradient. However, projected maximum changes in the water table elevation and the hydraulic gradient are too small to have a significant effect on the groundwater chemistry (SNL 2008b, pp. 6-205 to 6-206). Therefore, a change in the source waters for the saturated zone or a change in the saturated zone flow paths resulting from tectonic or seismic activity that would, in turn, cause a significant temporal change in groundwater composition in the saturated zone is not expected.

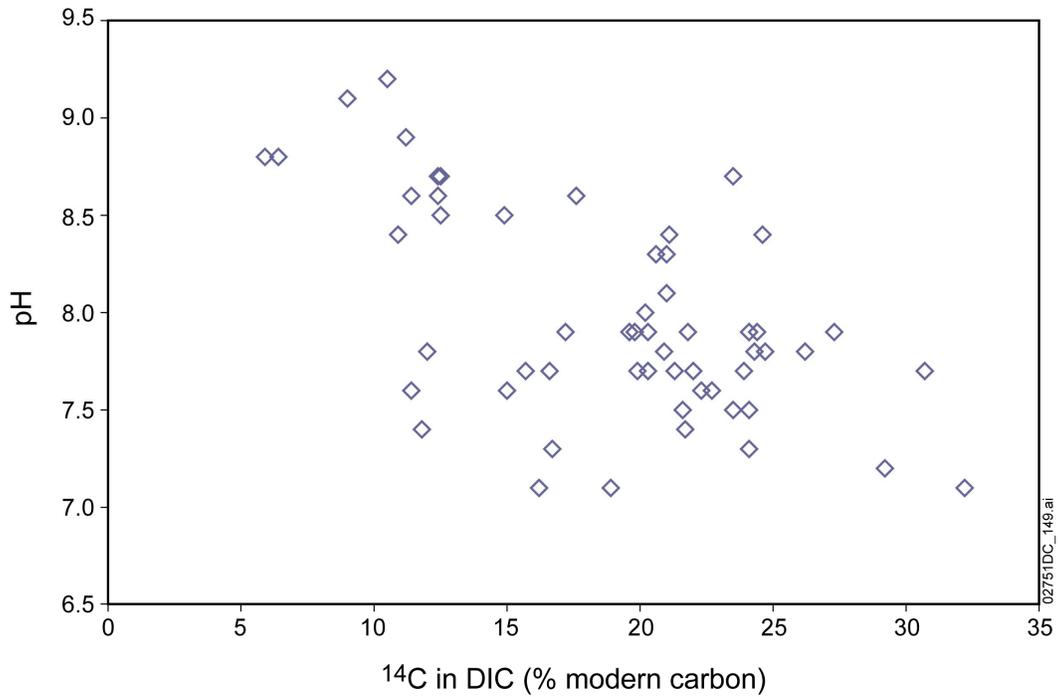
1.3 RESPONSE SUMMARY

Temporal changes in groundwater composition in the saturated zone have the potential to induce a limited reduction in sorption along flow paths to the accessible environment causing net desorption of previously sorbed radionuclides. The lower sorption due to such a temporal change is expected to be within the ranges of the K_d distributions defined for the hydrostratigraphic units of the saturated zone because these ranges are based on sorption measurements using a wide range of groundwater and mineral compositions and are generally biased toward lower measured values. Significant temporal changes in groundwater chemistry are not evident from the geologic record for the past several thousand years in the repository area, and significant temporal changes in groundwater composition are not expected to occur in the next 10,000 years. Any realistically expected temporal changes in groundwater composition are not expected to have a significant effect on dose within 10,000 years after repository closure because there are no realistic scenarios that could produce a change in groundwater composition large enough to cause a temporal change in sorption that could affect dose calculations. Therefore, the above information supports the original FEP 2.2.08.03.0A exclusion justification on the basis of low consequence.



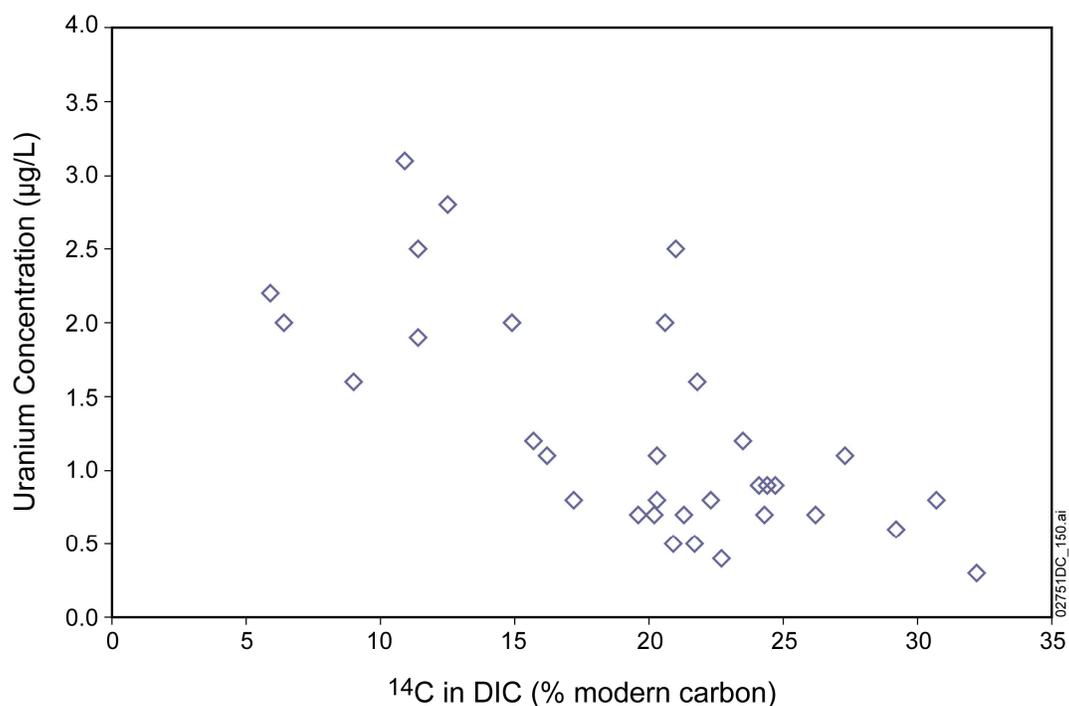
Source: SNL 2007a, Appendices A and B.

Figure 1-1. Bicarbonate Concentration versus Percentage ¹⁴C in Dissolved Inorganic Carbon (DIC) along Potential Flow Paths



Source: SNL 2007a, Appendices A and B.

Figure 1-2. pH versus Percentage ¹⁴C in Dissolved Inorganic Carbon (DIC) along Potential Flow Paths



Source: SNL 2007a, Appendices A and B.

Figure 1-3. Dissolved Uranium versus Percentage ¹⁴C in Dissolved Inorganic Carbon (DIC) along Potential Flow Paths

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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NOTE: ^a Provided as an enclosure to letter from Williams to Sulima dated 02/17/2009. "Yucca Mountain – Request for Additional Information Re: License Application (Safety Analysis Report Section 2.1), Safety Evaluation Report Volume 3 – Postclosure Chapters 2.2.1.1 and 2.2.1.3.7 – Submittal of Department of Energy Reference Citations."