RAI Volume 3, Chapter 2.2.1.3.9, First Set, Number 2:

Justify the assumption, implicit in the SAR, that groundwater flow paths under future climates and associated water table rise can be characterized using the same fate and transport characteristics as those under current conditions.

Basis: The applicant states that climate change is implicitly and conservatively included in the site-scale saturated zone transport model by increasing flow rates without raising the water table or changing flow paths (SAR p.2.3.9-83). The applicant states that particle tracking simulations incorporating the water table rise (effect of climate change) produce longer simulated transport times because some transport occurs in lower permeability units.

Staff requires confirmation and justification of the assumption that these longer flow paths through lesser permeability units can be represented using the same geochemical assumptions and data as the more permeable units to evaluate compliance with 10 CFR 63.114(a)(1-3).

1. RESPONSE

The geochemical assumptions and data relevant to the fate and transport characteristics along the groundwater flow paths expected during future climates and the associated water table rise are related to those fate and transport characteristics that could affect the sorption of radionuclides along these flow paths, because sorption is the principal saturated zone geochemical characteristic relevant to the Yucca Mountain postclosure performance assessment. Radionuclide sorption is included in the performance assessment through the use of the sorption coefficient, K_d. Because the K_d distribution is either unchanged or is increased due to a water table rise (allowing for more sorption and therefore slower transport times and lower concentrations and doses at the accessible environment than are actually used in the performance assessment), using the same fate and transport characteristics as under current conditions is appropriate and conservative.

1.1 INTRODUCTION

The potential effects of a raised water table during future climates on groundwater flow paths and radionuclide transport has been evaluated in *Saturated Zone Site-Scale Flow Model* (SNL 2007, Section 6.6.4) and *Site-Scale Saturated Zone Transport* (SNL 2008a, Appendix E), respectively. These analyses indicate that the modified flow paths associated with a raised water table are not expected to decrease the saturated zone transport times from the repository to the accessible environment and therefore the effects of water table rise with climate change are conservatively included in the saturated zone radionuclide transport model (SAR, p. 2.3.9-83).

However, during the preparation of the response to this RAI, DOE identified an error in the radionuclide breakthrough curves plotted in Figures E-1 and E-2 in *Site-Scale Saturated Zone Transport* (SNL 2008a, Appendix E) for both the elevated water table case and the scaled recharge and permeability case (the green and red curves of these figures, respectively). The corrected results are presented in Section 1.2 (Figures 1 and 2).

Geochemical characteristics along the groundwater flow path can affect the transport of sorbing radionuclides through changes in K_d. The geochemical characteristics that could affect the K_d distribution include the mineral composition, the groundwater chemistry, and the type of radionuclide.

For nonsorbing (i.e., $K_d = 0$) radionuclides carbon, technetium, and iodine, changes in geochemical characteristics along the flow path have no effect in the performance assessment. For sorbing radionuclides americium, thorium, protactinium, selenium, tin, strontium, and radium, K_d distributions used in the saturated volcanic rock and alluvium units are based on the smaller of either the zeolitic or devitrified K_d distribution. Therefore, the K_d distributions for these radionuclides are not affected by the potential change in geochemical characteristics along the changed flow paths associated with a raised water table because the K_d distribution used in the performance assessment is the more conservative distribution.

For the sorbing radionuclides cesium, neptunium, plutonium, and uranium, the K_d distributions used in the saturated volcanic rock units were based on composite upscaled K_d distributions that did consider the percentage of zeolitic and devitrified rock units along the expected flow path within the volcanic rock units and therefore are potentially impacted by a change in the expected flow path associated with future climates and a raised water table. The K_d distributions used in the alluvium units for these sorbing radionuclides were based on the small-scale probability distribution functions developed on the basis of laboratory data (SNL 2008a, Table A-4) and are not expected to be impacted by a raised water table. The insignificance of the changed flow paths on the K_d distribution used in the volcanic rock units in the performance assessment is discussed in Section 1.3.

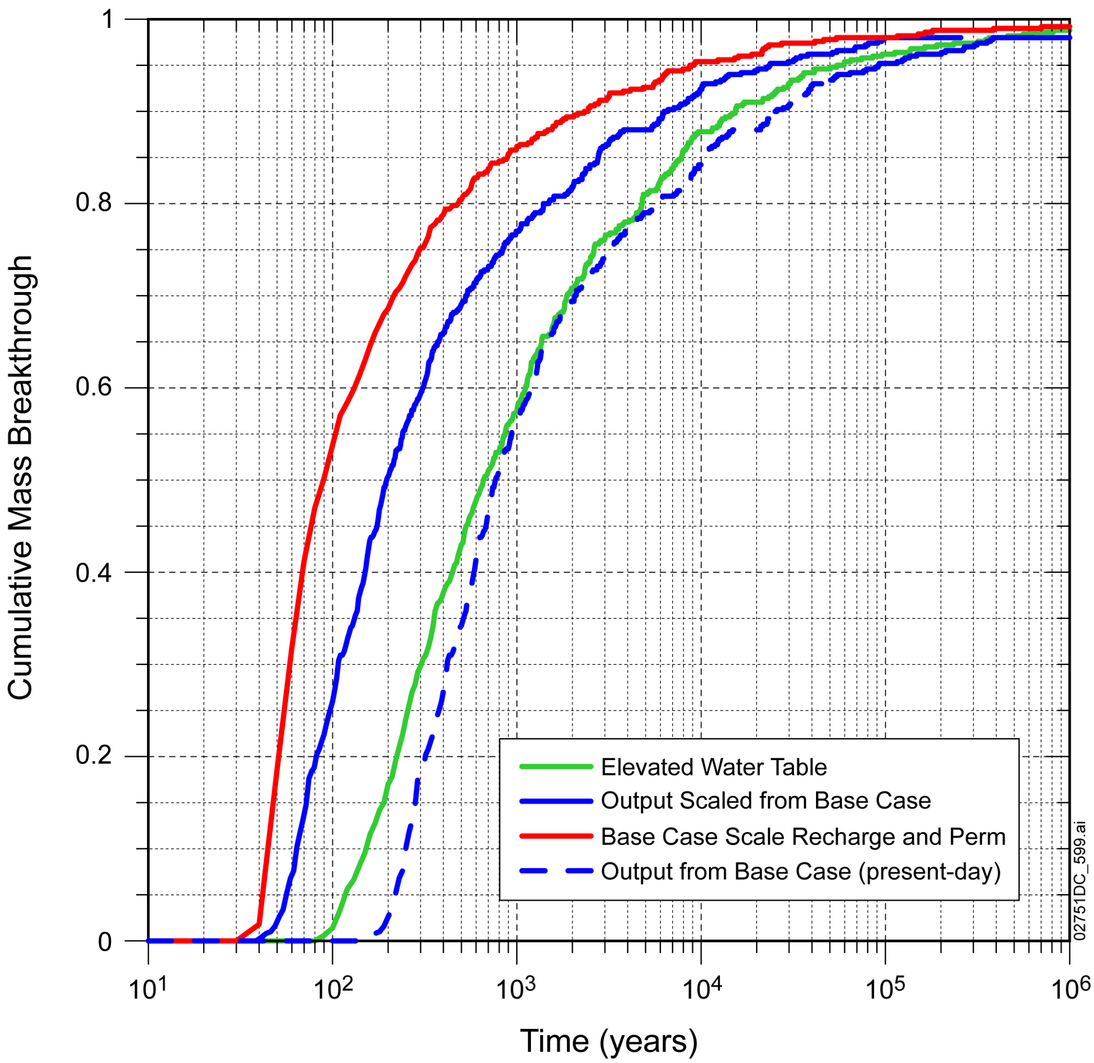
1.2 CORRECTED BREAKTHROUGH CURVES FOR ALTERNATIVE METHODS OF MODELING GLACIAL-TRANSITION CLIMATIC CONDITIONS

Revised analyses of the alternative methods of modeling the glacial-transition climatic conditions have been performed to correct the breakthrough curves in *Site-Scale Saturated Zone Transport* (SNL 2008a, Appendix E). The revised results are plotted as Figures 1 and 2 for nonsorbing radionuclides and neptunium, respectively. The red and green curves plotted on these figures are corrected from the previous results (SNL 2008a, Figures E-1 and E-2), while the blue curve is not affected by the error. The dashed blue curve on these figures represents the present-day climate base-case results (SNL 2008a, Section 6.7).

The corrected red curve on these figures represents the case where the permeability of all the hydrostratigraphic units and vertical recharge rates are increased by a factor of 3.9 above the base-case values, with the same boundary heads used as in the present-day climate case. This case reflects an increased specific discharge along the expected travel paths from the repository to the accessible environment of a factor of 3.9, the ratio of the saturated zone groundwater fluxes for the glacial-transition climate state to the present-day climate state derived from the Death Valley regional flow model (SNL 2008b, Table 6-4[a]). This is the same approach and scaling factor used in the Total System Performance Assessment (TSPA) compliance simulations.

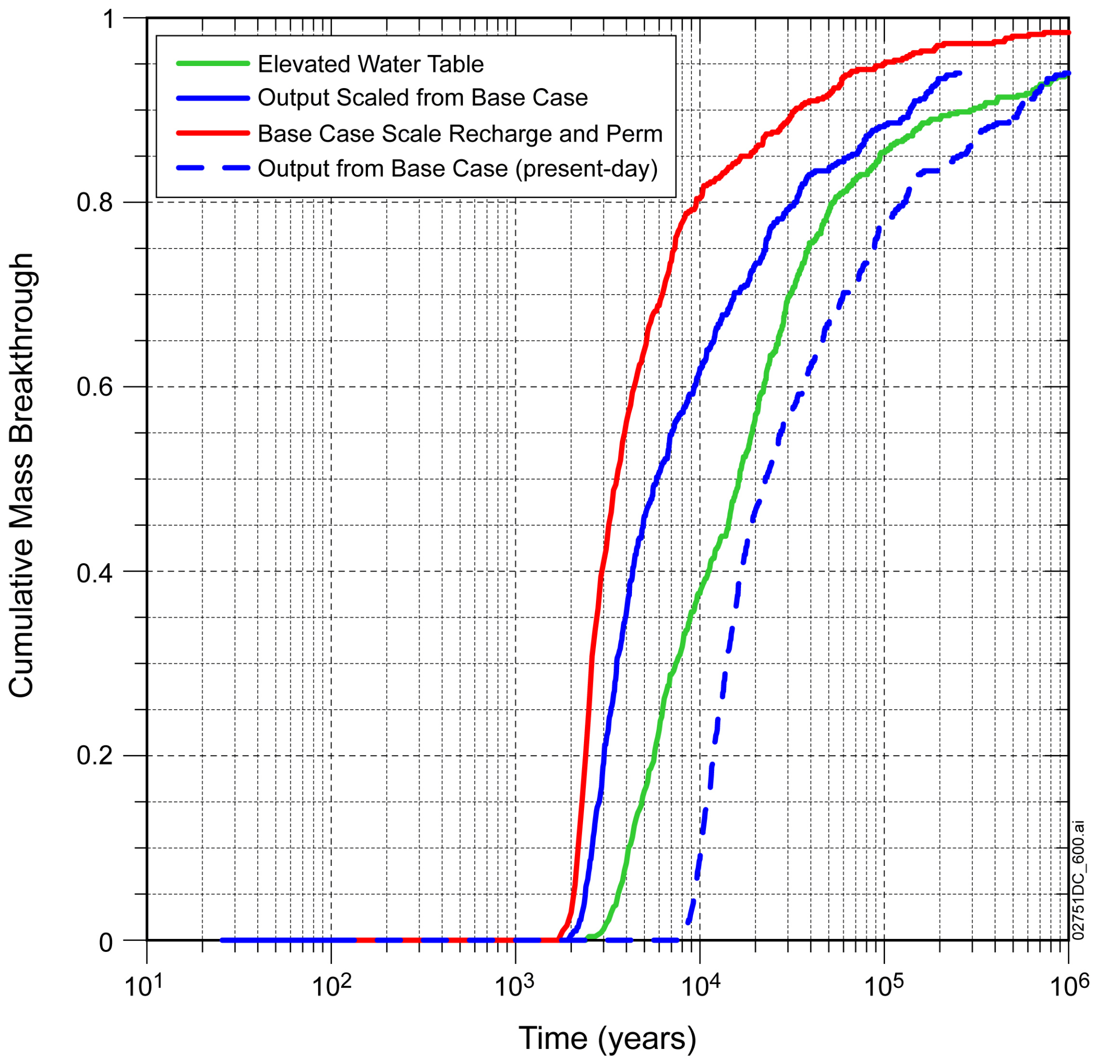
The blue curve on these figures represents the case where the present-day climate base-case results are scaled by a factor of 3.9 by scaling the time axis. This approach is included on these plots because the original figures included this blue curve.

The corrected green curve on these figures represents the case where the water table is raised and the vertical recharge increased by a factor of 3.9. In this case, the present-day water table is raised by 20 m in locations with a present-day water table elevation of 700 m, 50 m in locations with a present-day water table elevation of 740 m, and 100 m in locations with a present-day water table elevation of 1,000 m, with other locations assigned a water table rise calculated by linear interpolation or extrapolation, as suggested in *Saturated Zone Site-Scale Flow Model* (SNL 2007, Section 6.6.4.2). This case represents an expected rise in the water table combined with an increase in the vertical recharge to the saturated zone associated with the glacial-transition climate state.



NOTES: Mass breakthrough curves are for an instantaneous source and do not include radionuclide decay. Particle source location was a point near the middle of the repository footprint. The red line is the saturated zone breakthrough curve at 18 km for future glacial-transition climatic conditions, represented by scaling the base-case recharge and permeabilities by a factor of 3.9 from transport simulations for present-day climatic conditions. The dashed blue line is the saturated zone breakthrough curve for the present-day climatic conditions. The blue line is the output of the base-case present-day climatic conditions scaled by a factor of 3.9. The green line is the saturated zone breakthrough curve for future glacial-transition climatic conditions that have been simulated with a higher water table and increased recharge. The TSPA compliance calculations used the scaled recharge and permeability method (red line).

Figure 1. Corrected Breakthrough Curves for Nonsorbing Radionuclides for Future Glacial-Transition Climatic Conditions Using Three Alternative Methods



NOTES: Mass breakthrough curves are for an instantaneous source and do not include radionuclide decay. Particle source location was a point near the middle of the repository footprint. The red line is the saturated zone breakthrough curve at 18 km for future glacial-transition climatic conditions, represented by scaling the base-case recharge and permeabilities by a factor of 3.9 from transport simulations for present-day climatic conditions. The dashed blue line is the saturated zone breakthrough curve for the present-day climatic conditions. The blue line is the output of the base-case present-day climatic conditions scaled by a factor of 3.9. The green line is the saturated zone breakthrough curve for future glacial-transition climatic conditions that have been simulated with a higher water table and increased recharge. The TSPA compliance calculations used the scaled recharge and permeability method (red line).

Figure 2. Corrected Breakthrough Curves for Neptunium for Future Glacial-Transition Climatic Conditions Using Three Alternative Methods

The corrected results presented in Figures 1 and 2 illustrate that the scaled recharge and permeability method (red curve), which increases the specific discharge fluxes throughout the modeled domain by a factor of 3.9, provides the shortest transport times from the repository to the accessible environment, and is therefore conservative from a performance perspective. The results from the scaled recharge and permeability method (red curve) indicate a shorter transport time than the base-case present-day results scaled by a factor of 3.9 (blue curve) due to the decreased role of matrix diffusion in delaying the transport to the accessible environment.

The corrected results indicate that raising the water table in the method suggested in *Saturated Zone Site-Scale Flow Model* (SNL 2007, Section 6.6.4.2) (green curve) has a slight effect on the predicted mass breakthrough from the base-case present-day climatic conditions case (dashed blue curve). This is a result of the small change from the present-day hydraulic gradient downgradient from the repository associated with the applied boundary condition changes in this elevated water table case.

In conclusion, the difference in transport times between the scaled recharge and permeability case (red curve) and the elevated water table case (green curve) is related to the differences in specific discharge along the travel path between the repository and the accessible environment. These differences in specific discharge are the result of both the different hydraulic gradients and permeabilities along the travel path as well as the differences in the travel paths.

1.3 IMPACT OF CHANGED FLOW PATHS ON COMPOSITE UPSCALED K_d DISTRIBUTIONS

The composite upscaled K_d distributions for cesium, neptunium, plutonium, and uranium were developed based on stochastic modeling of small-scale K_d distributions that were correlated spatially. The spatial distributions considered the dependence of the rock types on the mineralogy and the differences in the small-scale K_d distributions based on the relative amount of zeolite abundance. Rock units with greater than 20% zeolite abundance were labeled as zeolitic while rock types with greater than 80% glass abundance were labeled as vitric. Otherwise, the rock type was labeled as devitrified. Considering the mineral abundance in the upper 200 m of the ambient saturated zone from 11 wells (UE-25a#1, UE-25 UZ#16, USW G-1, USW G-2, USW G-3/GU-3, USW G-4, USW SD-7, USW SD-9, USW SD-12, USW WT-24, and H-6), it was determined that the proportion of zeolitic rocks is 60% and the proportion of devitrified rocks is 40% (SNL 2008a, Appendix C1.2.1). The upper 200 m of the ambient saturated zone approximately corresponds to the depth of the flow paths in the vicinity of the repository (SNL 2008a, Figure 6.7-2b) and also contains the principal volcanic tuff units along these flow paths, notably the Prow Pass, Bullfrog, and Tram tuff units of the Crater Flat Formation. Because zeolitic rock units have greater sorption than devitrified rock units for cesium, neptunium, and uranium and the same sorption for plutonium, the relative abundance of zeolitic rock units in the upper 200 m of the saturated zone tends to increase the composite upscaled K_d.

To evaluate the potential impact of a raised water table due to climate change on the likely distribution of zeolitic and devitrified rocks, the same approach is used. For a water table 50 m higher at the repository (consistent with the adaptation of the saturated zone site-scale flow model (SNL 2007, Section 6.6.4.1)), the ratio of zeolitic to devitrified rock units in the upper 250 m of this potential future climate saturated zone in the 11 wells is 64/36, a slight increase in the zeolitic fraction from the current water table elevation conditions. For a water table 100 m higher at the repository, the ratio of zeolitic to devitrified rock units in the upper 300 m of this potential future climate saturated zone in the 11 wells is still 64/36, again a slight increase in the zeolitic fraction from the current water table elevation conditions.

Because the average zeolitic fraction of the saturated volcanic rock units in the representative boreholes is higher with respect to both the 50 and 100 m water table rise, the composite upscaled K_d distribution is also expected to be increased for the higher water table condition, given that the zeolitic rock units have a greater K_d than the devitrified rock units for cesium, neptunium, and uranium and the same K_d distribution for plutonium. Because the K_d distributions for cesium, neptunium, and uranium are potentially increased along the saturated zone pathways associated with the water table rise for future climates, the transport times for these radionuclides to travel in the saturated zone from the repository to the accessible environment is also expected to increase. Therefore, using the same fate and transport characteristics as those under current conditions would not lead to an overprediction of transport times or an underprediction of dose.

1.4 CONCLUSION

The change in groundwater flow paths under future climates and associated water table rise can be characterized using the same fate and transport characteristics (notably the same K_d distribution) as those under current conditions. This is because either the geochemical assumptions do not impact the transport characteristics (as is the case for the nonsorbing radionuclides iodine, technetium and carbon and the sorbing radionuclides americium, thorium, protactinium, selenium, tin, strontium, and radium) or the geochemical assumptions would underestimate the expected sorption and transport times thus overestimating the concentration and dose at the accessible environment (as is the case for those sorbing radionuclides which use a composite upscaled K_d distribution, i.e., plutonium, neptunium, cesium, and uranium).

Given that flow path characteristics are not significantly affected by the assumptions in the elevated water table case, it is reasonable and conservative to use the same geochemical characteristics along the likely flow paths in the future climate conditions. In addition, because the scaled permeability and recharge case used to evaluate the effects of future glacial-transition climatic effects on saturated zone flow and transport has significantly shorter transport times than the elevated water table case, it is reasonable and conservative to use the scaled permeability and recharge method in the TSPA because this does not result in an underestimation of the predicted dose.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

SNL (Sandia National Laboratories) 2007. *Saturated Zone Site-Scale Flow Model.* MDL-NBS-HS-000011 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070626.0004.

SNL 2008a. *Site-Scale Saturated Zone Transport.* MDL-NBS-HS-000010 REV 03 AD01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080121.003.

SNL 2008b. *Saturated Zone Flow and Transport Model Abstraction.* MDL-NBS-HS-000021 REV 03 AD 02. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080107.0006